Socioeconomic Impacts of Transitioning to Collaborative Port Operations
A case study of the Port of Gothenburg

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Abstract
The purpose of this study is to derive a method for estimation of costs and benefits of implementing Port Collaborative Decision Making (Port CDM), and to apply this method to the Port of Gothenburg. By using the Port of Gothenburg as a case study, conclusions can be drawn regarding the economic viability of Port CDM in one of Scandinavia’s largest ports. This study considers two major sources of benefits that are hypothesized to result from transitioning to collaborative port operations: improved possibilities for speed optimization prior to arrival in port due to increased predictability in estimated berthing times, and shortened service times due to increased possibility for planning and resource optimization by port service providers.

The estimation of impacts is based on one month’s traffic data in the Port of Gothenburg. Predictability of estimations is analyzed to determine the benefit potential of Port CDM. The estimated cost savings for cargo vessels can be divided into 5 categories: bunker, emission, time, manning and capital cost savings. The costs of implementing and maintaining Port CDM are estimated with values from relevant previous research.

The results of this study indicate that the implementation of Port CDM in the Port of Gothenburg is a profitable investment, for the shipping industry and for society as a whole. The estimated annual net benefit is 27.3 million euros. A sensitivity analysis using alternative unit valuations for emissions, as well as low and high estimations of the effectiveness of Port CDM, indicates that the economic viability of the project is robust under all assumptions considered.
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Table of contents

ABSTRACT.................................................................................................................................................. I

ACKNOWLEDGEMENTS.............................................................................................................................. III

TABLE OF CONTENTS.................................................................................................................................. IV

LIST OF TABLES ......................................................................................................................................... V

LIST OF FIGURES ...................................................................................................................................... V

1. INTRODUCTION....................................................................................................................................... 1
   1.1. BACKGROUND ..................................................................................................................................... 1
   1.2. PROBLEM .......................................................................................................................................... 2
   1.3. PURPOSE .......................................................................................................................................... 3
   1.4. METHOD .......................................................................................................................................... 3
   1.5. DISPOSITION ..................................................................................................................................... 6

2. WELFARE THEORY AND COST BENEFIT ANALYSIS ............................................................................. 7
   2.1. PERFORMING A COST BENEFIT ANALYSIS ..................................................................................... 7
   2.2. COSTS AND BENEFITS FOR WHOM? ............................................................................................... 8

3. PORT ECONOMICS.................................................................................................................................. 9
   3.1. THE PORT AS A PRODUCTION FACILITY ......................................................................................... 9
   3.2. PORT EFFICIENCY AND THE ROLE OF TIME IN PORT OPERATIONS .................................................. 10
   3.3. QUEUING TIME .................................................................................................................................. 12
   3.4. ENERGY CONSUMPTION AND EMISSIONS FROM PORT ACTIVITIES ........................................... 13
   3.5. ENERGY CONSUMPTION AND EMISSIONS FROM SHIPS ................................................................ 14
   3.6. WHY THE EFFICIENCY GAP? – POSSIBLE REASONS FOR CURRENT INEFFICIENCY ...................... 17

4. SEA TRAFFIC MANAGEMENT AND THE COLLABORATIVE PORT ....................................................... 19
   4.1. THE FUNNEL MODEL OF EFFICIENTLY DEVELOPING ESTIMATES .................................................... 21

5. METHODOLOGICAL APPROACHES TO ESTIMATING EFFECTS OF THE POLICY ............................... 25
   5.1. BENEFITS OF COLLABORATIVE PORT OPERATIONS ....................................................................... 25
   5.2. COSTS OF COLLABORATIVE PORT OPERATIONS ............................................................................ 31

6. ESTIMATED BENEFITS AND COSTS OF PORT CDM IN THE PORT OF GOTHENBURG .................... 35
   6.1. AREA OF STUDY – THE PORT OF GOTHENBURG DESCRIBED ......................................................... 35
   6.2. ANALYSIS OF PORT APPROACH DATA ............................................................................................. 37
   6.3. DEVIATION IN ESTIMATION FOR DIFFERENT STATES ....................................................................... 40
   6.4. IMPLICATIONS OF THE OBSERVED DEVIATIONS ............................................................................ 41
   6.5. CALCULATION OF COST SAVINGS RELATED TO SPEED REDUCTION PRIOR TO ARRIVAL AT PORT .................................................................................................................. 42
   6.6. CALCULATION OF COST SAVINGS RELATED TO SHORTENED TURNAROUND TIME IN PORT .............. 45
   6.7. SUMMARY AND COMMENTARY ON ESTIMATED BENEFITS ............................................................. 49
   6.8. CALCULATION OF BENEFITS UNDER ALTERNATIVE EMISSION UNIT VALUES ............................... 51
   6.9. NET ESTIMATED EFFECTS TO SOCIETY OF PORT CDM IN THE PORT OF GOTHENBURG ................ 54

7. DISCUSSION OF RESULTS AND FURTHER IMPLICATIONS OF PORT CDM ......................................... 55
   7.1. BASELINE SPEED ASSUMPTIONS ....................................................................................................... 55
   7.2. ALTERNATIVE EXPRESSIONS OF BENEFITS ..................................................................................... 55
   7.3. EFFECTS ON QUEUING ....................................................................................................................... 57
   7.4. INCENTIVES TO PARTICIPATE IN INFORMATION SHARING SERVICES ............................................. 58
   7.5. EMISSION COST SAVINGS – AN INCENTIVE FOR WHOM? ................................................................. 59
   7.6. SENSITIVITY OF RESULTS WITH REGARD TO SAMPLE LIMITATIONS............................................... 60
8. CONCLUSIONS ........................................................................................................................................61
8.1. Derived method for estimating the impacts of Port CDM .................................................................61
8.2. Economic viability of Port CDM in the Port of Gothenburg .............................................................61
REFERENCES ..............................................................................................................................................63
APPENDIX 1: SHIPPING TERMS, ABBREVIATIONS AND DEFINITIONS ..............................................67

List of tables
TABLE 1 - Speed reduction rates and CO2 emission reduction rates ..........................................................16
TABLE 2 - Abbreviations of state occurrences and estimates .................................................................21
TABLE 3 - Categorized benefits that are hypothesized to result from Port CDM .......................................26
TABLE 4 - Unit values of air pollutants in euros per kg ...........................................................................27
TABLE 5 - Cost estimates of Port CDM by category divided by category ..................................................34
TABLE 6 - Cost estimates of Port CDM by chronological order .................................................................34
TABLE 7 - Cargo vessels approaching the Port of Gothenburg during August of 2014 .........................37
TABLE 8 - GT, assumed baseline speeds and emission costs for vessel types .............................................43
TABLE 9 - Monetary impacts of speed reduction scenarios .......................................................................45
TABLE 10 - Coefficients for estimating fuel consumption at berth .........................................................46
TABLE 11 - Emission cost factors .............................................................................................................46
TABLE 12 - Crewing cost profiles of ship categories ...............................................................................47
TABLE 13 - Hourly cost of laytime for sample .......................................................................................48
TABLE 14 - Cost savings of reduced laytime for different scenarios .......................................................49
TABLE 15 - Estimated annual benefits of Port CDM: low, median and high-impact scenarios .............50
TABLE 16 - Estimated annual benefits of Port CDM under low emission unit values ............................51
TABLE 17 - Estimated annual benefits of Port CDM under high emission unit values .........................52
TABLE 18 - Estimated annual benefits under median-impact scenario for low, main and high emission values ..................................................................................................................52
TABLE 19 - Estimation of benefits under the assumption that not all vessels can save costs by reducing speed ..................................................................................................................55

List of figures
FIGURE 1 - “Metro map” of states in a generalized port approach process ...........................................22
FIGURE 2 - Funnel with four phases ........................................................................................................24
FIGURE 3 - Types of goods in the Port of Gothenburg annual throughput .............................................35
FIGURE 4 - Division of empty and full containers in the Port of Gothenburg ..........................................36
FIGURE 5 - Distribution of handled cargo by type for Gothenburg and the 12 largest European ports 37
FIGURE 6 – Comparison of sample and average traffic distribution ......................................................38
FIGURE 7 - Sample distribution of hours at quay in the Port of Gothenburg ..........................................39
FIGURE 8 – Error in estimates of berthing times .....................................................................................40
FIGURE 9 - Average error in estimates of berthing times .......................................................................41
FIGURE 10 - Division of benefits .............................................................................................................53
FIGURE 11 - Flow of estimated impacts ................................................................................................62
1. Introduction

1.1. Background

Shipping has been an enabler for global trade for centuries, accounting today for 80 percent of world trade by volumes (UNCTAD, 2014). Being of such importance to the world economy, it is naturally motivating to find room for improvements in shipping efficiency. The industry is characterized by a wide network of different actors with different tasks in the value chain of transporting cargo. This network encompasses several key actors, including owners of ships and cargo, intermediaries providing transport, terminal operators, port service providers and infrastructure.\(^1\) It is through these interdependent actors that the shipping of cargo is carried out.

Though shipping in general is comparatively an environmentally efficient mode of transport, not all categories of shipping are more environmentally efficient than all other modes of transport. In 2007 emissions from ships accounted for a 3.3 % share of total global CO\(_2\) emissions and the current development indicates that this share is increasing.\(^2\) This can help explain why recent strategies in operational efficiency in shipping have been focused on the mitigation of environmental costs. The International Maritime Organization concludes in a report that CO\(_2\) emissions from world shipping could potentially be cut by 25 % to 75 % below current levels if cost effective technical and operational measures are taken. (Buhaug et al, 2009)

If air travel serves as a good comparison, there are reasons to believe that there are efficiency gains to be made from implementing an information sharing network, similar to the air traffic reform program SESAR (Single European Sky Air Traffic Management Research). This is what is suggested with the development of the project MONALISA, which intends to improve the efficiency and safety of shipping, while reducing its environmental footprint (MONALISA, 2015). The overall concept is known as Sea Traffic Management (STM) and includes four parts, which are Strategic Voyage Management, Dynamic Voyage Management, Flow Management and Port Collaborative Decision Making, the last of which is the focus of this study. STM proposes to put in place infrastructure that allows for sharing of vessels’ locations and intentions and dynamically optimized planning of routes, based on factors such as weather and traffic.

\(^{1}\) For any reader unfamiliar with shipping specific terms, Appendix 1 provides a list of explanations and definitions.

\(^{2}\) For reference, 0.5 % of global CO\(_2\) emissions are produced by rail transport, 1.9 % by international aviation and 21.3 % by road transport (these figures do however not exclusively concern freight of goods). (Buhaug et al, 2009)
The economic research so far has estimated that implementing dynamic route planning for the Baltic Sea region would result in a positive impact for society of approximately 100 million euros per year (Andersson and Ivehammar, 2014). These results are based on the cost savings that would come from a 1% reduction in travelled routes, and the benefits of ships being able to respond to actual available capacity in ports (meaning that ships can slow down and save fuel instead of spending unproductive time at anchor). The majority of the benefits show up in the former category, and the single most important cost saving overall is the mitigation of environmental costs to society of greenhouse gas emissions. In addition to environmental cost savings, the study finds that there is significant operational cost savings potential for shipping businesses. Bunker costs, which make up the largest cost category for shipping companies according to Stopford (2010), are highly sensitive to vessel speeds (see for instance Wang, 2009). This relationship implies that operational reforms that give rise to increased opportunities for speed optimization are valuable for business reasons as much as for environmental reasons (to the extent that these are separate).

A study on the role of sea ports in the emissions from the maritime transport chain concluded that while ports do not themselves produce a significant share of the emissions, they can have a large impact through focusing efforts to reduce the emissions of ships (Gibbs et al. 2014). One of the recommended courses of actions for ports is to share information regarding delays and capacity updates in berthing, so that incoming ships can optimize their fuel consumption by adjusting speed prior to arriving in port. Information regarding delays can also be shared in the other direction, i.e. from ships to terminals, enabling an optimization of preparation and resources in port. This idea for increased efficiency in port calls through dynamic sharing of information is also described elaborately in the MONALISA project as the collaborative decision making in port activities, abbreviated as Port CDM (Lind et al, 2014).

1.2. Problem
MONALISA prescribes through the concept Port CDM a port in which involved actors collaboratively through real-time sharing of information optimize the port approach and turnaround process. This means that locations, intentions and capabilities of terminal operators, service providers and ships are shared to ensure:
1) Higher predictability in estimated berthing times, giving rise to shortened time spent waiting for berthing by approaching the port at a more optimized speed.

2) Improved readiness of terminal operators and service providers in port, resulting in shortened service times and total port turnaround times.

The problem at hand is identifying, quantifying and monetizing the effects of this proposed reform of port activities. The concept of port collaborative decision making (Port CDM) has not yet been included in a cost benefit analysis, which motivates the attempt to value the port activities proposed by MONALISA. Since the operational reforms concern many maritime ports in Europe, there is a need for developing a method of estimating costs and benefits of collaborative operations. This need can be alleviated with a pilot study.

1.3. Purpose

The purpose of this study is to derive a method for estimation of the total societal benefits and costs of transitioning to collaborative port operations that are planned on the basis of dynamically shared information (the benefits and costs of Port CDM). The method is applied for sea traffic in the Port of Gothenburg.

1.4. Method

1.4.1 Case study

Since port operations are logistically complex and the particulars of the approach processes may differ between ports, this is an area that is well suited for a case study. According to Ellram (1996), case study research methodology in logistics is valuable when exploring implementation or adaption of new systems or for theory building. The Port of Gothenburg is chosen as the area of study, since there is availability of data for this purpose. The Port of Gothenburg is also a relevant area of study from a European perspective, since it has a relatively diversified traffic flow by type, though there is an underrepresentation of dry bulk and an overrepresentation of RoRo traffic in comparison to large European sea ports (see section 6.1 for elaboration).

1.4.2. Estimation of impacts

This study is based on welfare theory and port economics. A methodological approach is used that allows for estimation and approximation of all benefits and costs that are expected to result
from the implementation of the collaborative port policy. This approach considers two separate benefit categories owing to the dynamic exchange of information in the collaborative port:

- Voyage speed optimization prior to port approach, enabling operational and environmental cost savings.
- Shorter service times and subsequently shorter total port turnaround times, enabling operational, capital, time and environmental cost savings.

The magnitude of benefits is estimated by analyzing data for port approaches in the Port of Gothenburg during the month of August of 2014. Estimated total costs of aggregated waiting and service times as well as an analysis of the precision in estimated times of arrival provide a benchmark for estimating cost savings for different scenarios of policy effectiveness. Inputted values for unit costs are estimated with market prices where applicable, such as for the price of fuel. For costs where market prices are not readily available, such as air emissions, recommended inputs from for instance the Swedish Transport Administration are used. For costs that cannot be easily approximated, values from previous research are used.

Investment and operational costs related to implementation, maintenance and surveillance of the Port CDM policy are estimated through comparison with previous studies.

1.4.3. Data
The data used in this study was collected and structured by Viktoria Swedish ICT, and is a detailed set of information regarding the port calls made to the Port of Gothenburg during the month of August in 2014. The information regards estimated times of arrival, actual arrival and departure at certain states in the port approach. For reasons of confidentiality, no specific information regarding any vessel, agent or service provider is disclosed. A more exhaustive explanation of the data used is given in section 6.2. The limited time frame of one month’s data poses the question of whether the results of the estimation of benefits are representative for the long run. This question of sample sensitivity is discussed in section 7.6.

1.4.4. Basic assumptions
This study considers the effects of a fully implemented Port CDM concept in the Port of Gothenburg against a business-as-usual scenario. It is assumed that Port CDM is neutral with

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3 The reader may note that all estimated benefits in this study are cost savings. For this reason, the terms cost savings and benefits can be seen as synonymous.
regard to changes in traffic safety. Therefore, neither effects of increased nor decreased safety of operations are estimated. The real rate used for discounting future costs and benefits to the present is 3.5 %, which is the recommended rate by the Swedish Transport Administration (2015). The financial discount rate or opportunity cost of capital used is 5 %, which is recommended by the European Commission (Florio et al, 2008).

1.4.5. Delimitations
The benefits that are estimated in this study are those hypothesized within the Port CDM concept, and there is therefore a possibility that there are effects which are not described in the concept that will be ignored in this study. The object of study is the cargo ship, and benefits in the form of cost savings are related to the operation of cargo ships. The reason for this is that the overwhelming majority of effects are expected to relate to the voyage and turnaround process of cargo ships. This does however mean that potential changes in other modes of traffic, such as road or rail, are not considered in monetary terms.

1.4.6. Methodological considerations and possible shortcomings
Since some effects of implementing Port CDM are not directly measurable, this study makes use of unit values from different sources. These values are used in attempt to come as close as possible to estimating figures that are not directly observable, such as for instance the societal cost of emissions. This may lead to erroneous estimates of effects, because such costs may be difficult or technically infeasible to derive a unit value for. However, given that care is taken by the researcher to find the most appropriate measures, and sensitivity analyses are carried out where uncertainty is high, the risk of erroneous conclusions can be minimized. (Boardman et al. 2010)

As Johnson and Styhre (2015) notes, because real world logistical problems are complex, ill-structured and messy, research in the area of shipping efficiency would do well to try to gain an understanding what causes inefficiencies at the micro level. Ignoring this level may lead to a lack of understanding for the actor incentives that may not be aligned with the incentives of the system as a whole. While this study does have some plurality in its methodological approach, a deeper understanding for incentives of individual actors in the port system would perhaps lead to different conclusions regarding potential improvements.
1.5. Disposition
The structure of this study is as follows:

- In Chapters 2 and 3 the relevant theoretical foundations of Welfare and Port Economics are reviewed.
- In Chapter 4 the Port CDM concept is described, together with a justification of the logistical and analytical framework that is used as a basis for estimation of benefits.
- In Chapter 5 a detailed explanation of the methodological approaches used to estimate the benefits of increased port efficiency is given, as well as a presentation of a feasible cost scenario for Port CDM.
- In Chapter 6 the results arrived at through applying the methodology outlined in chapters 4 and 5 are presented and analyzed.
- In Chapter 7 the results arrived at in this study are discussed, together with additional effects that are not included in the results.
- In Chapter 8 conclusions regarding the estimation of economic viability for Port CDM in the Port of Gothenburg are presented.
2. Welfare Theory and Cost Benefit Analysis

2.1. Performing a Cost Benefit Analysis

Cost benefit analysis (CBA) is a method of policy or project evaluation, in which costs and benefits to society are estimated to determine economic viability. Cost benefit analysis is based on welfare theory and its fundamental utilitarian assumptions. Welfare theory can be described as the study of how the utility of individuals and firms is affected by the allocation of resources. CBA is normative, in that it is concerned with how resources ought to be allocated, and the analyst performing the CBA is tasked with making a recommendation for a course of action. A measure of economic viability of a project is the net present value, which is the net of benefits and costs discounted to the present. Given a defined project or policy, it is the analyst’s job to choose a scope for the analysis (i.e. whose costs and benefits to consider), identify the effects of the project or policy, estimate the impacts quantitatively or otherwise over the project’s lifetime and monetize them, discount the monetized impacts, perform sensitivity analyses and make recommendations based on the computed net present value. Valuing the impacts of a policy change requires predicting all of the impacts that this alternative policy would lead to. If one cannot predict these impacts in a straightforward way, it is necessary to find an indirect method of prediction, such as a statistical estimation or a theoretical basis for forecasting. In the absence of directly observable market prices, the monetizing of impacts has to be done with estimations of unit values. The uncertainty associated with these unit values further necessitates the use of sensitivity analysis. (See for instance Boardman et. al, 2010)

A relevant question to ask in a study of shipping efficiency is: If there is an efficiency gap in shipping (see for instance Johnson et al, 2014), meaning that there appear to be cost-effective measures that have not been implemented, why has not this gap been closed? What about the current situation is evidence that introducing a collaborative framework for ports would improve the efficiency of operations? If this question can be answered – the analytical task of the CBA can be defined as evaluating the economic viability, by assessing whether the benefits of implementing such a framework would outweigh the costs. Some possible reasons for the apparent efficiency gap in shipping are elaborated on in section 3.6.
2.2. Costs and benefits for whom?
A common problem in cost benefit analysis is defining what is meant by societal impacts – the question of who is included in society. Typically, cost benefit analysis includes impacts incurred on anyone within a nation that is affected by the project under evaluation (Mattson, 2006). One reason for limiting the scope to national borders is practical; impacts incurred on other nations may be small enough to ignore. Another reason is that political decisions concerning the project under evaluation are often made by a national entity. Since MONALISA is a cooperative project including several European countries, the scope of this analysis extends to anyone within the European Union that is affected by impacts of the policy.

Since the term societal cost is used frequently in this study, a clarification may be necessary. Societal costs and benefits can be distinguished from internal or private costs and benefits. Societal costs and benefits include both internal and external effects. To make this clear, an example for shipping can be made. Aside from the costs of bunker to shipping companies, there are external costs to society of the air pollutants that are emitted in the process of burning fuel. An externality can be defined as an uncompensated impact, positive or negative, from the actions of one person on the safety, health or happiness (i.e. well-being or welfare) of another person. The occurrence of externalities in a market implies that inefficiencies will be persistent if no action to internalize the effect is taken. This efficiency occurs because there is a discrepancy between private and social costs. Continuing with the relevant example of pollution (which is a negative externality), the social cost of the burning of fuel is higher than the private cost since it includes the long-term societal cost of global warming. (See for instance Mankiw, 2014)
3. Port Economics

3.1. The port as a production facility

The port can be thought of as a production facility, where production is measured in throughput per year, either in tons or equivalent size containers (such as TEU containers). The inputs related to throughput, or factors of production, are quays, cranes, stevedoring labor, administrative staff, transit storage space and time of ships and land transport vehicles. The production unit is a terminal, consisting of a number of berths where cargo is loaded and ship services are performed. To get an idea of how port throughput is produced, Jansson and Schneerson (1982) defines the following identity of demand and supply in ports:

\[ Q = \varnothing \cdot n \cdot \mu \]  

Where \( Q \) is total throughput, measured in number of containers or tonnage per year, and \( \varnothing \) is expected occupancy rate of berths, which is defined by the average time that berths are being used divided by the total time they are available. \( \varnothing \) is therefore a number between 0 and 1, where 1 indicates that berths are always occupied. \( n \) is the number of berths in the port and \( \mu \) is the expected throughput capacity per berth per unit of time (e.g. potential container throughput per berth per year). It is clear from this identity that there are several ways for the port to meet increased demand. In the short run it is possible to run a higher occupancy rate of berths, and in the long run it is possible to increase capacity by building more berthing locations or by increasing the productivity of berths.

Jansson and Schneerson go on to define a function for long run total costs of port services. Note that these costs are not only costs incurred on the port operator, but the total costs to all actors involved in port operations. This category includes cargo owners, ship owners, transport intermediaries (shipping companies), terminal operators and service providers.

\[ LRTC = A + cn + \nu \lambda [q(n, \lambda) + s] + \sum_i f_i(Q) \]

Where \( A \) is long run fixed costs – for example of the approach channel facility and other major infrastructure linked to the port, \( n \) is number of berths, \( c \) is capital cost per berth, \( \lambda \) is number of ship arrivals per unit of time, \( \nu \) is the time cost of a ship per unit of time (e.g. hours or days), \( q \) is the expected time that each ship will spend queuing and is a function of \( n \) and \( \lambda \), \( s \) is the expected
service time of ships and is given by the state or technology of the cargo handling. $Q$ is total throughput, $f$ is the complementary factors required for different stages of transferring goods, and can also be thought to include labor costs. There are also emissions associated with port operations, which can be thought to be included in the last term of the function if the costs are expanded to include total societal costs of port operations (though the emission variable is not explicitly mentioned in Jansson and Scheerson (1982)).

When the number of berths is regarded as fixed, the following short run cost function is defined:

$$SRTC = F + v\lambda[q(\lambda) + s(\lambda)] + \sum_j g_j(Q)$$

(3)

Where $F$ is short run fixed cost, including both those costs that were assumed to be fixed in the long run, and the capital cost of berths, which is not variable in the short run. The dynamic of the short run cost is different. For instance it cannot be assumed that service time per ship is independent of the level of traffic volume. Since capital inputs are given it is expected that service times increase (possibly quite drastically) with the level of traffic volume – which can lead to the problem of port congestion.

3.2. Port efficiency and the role of time in port operations

In evaluating efficiency improvements of port operations, it becomes necessary to discuss definitions of port efficiency. According to Suarez-Aleman and Hernandez (2014), it is difficult to reach a precise agreement of the definition of port efficiency because the complicated network of agents comprising the shipping logistics chain may all be the cause of delays and bottlenecks. Importance of such a definition is however vital, since policy to improve efficiency must be correctly evaluated. In a recent study investigating ways to evaluate subsidies and grants given by the European Union to various projects aimed at increasing the competitiveness of maritime corridors over modal alternatives such as rail or road transport, it is found that port efficiency mainly comes down to time. The more time it takes to move cargo through a port, the less efficient the port, and in effect the entire maritime corridor is. In short sea shipping, which is subject to intermodal competition, reducing total time spent in port is an efficiency increasing
measure that is incentivized for ports and government since it increases the competitiveness of a relatively environmentally efficient mode of transport.\footnote{Suarez-Aleman and Hernandez, 2014}

A recent study of the technical efficiency of African ports indicates that ports with high technical efficiency with regard to only total throughput (Q) relative to inputs are not generally time efficient; where time efficiency is defined as being technically efficient with regard to throughput divided by time (Q/t) relative to inputs (Suarez-Aleman et al, 2014). The authors admit that the ports that are only efficient with regard to quantities may not be facing much or any competition. The point is however, that ports, especially those that handle short sea shipping, need to be properly evaluated on the basis of time efficiency, preferably with disaggregate data, decomposing the port approach to identify specific bottlenecks. The reason why this is especially important in short sea shipping is that ships engaged in short sea voyages spend a much larger portion of their time in port and are therefore more sensitive to the efficiency of ports.

In a case study of two bulk shipping companies primarily engaged in short sea voyages, Johnson and Styhre (2015) find that approximately 40 % of ships’ time is spent in port, and that half of this time is devoted to unproductive waiting.\footnote{Johnson and Styhre, 2015} According to interviews with respondents at the studied shipping companies, time savings of 1 to 4 hours in port would be possible if such factors that can be influenced by better planning were improved. The instances of unproductive waiting time that could be reduced are for instance waiting for the pilot, waiting for cargo to reach the quay, port congestion and low productivity. According to a quantitative analysis of the companies’ voyage history, the estimates of 1 to 4 hours are conservative estimates of the time savings potential, if the factors causing unnecessary waiting time are addressed. (Johnson and Styhre, 2015)

It should be noted however that there are significant differences in voyage planning capabilities between shipping companies that operate liner services (regular, pre-scheduled services), and companies that operate tramp services (irregular services both in space and time, often dealing with spot contracts) (Stopford, 2009). An easy way of understanding the distinction between liner and tramp shipping is to view liner shipping as a bus service and tramp shipping as a taxi service.

\footnote{Short sea shipping can be defined as shipping that does not involve an ocean crossing.}
\footnote{Unproductive waiting time constitutes time in port that is spent waiting for processes to start. Processes include for instance administrative procedures and loading/unloading.}
3.3. Queuing time

A fundamental problem for port activities is that there is a tradeoff between capacity utilization and queuing times. A large capacity supply results in low queuing times for arriving ships, but also in a relatively low utilization of capacity. A smaller supply results in a higher rate of utilization/occupancy of capacity but at the risk of incurring queuing costs for shippers. If there are significant fluctuations in short-term demand, this optimization problem becomes even more difficult. There is therefore an inherent need for the port to be able to predict flows of incoming traffic. In the standard model it is assumed that arrivals can be approximated with well-known probability distributions, such as the Poisson distribution. This approach is taken and modeled by Jansson and Schneerson (1982).

Jansson and Schneerson (1982) show that the probability distribution function that corresponds to the arrival of ships in the studied areas can be approximated as Poisson. In doing this it is possible to derive a simple function for expected queuing time for ships arriving at the port. The factors that influence expected queuing time are expected service time, number of berthing locations and berth capacity utilization. The standard model predicts a couple of interesting things: First, the expected queuing time is expected to increase exponentially when capacity utilization is high. This gives rise to a J-shaped curve. Second, in a multiberth facility there are economies of scale, meaning that if the number of berths increases at the same rate as demand, queuing times will actually go down. Put differently, to keep queuing times constant, a port does not need to expand its number of berths at the same rate as the volumes are increasing. This second part has to do with the probability of arriving to find that no berths are available, which is a decreasing function of the number of berths, even with capacity utilization held constant.

For a multiberth facility, the mean queuing function can be expressed as:

\[ q = \frac{s}{n(1 - \varnothing)} * p \]  

(4)

Where \( n \) is number of berths, \( s \) is mean service time at a berth, \( \varnothing \) is the mean occupancy rate, and \( p \) is the probability that there will be no free capacity when a ship arrives. It should be noted that this function requires that the port applies a first come, first serve policy – which may not always be the case.
It can be seen from equation 4 that queuing is linearly related to service time, implying that a decrease in service time is instrumental to alleviating problems of congestion. However, it is not only the average service time that matters, but also the variance of service times. The Pollaczek-Khinchine formula (Pollaczek, 1930) illustrates that no matter the distribution of $s$, the queuing time (for a single berth facility) can be stated as:

$$q = \frac{\lambda [s^2 + Var(s)]}{2 \times (1 - \lambda \times s)}$$  \hspace{1cm} (5)$$

Or, substituting $(\lambda \times s)$ for $\emptyset$ and denoting the relative variance $\nu(s)$ as $Var(s)$ divided by $s$:

$$q = \frac{\emptyset [s + \nu(s)]}{2 \times (1 - \emptyset)}$$  \hspace{1cm} (6)$$

The implication of the Pollaczek-Khinchine formula is therefore that, given a rate of occupancy, reducing the mean and the variance of service time are equally important to lowering expected queuing time (Jansson and Schneerson, 1982).

Empirical findings presented in Jansson and Schneerson (1982) seem to indicate that this general prediction of equation 4 does not exactly hold true, though it does approximate the general form of the “true” queuing curve. It turns out that the slope of the J-formed curve is not as dramatically increasing at the right end, and the level of the function is not as low as predicted for the lower spectrum. Some of the realities not captured by the simplified model are:

- There is an upper bound to queuing (if a queue is too long ships may go somewhere else).
- Service times may not stay constant as capacity utilization rises.
- There may be bottlenecks in the chain of throughput that are not related to the loading or unloading of cargo.

### 3.4. Energy consumption and emissions from port activities

According to the World Port Climate Initiative, the greenhouse gas emission producing activities in ports can be grouped into three scopes (WPCI, 2010):
1) Port direct sources. These are emissions that come from activities directly under the control of the port administration. Examples may include port owned or leased vehicles, buildings or port owned equipment.

2) Port indirect sources. These are emissions that come from for instance purchased electricity to run port owned buildings and operations.

3) Other indirect sources. These are emissions that are associated with for instance the operations of port tenants. These include both lesser emission factors such as employee commuting and greater factors such as emissions from ships while waiting and during berthing operations.

A study of the relative magnitude of these scopes for a selection of British ports concludes that the latter category is the greatest contributor to emissions (Gibbs et al, 2014). Different estimates are given for what proportion of ships total emissions are incurred during port activities, ranging from 6 % (Fitzgerald et al. 2011) to 10 % (Habibi and Rehmatulla, 2009). Though there are some measuring uncertainties, total emissions from vessels at berth are estimated to be comparable to all emissions that are related to port operations (i.e. category 1 and 2 put together). The study by Gibbs et al. suggests that port policy should be focused to influence the behavior of vessels that use the port services, in order to reduce emissions both from seaside operations and from voyages. Different methods of action to this end are discussed, such as strategies for rewarding ships that slow down by offering discounted port fees. A point that is argued is that strategies that focus on voluntary action, as opposed to for instance mandatory speed limits, do not impact port competitiveness negatively and are therefore preferable.

3.5. Energy consumption and emissions from ships

The air pollutants that are emitted by the consumption of bunker fuel are $NO_x$ (a generic term for the nitrogen oxides $NO$ and $NO_2$), PM (fine particulate matter), $SO_2$ (sulphur dioxide) and $CO_2$ (carbon dioxide). The largest of these emissions (not to be confused with the most costly) is by far $CO_2$ (SEPA, 2010). The amount of $CO_2$ that is emitted can be described as a linear function of fuel consumption: a fixed factor multiplied by the fuel consumption of a vessel. The factor can be assumed to be fixed if the diesel combustion is very efficient, i.e. if nearly all carbon can be converted to $CO_2$. Assuming this is the case, Wang (2009) proposes a coefficient of 3.13. This gives the following function for $CO_2$ emissions:
\[ CO_2 = 3.13 \times FC_{ij} \]  

Where \( FC_{ij} \) is the amount of fuel used for a vessel for a trip between a port of origin \( i \) and a port of destination \( j \). The fuel consumption of a vessel \( k \) during this trip can, according to Wang (2009), be approximated as:

\[
FC_{ij} = \left[ MP_k \times MFOC_k \times ML_k \times \left( \frac{S_{tk}}{S_{ok}} \right)^3 + AP_k \times AFOC_k \times AL_k \right] \times \frac{d_{ij}}{24 \times S_{tk}}
\]  

(8)

Where \( MP_k \) is the power of the main engines, \( MFOC_k \) is the bunker consumption rate of this main engine, \( ML_k \) is the load factor of the main engine, \( AP_k \) is the power of the auxiliary engine, \( AFOC_k \) is the bunker consumption rate of this auxiliary engine and \( AL_k \) is the load factor of this auxiliary engine. The term \( S_{tk} \) represents the operational speed of the vessel and \( S_{ok} \) represents the design speed of the vessel, both measured in nautical miles per hour. The quota of these therefore measures the ‘off design’ conditions of the trip, and can from the function be seen to carry a relatively large importance to fuel consumption. The term \( d_{ij} \) is the distance between the port of origin and the port of destination.

An alternative, but quite similar representation of the relationship between fuel consumption and speed is given by Stopford (2009):

\[
F = F^* \left( \frac{S}{S^*} \right)^a
\]  

(9)

Where \( F \) is actual fuel consumption, \( S \) is the actual speed, \( S^* \) is the design speed and \( F^* \) is the design fuel consumption. Stopford notes that the exponent \( a \) can be approximated as 3 for diesel engines. This relationship is sometimes called the cube rule, since the exponent can in many cases roughly be assumed to be 3.

Given the linear relationship between \( CO_2 \) and fuel consumption, and the cubic relationship between fuel consumption and the quota of operational and design speed, it is clear that a percentage reduction in speed will lead to a greater reduction in \( CO_2 \) emissions. According to a simulation by Wang (2009) of container ships calling to U.S. ports in 2005, the relationship between speed reduction rates and \( CO_2 \) reduction rates is as presented in table 1.\(^6\) The vessels are

\(^6\) Note that this scenario assumes that no extra ships are employed to cover the loss of output.
assumed to travel at optimally profitable speeds at 2005 fuel prices and freight rates, and then stepwise lower speed in response to policy mandates.

Table 1 - Speed reduction rates and CO₂ emission reduction rates

<table>
<thead>
<tr>
<th>Reduction in speed (%)</th>
<th>Reduction in fuel consumption and CO₂ emissions (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>18</td>
</tr>
<tr>
<td>20</td>
<td>34</td>
</tr>
<tr>
<td>30</td>
<td>49</td>
</tr>
<tr>
<td>40</td>
<td>61</td>
</tr>
<tr>
<td>50</td>
<td>71</td>
</tr>
</tbody>
</table>

Note: The described relationship between speed and fuel/emission reduction is estimated by Wang (2009).

Note that depending on the operational and design speeds of the vessel, this may be an underestimation of the reductions in emissions implied purely by the cube rule. This is because not all fuel use is variable with respect to speed. As can be seen from equation (6), the fuel consumed by the auxiliary engine is independent of speed. In calculating plausible savings in emissions and fuel from speed adjustment, the cube rule may thus be too simplistic.

It might be assumed that ships on average select voyage speeds that optimize profits. An implication of this is that if saved bunker costs from slowing down would exceed the additional time costs that are incurred by slowing down; the ship would opt for a lower speed (and similarly, if time costs saved from speeding up would exceed the additional bunker costs; the ship would choose to steam at a higher speed). If the external costs to society were fully internalized, we would expect ships to find it optimally profitable to travel at the socially optimal speed. The degree of internalization in shipping is however relatively low, meaning that the industry does not carry a large extent of its marginal costs to society (SEPA, 2010). The implication of this is that speed reductions which would be beneficial to society as a whole may not always be profitable for shipping companies.

In reducing speed there is normally the tradeoff between bunker costs and time costs. In the case of slowing down to decrease unproductive time spent at port waiting for berthing, this is not the case since no time is assumed to be added to the total port approach time.
3.6. Why the efficiency gap? – Possible reasons for current inefficiency

A necessary starting point for any cost benefit analysis is defining the root of inefficiency in the current situation. Some markets do not function efficiently because of market failures, meaning that deadweight loss occurs because some sort of distortion is present in the market. Market failures may for instance be related to information asymmetry or externalities. Other markets are inefficient because of non-optimal government intervention. The reason why it is necessary to define a root cause of inefficiency is that if the market is considered to work properly, efficiency would presumably be obtained without any intervention. (Boardman et al., 2010)

In the case of shipping, the premise for the MONALISA project is that if communication were better shared among actors, there would be efficiency gains to be had that are linked to better coordination and governing towards efficiency for the whole transport system. The distortion is therefore at least in part related to lack of information and system-wide integration, which is the primary concern of STM.

Another potentially distorting aspect that could be considered is whether there are contractual incentives that prohibit efficiency gains. As noted by Buhaug et al. in the IMO report “Prevention of Air Pollution from Ships” (2009), theoretically sound improvements to efficiency may not be successful if the involved actors do not have any incentives to contribute. The full potential of STM as a whole, and Port CDM as a sub concept, therefore hinges on contracts being formulated in such a way that there is not an incentive for involved actors to contribute to inefficient behavior. Shipping contracts that require chartered vessels to arrive in their destination port as soon as possible, or at “utmost despatch”, are standard practice (Alvarez et al, 2010). A related instance of contractual inefficiency that may limit the potential for STM is demurrage. Demurrage is compensation paid to a ship operator for days in port spent waiting, for instance because of congestion (Buhaug et al, 2009). If demurrage is high relative to fuel costs, there is an obvious tendency for the ship operator to arrive as early as possible, even if not contractually obliged to do so, diminishing the fuel (and emissions)-reducing incentive. It is important to note that under such contracts, many potential benefits of STM (including those arrived at in this study) are seriously put to question.

Part of the distortion is also related to the negative externalities of air pollution. As previously mentioned, the degree of internalization in shipping with regard to air pollution is low, and as
such the incentive for ships to sail at socially optimal speeds is low. Though increasing the degree of internalization is not within the scope of MONALISA, a part of the hypothesized efficiency gain is related to reduced environmental costs due to the fact that ship speeds are currently not socially optimal in general. (See for instance Andersson and Ivehammar, 2014)

Though these sources of barriers to efficiency are interesting to study individually, this study explores the potential long run benefits of Port CDM under the assumption that contracts are efficient, in the sense that costs and cost savings are incurred on the party who is in charge of making the decisions concerning these, and that systemically inefficient behavior is not contractually rewarded.
4. Sea Traffic Management and the collaborative port

As stated in the introduction to this study, the MONALISA project, initiated by the Swedish Maritime Administration, aims for increased safety and environmental efficiency as well as operational efficiency through the implementation of a new organizational structure known as Sea Traffic Management (MONALISA, 2015). The idea for Sea Traffic Management (or STM) is to be realized in four operational concepts: Strategic voyage management (SVM), Dynamic voyage management (DVM), Port collaborative decision making (Port CDM) and Flow management (FM). The three former concepts respond to different phases of a voyage, where SVM represents preliminary planning and routing, DVM represents changes and updates in route planning along the way, and Port CDM represents the berthing and turnaround process of a vessel. The fourth concept FM is related to the overall guidance of vessels through difficult parts of the voyage. (Lind et al, 2014)

The four “legs” of STM are not however viewed as isolated from each other, since the success of one leg depends on the functionality of the others. Therefore there is some difficulty in isolating costs and benefits of one leg without regard for the costs and benefits of STM as a whole concept. Though some costs and benefits can be viewed as specific to Port CDM, the effects at large are system-wide. The concept Port CDM is further described here, since it includes the relevant implications for a study of port efficiency.

The purpose of having a “collaborative port” is to enable smoother and more seamless operations at sea. Since ports are a potential bottleneck in shipping efficiency, coordination in ports is necessary for reaching the full potential of Sea Traffic Management. By homogenizing the terminology used by involved actors and linking the communication in a port approach, high accuracy in predictability of arrival and berthing times are enabled. This in turn leads to more optimal berth productivity. The meaning of homogenized communication and terminology is that all actors should use the same terms to describe states, and that the process should be described in a standardized format. Actors involved in the port approach process in turn subscribe to this standardized information service, and are thereby informed of any changed states in the process. Another key service in Port CDM is the Port Call Synchronization (or alternatively ETA Planner), which is a service that informs a vessel operator when it is suitable to arrive at the port traffic area, based on the expressed capacity of terminal operators. (Lind et al, 2014)
The port approach process can be illustrated as a series of states reached by the approaching vessel in collaboration with service providers and terminal operators in port. The states are for example arrival at traffic area, towage and pilotage to quay, berthing for loading and service operations, towage and pilotage from quay, and finally departure. A smooth turnaround necessitates that the actors providing services to incoming vessels are ready on time, and that terminal operators are able to provide berthing capacity on time. Port operations that are collaboratively planned by these actors therefore strive to increase transparency regarding intentions, capacity and readiness – enabling efficient turnarounds. An illustration of the turnaround process is given in figure 1 on page 22.

In a cost benefit analysis where the effects of a new policy are estimated, it is important to focus only on that which can actually be expected to be caused by the new policy (Boardman et al., 2010). In the defining stages of MONALISA, and specifically in the work that concerns efficiency in ports, the hypothesis is that the implementation of collaborative operations in ports will lead to higher efficiency through higher predictability. The proposal to measure the efficiency change in port organization is therefore to estimate the value of increased predictability in estimated arrival and berthing times. For instance, it is desirable to observe low differences between estimated time of arrival or berth and actual time of arrival or berth. The same holds for estimated and actual times of departure of ships to the port area. Key performance indicators of predictability in port operations are therefore:

\[
(Actual\ time\ of\ X - Estimated\ time\ of\ X) = Error\ in\ estimate\ of\ reaching\ the\ state\ x
\]

\( (10) \)

X is the relevant state that is being described, such as arrival, berth or departure. For brevity some short hand descriptions of estimated and actual times of occurrence are used throughout this study. These are summarized in table 2.
### Table 2 - Abbreviations of state occurrences and estimates

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>ETA</td>
<td>Estimated time of arrival at traffic area</td>
</tr>
<tr>
<td>ATA</td>
<td>Actual time of arrival at traffic area</td>
</tr>
<tr>
<td>ETB</td>
<td>Estimated time of berth</td>
</tr>
<tr>
<td>ATB</td>
<td>Actual time of berth</td>
</tr>
<tr>
<td>ETD</td>
<td>Estimated time of departure</td>
</tr>
<tr>
<td>ATD</td>
<td>Actual time of departure</td>
</tr>
</tbody>
</table>

Because uncertainty regarding the readiness of port service providers is decreased as the port approach draws closer, the deviation described in equation 10 is supposed to become smaller and smaller as the execution phase draws closer. The intuition of why low deviations between estimated and actual times are desirable is that both vessels and service providers can optimize their operations prior to actual arrival and berthing. Vessels can adjust speed to avoid as much unproductive waiting time at anchor as possible if there is a delay, thereby making operational cost savings in terms of fuel consumption. Service providers can ensure the best available readiness to perform operations without causing unnecessarily lengthy service times for vessels in the port.

#### 4.1. The funnel model of efficiently developing estimates

Since the typical port approach has several sequential states, and these require coordination of different actors, there are plenty of potential phases where delays can occur. To study efficiency, it is necessary to observe the precision of estimated arrival times to different states. The states are those described in the “metro map” (see figure 1 on next page), and are: arrival at port traffic area, arrival at pilot station, arrival at tug station, arrival at berth and departure from berth. For the different ETA:s, different areas of time can be defined to indicate how far away in time the state is and thus how large the deviation between estimated and actual time is allowed to be.
For the different areas of time in each process, a reasonable or acceptable deviation can be defined. This deviation should be defined as the amount of deviation that does not disturb planning or prevent “just in time” operations. For example, a relatively large margin of error in ETA is acceptable 48 hours before arrival at the port traffic area, since other actors are not dependent on a precise estimated arrival time at this point. Up to this acceptable limit for error, there is no cost in the estimate deviating from the actual time, and it is according to this principle that the acceptable level of deviation could reasonably be decided.

For a vessel’s approach to port (or for the aggregate of all vessels during a period of time) any observed deviations that are large enough to disrupt planning can be summed up and estimated as a cost. This cost can consist partly of unproductive laytime and partly of fuel and emission costs that come from a missed opportunity to optimize voyage speed prior to port approach. These costs are dependent on ship characteristics, since expected bunker consumption and time cost differs between ship types, sizes, load etc.

---

7 The term “just in time” can be taken to have different meanings and connotations. The term is used here to signify that port operations should be planned as to ensure that no actor should have to wait for another actor at a station for an unnecessary amount of time.
In a hypothetical scenario where all actors involved in the vessel’s approach to port have the same correct and updated information about estimated arrival times well in time to plan their operations, it is reasonable to expect that the margin of error in estimates should be diminishing and approaching zero as arrival to the state draws closer. This relationship can be visualized as a funnel, which is depicted in figure 2 on page 24. The percentage values of deviation (arbitrarily chosen here) represent acceptable deviations.

It is possible to divide the process of arriving at a state in junctures or phases (as described by Lind et al (2014)), for example:

1) Long-term planning
2) Mid-term planning
3) Short-term planning
4) Operational planning

The different phases represent different demands of predictability for planning. Long-term planning can for instance be based upon a first estimate of when the vessel will arrive in the port traffic area, which is given as soon as the vessel leaves the previous port. As the voyage to the port of call goes on, the precision of the estimated time of arrival becomes more important, for the terminal which needs to supply a berthing location and for the pilot and the tug operator who need to be available to enable the port approach. Preparation and planning of port actors that is based upon a precise estimate of arrival decreases the risk that the vessel will have to wait when it arrives to the traffic area. Given a precise and continuously improving estimate, the terminal, in collaboration with other port actors, can give the vessel an ETB – which for example provides the vessel with the opportunity of responding to a delayed berthing time by lowering speed and postponing its ETA.
The idea is not that there is a certain function of time that deviations should evolve according to. Implementing Port CDM is intended to improve the accuracy of estimates, and therefore it is helpful to consider the funnel concept as a benchmark of efficient predictions. Observing the actual deviations with this concept in mind, it is easier to define where the largest room for improvement is, and to hypothesize what impact might result from the policy implementation. The impact categories of higher predictability are the cost savings described in the next chapter.
5. Methodological approaches to estimating effects of the policy

5.1. Benefits of collaborative port operations

If the deviations that are disturbances to planning of port operations can be seen as causing non-optimal vessel speeds prior to a port approach, it is relevant to consider the potential savings in fuel and emission costs from optimizing speed – since non-optimal speed choices prior to port approach leads to unproductive laytime. The total societal cost savings that are related to speed optimization therefore consist of bunker and emission costs. This can be defined as the first category of benefits:

Benefit category 1: potential savings in time spent waiting for berthing by approaching the port at a more optimized speed:

\[ B1 : \text{bunker} + \text{emission cost savings} \]  \hspace{1cm} (11)

Deviations that disturb the planning of port operations might also lead to extra service times that could have been avoided altogether. Since departure from a state (commencing of towage to berth for instance) is a coordinated process that demands that all participating actors are on location at the same time, poor precision means that one or more of the actors will have to wait for another actor before the port approach can continue. This also constitutes unproductive laytime, but the difference is that this laytime could not have been avoided through speed optimization. Instead it can be assumed that more precise estimates would have led to better preparation in port for the vessel’s arrival, and a possibility of reducing the overall service time. The total societal cost savings that are related to shortened service times consist of the time cost of cargo, as well as manning, capital bunker and environmental costs. This can be defined as the second category of benefits:

Benefit category 2: decreased time at quay (service time), reduction of total port turnaround time:

\[ B2 : \text{time cost} + \text{fuel and emission cost of laytime} + \text{manning cost} \]
\[ + \text{capital cost savings} \]  \hspace{1cm} (12)
The potential cost savings described in both categories are summed up in table 3, which also specifies to whom this cost saving is incurred and what inputs can cause variations in estimates.

Table 3 - Categorized benefits that are hypothesized to result from Port CDM

<table>
<thead>
<tr>
<th>Cost saving</th>
<th>Category</th>
<th>Incurred on</th>
<th>Sensitive to inputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time cost</td>
<td>Opportunity cost of capital</td>
<td>Cargo owner</td>
<td>Financial discount rate, assumed per-ton value and load rate</td>
</tr>
<tr>
<td>Bunker cost</td>
<td>Voyage cost (internal)</td>
<td>Shipping company (or other party if contractually stated)</td>
<td>Fuel price and assumed baseline vessel speed</td>
</tr>
<tr>
<td>Emission cost</td>
<td>Voyage cost (external)</td>
<td>Society</td>
<td>Emission unit values and assumed baseline vessel speed</td>
</tr>
<tr>
<td>Manning cost</td>
<td>Operational cost</td>
<td>Shipping company (or other party if contractually stated)</td>
<td>Wage costs</td>
</tr>
<tr>
<td>Capital cost</td>
<td>Operational cost</td>
<td>Ship owner</td>
<td>Assumed ratio of capital costs to total operational costs</td>
</tr>
</tbody>
</table>

5.1.1. Bunker and emission costs of ships in motion
In this subsection the method used for calculating fuel and emission costs for ships in motion will be described. To make the method of calculation completely transparent, hypothetical benefits will be calculated using an example. Recall that a suggested effect of the policy under evaluation is that ships can adjust speed prior to port approach, and that speed adjustments may have relatively large effects on fuel consumption. The estimates of fuel consumption per kilometer, and emissions of air pollutants per kg of fuel are given by the Swedish Environmental Protection Agency (SEPA) in a report from 2010 that assesses the pollution from the maritime sector. Because SEPA’s estimates of fuel consumption and emissions are based on specific vessel sizes, some interpolations will be needed to estimate the costs of ships of varying sizes. The main estimates of emission unit values are those of ASEK 5 (Swedish Transport Administration, 2015), and the differing unit values used as low and high sensitivity estimates are from the EU
program Clean Air for Europe (CAFE) (Holland et al, 2005) and the Stern Review (Stern, 2006). The unit values per kg of air pollutants emitted are shown in table 4.

**Table 4 - Unit values of air pollutants in euros per kg**

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Low unit value</th>
<th>Main unit value</th>
<th>High unit value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nox</td>
<td>3.08 (CAFE)</td>
<td>9.23</td>
<td>9.23</td>
</tr>
<tr>
<td>PM2,5</td>
<td>0</td>
<td>0</td>
<td>41.32 (CAFE)</td>
</tr>
<tr>
<td>SO2</td>
<td>3.11</td>
<td>3.11</td>
<td>12.97 (CAFE)</td>
</tr>
<tr>
<td>CO2</td>
<td>0.07 (Stern)</td>
<td>0.12</td>
<td>0.40 (ASEK, high)</td>
</tr>
</tbody>
</table>

Note: Estimates are from ASEK 5 unless otherwise stated. All values are converted to 2014 prices.

As noted, the fuel consumption of the main engine of a vessel can be approximately described as proportional to the quota of actual speed to design speed to the power of three. This means that as a ship reduces its speed, it saves a relatively large amount of fuel consumed by the main engine, while the auxiliary engine(s) basically consumes a fixed amount. For a hypothetical container ship with a capacity of 14,000 TEU, the fuel consumption per kilometer is 0.372 tons at an average speed of 19 knots (35.2 kilometers per hour) (SEPA, 2010). The fuel consumption per day is 314 tons. The total cost of the ship’s emissions of air pollutants can be computed using the unit values for these pollutants.

According to SEPA (2010), the container vessel emits per every kg of fuel consumption 0.0722 kg of NO\textsubscript{x}, 0.00108 kg of PM, 0.00156 kg of SO\textsubscript{2} and 3.188 kg of CO\textsubscript{2}. Since the fuel consumptions of the vessels per kilometer have been computed, it is possible to derive the amount of emissions per kilometer. Per kilometer the container vessel emits roughly 27 kg of NO\textsubscript{x}, 0.4 kg of PM, 0.58 kg of SO\textsubscript{2} and 1,186 kg of CO\textsubscript{2}. Using the main unit values shown in table 4, the emissions cost per kilometer travelled can be summarized to 397 euros. Per day (assuming that the vessel operates at the average observed speed of 35.2 km/h) these costs are summarized to 336,000 euros.

Regarding bunker costs, there are reasons to consider what type of marine fuel that is to be used as a benchmark for costs. From January 1:st 2015, the limit values for sulphur content in fuel in emission control areas (ECA), including the North Sea and the Baltic Sea, have been changed.
from 1 % of weight to 0.1 % (IMO, 2015). The implications of this is that ships that are not already using marine fuel with a sulphur content lower than 0.1 % will have to switch to a fuel type that satisfies this regulation. The type of fuel that is generally considered to be in use from 2015 is marine gas oil (MGO). Therefore, the appropriate benchmark cost for shipping fuel should be the price of MGO, and not previously used fuel types, such as LS180 (which has a sulphur content of lower than 1 %). According to a news and intelligence agency for the marine fuel industry, the Rotterdam price of MGO stood at 654 euros per ton in August of 2014, which is the time that the sample used in this study concerns (Ship and Bunker, 2015). Using this price, the fuel cost of a day’s travel for the example container ship would be 206,000 euros.

Summarizing the bunker and emission costs, the cost per day that is relative to the operational speed of the vessel is 542,000 euros. It can be noted that the emission costs to society are larger than the fuel costs.

Assuming that the calculations by Wang (2009) can be used to describe ships in the general sense, a 10 % reduction in speed would lead to an 18 % reduction in these costs. For the large container vessel, this would mean a cost saving of around 97,500 euros per day, given that the alternative would have been to keep a high speed and spend time waiting for berthing.

5.1.2. Ship costs of laytime

*Time cost of cargo*

In assessing the costs of unproductive laytime, it is necessary to consider not just the costs of running a ship, but the time cost for the cargo owner. The intuition is that during the time that cargo is in transit (including the time it spends in port) there is an opportunity cost of capital for the cargo owner. If the cargo owner had used her capital for investment elsewhere, she would have earned a certain rate of return. This rate of return is the (opportunity) cost of capital. During a port to port transit of \( d \) days, the cargo owner foregoes a capital return that is equal to the time cost \((TC)\):

\[TC = d \times \text{rate of return} \]

\(^{10}\)Price of MGO is converted from the USD market price to euros using the average 2014 EUR/USD rate.
Where $V$ is the value of the cargo and $r$ is the annual rate of return of the foregone investment opportunity, known as the cost of capital or financial discount rate. Choosing the appropriate financial discount rate is difficult. In this study a rate of 5% will be used, since this is the rate that is recommended by the European Commission’s Guide to Cost-Benefit Analysis (Florio et al, 2008).

Though this measure is subject to rough estimations, since the true value of cargo is seldom easy to know, it does provide a necessary approximation of the time cost aspect of laytime. A problem with this method is that varying types of cargo have differing values. A dry bulk carrier loaded with wood chips will for instance have a significantly lower per-ton value than a container ship carrying clothes or consumer electronics. To avoid having to guess the cargo value of every vessel in the studied sample, an average per-ton value of 795 euros is assumed. This figure is estimated by UNCTAD (2008) to be the average value of seaborne cargo.

**Bunker and emissions**

Ships consume fuel when they are not in motion, and the extent is largely determined by vessel-specific factors. To assess the likely fuel consumption of a ship at berth or at anchor without having to pore over the details of every ship and engine construction, it is useful to turn to a recent international survey. In a survey of a number of northern European ports, Hulskotte and van der Gon studies the fuel consumption of a number of different types of seagoing ships while at berth (Hulskotte and van der Gon, 2010). For several ship types, they find significant relationships between ship sizes (gross tonnage) and fuel consumption per hour (measured as the total fuel consumption at berth divided by the time the ship is at berth). These relationships, which are estimated as regression equations, are used here to approximate the fuel consumptions of the relevant vessels for this study. Though there may be differences in actual fuel consumption and that which is predicted by these relationships, the estimations are based on empirical work that concerns similar vessel traffic to that of the Port of Gothenburg. The regressions are of the simple linear form:

$$TC = V \cdot \frac{d}{365} \cdot r$$  \hspace{1cm} (13)
\[ FC_h = \alpha + \beta \times GT \] (14)

Where \( FC_h \) is the estimated fuel consumption at berth per hour, \( \alpha \) is an intercept, and \( \beta \) is the slope factor for the influence of gross tonnage on fuel consumption.

**Manning**

Though the development toward automation has lessened the amount of crew needed to operate a ship, manning costs may account for as much as half of total operating costs for some vessels. The level of these costs depends primarily on the size and employment conditions of the crew, and on the ship’s flag state. The flag state of a ship sets certain regulations that affect the costs of manning, such as the minimum crew number for a certain vessel. The trend toward fewer crew members on board any merchant ship is however clear; average crew numbers have gone from 40-50 in the 1950’s to closer to 15 today. (Stopford, 2009)

Through interviews with shipping companies and the Swedish Shippers Association, Andersson and Forsblad (2010) estimates average monthly labor costs for two broad categories of crew members: officers and mates. Though this information is regarding Swedish shipping conditions, it is assumed that the net wages are more or less competitive and represent the value that would be created by an employee in a best possible alternative scenario. The reason why net wages are used instead of gross wages is that the wages in high-cost countries are heavily subsidized by the public sector. (Andersson and Forsblad, 2010)

As in the CBA report of implementing dynamic route planning in the Baltic Sea region (Andersson and Ivehammar, 2014), the approximations of crew numbers and costs are used here to estimate the costs of manning. It is worth noting that both the estimated wages and crew numbers are subject to variance around their respective means. Since this study deals with broad categories of vessel types and sizes, this may be even more so.

**Capital costs**

Consider a hypothetical short sea shipping company which owns and operates a fleet of 25 cargo ships. These ships each make an average of 182 port calls per year, meaning that each trip on averages takes 48 hours, of which one third are spent in port, and the entire fleet makes a total of 4,562 port calls annually. If ships can reduce their annual time in port by 2.5 hours per trip, or 456 hours annually, this means that each ship can on average make nearly 10 more trips per year.
at the same speed and in order to reach the previous figure of 4,562 port calls annually, one less ship is needed.

In the long-term perspective where all resources are variable, it is reasonable that a given reduction in port turnaround time (and therefore a reduction in fleet size) should lead to an equal reduction in capital costs. The monetary benefit of capital cost savings is however difficult to determine and may vary greatly between ship owners, since the capital cost is largely determined by specific characteristics such as ship age and size. Stopford (2010) finds that capital costs is in fact the second largest cost category in terms of running ships. Andersson and Ivehammar (2014) assume that capital costs make up between 30 and 35 % of total costs of ship operation (that is bunker, manning and capital costs). As not to overestimate the potential cost savings in the face of uncertainty, capital costs will in this study be assumed to make up 30 % of total operational costs.

5.2. Costs of collaborative port operations
The costs of transitioning to and running the concept of collaborative port operations are somewhat difficult to define, since the MONALISA project is not yet fully developed as this study is being made. Costs of STM as a whole can be assumed to fall intensively on the physical investments of infrastructure such as the proposed Sea Traffic Coordination Centers (STCC:s) that advise vessels in route planning, and the manning and operation of these. However, since STCCs, or any equivalent sea traffic coordination mechanisms, are not included in the scope of Port CDM, they are not relevant for this study. It should however again be noted that the parts of STM are difficult to separate, and the success of Port CDM hinges on the benefits that are provided by the other parts. But since the scope of this study is isolated to port operations, no specific concern is paid to the physical investments in STCCs. Instead, the coordination costs are assumed to fall on Port Control. Though the concept of Port CDM does not require collaborating actors (ships, agents, tow operators etc.) to implement new systems but instead allows these actors to share information in a way that integrates existing systems, there are assumed to be some costs of learning and transitioning to subscribing to and being able to supply data to this service.
To provide reference and validity to the figures, this study bases the assessment of costs from implementing and maintaining Port CDM on a comparable project: the aviation project that is the counterpart of Port CDM, Airport CDM.

In a CBA of Airport CDM (EUROCONTROL, 2008) it is estimated that the total implementation cost of the concept in one representative airport is 3.83 million euros spread out over ten years. Added to this is a figure of 7.03 million euros for operating costs, also divided over the ten following years. The total cost estimated for Airport CDM in one airport with a horizon of ten years is thus 10.86 million euros. The effects of the policy are divided into four categories, where each category represents a collaborative partner. These partners are: airlines, ground handlers, the airport, and air traffic control. The costs are largely related to training, development and improvement of IT, project management and operation. Though the concept Airport CDM is similar to (Sea)Port CDM, there are obviously some major differences between airport and seaport operations, one being the volume of arrivals and departures. For the representative airport considered in the CBA of Airport CDM, 140,000 aircraft movements were assumed annually (counting only departures). This can be compared to the number of port approaches in the Port of Gothenburg in 2013, which was 5,581. The obvious difference is that air traffic handles a larger frequency of movements, while shipping handles larger volumes per unit. In terms of operating costs for coordinated arrival planning services, this should imply that shipping is less cost intensive.

Even though the ETA and ETB planning interface of Port CDM is not intended to replace any existing system, but rather integrate with existing systems, it can be assumed that some level of adjustment for ships is needed, as not to underestimate the cost. A previous discussion on the subject has suggested that on average ships would have to make investments of 5,000 euros to comply with STM (Andersson and Ivehammar, 2014). A difficulty here is knowing how many unique ships that call to the port every year. Assuming a high figure, 50 % of the 5,500 calls are estimated to be made by ships that are not recurrent tenants. In this case, 2,250 unique ships

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11 For reference, Arlanda airport handles 112,500 movements annually (counting only departures).
12 In the observed sample (one month of traffic in the Port of Gothenburg) the 276 approaches are made by a total of 118 unique vessels, the majority of which are recurring during this month. Against this background it can be assumed that 50 % non-recurring tenants annually is a high-cost scenario.
visiting the Port of Gothenburg annually would mean an annual cost of 2.25 million euros. To compare this figure to Airport CDM, the implementation costs for airline carriers are estimated at a total of 0.15 million euros. This may however be an unfair comparison, since the systems are not identical and different levels of existing digital infrastructure may already be in place. The point is however to assess the costs in a way that makes understatement very unlikely. The operators of vessels that intend to approach a port are one of the key collaborators in Port CDM, since they supply data and take part in the collaborative decision of when it is appropriate to reach a certain state. Another group of key collaborators are port operators, such as terminals, tugboat operators and linesmen. Like vessel operators, these actors are collaborators in the sense that they provide data in the form of estimates of when their services can be supplied, and are as such a link in the collaborative decision making process. The cost for port operators is difficult to estimate with much certainty. As with vessels it can be assumed that there is a cost of investment and a cost for managing and running the concept. Turning again to Airport CDM, the highest estimates of investment costs incurred to the airport and ground handling are 0.14 million euros every year for IT improvements, 0.28 million euros for project management every year during the first four years 0.11 million euros for software development during the first three years and 0.28 euros for service providers’ IT costs every year. Added to these are annual operating costs of 0.67 million euros per year, incurred only to the airport (and is noted by the Airport CBA study to be an unlikely high-cost case scenario, in which the airport needs to purchase a whole new system). In absence of other estimates, these costs are assumed to be valid for Port CDM, and are summarized in table 5 and table 6. (EUROCONTROL, 2008)

There are also costs of coordination related to Port CDM, where Port Control is the service provider. The relevant comparison in terms of Airport CDM is the Air Traffic Control, for which the high estimates of costs are estimated to be 0.34 million euros for implementation and 0.095 million euros annually for maintenance.

---

13 This is assuming that depreciation occurs over 5 years, which is the same assumption that is made by Andersson & Ivehammar (2014).
Table 5 - Cost estimates of Port CDM by category divided by category

<table>
<thead>
<tr>
<th>Cost category</th>
<th>Estimate (million euros)</th>
<th>Frequency</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ship investment</td>
<td>2.23</td>
<td>Annual recurrence in perpetuity</td>
<td>Author's calculations based on Andersson and Ivehammar (2014)</td>
</tr>
<tr>
<td>Port IT improvement</td>
<td>0.14</td>
<td>Annual recurrence in perpetuity</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
<tr>
<td>Project management</td>
<td>0.28</td>
<td>Annual recurrence first 4 years</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
<tr>
<td>Software development</td>
<td>0.11</td>
<td>Annual recurrence first 3 years</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
<tr>
<td>Operating costs</td>
<td>0.67</td>
<td>Annual recurrence in perpetuity</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
<tr>
<td>Service provider IT costs</td>
<td>0.28</td>
<td>Annual recurrence in perpetuity</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
<tr>
<td>Port control implementation costs</td>
<td>0.34</td>
<td>One-off</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
<tr>
<td>Port control maintenance costs</td>
<td>0.11</td>
<td>Annual recurrence in perpetuity</td>
<td>Airport CDM (high-cost scenario)</td>
</tr>
</tbody>
</table>

Note: All estimates are converted to 2014 prices

Table 6 - Cost estimates of Port CDM by chronological order

<table>
<thead>
<tr>
<th>Frequency category</th>
<th>Estimate (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>One-off costs (year 1)</td>
<td>0.336</td>
</tr>
<tr>
<td>Annual costs years 1-3</td>
<td>3.815</td>
</tr>
<tr>
<td>Annual costs year 4</td>
<td>3.703</td>
</tr>
<tr>
<td>Annual costs in perpetuity (after year 4)</td>
<td>3.423</td>
</tr>
</tbody>
</table>
6. Estimated benefits and costs of Port CDM in the Port of Gothenburg

6.1. Area of study – the Port of Gothenburg described
The Port of Gothenburg is the largest port in Scandinavia when it comes to container traffic, with an annual throughput of around 860,000 containers in 2013. Other important categories of traffic in the port are motor vehicles (the number of car imports and exports passed through the port stood at 163,000 units in 2013) and crude oil (20,000,000 tons in 2013). The incoming and outgoing traffic in the port is to a large extent international; in fact 90 % of port approaches in 2013 were made by ships coming from or headed for international destinations. The total number of port approaches to the Port of Gothenburg during 2013 was 5,581. (ESPO, 2014)

Examining the European Sea Ports Organizations (ESPO) data for 2011-2014, three major types of traffic can be identified for the Port of Gothenburg. These are categorized as: liquid bulk carriers (tankers), general containerized cargo carriers (GCC) and roll on- roll of vehicle carriers (RoRo). The distribution of these types of traffic during 2011-2014 has been relatively stable, as is shown in figure 3.

Figure 3 - Types of goods in the Port of Gothenburg annual throughput

Liquid bulk represents approximately 50-55 % of total tonnage, GCC is at 20 % and RoRo represents 25-30 %. A fourth category, which is not shown in the graph is solid bulk which represents approximately 0.3 % of tonnage during these years. (ESPO, 2014)
Of liquid bulk there are two categories, which are of interest to discriminate between since petroleum products are often carried by special purpose vessels. These categories are crude oil and refined petroleum products. For the purposes of this study, tankers in the observed sample have been classified as either oil or chemical tankers. For the years 2012 and 2013 the division of tonnage between these categories is approximately 60% refined products and 40% crude. For 2014 the difference is reduced somewhat, owing primarily to a reduction of tonnage in refined products. Note that these figures concern both imports and exports (though crude oil is exclusively an import and refined products are mostly an export). (ESPO, 2014)

Another interesting fact to note from the ESPO data is the percentage of containers passed through the port that are empty. Noting the figures from the years 2012 to 2014, the ratio of empty containers appears to be approximately 20%.

**Figure 4 - Division of empty and full containers in the Port of Gothenburg**

![Division of empty and full containers in the Port of Gothenburg](image)

Note: Figure is based on data from ESPO (2014)

Figure 5 shows how the division of cargo types differs between the averages of the 12 largest ports in Europe (measured as total tonnage throughput).\(^1\) As can be seen, in Gothenburg there is a large underrepresentation of solid bulk and a large overrepresentation of RoRo traffic in relation to other major ports in Europe.

\(^1\) The 12 largest European ports by throughput are Rotterdam, Antwerp, Hamburg, Amsterdam, Algeciras, Marseille, Bremen Bremerhaven, Le Havre, Valencia, Genova, Dunkerque and London (ESPO,2014).
6.2. Analysis of port approach data

The dataset used in this study is a collection of information of port approaches to the Port of Gothenburg during the month of August in 2014. The data describe a total of 487 approaches in varying detail, with data of occurrences and estimates from a number of different actors involved in the approach process. \(^{15}\) With this information, analyses of arrivals at certain states can be carried out with regard to the development of arrival estimates to the state and the actual time of arrival.

The number of cargo vessels which are included in the dataset is 276. \(^{16}\) The distribution of vessel types and capacities is presented in table 7.

**Table 7 - Cargo vessels approaching the Port of Gothenburg during August of 2014**

<table>
<thead>
<tr>
<th>Type</th>
<th>Number</th>
<th>Mean DWT</th>
<th>Mean GT</th>
<th>Total tonnage capacity (number times mean DWT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>62</td>
<td>34,253</td>
<td>31,605</td>
<td>2,123,680</td>
</tr>
<tr>
<td>Tankers</td>
<td>111</td>
<td>13,454</td>
<td>8,595</td>
<td>1,493,423</td>
</tr>
<tr>
<td>General Cargo</td>
<td>12</td>
<td>4,252</td>
<td>3,290</td>
<td>51,022</td>
</tr>
<tr>
<td>RoRo</td>
<td>91</td>
<td>12,363</td>
<td>28,105</td>
<td>1,125,052</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>276</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\(^{15}\) The collection of these data was performed by Viktoria ICT.

\(^{16}\) Passenger ferries and cruise ships have been excluded from the analysis.
The distribution of vessels is quite similar to the annual distribution of cargo handled in the port (see figure 3), but seen from the perspective of cargo capacity there appears to be a relative overweight of container traffic, which can be seen in figure 6.\textsuperscript{17}

**Figure 6 – Comparison of sample and average traffic distribution**

![Graph showing comparison of sample and average traffic distribution.](image)

**Note:** 2011-2014 average throughput figures are based on data from ESPO (2014)

For each of these 276 vessels, there is information regarding at which time the vessel arrived at quay to begin berthing operations, and at which time the vessel departed from quay, meaning that total time spent at quay can be defined as:\textsuperscript{18}

\[
(\text{ATD from quay} - \text{ATB}) \times 24 = \text{Hours spent at quay}
\]

The most frequently occurring time spent at quay is 7 hours, and the mean is around 15 hours. Around these values, the distribution is quite scattered, which can be seen in the distribution plot in figure 7.

\textsuperscript{17} This figure is complicated to interpret, as it compares deadweight tonnage (vessel cargo capacity) with actual throughput. If there is a systematic difference between capacity and how much is actually loaded/unloaded in the Port of Gothenburg for any of the categories, this comparison is not accurate.

\textsuperscript{18} Since the values in the dataset are formatted as days, the multiplication factor 24 is used to compute hours.
Figure 7 - Sample distribution of hours at quay in the Port of Gothenburg

Given this information about each vessel’s specific time at quay, it is possible to calculate the benefits of reducing this laytime, using the methodology outlined in chapter 5. This will be elaborated upon in coming sections.

There is also the question of vessels waiting at anchor before proceeding to the terminal of destination. In the traffic area of the Port of Gothenburg, there are multiple designated anchoring areas. In a study by SSPA and Viktoria Swedish ICT (2015) of bunker savings potential for anchoring vessels approaching the Port of Gothenburg (also during August of 2014), it is found that 17% of vessels approaching the port lay at anchor for more than 1 hour before continuing to a terminal. The mean time spent at anchor for these vessels was 17.9 hours. Using AIS data to construct speed profiles of the observed vessels, it is found that not all the anchoring vessels would benefit from slowing down, since some vessels are already travelling at very low speeds. Out of the studied sample of 320 vessels, 39 vessels, or 12%, could have saved fuel by slowing down prior to approaching the area. The results of the study thus indicate that the average vessel approaching the Port of Gothenburg spends \((0.17 \times 17.9) = 3\) hours at anchor outside the port before berthing operations and that \((0.12 \times 17.9) = 2.15\) hours can be assumed as a cost saving potential.
6.3. Deviation in estimation for different states
For 83 of the port approaches, the dataset includes logs describing the update of estimates and states reached during the port call process. Most notably, these logs include dynamic updates of when the vessel is expected to arrive at berth. For each event logged there is a timestamp, so that every ETB update can be traced to an exact time. Since there is also information about what time the vessel arrived at berth (ATB), it is possible to construct a picture of the ETB updating process that resembles that of the funnel concept presented in figure 2. A complete picture with aggregate data for all of the logged approaches is given in figure 8.

Figure 8 – Error in estimates of berthing times

Note: This figure plots the error in estimate of when a ship is expected to arrive at berth versus time until a ship actually arrives at berth. All 83 approaches and their respective estimates are presented in aggregated form.

It can be observed that, while deviations are larger early in the port call process, not all uncertainties disappear as arrival draws closer. This may be a symptom of inefficiency in communication. A breakdown of average deviations for different voyage phases shows this picture more clearly, which is seen in figure 9.
Figure 9 - Average error in estimates of berthing times

Note: This figure plots the average of errors in estimates presented in figure 8. Errors have been divided into five segments, representing different phases. Averages are calculated from absolute deviations, so that negative and positive values do not cancel out. In practice this is done by recalculating deviations as \( \sqrt{(ATB - ETB)^2} \).

The upward shift in average deviations marks an inconsistency with the funnel model of efficiently developing estimates. Assuming that inefficient estimates lead to inefficient planning and utilization of resources, the detection of this anomaly can be seen as evidence that there is room for significant improvement in the port planning process.

6.4. Implications of the observed deviations
During the last 48 hours of a port call process, the data in this sample indicates that the error in estimate of arrival is highest during the final 8 hours. Because of this anomaly, there is reason to assume that efficiency gains can be made in the short-term planning of ships and port operators. Given that the implementation of Port CDM successfully enables terminal operators, service providers and ships to decide collaboratively at which time arrival is appropriate, the result ought to be decreased service time and/or better opportunities for speed optimization during these last hours of the voyage.

It should be considered that the poor precision in late estimates may be due to the fact that ships have arrived in the traffic area but are forced to lie at anchor until berthing slots become available. There is unfortunately little information to say conclusively whether this is so, but the logs of a number of port approaches do reveal that for these vessels long periods of anchoring prior to berthing are at least not uncommon. This would help to explain the rise of uncertainty during the latter stages of a port approach; certainty regarding physical arrival may be quite high.
as the vessel is approaching the port, but as the vessel arrives it is faced with the problem of having to wait for an available slot. If there was better back-and-forth communication between terminal/service operators and the ship during the whole port call process, this capacity problem could be dealt with earlier and anchoring times could potentially be reduced.

Another fact to note from figure 8 is that the overwhelming majority of the deviations are positive, meaning that arrival occurs later than estimated. Estimates appear to be biased towards time optimism. Another way of putting it is that the planned or estimated arrival is subject to continuous delays; postponing rather than bringing forward the time of arrival. The implication of this is that for ships to be “just in time”, slowing down, rather than speeding up, appears to be the wide-ranging solution.

In terms of voyage costs this is indicative of that the most relevant scope of time in which speed optimization can be improved is the final few hours of the voyage. Better information through sharing of intentions and capabilities should help to smooth the port call process and allow for fine tunings in speed.

As far as the potential for reducing unproductive laytime goes, it is difficult to give an empirically founded estimate of how much reduction in total laytime that would result from the implementation of Port CDM. This is partly because it is difficult to distinguish how much of time spent at berth that is due to actual service and loading operations and how much that is due to other factors. As referred to earlier, Johnson and Styhre (201) find that an improvement of 1 to 4 hours is well in the realm of what can be considered to be possible. This can at least be considered as a benchmark estimate.

6.5. Calculation of cost savings related to speed reduction prior to arrival at port
Recall from section 3.6 that both fuel consumption and air pollution emitted by a ship is highly sensitive to the speed of the vessel. Given that Port CDM allows for planning of arrival at port that is based on the expressed capacity of terminal and service operators in port, and the vessel is therefore able to incorporate this information earlier in the port call process, there is an opportunity for ships to reduce speed during the final few hours of a voyage. The costs that can be saved in substituting unproductive waiting time for time spent approaching the port at a slower speed are bunker and emissions costs. To calculate the possible impacts of the implementation of
Port CDM, it is helpful to first calculate the total hourly emissions and bunker cost for the vessels in the sample. The emissions costs are calculated as:

\[
\text{Emission cost per hour} = \text{Operational speed (km per hour)} \times \text{Emission cost per kilometer}
\]  

(16)

Where the assumed speeds for different types of vessels are those observed for different ship categories by SEPA (2010). These are presented in the third column of table 8.

**Table 8 - GT, assumed baseline speeds and emission costs for vessel types**

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>GT</th>
<th>Assumed baseline speed (km/h)</th>
<th>Emissions cost per km (euros)</th>
<th>Fuel cost per km (euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large container ship</td>
<td>140,000</td>
<td>35</td>
<td>397</td>
<td>243</td>
</tr>
<tr>
<td>Small container ship</td>
<td>10,000</td>
<td>46</td>
<td>63</td>
<td>38</td>
</tr>
<tr>
<td>Tanker</td>
<td>64,000</td>
<td>20</td>
<td>109</td>
<td>66</td>
</tr>
<tr>
<td>RoRo</td>
<td>18,000</td>
<td>33</td>
<td>61</td>
<td>39</td>
</tr>
<tr>
<td>General cargo</td>
<td>3,000</td>
<td>22</td>
<td>16</td>
<td>10</td>
</tr>
</tbody>
</table>

Note: Author’s calculations based on SEPA (2010) and ASEK 5

Emission cost per hour for the different vessels is calculated using SEPA estimates for air pollutants emitted per kilometer travelled (which is based on specific assumptions on ship size and characteristics), multiplied by the respective unit value of these pollutants (see table 4 for these unit values). To allow for a more realistic assessment of fuel consumed, the calculations in this study are adjusted for how much the gross tonnage of each ship deviates from the benchmark calculations by SEPA. The calculation of total emission cost (EC) per kilometer can be broken down as:

\[
\sum_{i=1}^{\text{GT}_i} \left( \frac{\text{GT}_i}{\text{GT}_{\text{type}}} \times \text{Emissions per km}_i \times \text{Unit values for emissions} \right)
\]  

(17)

A large deviation in GT from the examples used by SEPA results in a figure that may be much higher or lower than the emission costs presented in table 8, while a ship that closely resembles the example will have an estimate which is close to these figures. It should be noted that there may be a tendency of underestimating the fuel consumption of smaller vessels when using this method. This is because not all fuel consumption is variable with respect to size. This means that
a vessel that is much smaller than the type vessel which is used as a benchmark for that category will actually consume more fuel than estimated, because there is a lower bound to fuel consumption. The risk implied by this is thus that the benefits of speed adjustment may be underestimated. This will be addressed further when all benefits and costs are evaluated.

The hourly emissions costs calculated for the 276 ships in the sample summarize to a total of approximately 586,000 euros.

For calculating the cost of fuel, the same method is used to allow for deviations in ship size from the type vessels in SEPA’s calculations. The total bunker cost (BC) per km is calculated as:

\[ \sum_{i=1}^{276} BC_i = \sum_{i=1}^{GT_{type}} \left( \frac{GT_i}{FC_i \text{ per kilometer} \times \text{Market price of MGO fuel}} \right) \]  

(18)

Multiplied by the assumed speed of the vessel, the costs per km can be used to determine hourly costs. Assuming a market price of MGO fuel at 654 euros per ton, these costs summarize to a total of 367,200 euros.

The total of hourly emissions and bunker costs for the sample therefore summarize to approximately 953,200 euros of which roughly two thirds is made up of emission costs and one third of bunker costs. To state this as an annual figure, the sample size as a fraction of annual cargo ship approaches must be considered. Recall that this sample of 276 approaches is part of the total 5,581 (2013 figure) approaches. The annual (bunker and emissions) cost of one hour travelled at the assumed operational speed for all cargo traffic approaching the Port of Gothenburg can thus be estimated as:

\[ \frac{953,200}{\frac{276}{5,581}} \approx 19,300,000 \]  

(19)

The interpretation of this figure is that the total hourly bunker and emission cost for all sea traffic approaching the Port of Gothenburg during a year is estimated at approximately 19.3 million euros. The figure 19.3 million euros is estimated as a basis for estimating cost savings from speed optimization. Using Wang’s estimates (table 1), the cost savings of a 10, 20 and 30 % reduction in speed can be calculated. These figures are computed and presented in table 9 for three scenarios; vessels being able to slow down 1,2 or 4 hours before reaching the port.
### Table 9 - Monetary impacts of speed reduction scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Emission cost savings (million euros)</th>
<th>Bunker cost savings (million euros)</th>
<th>Total monetary impact (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 % reduction in speed for 1 hour</td>
<td>2.13</td>
<td>1.34</td>
<td>3.47</td>
</tr>
<tr>
<td>10 % reduction in speed for 2 hours</td>
<td>4.26</td>
<td>2.67</td>
<td>6.94</td>
</tr>
<tr>
<td>10 % reduction in speed for 4 hours</td>
<td>8.52</td>
<td>5.35</td>
<td>13.87</td>
</tr>
<tr>
<td>20 % reduction in speed for 1 hour</td>
<td>4.03</td>
<td>2.52</td>
<td>6.55</td>
</tr>
<tr>
<td>20 % reduction in speed for 2 hours</td>
<td>8.05</td>
<td>5.05</td>
<td>13.10</td>
</tr>
<tr>
<td>20 % reduction in speed for 4 hours</td>
<td>16.10</td>
<td>10.10</td>
<td>26.20</td>
</tr>
<tr>
<td>30 % reduction in speed for 1 hour</td>
<td>5.80</td>
<td>3.64</td>
<td>9.44</td>
</tr>
<tr>
<td>30 % reduction in speed for 2 hours</td>
<td>11.60</td>
<td>7.28</td>
<td>18.88</td>
</tr>
<tr>
<td>30 % reduction in speed for 4 hours</td>
<td>23.21</td>
<td>14.55</td>
<td>37.76</td>
</tr>
</tbody>
</table>

Note: The estimates presented in this table are based upon the speed-fuel reduction relationship presented in table 1. For instance: the calculation of a 10 % speed reduction for 1 hour is performed according to: 

\[
(0.18 \times \text{Hourly bunker and emission cost} \times 1) \times \text{1 hour}
\]

6.6. Calculation of cost savings related to shortened turnaround time in port

The costs associated with laytime in port are, as outlined in chapter 5, bunker cost and resulting emission cost of laytime, time cost of cargo and manning costs. For 270 of the 276 cargo ships in the dataset, these costs are estimated.\(^{19}\) Fuel consumption at berth is estimated according to the formula derived by an international survey (Hulskotte and van der Gon, 2010), and previously presented in section 5.1.2. The coefficients that are used to estimate the differing relationships (see equation 14) between gross tonnage and fuel consumption at berth are presented in table 10.

---

\(^{19}\) 6 of the observations had to be removed because of lack of information regarding arrival at berth.
Table 10 - Coefficients for estimating fuel consumption at berth

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Intercept</th>
<th>FC (kg per 1,000 GT per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Container</td>
<td>134</td>
<td>0.0043</td>
</tr>
<tr>
<td>Tanker</td>
<td>34</td>
<td>0.0169</td>
</tr>
<tr>
<td>RoRo</td>
<td>18</td>
<td>0.0056</td>
</tr>
<tr>
<td>General Cargo</td>
<td>7</td>
<td>0.0031</td>
</tr>
<tr>
<td>Chemical Tanker</td>
<td>34</td>
<td>0.0138</td>
</tr>
</tbody>
</table>

Note: Estimates in this table are based on Hulskotte and van der Gon (2010)

The average fuel consumption at berth of the ships in the sample implied by the coefficients in table 10 is 188 kg of fuel consumption per hour. This can be seen in relation to the average estimated fuel consumption of the same set of vessels while traveling at their assumed operational speeds, which is over 2 tons of fuel per hour. The total hourly bunker cost of laytime is calculated as:

\[ \sum_{i=1}^{n} BC_i = \sum_{i=1}^{n} (\hat{FC}_{i \text{ at berth}} \times \text{Market price of MGO fuel}) \]

(20)

BC for this sample totals to a sum of approximately 34,000 euros per hour, once again using a market price of MGO fuel of 654 euros per ton.

Analyzing the emission profiles of different vessels, the amount of air pollutants which are typically produced by consumption of one kilogram of fuel, it is possible to construct emission cost factors for each ship type. For the main cost scenario for emissions, these factors are summarized in table 11.

Table 11 - Emission cost factors

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Emission cost factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large container</td>
<td>1.068</td>
</tr>
<tr>
<td>Small container</td>
<td>1.079</td>
</tr>
<tr>
<td>Tanker</td>
<td>1.082</td>
</tr>
<tr>
<td>RoRo</td>
<td>1.013</td>
</tr>
<tr>
<td>General Cargo</td>
<td>1.077</td>
</tr>
</tbody>
</table>

Note: Emission cost factors represent the cost in euros per kg of fuel consumption for a certain type of vessel. Calculation of cost factors is based on SEPA (2010).
Hourly emission costs are estimated according to:

$$\sum_{i=1}^{\infty} EC_i = \sum_{i=1}^{\infty} (FC_i \text{ at berth} \times \text{Emission cost factor})$$  \hspace{1cm} (21)

The sum of these costs for the sample amount to approximately 55,000 euros per hour.

The third category of laytime costs, time cost of cargo, is determined by first estimating the value of the cargo carried by the ships. The calculations are sensitive to the variables load rate and assumed value per ton. Assuming a load rate of 60 %, which is below the observed 80 % ratio of full to empty containers arriving in the port (see figure 4), and an average value of 795 euros per ton of cargo (based on UNCTAD, 2008), the total value of cargo handled is approximately 2.29 billion euros. Assuming an interest rate of 5 %, the time cost of this cargo per hour is about 13,100 euros. This calculation is given by the formula for time cost (TC):

$$\sum_{i=1}^{\infty} TC = \sum_{i=1}^{\infty} \left[ \left( \frac{1}{365} \right) \times \left( \frac{1}{24} \right) \times r \times V \right]$$  \hspace{1cm} (22)

Regarding manning costs, it is difficult to determine the exact crewing information of each vessel, which is why it is helpful to consider rough estimates of crewing details by ship category. For calculating the hourly manning costs, estimates developed by Andersson and Forsblad (2010), and also used by Andersson and Ivehammarr (2014) are used. These are presented in table 12. The estimated sum of the hourly manning costs in the sample is approximately 17,100 euros.

### Table 12 - Crewing cost profiles of ship categories

<table>
<thead>
<tr>
<th>Ship type</th>
<th>Monthly crew cost (euros)</th>
<th>Daily crew cost (euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>General cargo</td>
<td>26,000</td>
<td>867</td>
</tr>
<tr>
<td>RoRo</td>
<td>49,800</td>
<td>1,660</td>
</tr>
<tr>
<td>Container small</td>
<td>43,900</td>
<td>1,462</td>
</tr>
<tr>
<td>Container large</td>
<td>55,800</td>
<td>1,859</td>
</tr>
<tr>
<td>Tanker small</td>
<td>35,700</td>
<td>1,190</td>
</tr>
<tr>
<td>Tanker medium</td>
<td>43,800</td>
<td>1,462</td>
</tr>
<tr>
<td>Tanker large</td>
<td>55,800</td>
<td>1,859</td>
</tr>
</tbody>
</table>

Note: Crewing cost profiles are based on Andersson and Forsblad (2010), and are converted to 2014 prices.
As mentioned in section 5.1.2, capital costs are assumed to be 30% of total operational costs. Operational costs are to be understood as the costs running a ship at sea. Therefore the relevant operational costs are bunker costs, manning costs and capital costs. Summarizing the two former cost categories, capital costs for the sample can be found to amount to an hourly figure of approximately 164,700 euros.

The sum of all these categories of laytime costs reveals that the total hourly cost of laytime for all the vessels in the sample is estimated at 283,874 euros, of which 58% is accounted for by capital costs. The division of costs among these categories is presented in table 13.

Table 13 - Hourly cost of laytime for sample

<table>
<thead>
<tr>
<th>Cost category</th>
<th>Monetary estimate (euros)</th>
<th>Fraction of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunker</td>
<td>34,017</td>
<td>12%</td>
</tr>
<tr>
<td>Emissions</td>
<td>55,006</td>
<td>19%</td>
</tr>
<tr>
<td>Time costs</td>
<td>13,053</td>
<td>5%</td>
</tr>
<tr>
<td>Manning</td>
<td>17,092</td>
<td>6%</td>
</tr>
<tr>
<td>Capital</td>
<td>164,705</td>
<td>58%</td>
</tr>
<tr>
<td>Total</td>
<td>283,874</td>
<td></td>
</tr>
</tbody>
</table>

Given the information in the dataset regarding time spent at quay, it is possible to estimate the cost of each vessel’s total time spent at quay. This is done by multiplying the hourly cost estimates (fuel + emissions + time cost + manning + capital) by the vessel’s specific time spent at quay. The total cost of time at quay for the sample amounts to approximately 3.61 million euros.

The cost savings implied, for different efficiency levels of outcome, are presented in table 14. Assuming that all ships can on average trim one hour off the time spent in port, the cost saving is estimated at roughly 5.87 million euros annually. This figure rises to 23.47 million euros under the more optimistic scenario in which ships can reduce turnaround times by 4 hours.

---

20 Note that bunker costs here are to be understood as bunker costs of ships in motion (as estimated in 6.5), and not to be confused with bunker costs of laytime.

21 Considering an annual estimate of hourly cost as \( \frac{283,874}{5,587} \approx 5,870,000 \)
Table 14 - Cost savings of reduced laytime for different scenarios

<table>
<thead>
<tr>
<th>Cost savings scenario</th>
<th>Monetary impact (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 hour reduced laytime</td>
<td>5.87</td>
</tr>
<tr>
<td>2 hours reduced laytime</td>
<td>11.74</td>
</tr>
<tr>
<td>3 hours reduced laytime</td>
<td>17.60</td>
</tr>
<tr>
<td>4 hours reduced laytime</td>
<td>23.47</td>
</tr>
</tbody>
</table>

6.7. Summary and commentary on estimated benefits

It should be reiterated that the only laytime in this study that is empirically observed for a large number of ships is the time that a vessel spends at quay. In practice, it is probable that ships spend comparable amounts of time waiting prior to actually being given a slot. This is waiting time that could be avoided by slowing down, as previously discussed, and is therefore not to be viewed in the same way as waiting time after having arrived at a loading slot. In fact, it becomes crucial to distinguish between these two types of waiting, since they have entirely different cost savings implications. When assuming that time spent at quay could be reduced, this is a benefit of reduced time in port in total, and subsequently reduced time for the entire voyage. There are major indirect benefits of this fact, including the increase in output that the ship can produce annually, provided that Port CDM or similar concepts are implemented system-wide (consider that the ship could shave off 1-4 hours of time in every port approach), and the reduced congestion that follows from the reduction in service time. To elaborate on the latter, consider again the mean queuing function (equation 4 of section 3.3), and think of this as a decrease in the variable $s$. Given that ships do actually face delays when arriving in port (probability of delay equal to 1 for simplicity, and holding occupancy rates constant), a reduction in service times will have significant domino effects for the waiting time costs of the entire transport system. This effect can however presumably be somewhat suppressed by the fact that ships can make additional trips every year (an increase in $\lambda$ and subsequently also in $\emptyset$) thereby increasing the expected number of annual arrivals in port. The system-wide effects will be elaborated on in chapter 9.

Turning to the direct benefits that have been estimated for the two major cost savings categories that are considered in this study, time spent waiting for berthing slot substituted for slower arrival speed and reduced unproductive laytime, these can be summarized in a series of different scenarios. To provide a scope which encompasses the possible benefits of Port CDM, one low-
impact scenario and one high-impact scenario are defined. Under the low-impact scenario, it is assumed that ships approaching the port can reduce their speed by 10 % for 1 hour, and that service times can be reduced by 1 hour on average. Under the high-impact scenario ships can reduce speed by 30 % for 4 hours before the port approach, and service times can be reduced by 4 hours. Under a median scenario, impact from speed reduction is estimated at the average point of the low and high scenarios, and laytime can be assumed to be reduced by 2.5 hours.

Table 15 - Estimated annual benefits of Port CDM: low, median and high-impact scenarios

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost savings from speed optimization (million euros)</th>
<th>Cost savings from reduced service time (million euros)</th>
<th>Total estimated benefits (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-impact</td>
<td>3.47</td>
<td>5.87</td>
<td>9.34</td>
</tr>
<tr>
<td>Median-impact</td>
<td>20.61</td>
<td>14.67</td>
<td>35.28</td>
</tr>
<tr>
<td>High-impact</td>
<td>37.76</td>
<td>23.47</td>
<td>61.23</td>
</tr>
</tbody>
</table>

Note: The low-impact scenario assumes that ships can reduce their speed by 10 % for 1 hour prior to reaching the port, and that service times can be reduced by 1 hour. The high-impact scenario assumes a 30 % speed reduction for 4 hours and service time reduction of 4 hours. The median-impact scenario assumed the average impact of the low and high cases, and a service time reduction of 2.5 hours.

There are a few things that should be noted regarding these results, such as why 30 % reduction in speed for 4 hours is considered as the high-impact scenario. It is not possible to reduce speed by 30 % for 4 hours and be just in time, if the sum of a vessel’s waiting time before berthing is less than one hour. Such a reduction of speed would lead to the ship arriving too late rather than on time. Judging from the estimation precision data from the larger sample of 83 approaches (figure 9), there is significant uncertainty regarding berth availability during the final hours before the berthing state is reached, which is an indication that uncertainty may cause longer waiting times than those observed for many vessels. Additionally, as the aforementioned anchoring study by SSPA and Viktoria Swedish ICT (2015) finds, ships wait at anchor outside the port for an average of over 2 hours. Considering the uncertainty of these figures with regard to representativeness for the annual flow of traffic, a 30 % reduction for 4 hours is justified as the high-impact scenario even though this is a slight underestimation of the total waiting times observed.

---

22 For a vessel that is 4 hours away from its destination at baseline speed, the impact of a 30 % speed reduction (high impact scenario) is an increased trip time of 43 %, or 1.7 hours. For the low-impact scenario (10 % reduction in speed for one hour) the corresponding trip time impact is 11.1 % or 0.11 hours.
As briefly mentioned in section 6.5, there may be a tendency of underestimating the benefits from fuel and emission cost savings at berth due to not regarding lower bounds to fuel consumption when adjusting for GT. Though it is difficult to determine the magnitude of this bias, it can be stated that 184 of the vessels in the sample of 276 are in fact smaller than the benchmark examples, meaning that two thirds of the vessels are potentially affected. This bias may be seen as less serious considering that the tendency is to underestimate benefits, in light of the fact that all estimation scenarios of benefits do in fact appear to be larger than costs (see section 6.9 for elaboration), meaning that the risk of coming to a false conclusion because of this potential error is minimal.

6.8. Calculation of benefits under alternative emission unit values
Another central issue that should be addressed is the magnitude of emission cost savings, relative to other categories. Since the total benefits are to a large extent made up of emission cost savings, there is a significant sensitivity to the assumed unit values of the emitted pollutants. This necessitates analyzing how the results are affected by choosing alternative estimates of these unit values. This sensitivity analysis is carried out by redoing the calculation of impacts in section 6.5 and 6.6 using the low and high unit values of emissions described in table 4. Tables 16 and 17 show the results of these calculations under the low, median and high-impact scenarios described in 6.7.

**Table 16 - Estimated annual benefits of Port CDM under low emission unit values**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost savings from speed optimization (million euros)</th>
<th>Cost savings from reduced service time (million euros)</th>
<th>Total estimated benefits (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-impact</td>
<td>2.26</td>
<td>5.22</td>
<td>7.47</td>
</tr>
<tr>
<td>Median-impact</td>
<td>13.41</td>
<td>13.05</td>
<td>26.45</td>
</tr>
<tr>
<td>High-impact</td>
<td>24.56</td>
<td>20.88</td>
<td>45.43</td>
</tr>
</tbody>
</table>
Table 17 - Estimated annual benefits of Port CDM under high emission unit values

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cost savings from speed optimization (million euros)</th>
<th>Cost savings from reduced service time (million euros)</th>
<th>Total estimated benefits (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-impact</td>
<td>5.42</td>
<td>6.90</td>
<td>12.32</td>
</tr>
<tr>
<td>Median-impact</td>
<td>32.24</td>
<td>17.24</td>
<td>49.49</td>
</tr>
<tr>
<td>High-impact</td>
<td>59.07</td>
<td>27.59</td>
<td>86.66</td>
</tr>
</tbody>
</table>

With these figures, the spectrum of total societal benefit estimates is broadened. The low-impact, low emission valuation case produces an estimate of 7.47 million euros in annual benefits while the high-impact, high emission valuation case produces a corresponding annual estimate of 86.66 million euros. A narrower spectrum is given by comparing the median-impact scenario under the three different emission valuation assumptions. These estimates are compared in table 18.

Table 18 - Estimated annual benefits under median-impact scenario for low, main and high emission values

<table>
<thead>
<tr>
<th>Emission values</th>
<th>Total estimated benefits (euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>26.45</td>
</tr>
<tr>
<td>Main</td>
<td>35.28</td>
</tr>
<tr>
<td>High</td>
<td>49.49</td>
</tr>
</tbody>
</table>

To make clear how these estimated benefits are divided among different cost savings categories, figure 10 depicts the division of estimated benefits in the median-impact, main emission valuation case. The cost categories are those described in table 3.
Figure 10 - Division of benefits

Note: This division of cost savings applies for the median-impact, main emissions valuation scenario.
6.9. Net estimated effects to society of Port CDM in the Port of Gothenburg

Using Airport CDM and previous MONALISA studies as a benchmark, the costs of operating the Port CDM concept are estimated to be approximately 3.42 million euros annually, with higher costs during the first four years. Including the implementation and transitioning costs, the costs for the first year are expected to be 4.15 million euros. For the second and third year the costs are expected to be 3.82 million euros and for the fourth year the expected cost is 3.7 million euros. See tables 5 and 6 for a more detailed account of these costs. The estimation of these costs is based on as much up-to-date information about the Port CDM concept that is possible at the time of writing, and careful consideration has been taken to make underestimation of these costs unlikely.

The estimated benefits using the main emission unit values and a median-impact scenario, where it is assumed that ships can reduce total service time in port by 2.5 hours on average and reduce speed prior to port approach by an amount that is equivalent to the average of the low scenario of 10 % for one hour and the high scenario of 30 % for four hours, is 35.28 million euros per year. Under this scenario the net benefit during the first and most cost intensive year is 31.13 million euros. For the years 5 and onwards the annual net benefit is 31.86 million euros. This implies a long-term benefit to cost ratio of over 10, which indicates that the economic viability of the project is very high. Using the estimates arrived at in this study, the net present value over a period of 10 years is approximately 273 million euros, or 27.3 million euros per year on average.\(^{23}\)

Using the estimations of benefits under different assumptions both regarding the impact potential of Port CDM and the valuation of emission costs to society, different levels of economic viability are reached. The reader can confirm by comparing these benefit estimates (tables 16 and 17) to the costs that the net benefit is positive under all assumptions considered. The factor by which benefits outweigh costs ranges from 2.2 (low-impact, low emission valuation) to 25.3 (high-impact, high emission valuation).

\(^{23}\) Net present value is computed by summing annual flows of benefits minus costs for ten years, using a discount rate of 3.5 %. \(\text{NPV} = \sum_{i=1}^{10} \frac{CF_i}{(1+r)^i} \)
7. Discussion of results and further implications of Port CDM

7.1. Baseline speed assumptions
Since estimated bunker and emission cost savings that are related to reducing time spent waiting prior to berthing (either in the port traffic area and/or in an anchoring area outside the port) are sensitive to the assumption of baseline speed of the vessels, it is relevant to test the sensitivity of these estimates to different scenarios. The baseline speeds assumed thus far in this study are those defined by SEPA (2010) for the different vessel categories. A question that might be posed is whether these speeds actually apply to vessels in close proximity of a port, and to what extent vessels are already applying some form of speed adjustment policies. To give more critical estimations of the benefits of speed adjustment, table 19 shows total estimated benefits under the median-impact scenario, under the additional assumptions that 25 % or 50 % of all vessels already apply speed adjustment policies or that waiting times are non-existent for these approaches. For these vessels, the benefit potential of speed adjustment is assumed to be 0. As is shown by these figures, the estimated benefits are significantly reduced.

Table 19 - Estimation of benefits under the assumption that not all vessels can save costs by reducing speed

<table>
<thead>
<tr>
<th>Scenario (median-impact)</th>
<th>Total benefits if 75 % of vessels can adjust speed (million euros)</th>
<th>Total benefits if 50 % of vessels can adjust speed (million euros)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low emission cost scenario</td>
<td>19.84</td>
<td>13.23</td>
</tr>
<tr>
<td>Main emission cost scenario</td>
<td>26.46</td>
<td>17.64</td>
</tr>
<tr>
<td>High emission cost scenario</td>
<td>37.12</td>
<td>24.74</td>
</tr>
</tbody>
</table>

While these estimates are no substitute for a survey of actual vessel speeds prior to port approaches, they may serve to reassure the reader that even if the baseline speed assumptions in this study are too high, the economic case for Port CDM will likely still remain strong.

7.2. Alternative expressions of benefits
The consequences of shortened turnaround times in ports are, as estimated in chapter 6, largely beneficial. What is not discussed in these calculations is how shortened time in port will affect operations in the long run. A relevant question to ask is how a shipping company will make use of the time it saves from reducing the total time of its port operations. In section 5 and 6 it is
assumed that shortened turnaround in port will lead to a reduction in fleet sizes and consequently lower capital costs for ship owners. After discussion with personnel involved in the MONALISA project, another scenario can be hypothesized: slower speeds for overall voyages, leading to lower bunker costs for the shipping company (and lower emission cost for society).

Consider again the hypothetical short sea shipping company described in section 5.2.3, with 25 vessels operating an average of 182 port calls, averaging 48 hours of which one third represents time in port, per year. In this alternative scenario the hypothetical shipping company does not reduce the size of its fleet, but instead operates the initial 25 vessels at a lower speed. Under the low-impact scenario, the shortened time in port of one hour represents around 3 % of voyage time, meaning that speed can be lowered by 3 % during every sea transit. Under the high-impact scenario of a four hour reduction in port, the corresponding potential for speed reduction is 12.5 %. Assuming that the relationship between reduced speed and fuel consumption in both cases can be approximated by a factor of 1.8 (see first row of table 1), the costs of bunker for the ship operators should decrease by 5.4 % and 22.5 %, for the low and high-impact scenarios respectively. Since the routes or operations of the vessels in the sample before and after their approach to the Port of Gothenburg are not known, it is not possible to estimate a realistic monetary impact of these possible speed reductions in this study. It is however clear that a reduction of bunker costs, which according to Stopford (2009) is the single most important cost item for ship voyages, by 5 – 20 % is significant to say the least. The plausibility of such a development can however be put into question. Following the reasoning of section 3.7, it is not certain that ship operators are motivated by bunker savings. Depending on the design of charter-parties, there may be incentives to travel at speeds that are different from the theoretically optimal with regard to fuel cost and freight revenue. There may also be a difference between being able to slow down during the last phase of a port approach and during the entire voyage, since certainty regarding destination port capacity can be assumed to be relatively low during the early phase of a port-to-port voyage. Market factors also play a role in the speed decision of vessels. High freight rates relative to bunker prices will likely result in ship operators selecting high speeds and vice versa.

The total societal net benefit of Port CDM is not necessarily dependent on which of these scenarios is considered. In the long run, the market might be assumed to adjust according to
whichever principle is the most beneficial, meaning that the theoretically correct scenario to consider is that which constitutes the best possible use of capacity.

7.3. Effects on queuing

It is probable that better organized interactive communication prior to and during the port call process would result in not only decreased time at berth, but also in increased consistency of service. The Port Call Synchronization service proposed in Port CDM enables service providers and terminal operators to advise and inform vessels on when they expect to be able to provide necessary capacity and services for the incoming ship. Even if the implementation of this system would be subject to flaws or fall short of logistical perfection, it is a modest assumption that a higher level of transparency in locations, intentions and capacity would significantly alter the variability in times spent at quay.

As implied by the Pollaczek-Khinchine formula (see section 3.3), variance in service time is in fact equally important to queuing as the mean duration of service in a simple queuing model. A clear consequence of this is that reducing laytime and optimizing approach speeds is only part of the potential of Port CDM.

The estimation of benefits of reduced queuing is empirically challenging. Judging from the (somewhat unclear) data on time spent actually waiting for service in the traffic area, as well as the survey of anchoring times outside the port area (SSPA and Viktoria Swedish ICT, 2015), there are virtually no congestion problems during the sample period. The nature of queuing is however rather explosive. Given a short-term increase in demand for port approaches, queuing is naturally expected to happen since supply is inflexible. The J-form of the queuing curve also implies that congestion can cause seriously problematic waiting times when capacity is under strain. This is an all too familiar problem for ports. The Port of Naples can be given as an example of a European sea port that is continually exposed to the problems of congestion (Veloqui et al, 2014). To determine the benefit potential of STM, it would be interesting to gather a larger set of data, from one or many major terminals, with berth occupancy rates and segmented waiting times during port approaches in order to analyze the impact of service time duration and variability on mean queuing times. As shown by Velqui et al (2014), simulation based on queuing theory can function as a highly cost effective method of determining the best investments for reducing costs of laytime in ports.
A reasonable hypothesis based on the standard model of queuing is that Port CDM, if systemically implemented, will have a noticeable impact on reducing the costs of queuing in ports, not only through reduction in service times but also through reduction in the variability of service times. To confirm this hypothesis and determine the magnitude, more detailed studies are needed. If this does indeed hold true, it provides a case for further developing Port CDM to include reduced service time variability as a desired outcome.

7.4. Incentives to participate in information sharing services
This study builds upon the assumption that the current inefficiencies of port operations can be alleviated by enabling solutions for enhanced and organized information sharing between actors. It might however be put into question whether there are other reasons for the inefficiency.

An alternative approach is to view the problem from an institutional perspective. Contractual arrangements involving for instance demurrage and other incentive schemes to keep the captain of a ship from selecting optimal speeds are a potential limitation to the benefits described in this study. It can on the other hand be argued that under freedom of contract, the standard charter-parties should develop into a more efficient form. The task of STM might therefore be described as unlocking untapped potential in the market, while it is up to the industry to comply and adjust to access this potential. Given that many of the planned services of STM are aimed to be non-mandatory, the incentives of actors to participate in such schemes must be carefully considered. 24

The effects of integrated and organized information sharing are network effects, in the sense that the value of the services is increasing with the number of users participating in the sharing of information. The rational decision of whether or not to participate in information sharing services is to a large extent determined by the expectations of each actor, and the amount of certainty regarding the outcome. A products or services market that is characterized by network effects can be hypothesized to have two extreme points of equilibria (see for instance Katz and Shapiro, 1994). If it is assumed by each shipping company that no other companies will participate in the service, no one will participate. This constitutes the first point of equilibrium, and a fulfillment of expectations. If it is on the other hand assumed by each shipping company that many other shipping companies will participate in the services, many will participate. This constitutes a

24 It should be reiterated that the specific services within STM are not fully developed at the time of writing. It may therefore be that some services aim to subject actors to mandates and regulations, but an overall objective of STM is to not impose mandates where mandates are not needed.
fulfillment of expectations and a point of equilibrium where virtually all actors choose to be a part of information sharing services. The implication of this is that STM needs to illustrate convincingly the benefits of participating in its services to all concerned actors, and should facilitate coordinated action from the industry, making possible joint declarations of participation. This could for instance be done in industry council bodies.

### 7.5. Emission cost savings – an incentive for whom?
An aspect of the results that can be discussed is the large relative portion of emissions cost savings that are estimated to be possible through Port CDM. This benefit category constitutes roughly 41 % of total impact (see figure 10). This poses the question: Which of the collaborative actors in Port CDM are incentivized by this efficiency potential of improved environmental performance? The answer to this question depends of course on future regulatory frameworks for emissions. The overall tendency in environmental regulation for shipping is to tighten, rather than loosen pressure to mitigate pollution (see for instance Buhaug et al, 2009). Given that this is the case, emissions reduction may be incentivized for reasons of competition both for shipping companies and ports. Even if emissions reduction may not be incentivized for all actors under the current business scenario, it might be assumed that there is a growing interest for companies to be environmentally efficient.

Another way to view the emission cost savings is as a side effect, or a positive externality, of the Port CDM implementation. Under the median-impact and main emission cost scenario, private benefits (roughly 59 % of total benefits, or 20.8 million euros) significantly outweigh costs. This means that the economic viability of the project is high, even without considering the value of reduced air pollution. Given that collaborative actors in Port CDM are incentivized only by the benefits that can be categorized as private, the resulting benefit of emissions mitigation can be viewed as a positive externality. The net present value from a societal point of view is higher than the net present value from an industry perspective.

To summarize the discussion of emission cost saving incentives: In light of current and increasing pressure on the shipping industry to reduce emissions and switch to environmentally efficient operations, it is probably a mistake to view costs of pollution as entirely external in the long run. However, as the estimation of benefits in this study show, the implementation of Port CDM is economically viable even if emission cost savings are excluded as a benefit.
7.6. Sensitivity of results with regard to sample limitations

There are limitations to the level of certainty in estimations that are based upon one month of port approach data. First of all, the data may not accurately represent the annual flow of traffic. As seen in figure 7, the data used in this study appear to deviate significantly from the aggregated annual port approaches with regard to distribution of vessel types. The extent of this deviation is however difficult to determine, since there is no information regarding the actual load rate of the observed vessels. Another issue that should be addressed, considering that this analysis concerns long-term effects, is that shipping activity to a large extent is cyclical and that a different underlying freight market environment might lead to different observations with regard to port access demand and possible congestion problems. To better estimate the effects with regard to market fluctuations, two or more observation periods spread out over a business cycle would be necessary. Extrapolating the estimated impacts of a short sample of traffic (even if this sample would be representative for the last few years) into the future is therefore perhaps naïve, but given certain limitations on time and data it may be the best method of estimation that is possible.

As also noted by Suarez-Aleman and Hernandez (2014) and Suarez-Aleman et al (2014), disaggregate data on waiting times in port approaches is needed to determine more precisely the current (in)efficiencies of port operations. Data of this sort appears to be in very short supply, which constitutes both a problem and a possibility for Port CDM. It is a problem in the sense that it diminishes the accuracy of estimated STM potentials and therefore also diminishes the evidence for economic viability. It is on the other hand a possibility in that the implementation of Port CDM would lead to an increased recording of approach data with standardized terminology used to describe states, which constitutes in itself a potentially major asset for the continuing development of efficient port practices.
8. Conclusions

8.1. Derived method for estimating the impacts of Port CDM
The method derived for estimating the impacts of Port CDM in the Port of Gothenburg proves to be useful in several ways. Assessing the deviation of error estimates from the funnel framework serves as an evaluation of current port inefficiencies that could be alleviated through better sharing of information. The efficiency improvement that would be provided by the implementation of Port CDM is hypothesized to be twofold: more optimized speeds prior to arrival and shorter service times. An advantage of the method is that it can easily be applied to other ports and/or different spaces of time. This means that a continued economic evaluation of Port CDM across the participating MONALISA partner countries is possible within the same methodological framework. A current limitation of the method is that some perhaps overly simplifying assumptions have to be made due to lack of data. There is room for improvement in for instance the assessment of vessel baseline speeds and cargo values.

To more precisely determine the benefit potentials of Port CDM and improve the method used in this study, disaggregate data of waiting and service times for a large number of port approaches would be instrumental. The reason for this is that in absence of specific and consistent information for port approaches, simplifying assumptions regarding waiting and service times during different states have to be made. Another research area that could potentially contribute to the case for (or against) a system-wide implementation of Port CDM is quantitative analysis of queuing for large terminals, simulating the effects of increased predictability in arrivals and departures.

8.2. Economic viability of Port CDM in the Port of Gothenburg
This study finds that the average net benefit of implementing Port CDM in the Port of Gothenburg is 27.3 million euros per year. The flows of impacts estimated under the low, median and high-impact scenarios, as well as the costs (which are estimated only as a high scenario) are shown in figure 11. The estimated benefits are to a majority made up of emissions cost savings, capital cost savings and bunker cost savings. The sensitivity analysis regarding emission unit values indicates that the economic viability of Port CDM is strong under all scenarios. The results of this study therefore indicate that the implementation of Port CDM is economically viable and profitable both for society as a whole and for the shipping industry.
Figure 11 - Flow of estimated impacts

Note: The flows of impacts in the figure refer to total societal effects, and are discounted to present values. Low, median and high approximations of benefits are estimated under different assumptions of the effectiveness of Port CDM. Costs refer to both investment and maintenance costs of Port CDM.

The most noteworthy source of uncertainty in the estimations is related to the size of the traffic sample, and its representativeness for long term flows of traffic in the Port of Gothenburg. As discussed, it is difficult to determine the extent of this possible misrepresentation. Other uncertainties involve difficult-to-obtain-parameters, such as load rates and cargo values. However, as is shown in the results, the time cost (which is associated with load rates and cargo values) represents only a small fraction of the estimated benefits.

Given the results arrived at in this study, it appears recommendable to implement Port CDM in the Port of Gothenburg and to facilitate the evaluation of cost savings potentials for other European sea ports that are within the scope of STM.
References


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IMO, 2015. *Sulphur oxides (SOx) – Regulation 14*


Appendix 1: Shipping terms, abbreviations and definitions
The following is a list of essential shipping terms, provided to help the reader. Definitions are from Stopford’s “Maritime Economics” (2009), unless otherwise noted.

**Auxiliary engines**: Small diesel engines that burn diesel oil and are used to provide electrical power. Typically, a ship has between three and five auxiliary engines.

**Berth**: Area of the quayside which is designated for cargo operations.

**Bulk carrier**: Ship which is built for carrying dry bulk cargo. Dry bulk is for instance ore, coal or grain.

**Bunkers**: Fuel that is burned in the main engine of a ship.

**Charterer**: Someone who hires a ship for a period of time or reserves space on a ship for a voyage. (Time charter or voyage charter)

**Charter-party**: Contract between a shipper and a cargo owner, or a shipowner and a charterer, which defines the terms that apply to the transportation of cargo or the hire of the ship.

**Container ship**: Ship which is specialized in and designed for handling containers.

**Deadweight tonnage (DWT)**: The maximum amount of weight which the ship can safely carry. This measure does not include the weight of the ship itself.

**Demurragge**: Compensation paid to a shipowner for delay for which the shipowner is not responsible.

**Despatch**: Money paid by a shipowner to a charterer if loading or unloading is performed in less time than was allowed in the charter-party.

**Freight rate**: The amount of money that is paid for carrying a unit of cargo from port to port.

**Gross tonnage (GT)**: Indexed measurement of the open spaces of a ship.

**IMO**: Abbreviation of the International Maritime Organization, which is a UN agency that is responsible for regulating the maritime industry.

**Port**: An area where ships come alongside land for cargo operations.

**Quay**: A wharf, or landing place, which is parallel to the waterline (American Association of Port Authorities, see http://www.aapa-ports.org/Industry/content.cfm?ItemNumber=1077)

**Roll on/Roll off (Ro-Ro) carrier**: Ships in which the cargo holds are accessed by ramps. Designed for carrying vehicles such as cars. Similar in design to ferries, but have no public areas or passenger accommodation.
**Tanker**: Ship that is designed for carrying liquid bulk, such as crude oil or petroleum products.

**Terminal**: Section of a port which contains one or more berths. Often, a terminal is devoted to handling a particular type of cargo.

**TEU container**: Twenty-foot equivalent unit. Standardized measure for containers.

**Vessel Traffic Service (VTS)**: System which provides information messages to ships from shore-side. Such information may include for instance position of other traffic or meteorological warnings. (IMO, see http://www.imo.org/OurWork/Safety/Navigation/Pages/VesselTrafficServices.aspx)

**Short sea shipping (SSS)**: Shipping that deals with transport within regions. Short sea shipping can also be defined as shipping which does not involve an ocean crossing (deep sea shipping). SSS is often in direct competition with modal alternatives, such as rail traffic.