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AHP Analysis for Evaluation of European Container Port Performance

by

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Abstract

Under the fierce competition in the port industry, port performance evaluation is becoming increasingly important for port authorities, shareholders, local governments, port users, etc. However, most of the current port-ranking lists are based on single criteria—throughput, which cannot fully reflect the underlying port performance. Therefore, this thesis aims to find a more comprehensive way for port performance evaluation.

As the first step of the evaluation, several existing projects regarding the selection of port performance indicators have been reviewed and compared. A set of port performance indicators from PPRISM project are chosen to be part of the ideal indicator list. The list consists of 14 indicators, crosses 5 categories, including market, socio-economic, environmental, logistic chain and governance perspectives.

Meanwhile, this thesis also compares the existing multi-criteria decision making methods, and deems AHP method as the most appropriate method, which is capable of involving all the indicators into evaluation. With the help of AHP software, qualitative information such as evaluators' judgments and interviews feedback can be converted into measureable data.

In this thesis, assessment of the relative importance of indicators is based on the port authorities' perspective, which means a higher weight will be given to maritime traffic indicator (throughput). Consequently, the final ranking list is identical with the existing ranking lists, which are simply based on throughput. (Port of Rotterdam is still at the leading place, with Port of Hamburg and Antwerp following behind) The result is within expectation, and the meaning behind this ranking list is richer than existing single-criteria ranking lists.

Due to the limitation of data availability, this thesis applies limited number of sample ports and indicators into evaluation. This thesis aims to provide an example of involving multiple indicators into port performance evaluation to help port authorities and other port related interest groups get an overall insight about strengths and weaknesses over their rivals.

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List of Abbreviations

AHP Analytic Hierarchy Process

CR Consistency Ratio

CSR Corporate and Social Responsibility

DEA Data Envelopment Analysis

ESPO European Sea Ports Organization

EU European Union

GHG Greenhouse Gas

HHI Herfindahl-Hirschman Index

KPI Key Performance Indicators

MAMCA Multiple Criteria Decision-Making Analysis

MCDM Multi Criteria Group Decision Making

MWS Meetings With the Community and the Stakeholders

PA Port Authority

PAR Public Availability of an Annual Report

PFR Port authorities Financial Reports

PORTOPIA Ports Observatory For Performance Indicators Analysis

PPM Published Performance Metrics

PPRISM The Port Performance Indicators--Selection and Measurement

PRSRI Public Reports of Socially Responsible Initiatives

RAM Requirement for an Annual Meeting

SPA Strategic Positioning Analysis

UNCTAD United Nations Conference on Trade and Development

VPA Venice Port Authority

VUB Vrije Universiteit Brussel

WP Work Package

1.Introduction

1.1 Problem statement

As a core segment in seaborne transportation, ports act as the connections between seaway and inland transportation. Meanwhile, ports have a profound influence on the cargo flow, commercial trade and local economy. The slowing down of global economy and commercial trade has a significant influence on the volume of seaborne trade, while at the same time, the construction of new ports is still growing in Europe, which contributes to a more competitive environment in the port sectors.

In order to stand out from competitors, port authorities make great efforts to improve performance. Nowadays, port authorities may mainly focus on improving the throughput or TEU, as most of the port-ranking lists published by media are based on these two indicators.

Port ranking list has been widely accepted as a direct way to show the comparison of the port performance. The results of how ports rank may have vital importance for many interest parties such as port authorities, investors, shareholders, local governments, shipping lines, etc. Many organizations (such as port authority, Lloyds' list, Eurostat, regional associations, etc.) publish port-ranking lists annually, but it is not surprising to find that ranking list turn out to be partial and different.

Table 1. Ranking list for the top 10 EU ports in 2013 (TEU)

Ranking	Port	TEU
1	Rotterdam	11.621.249
2	Hamburg	9.302.219
3	Antwerp	8.578.269
4	Bremerhaven	5.830.711
5	Algeciras	4.500.600
6	Valencia	4.327.838
7	Felixstowe	3.740.000
8	Piraeus	3.163.755
9	Gioia Tauro	3.087.000
10	Le Havre	2.486.000

Source: Rotterdam Port Authority

Table 2. Ranking list for the top 10 EU ports in 2013 (Throughput)

Ranking	Port	Metric Ton (000s)
1	Rotterdam	440.464
2	Antwerp	190.849
3	Hamburg	139.050
4	Amsterdam Ports	95.753
5	Algeciras - La Linea	85.622
6	Bremerhaven	78.768
7	Marseilles	74.856
8	Le Havre	67.172
9	Valencia	64.551
10	Grimsby and Immingham	62.615

Source: American Association of port authorities

As is shown on the Table1 and Table 2, many organizations publish their result of port ranking list annually, but apparently, they get different lists by using different indicators. The TEU and throughput rankings are frequently used in most popular press and reports. However, since ports have their specialty, when port authorities want to show their competitiveness advantages over the others, they are more likely to choose one of the lists, which show higher ranking position. The ranking list from an instinctive and partial appraisal may cover the real situation and mislead the decision maker.

Ports can be compared from many perspectives such as throughput, volume, revenue, port capacity, etc. When compare ports with each single indicator, the result comes out to be the competitive advantage of strength over arrivals in that specific perspective. However, the performance of the port is a more comprehensive understanding of the overall strength of different ports, rather than based on one-side criteria.

Currently, the widely used ranking lists are simply based on throughput and TEU. These two economical parameters can be easily measured and compared, which is one of the main reasons for being selected as the indicators for port performance. As the availability of data being an obstacle for comprehensive evaluation, ports only have limited information available. Indicators such as the tonnes of cargo handled, and the number of passengers becomes the most easy and effective way to assess the performance.

However, although throughput is widely accepted in the port industry, the limitations of using throughput as a single indicator for port performance cannot be neglected. Peter de Langen summarised three main drawbacks of using throughput as port performance indicator:

- First, simply sum up of the throughput volumes of different commodities into one aggregated throughput number leads to a valueless comparison between ports. (Langen, 2007) For example, the time and efforts for handling one ton of crude oil are significantly different with one ton of fruit juice. (Langen, 2007) Same theory can be applied to the handling and storage of standard containers and reefer containers.
- Second, throughput volume cannot represent the economic impact of a port comprehensively. (Langen, 2007) For example, Port of Rotterdam handles the largest volume of containers in Europe every year, however, because of the automation of the terminal handling system, the direct employment opportunities created by port are imitated. Therefore, the port economic contribution (such as employment and added value) cannot be simply reflected by a throughput number.
- Last but not least, the growth of throughput volume is mainly influenced by international trade flows, rather than the performance of a port. (Langen, 2007) Throughput volume is influenced by seaborne transportation, while the demand for transportation is derived from the commodity trade. In this case, throughput of the port is largely decided by the activeness of cargo flow and attractiveness of commodity trade of the city and its hinterlands.

Port performance is a more comprehensive understand of the overall strength of the port, which leads to competitive advance over rivals. Although some indicators are neglected because of the availability of data and incompatible of method, they should play an important role when evaluating the port performance. The results of the ranking lists are not convincing to show the underlying performance. A set of comprehensive indicators should at least consist of economic achievements, social contributes, sustainability, etc.

With the absent of comprehensive and unified benchmark for port performance analysis, the different evaluation standards make the current ranking result partial and incomparable. The evaluation of port performance is of crucial importance for port authorities to assess previous work and build their future strategy. And the evaluation method should be flexible and comprehensive to keep the port authorities updated with latest policy and situation.

In addition, throughput is not the best evaluation criteria for other operators in port industry. For shipping lines, cargo handling efficiency, operational safety, congestion and the environmental condition of the ports are important as well. For local government, apart from the economic perspectives, they may also focus on environmental and social sides, such as greenhouse gas emission, noise pollution, social reputation of the port, etc. For the cargo owners, they may consider the port connections with inland hinterlands as well. Therefore, the evaluation of port performance is an on-going debate for each operator in this sector.

As most of the existing port ranking lists and performance evaluation methods are introduced based on one-sided criteria, the results are partial and fail to reflect the underlying port performance comprehensively.

1.2 Research objective

To solve the problem mentioned above, this thesis will start with reviewing the previous port performance indicators projects, analysing the existing port performance models, and then applying the ideal indicator list into the most appropriate method. To be precise, the following research questions will be solved:

- Why existing ranking lists and researches are not comprehensive enough to reflect port performance?
- What kinds of indictors need to be considered into a comprehensive port performance evaluation?
- What kinds of evaluation methods are required to include above mentioned performance indicators?
- How to proceed the most comprehensive evaluation method into practice, and come into a valuable outcome?

The outcomes of this thesis might be interesting for following people:

For stakeholders of the port industry, an ideal list of port performance indicators, which respond to their concerns, would help them achieve better management of the port. (PPRISM, 2011) For instance, the involvement of environmental performance indicators will help the port authorities make their future development plan, which closely apply to the current sustainable policies. Same theory can be applied to safety and employment issues.

“For the port industry, an overall monitoring of port performance will contribute to higher quality of port policies and societal acceptance of port activities.” (PPRISM, 2011)

For port authorities, on one hand, the introduction of a set of port performance indicators is an opportunity to benchmark against EU average and achieve competitiveness advantage over other rivals. (PPRISM, 2011) On the other hand, it’s also a challenge to for port authorities to improve port performance from various perspectives, rather than only the throughput.

For EU policy makers, a new evaluation process will help them check the whole EU port systems and make more practical and direct policies, which can introduce more appropriate instructions and constrains for different port operators. Furthermore, overall evaluation will also help policy makers to stand from a higher position, where they can observe a general picture with different interest party in it. In that way, they can help to make fair and rational policies to balance the economic, social, and environmental effects.

Last but not lease, the aim of the indicator selection and performance evaluation is to improve the overall port performance. Since port users are the direct receivers of port service, they are also the first party to benefit from the improvement of port performance. Furthermore, by involving port users’ opinions and suggestions, port operators will have a better understanding about their customer need.

Therefore, this thesis will introduce an appropriate method to proceed a comprehensive evaluation of port performance, which can replace the current one-side criteria evaluation and give instructive recommendation for different port

operators, shareholders and policy makers in port sector. Additionally, improved port performance will contribute to a wider societal acceptance of port activities and better investment environment for port industry. The outcomes of the thesis are expected to give constructive criticism for different operators in port sector to have a more comprehensive view about the port performance.

2. Relevant port performance indicators.

Current port ranking approaches mainly use parameters which are quantifiable, such as units of ton, euro, square meter, etc. However, besides quantifiable economic parameters, more and more researchers emphasize the importance of social and sustainable parameters on stakeholder approach.

When it comes to multiple criteria, there are risks running into the erroneousness of selecting indicators subjectively. To make decisions on the selection of indicators, this chapter will look into previous projects and researches, so as to introduce a set of more rounded performance indicators.

2.1 UNCTAD projects

Back in 1976, the United Nations Conference on Trade and Development (UNCTAD) published a report, namely port performance indicators, which aimed to help improving port operations, and provide an appropriate basis for planning future port development. (UNCTAD, 1976) The principle of choosing indicators is that they have to be numerical and easy to measure. UNCTAD involved indicators from two aspects: financial and operational.

Table 3. UNCTAD project selected Indicators

Indicators	Sub-indicators
Financial indicators	Tonnage worked
	Berth occupancy revenue per ton of cargo
	Cargo handling revenue per ton of cargo
	Labour expenditure
	Capital equipment expenditure per ton of cargo
	Contribution per ton of cargo
	Total contribution
	Arrival late
	Waiting time
	Service time
	Turn-around time

Operational indicators	Tonnage per ship
	Fraction of time berthed ships worked
	Number of gangs employed per ship per shift
	Tons per ship-hour in port
	Tons per ship hour at berth
	Tons per gang hours
	Fraction of time gangs idle

Source: (UNCTAD, 1976)

The financial indicators are for port authorities to achieve financial viability. UNCTAD believed that financial indicators are significant incentive to efficiency, and they are important when the port authorities have to negotiate the loans. (UNCTAD, 1976) The operational indicators are more related to port management, UNCTAD tried to choose the most important ones for port authorities, however, they also admitted that the chosen indicators are not exhaustive to evaluate the overall port performance.

2.2 PPRISM

As a coordinator, European Sea Ports Organization (ESPO) together with University of Antwerp-ITMMA, Vrije Universiteit Brussel (VUB) Cardiff University, University of the Aegean and Technical University of Eindhoven, launched a PPRISM project to take the first step in building a set of performance measurement in European ports. (ESPO, 2012) The Port Performance Indicators--Selection and Measurement (PPRISM) project is co-funded by the European Commission and introduces a set of indicators that are relevant and both accepted by port stakeholders. (PPRISM, 2010) This project provides advice for the operators in port sector to measure, assess and communicate the impact of the EU port system on society, environment and economy. (PPRISM, 2012)

PPRISM project fulfilled many achievements: first and foremost, it provides a final set of indicators that are comprehensive and accepted by port stakeholder and introduces applicable methods regarding to data collection and analysis. (ESPO, 2012)

Compared with the UNCTAD project, PPRISM introduced more comprehensive indicators, which give insight to the overall performance of the European port system. (ESPO, 2012) Based on literature review and industry current practice, the first Work Package (WP1) provided an initial pre-selection of port performance indicators which include the following 5 perspectives: Market Trends & Structure, Socio-Economic, Environment, Logistics Chain and Operational Performance, Governance" (Quintieri, 2014)

Table 4. Initial Pre-Selection of Port Performance Indicators of PPRISM

Indicators	Sub-indicators
Market Trends & Structure Indicators	Maritime traffic
	Herfindahl-Hirschman Index (HHI)
	Vessel Traffic
	Market Share
	Load Rate
	Container dependency
	Call size
	Modal Split
Socio-economic Indicators	Employment (Direct & Indirect)
	Added value (Direct & Indirect)
	Direct Gross added value per FTE
	Financial health
	Training per FTE
	Investment
Environmental Indicators	Total energy consumed
	Carbon footprint
	Total water consumption
	Amount of waste
	EMS standard
	Existence of Aspects inventory
	Existence of monitoring programme
	Maritime connectivity

Logistic Chain and Operational	Intermodal connectivity
	On-time performance (Sea-going)
	On-time performance (Inland waterways, Rail, Road)
	Mean-time customs clearance
	Availability of Port Community Systems
	Ship turnaround time
Governance Indicators	Integration port cluster
	Extent of performance management
	Existence of Performance Measurement
	Formal reporting CSR
	Market openness
	Port authority investment
	Safety/Security
	Port authority employee productivity
	Autonomous management

Source: (PPRISM, 2012)

After the introduction of above initial pre-selection of indicators, the project launched the Work Package 2(WP2), during which the ESPO member started to assess the pre-selected indicators, screen and discuss with the academic patterns to finalise the indicator list and propose definitions and appropriate calculation methods. (ESPO, 2012)

Furthermore, Work Package 2 asked opinions from external stakeholders, which have direct, or in direct interest in the port performance to have a more comprehensive and rational selection of indicators. (ESPO, 2012) The assessment from external stakeholders included 338 online questionnaires, which contribute to a fair and sound assessment. (ESPO, 2012)

After internal and external assessment, the final choice of indicators to be tested in the pilot phase were introduced, and here is the result:

Table 5. Final list of indicators piloted within PPRISM

Indicators	Pilot result	Next steps
Maritime traffic	Relevant and feasible	Building a "time series" mainly focusing on the relative changes in traffic volumes over time. A three dimensional approach is suggested with respect to the dimension of 'time', (quarterly figures), of 'commodity' [total throughput plus 5 categories of cargoes plus passenger traffic (7 in total)] and 'geography'(all European ports)
Call size	Relevant and feasible	Building a "time series" mainly focusing on the relative changes in traffic volumes over time. A three dimensional approach is suggested with respect to the dimension of 'time', (yearly figures), of 'commodity'[total throughput plus 5 categories of cargoes plus passenger traffic (7 in total)] and 'geography'(all European ports)
Employment (Direct)	Relevant and feasible	Getting data from a larger number of ports
Added value (Direct)	Relevant and feasible	Getting data from a larger number of ports
Carbon footprint	Relevant and feasible	Make Tool available to port associations and authorities. Provide training support where requested.
Total water consumption	Relevant and feasible	
Amount of waste	Relevant and feasible	
Environmental management	Relevant and feasible	Promote using Tool (see above) and populate from SDM and PERS responses.

Maritime connectivity	Relevant and feasible	Building a 'time series' to monitor maritime connectivity over time.
Intermodal connectivity	Relevant and feasible	Getting data from a larger number of European ports.
Quality of customs procedures	Relevant and feasible	This indicator can be substituted by something more detailed in the medium run. Until then, this is the best available indicator.
Integration of port cluster	Relevant and feasible	Revision of criteria used. The need to reduce the number of criteria is already anticipated. More detailed info for each criteria will be asked. Efforts to standardize and collect quantitative data as well. In the long run the objective is to measure the efficiency of a PAs initiatives related to the respective indicators. .
Reporting Corporate and Social Responsibility	Relevant and feasible	
Autonomous management	Relevant and feasible	

Source: (PPRISM, 2012)

As a ground-breaking project for the previous evaluation researches, the chosen indicators in this project are expected to comprehensively involving the overall performance of ports and providing an updated picture of the port performance regarding to governance models and market structure. (ESPO, 2012)

Although the final list of indicators are considered to be highly related to port performance, in terms of the feasibility of data, they still need to be tested. Work Package 3 was launched to proceed a EU wide pilot project to give a test on the availability of data and the willingness of port authorities to provide data. (ESPO, 2012) The pilot project figured out the feasibility and accuracy of data and give suggestions to build a more user-friendly data request procedure. (ESPO, 2012)

"The outputs of the last Work Package (WP4) include a proposal for a "European Port Observatory", addressing crucial elements such as the observatory's mission, scope, users and main functions." (ESPO, 2012)

By introducing 4 work packages mentioned above, PPRISM project presented a set of port performance indicators that give an overview of environmental, socio-economic and supply chain performance of European port system, and more importantly, this set of indicators involve both internal (ESPO members) and

external stake holders opinions when assessing the choice of indicators (PPRISM, 2012)

Moreover, “this project is the first systematic attempt from EU level to research and introduce a set of relevant port performance indicators widely accepted and commonly defined by the whole port sector and other relevant key stakeholders (such as policy makers, port users, societal groups, etc.)” (PPRISM, 2012)

Meanwhile, the introduction of standardised but targeted performance indicators can give useful information for the self-improvement of the port industry and lead to a more transparent port industry, which can provide better services and benefits to all the users and operators. (PPRISM, 2012) Although ports have their culture of measuring, monitoring and reporting their indicators, standardization from EU level is missing, and different definitions and ways for calculation for certain indicators make the result incomparable. (PPRISM, 2012)

PPRISM project provides groundwork and instructive experience for the future research, and as a pilot project, it allows implementing the indicators at a EU-wide scale and put into practice the European Port Observatory as defined. (PPRISM, 2010) With the introduction of port performance indicators, more accurate and more objective evaluation of the impacts of port projects will be communicated, and the newly proposed indicators are expected to be further tested through port activities. (PPRISM, 2012)

2.3 PORTOPIA

As a continuing project for PPRISM, “Ports Observatory For Performance Indicators Analysis (PORTOPIA) engaged in establishing track records in various domains of port performance management, contributing to existing systems of port industry endorsed port performance management in EU.” (PORTOPIA, 2014)

“The ambition of PORTOPIA is to develop a dynamic, user-friendly port performance management toolkit where stakeholders (port authorities, operators, etc.) can administer their own data in a secured, individual space.” (Quintieri, 2014) And the major goal of the project is to “moving towards a robust and sustainable port transport system that can cope with its internal and external challenges.” (PORTOPIA, 2014) This project is developed by universities, research institutes and industrial partners with a proven track record; as one of the project partner, “ESPO gave direct access to the port authorities within the EU, accession countries and partnering countries and integrated the existing projects on port governance (the so-called ‘fact-finding study’).” (PORTOPIA, 2014)

As an improvement over previous project, PORTOPIA not only include the 5 perspectives mentioned in PPRISM project, in addition, it also introduced the sixed one: “Users’ Perspectives in Port Performance Evaluation” (Quintieri, 2014)

In the end, the following six categories of indicators are involved:

- “Market trends and structure
- Socio-economic performance
- Environment and occupational health and safety and security
- Logistic chain and operational efficiency

- Governance and finance
- User perceptions of quality" (Quintieri, 2014)

These indicators are believed to link different domains and create an integrated knowledge base and management system for port performance management, by which the stakeholders in this port industry can improve their sustainability and competitiveness over their arrivals. (PORTOPIA, 2014) Some significant indicators involved in the project are not quantifiable, but closely linked to current policy, such as environment and safety indicators, governance indicators, and port users perspectives, etc. The comprehensive choice of indicators makes the PORTOPIA project an instructive example for the future evaluation of port performance.

The outputs of PORTOPIA are dedicated to introduce a user-friendly port performance management cloud service for stakeholders administer their own data in a secured and individual space. (Dooms M. , 2014) The PORTOPIA cloud service and data analysis module provides a convenient toolkit for operators in port section to achieve self-improvement; additionally, it is designed user-friendly for every possible user, and flexible enough to accommodate experts. (Dooms M. , 2014) These outputs closely meet the three main objectives, which the project what to achieve: "to support the European port industry with meaningful performance data, to increase individual port and port transport system performance; and to support policy formulation and monitor policy implementation." (PORTOPIA, 2014)

Similar to the PPRISM project, PORTOPIA brings benefits for stakeholders in the port sector. By implementing the cloud service, port industry users (such as shipping lines, terminal operators, shippers, ancillary service providers, etc.) will have a direct access to the port performance database. (PORTOPIA, 2014) Besides, PORTOPIA port performance database provides an efficient and meaningful way for stakeholders to manage their existing data, and they don't need to worry about the security of data, since the PORTOPIA database keeps good control of data confidentiality. (PORTOPIA, 2014) Additionally, with the data management solutions of the service performance (such as user perception measurement tool), the competitiveness of the whole port industry is expected to be improved, and it also provides a platform for stakeholders to learn with each other and meet their deferent needs. (PORTOPIA, 2014)

The investigation of the Key Performance Indicators (KPI) for comprehensive evaluation gives an idea and direction for many other projects. "For instance, in the Venice Port Authority (VPA): KPIs monitoring project, researchers introduced KPIs from operational, financial and customer perspectives and used the balanced scorecard, strategy map to monitor outcomes." (PORTOPIA, 2014) Inspired by the PORTOPIA project, Thanos and George stated that other than commercial and industrial outcomes, users perceptions and customer satisfaction should also be considered into the evaluation procedure. (Vaggelas, 2015)

2.4 Ideal indicators

As is mentioned above, apart from the current ranking list, which only based on the throughput indicators, there are some well-established projects working on exploring more indicators for a comprehensive evaluation. The indicators introduced by these projects all have significant impact on port performance; the difference is that each individual project may focus on different perspectives.

Table 6 shows a summary about the indicators introduced by existing projects:

Table 6. Indicators selected from existing projects

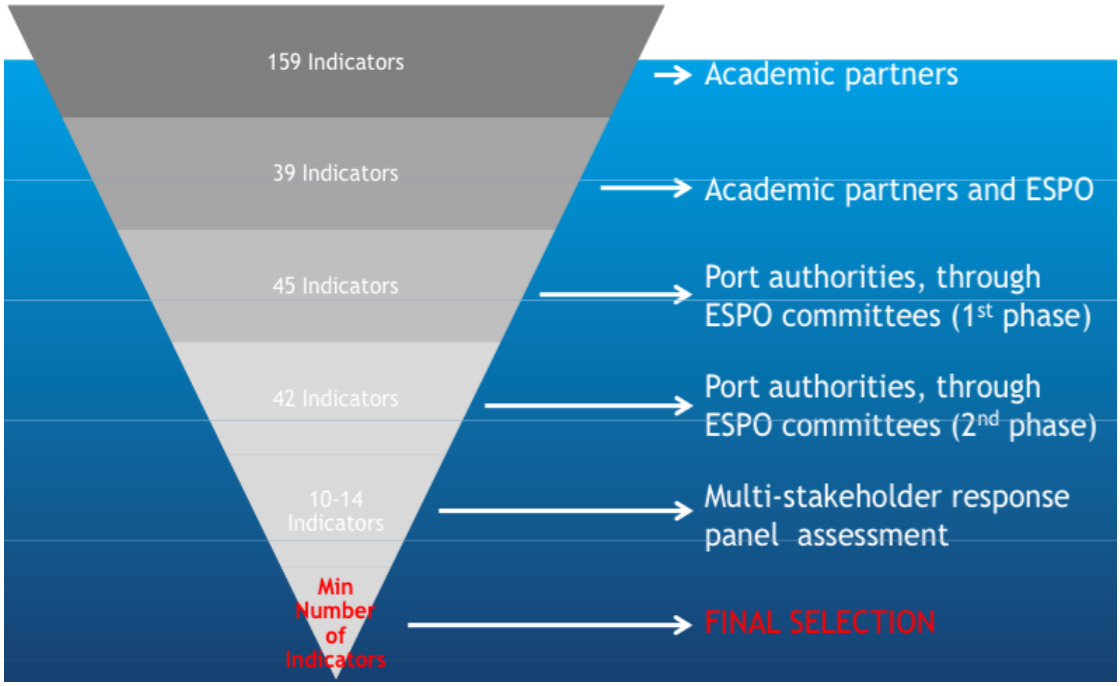
Indicators	Current Port Ranking	UNCTAD	PPRISM	PORTOPIA
Throughput indicators	✓	✓	✓	✓
Financial indicators		✓	✓	✓
Operational indicators		✓	✓	✓
Market Trends indicators			✓	✓
Socio-economic indicators			✓	✓
Environmental indicators			✓	✓
Logistic Chain indicators			✓	✓
Governance indicators			✓	✓
User perception indicators				✓

Source: summarised by author

As is shown in Table 6, the current EU project PPRISM and PORTOPIA include wider categories of indicators. The result of these current projects is considered to be convincible and objective.

As we can see from Figure 1, at the beginning of the project, 159 indicators have been selective by academic partners. After several selection processes and feasibility tests, the number of indicators has been reduced gradually. The final list only involves the indicators, which is available for collection and can represent the perception of stakeholder.

Figure 1. Selection process of the port performance indicators



Source: (PPRISM, 2011)

The academic partners of the projects have strong links with the port industry, and they all have established track records in various domains of port performance management. (PORTOPIA, 2014) Furthermore, they are also a group of professionals who are dedicated and specialised in existing systems of port industry, and endorsed the port performance management in the EU (PORTOPIA, 2014). With consortium budget support, indicators introduced by academic professionals with comprehensive experience can be considered as the ideal indicators so far. (PORTOPIA, 2014)

Inspired by previous projects, the ideal indicators can be summarized as 5 categories and 14 sub-indicators, which are all adopted from PPRISM project. Some of the categories and their sub-indicators mentioned in Table 7 might overlap with each other, so in order to present a clear and efficient indicator list; indicators will be integrated into the following 5 categories:

Table 7. The Ideal indicator list

Indicators	Sub-indicators
Market Trends indicators	Maritime traffic
	Call size
Socio-economic indicators	Employment (Direct)

	Added value (Direct)
Environmental indicators	Carbon footprint
	Total water consumption
	Amount of waste
	Environmental management
Logistic chain indicators	Maritime connectivity
	Intermodal connectivity
	Quality of customs procedures
Governance indicators	Integration of port cluster
	Reporting Corporate and Social Responsibility
	Autonomous management

Source: summarised by author, based on UNCTAD, PPRISM and PORTOPIA projects

The first category is market trends and structure indicators. The competitive environment and market structures of port industry are volatile by nature, which trigger the need for a performance measurement that depict market trends. (ESPO, 2012) Maritime traffic and call size are chosen, as they are most relevant and already widely used for port and shipping industry. (University of Antwerp ITMMA, 2011) As a sub-indicator, maritime traffic is quite straightforward and can represent the commercial importance and size of the port, and meanwhile, data collection can be easy and accurate. (University of Antwerp ITMMA, 2011) Call size is a combination of two widely accepted basic indicators: maritime traffic and vessel traffic. (University of Antwerp ITMMA, 2011) These two sub-indicators are considered to be comprehensive to represent the market trends and structures.

In the socio-economic category, direct employment and direct gross added value are selected as sub-indicators, as they can show how the port development contribute to local communities, central, regional and local government. (Vrije Universiteit Brussel , 2011) Dr. Francis Rome, the chairman of Flemish Port Commission stated that, “every person in the port community has great awareness of the importance of ports for the economy as generators of gross added value, employment and in Belgium, these parameters are calculated in an objective manner. Year after year, this allows us to reveal the social and economic significance of ports to the external world, and this on a consistent basis.” (ESPO, 2012)

However, in practice, according to the survey, only a limited number of ports (18% of the survey sample) measure socio-economic impacts on an annual basis. (Vrije Universiteit Brussel, 2011) Therefore, the introduction of socio-economic

parameters and the involvement of two socio-economic sub-indicators would be a significant and brave breakthrough for the measurements of port performance.

Environmental indicators have aroused the awareness and actions in many different industries, and environmental management has become an inescapable responsibility for every operator in this port industry. Port operations and activities will inevitably cause pollution on air, water, soil, and have impact on sediment of the terrestrial and marine environment. (PPRISM, 2012) The director of British Ports Association emphasized that, “it is so important that ports can generate the information and data to demonstrate their environmental achievements. Using these to regularly report on progress based on selected indicators is a real advance and a very welcome development for a sector which is so fundamental to the EU economy.” (ESPO, 2012) Cooperated with ESPO, Cardiff University introduces 4 significant environmental performance indicators out of 125 initial ones. (Wooldridge, 2011)

As one of the environmental indicators, carbon footprint is a common denominator and an inclusive indicator of air quality, which need prompt attention and action from port operators. (ESPO, 2012) Besides, carbon footprint can also reflect how much energy that the port consumes; therefore, by involving the carbon footprint into performance evaluation, the energy utilization and environmental quality would be both improved. Another environmental sub-indicator is waste management, which represents the port operators’ performance in terms of solid waste recycling. (ESPO, 2012) Waste management can be a significant indicator, as the waste might cause pollution for marine environment, household water resource and land resource. Additionally, water consumption is also involved in the ideal indicator list, as it is increasingly important for cost-reduction and resource consumption. (ESPO, 2012) As is introduced by PPRISM project, environmental management is also a sub-indicator for performance evaluation under environmental category. It is “a qualitative measure of a port authority’s capability to deliver effective environmental protection and sustainability through appropriate environmental management systems.” (PPRISM, 2012) The combination of quantitative indicators (carbon footprint, waste management, water consumption) and qualitative indicator (environmental management) is expected to contribute to a more comprehensive evaluation.

The logistic chain category is focus on the shippers’ perspectives. More attention is given to the hinterland connections, expenses of the transportation, reliability and ease of transactions. (PPRISM, 2012) Aernoud Willeumier, who works in Port of Rotterdam Authority also agreed that:“ in line with the EU ambitions for a core freight networks as key part of the TEN-T programme, indicators on intermodal connectivity are important for the EU port system and for each ports” (ESPO, 2012)

Under logistic chain category, 3 sub-indicators are selected in the ideal indicator list. The first one is maritime connectivity, which can be considered as the quality of the connections for transferring cargo between different points. (PPRISM, 2012) Maritime connectivity for container traffic is based on four elements: “frequency of services, transit time, the average ship size and level of competition between shipping lines to approximate costs, which monitors how the quality of connections between two ports changes over time.” (ESPO, 2012) The second indicator is intermodal connectivity. The aim to involve this indicator is to help the ports develop more intermodal services and hinterland connections. (ESPO, 2012) Quality of

customs procedures is the last sub-indicator under logistics chain category. This indicator is of vital important for shippers, as it shows the ease of transactions, which have significant impact on the whole supply chains, port operations and the efficiency of cargo transactions. (PPRISM, 2012)

Governance indicators are widely used in many other transactions such as: “civil society, corruption, democracy, e-governance, human rights, justice, public administration, etc.”, however, in terms of the port industry, such attention and efforts are lagging. (PPRISM, 2010) Involving governance indicators into evaluation will encounter with many difficulties, as there are no precedents can follow, uncertainty of the impact of policies to difficult ports, and difficulties on data collection, etc., but the innovative introduction of governance indicators will help identify the crucial aspects of the governance models used in ports and their influence on port performance, and develop a culture for monitoring port governance (PPRISM, 2010)

Three indicators are selected in the final list to help port adapted to changing economic and political environment. The indicator integration of port cluster expresses is chosen to help the stakeholders fully understand what is required for further cluster integration, and them make their future strategies to enhance the coordination within a specific cluster. (PPRISM, 2010) Reporting corporate social responsibility is to help assess the “how port corresponds to the corporate social responsibility obligation”. (PPRISM, 2010) Autonomous management indicator is involved to give insight on whether port authorities maintain features that could help the port to further develop their vital initiatives. (ESPO, 2012) The introduction of these three indicators will facilitate choices and boost port performance, as they can make timing adjustments and restructure models. (PPRISM, 2010)

Users perception indicators are introduced by PORTOPIA project. Port users may refer to shipping liners, forwarders, shippers, etc. As the receivers of port services, they may focus on different evaluation indicators such as port location, port due, port handling efficiency, possibility of congestion, connection to hinterlands, port information system, customer service system, etc. Widely accepted indicators like throughput and employment of the port have limited impact from port users perspectives. Relatively less attention has been paid to above-mentioned indicators by port authorities and stakeholders, however these indicators have more impact on port users perception. Under the increasingly competitive port environment, it’s necessary to keep in mind the indicators that come into the decision process of port users. (Ugboma, 2006)

Although users perception indicators are important for port performance evaluation, they are not involved in the ideal indicator list in this thesis. Because the choice of indicators is still under debate, and there are no widely accepted indicators to reflect the users perception.

3. Existing port performance models

A complete port performance evaluation consists of two parts:

- An ideal list of indicators
- An appropriate method to involve those indicators

In the chapter 2, ideal indicators have been introduced. This chapter will keep exploring the suitable method, which can be applied to all the indicators in the ideal list.

The ideal method for port performance evaluation should at least have the following functions. First and foremost, the method should be able to analyse multiple criteria. In addition, both tangible and intangible criteria should be taken into account. This chapter will introduce several widely used methods, which are design to solve multi-criteria problems.

3.1 DEA

Data envelopment analysis (DEA) is a non-parametric measure to evaluate the multiple decision-making units. This method is first designed by Charnes to assessing the efficiency of multiple decision-making units, and Charnes expected DEA method could be extended in a variety of additional sectors. (Charnes, 1978) This method can apply multiple inputs and outputs, and consider returns to scale in calculating efficiency, allowing for the changes of efficiency according to size and output levels. (Berg, 2010)

As a main advocator of this method, Peter B Marlow suggested that DEA could be used to evaluate a number of new ports performance indicators from different perspectives, such as timeliness in picking up shipment and in delivering it, responsiveness of transport suppliers in meeting, flexibility of operations, accuracy of information system, lead-time to service delivery, customer service, etc. (Marlow, 2003) DEA is further examined by Kevin Cullinane, who collected 8 years data from thirty ports, regarding to both characteristics of the container port industry (private or state owned) and the traditional indicators such as terminal length, terminal area, quayside gantry, yard gantry and number of straddle carriers. (Cullinane, 2005)

Many researchers use this method for analyzing the port efficiency. For example: Estache investigated 14 Mexican ports for evaluating the competitiveness and efficiency gains after port reform. (Estache, 2004) Barros compared the performance of two ports in Greece and Portugal (Barros C. P., 2004) He also investigated the technical efficiency and technological change of Portuguese seaports using DEA method. (Barros C. P., 2003) Park introduced the alternative DEA as a powerful approach to evaluate the overall efficiency of ports (Park, 2004)

However, this method also has its drawbacks. In the above research, each input or output of decision-making units is homogeneously treated, which may neglect the fact that the environmental and geographical condition, economic development and management systems of ports from different regions are not identical at all. (Wu, 2010) For instance, the length of the quay wall is frequently used as an input, but ports with same length of quay wall may perform differently, due to the differences in the number of quay crane, the efficiency of operation, and the design of the outline

of storage area, etc. Therefore, the homogeneity characteristic of the DEA method makes the outcome less accurate.

Additionally, the DEA method is based on assumptions, which may lead to inconsistency with a bias over the criteria. Besides, as we can see from the researches mentioned above, DEA is more production efficiency analysis rather than decision-making analysis. Therefore, it is not an ideal method for evaluation of port performance.

3.2 SPA

Strategic positioning analysis (SPA) is an analytical method for describing the performance of ports and traffic categories within ports by analysing market share, growth rate, diversification and value added, etc. (Haezendonck, 2006) The SPA approach was first established by Boston Consulting Group in 1968, and adapted from firm to market level, and applied into the port sector. (Haezendonck, 2015)

Three main purposes of SPA are as followed:

- "First, to process and present statistical information on the latest evolution in the competitive position of different ports
- Second, to evaluate the future economic potential of the ports and help with future developments
- Third, to provide options and alternatives for strategic decision- making, and give suggestions" (Verbeke A. , 1992) (Winkelmans, 1993) (Notteboom, 1994) (Verbeke, 1995)

Now, this method is further developed by other researchers, such as Prof. dr. Elvira Haezendonck and Prof. dr. Alain Verbeke, etc. She assessed the competitive position of the port by using three sub-approaches, namely:

- Product portfolio analysis (PPA)
- Shift-share analysis (SSA)
- Product diversification analysis (PDA)

These three analytical approaches are combined as the whole process of SPA, and they are interrelated with each other. Product portfolio analysis is about a growth-share matrix, which can assess the sustainable growth rate and market share, which are two of the criteria that the port authorities most interested in. (Haezendonck, 2006) The shift-share analysis is about estimating growth or decline by three parameters: share-effect, commodity-shift and competitiveness-shift. (Haezendonck, 2015) These three parameters can be presented graphically and involve different time period, which can provide an evidence of the change of favourable traffic structure. The product diversification analysis is to evaluate the diversification of the port traffic within a specific time period. (De Lombaerde, 1989) The diversification is also an important criterion for port authorities, which can indicate the degree of risk tolerant about the cargo volume under volatile market.

In the analysis of competitive position of 9 seaports in Hamburg-LE Hare range, apart from the nominal tons, which is widely used as the main criteria when evaluating performance, Elvira Haezendonck introduced the "value tons" concept, which involved contribution to local, regional or national gross product. Her SPA

analysis indicated the relation between structure of port traffic and economic impact for the port, and also objectified which traffic categories can create more added value per ton than others. (Haezendonck, 2015) The outcome of the analysis gives insights in the absolute added values and introduces a benchmark for ports of the same range in terms of created added value. (Haezendonck, 2015)

No confidential or complicated data sources are required for SPA method, which makes the SPA an easy approach for the researchers. (Haezendonck, 2006) However, Miles stated that the disadvantage of using the result of SPA is that, it has the risk of oversimplifying the evaluation. (Miles, 1986) The limitations of SPA also exist in no BCG implications such as internal banker function, and it's applicable if the number of competitors is limited. (Haezendonck, 2015) Moreover, the SPA cannot fully consider the all the indicators including social, sustainable, managerial perspectives, which is not a perfect comprehensive approach for port competitiveness evaluation.

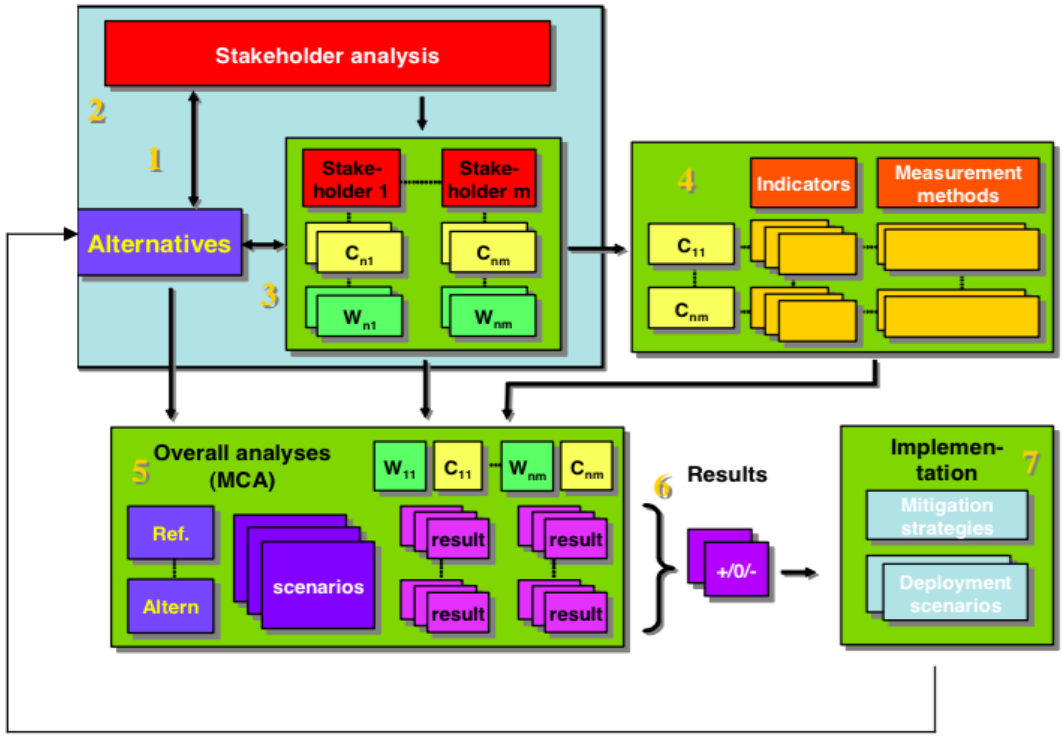
3.3 MAMCA

In most occasions, the evaluation of certain project is based on more than one or two parameters, which means the methodology applied is required to take multiple criteria into account. Multiple criteria decision-making analysis (MCDA) is developed to establish a model, which involves multiple criteria for strategic planning and decision making. Normally, this model solves problems without a clear solution, which means the decision makers' judgments should be taken into account when come into the conclusion.

Therefore, for the development of MCDA, an improved method that allows the explicit inclusion of stakeholders in the analysis is introduced. (Macharis, 2007) MAMCA, known as Multi-Actor Multi-Criteria Analysis, which allows stakeholders from different perspectives to make decisions for some complex problems. Unlike the conventional MCDA method, the MAMCA method explicitly includes the points of view of different stakeholders. (Macharis, 2010) And it focuses on diversified possibilities of evaluating the different criteria and provides both advantages and disadvantages of certain measures clearly.

The MAMCA methodology is proceed by the following 7 steps: "defining alternatives, stakeholder analysis, defining criteria and weights, criteria, indicators and measurement methods, overall analysis and ranking, results of ranking (sensitivity analysis), implementation.'' (Nijkamp, 1990) (De Brucker, 1998)

Figure 2. Methodology for MAMCA



Source: (Macharis C. , 2004)

The first step of the method is to identify the problem and classify the alternatives for the evaluation. (Macharis C. , 2009) These alternatives can differ for “infrastructure investments, technological solutions, possible scenarios, different policy measures, etc.” (Macharis C. , 2009)

The second step is to first identify the stakeholders, who have direct interest with the decision-making. (Macharis C. , 2009) Then the stakeholders should take part in the analysis to give their critical assessments regarding the alternatives and provide their understanding of the real business situation. (Macharis C. , 2009)

Next step is for stakeholders to identify criteria and give the weight to re the importance of each criteria. (Macharis C. , 2009) By involving different points of view of the stakeholders, such as government, users, local household, manufacturers, etc. will show whether a certain measure will be accepted or rejected by different interest groups. (Macharis C. , 2009)

For the fourth step, “the previously identified criteria are ‘operationalized’ by variables that can be used to measure whether, or to what extent, an alternative contributes to each individual criterion.” (Macharis C. , 2009) Most of the time, the

indicators are quantitative in nature, and can assess the contribution of multiple criteria. (Macharis C. , 2009)

The fifth step is to insert the assessments of different alternatives and establish the construction of evaluation matrix. (Macharis C. , 2009) Analytical hierarchy process (AHP) method can be used in this step to assess alternatives and make pair-wise comparison procedure for the evaluation of the weights. (Macharis C. , 2009) AHP and MAMCA are both multi criteria group decision-making methods (MCDM). One of the differences between the MGDM methods is the number of value trees. (Macharis C. , 2012) For AHP model, the decision makers agree on a common set of indicators, and same value tree will be applied for all evaluators. (Macharis C. , 2012) MAMCA is capable of several individual value trees and aggregates the output in the end. (Macharis C. , 2012)

After the multi-criteria analysis in the last five steps, the classification of the alternatives will be figured out. (Macharis C. , 2009) The following step is to proceed a sensitivity analysis, which can assess whether the result is volatile when the weights are modified. (Macharis C. , 2009) This step will improve the accuracy of the model.

The last step is an implementation process, which can be a feedback-loop towards the beginning of assessment. (Macharis C. , 2009)

The MAMCA method has been widely used in many decision-making problems in the transportation sectors. For instance, Macharis applied MAMCA into evaluating transport projects, which involved both qualitative as well as quantitative criteria defined by the multiple stakeholders. (Macharis C. , 2009) Eliza developed MAMCA method to support the policy making in maritime transport in Greece. (Gagatsi, 2014) Rickard used MAMCA to evaluate possible measures to improve sustainability of the ports' hinterland transport systems. (Bergqvist, 2015) Macharis applied MAMCA to solve a location problem for intermodal terminal in the Brussels region. (Macharis, 2000) In the evaluations of DHL's hub strategy at Brussels airport, Michael Dooms introduced the concept of stakeholders in the evaluations of transport infrastructure, by using MAMCA method. (Dooms M. , 2005)

The MAMCA also has its disadvantages, which need to be improved and further developed. "For example, researchers should take care that within crucial steps of the methodology, such as the choice of the stakeholders, the choice of the criteria, the choice of the weights of the criteria, and the choice of the weights of the stakeholders, strategic bias should be avoided." (Macharis, 2010) When there is a large set of non-dominated solutions for decision maker to choose, the disadvantages will show up. When decision makers have to make too much trade-off between criteria, the accuracy may be significantly affected.

With multiple value trees for each decision makers, MAMCA is an appropriate model for many transport projects, which need to distinguish the different points of view,

apply different value trees and achieve output level aggregation. (Macharis C. , 2012) However, for the port performance evaluation problem, decision makers agree on a set of evaluation indicators, and only one value tree will be applied to ensure the consistency. In this case, AHP method, which is based on single value tree, is more appropriate for port performance evaluation.

Moreover, in order to widely promote the MAMCA method, more researches should be done for the development and innovation of softwares, which can contribute to a better visualization of the multi actor view. (Macharis, 2010; Bichou, 2004)

3.4 Other models or tools

Other tools such as the logistic and supply chain management approach is also applicable for diverse range of techniques and analysis. “This approach is applied in solving the operational problems in shipping and ports, which allows a neutral and objective perception of problem’s definition and investigation; furthermore, it can solve the problem of channel identification and conflicting standpoints.” (Bichou, 2004)

The existing researches related to supply chain performance measurements could hardly linked to the port sector, meanwhile, the whole supply chain systems are not added into the evaluation of port competitiveness neither. There are not many researchers claim to apply the supply chain management measurement into the whole port organization. (Wang, 1999) However, from the perspective of whole trade channel, as the connection between seaway and inland transportation, port is acting as an important node in this system. The logistics and supply chain management approach extends the conventional port system to an “integrated channel management system”, where the port can be measured as an important position connecting different cargo flows, and a crucial part in the whole supply chain. (Bichou, 2004) Therefore, the logistic and supply chain management approach is developed to solve the above problem and give insight about the relationship between ports and the whole transportation systems.

This method proceeds the port competitiveness analysis through a supply chain management perspective, which is new and valuable. However, the disadvantage is also obvious: it cannot involve many important indicators in sustainable, social and managerial perspectives.

3.5 Overview of existing methodology

Table 8. Advantages and Disadvantages of possible methods

Method	Qualitative	Quantitative	Advantage	Disadvantage
DEA	-	✓	Transform multiple input and output into numerical factors without transform into same unit	More production efficiency analysis rather than decision-making analysis
SPA	-	✓	Take market share, growth rate, diversification and value added into account	Cannot fully complement with financial managerial and social aspects.
MAMCA	✓	✓	Allow using non-numeric or non-monetary values in the evaluation, and the stake holders are explicitly taken into account	Same drawbacks with MCDA: not applicable for a large set of non-dominated solutions
Logistic and supply chain management approach	-	✓	Distinguishes between logistics, trade and supply chain management within ports	Only focus on the logistics and supply chain perspective of the port performance.

Source: summarized by author

Table 9. Summary of application of possible methods

Method	Author	Year	Article	Indicators
DEA	Kevin Cullinanea, Ping Jib, Teng-fei Wangc	2005	The relationship between privatization and DEA estimates of efficiency in the container port industry	Privatization, terminal length, terminal area, quayside gantry, yard gantry and number of straddle carriers
SPA	Elvira Haezendonck, Alain Verbeke and Chris Coeck	2006	Strategic Positioning Analysis for Seaports	Market share, growth rate, share-effect, commodity-shift, competitiveness-shift, diversification and value added
MAMCA	Cathy Macharis, Laurence Turcksin, Kenneth Lebeau	2012	Multi actor multi criteria analysis (MAMCA) as a tool to support sustainable decisions: State of use	User perspective: transport time, cost, connections reliability; Operator/investor perspective: net present value, expanding possibilities, capacity available infrastructure; Community perspective: network efficiency, road congestion, environmental effects, economic benefits, etc.
Logistic and supply chain management approach	Khalid Bichou, Richard Gray	2004	A logistics and supply chain management approach to port performance measurement	Port operations and activities, profit, customer service, logistics channel, trade channel, channel profit

Source: summarized by author, based on (Cullinane, 2005) (Haezendonck, 2006) (Cullinane, 2005) (Bichou, 2004)

As is summarized above, the method mentioned is not exhaustive, but these are most used ones for port performance evaluation. All of the methods are good at multiple criteria analysis, which is the basic requirement for a comprehensive port performance evaluation. DEA, SPA and MAMCA are capable of transferring quantitative information into numerical values, which can be intuitively compared. However, they all have disadvantages, which cannot fully meet the requirement of a comprehensive evaluation process.

Therefore, this thesis is going to introduce a more comprehensive method: Analytic Hierarchy Process (AHP). AHP model is the methodology for making decision and ranking priorities. (Song, 2004)

AHP method can be applied as a proper tool for port performance evaluation for the following reasons:

- The indicators selected in chapter 2 can be fully integrated into AHP method.
- The point of view from port professionals can be collected and put into numerical scales to make a difference in the final result.
- The AHP model can balance the trade-offs between economic, social and environmental performance.

4. Methodology: AHP model

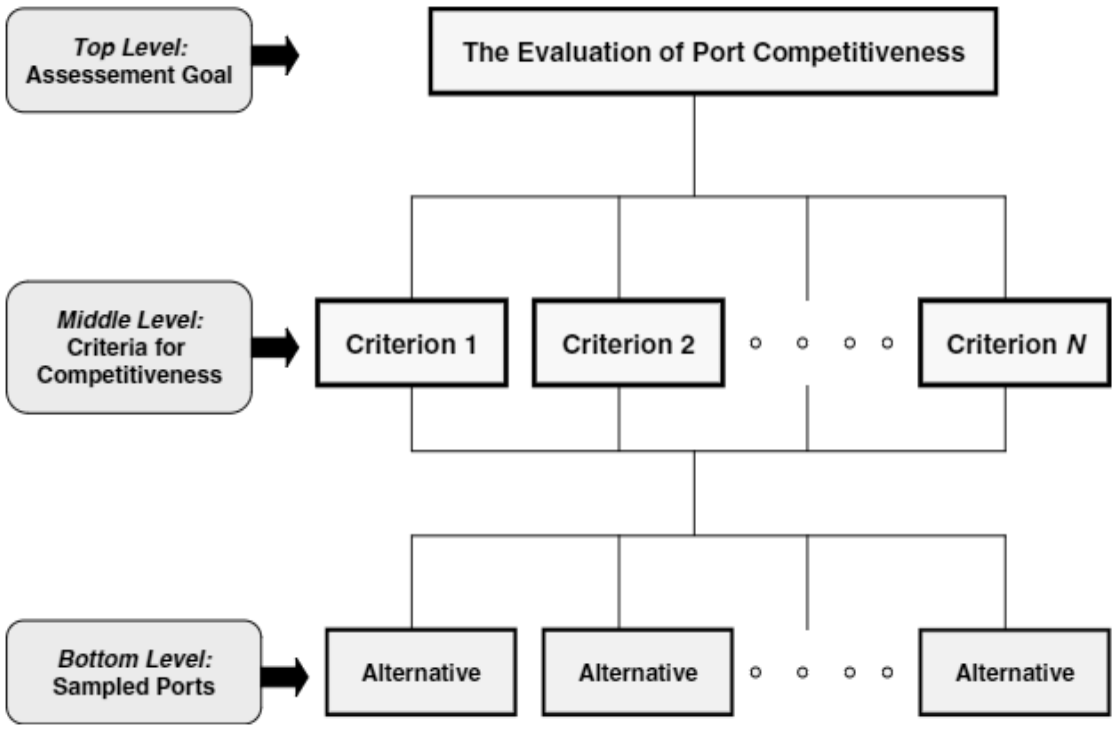
4.1 AHP as the proposed, comprehensive model

The Analytic Hierarchy Process (AHP) is one of the efficient models for port performance analysis. The AHP model was developed by Saaty to "combine both subjective and objective evaluation into an integrative framework based on ratio scales from simple pairwise comparisons." (Saaty, 1980)

The AHP model can be used in evaluating the weights of indicators and solving multiple criteria decision-making problems. At the same time, AHP model can enhance the reliability of the qualitative data such as questionnaire and interviews by the Consistency Ratio test. (Chou, 2010)

AHP model works out the result through three steps:

Figure 3. The conceptual framework of port competitiveness



Source: (Song, 2004)

First stage is to fully understand the problem, select relevant indicators for evaluation and then start establish the decision-making hierarchy. (Wedley, 2001) To be more precise, the first stage can be done by:

i) set up an ultimate objective for the assessment on the top of the hierarchy
ii) in the middle of the hierarchy, critical criteria should be built to achieving the ultimate objectives

iii) list the identified alternatives on the bottom, which can link with the above criteria and the ultimate objective of the evaluation. (Song, 2004)

Second stage is to make pairwise comparisons to build the priorities of the criteria. (Wedley, 2001) As suggested by Satty (1980), the ideal is to give a higher weight to the elements, which considered being more importance in evaluation process, so that these elements will be given more attention when making a decision or assessment. (Song, 2004)

The third stage is "to synthesizing the priorities into composite measures of the decision alternatives or options." (Wedley, 2001) The multiplied weight values of each criterion and alternative will be summed up in this stage. (Song, 2004) Then the result will be figured out: the port with highest score is assessed to be the most competitive one. (Song, 2004)

Many researchers in port sector applied AHP method into practice. Song used the AHP model into evaluation of Chinese container ports, and came into the conclusion that, Port of Hong Kong is the most competitive port in China, followed by Port of Shanghai and Port of Yantian. (Song, 2004) Song also found that location plays an significant role when evaluating the port performance.

Lirn applied AHP into the transhipment port selection in a global perspective. He found out that "in the global container terminal industry, handling cost of containers, proximity to main navigation routes, proximity to import/export areas, basic infrastructure condition and existing feeder network are considered to be the five service attributes with the highest importance weight above the global mean value for all sub-indicators." (Lirn, 2004)

Moghadam believed that port performance indicators are interrelated with each other, and through empirical analysis, he observed that AHP method could measure vast majority of decision-making problems dealing with vagueness and uncertainties of the ports prevailing circumstances. (Moghadam, 2014)

This method works much more than giving a ranking and making a right decision, it integrates the decision makers' understanding of problem and tries to achieve the real goal. By using the AHP method, the decision makers can use concrete data about each indicator, or they can use their judgments about the indicators' relative meaning and importance. (Lee, 2014) The combination of decision maker's intelligence with the theory of the AHP model contributes to more comprehensive and rational outcomes than other methods.

Compared with the other methods, AHP is straightforward, convenient and versatile, especially with the help of soft wares like MakeItRational and Expert Choice. (Awang, 2012)

However, some researchers found AHP has its weakness in analysing the port performance. There are a number of factors for port performance, and as mentioned before, the indicators for port competitive position can be both quantitative and qualitative. However, Chinonye Ugboma found that the distinction between quantitative and qualitative factors is not clear since different perceptions of port performance lead to a different evaluation of the actual performance. (Ugboma, 2006) In many cases, the perception gap between the port users and operators may lead to different judgements on the weight of indicators. In addition, another consideration for the AHP model is the fault of inconsistency. (Ugboma, 2006) "Consistency is the degree to which the perceived relationship between elements in the pairwise comparison is maintained." (Ugboma, 2006) Comparisons with inconsistency may indicate that the evaluators do not fully understand the differences of the choices and unable to evaluate the relative importance of the indicators presented. (Ugboma, 2006) Kahraman stated that, because of these vagueness and uncertainties in evaluators' judgments, the AHP model itself couldn't be able to present decision-makers' ideas exactly. (Kahraman, 2004) However, by monitoring the consistence ratio (CR), this disadvantage can be overcome. When the CR is controlled fewer than 10 percent, the judgments can be considered as consistent. (Ugboma, 2006)

Every model has its advantages and disadvantages. According to the analysis and comparison above, DEA is rather a production efficiency analysis than a decision-making analysis; SPA is a brave way to add market share, added value into evaluation, but it cannot fully complement with financial managerial and social aspects like AHP model; although MAMCA has been used in many transport projects, it is not applicable for a large set of non-dominated solutions, and the multiple value trees may cause inconsistency in evaluation; logistic and supply chain management approach is also an innovative method, but it is more developed as a specialized method, and cannot integrate other categories into evaluation. AHP method perfectly integrates quantitative and qualitative indicators, and it is applicable with every possible category like financial managerial, social and sustainable indicators. The single value tree and consistency check in AHP model ensures accurate and convincing outcomes from AHP model than other frequently used models. Therefore AHP is the most appropriate model for preceding an evaluation of the port performance.

4.2 Software for AHP model

As one of the most powerful decision making methodologies, Analytic Hierarchy Process (AHP) should be applied with the help of dedicated software. The ideal software should at least has following functions:

- "Hierarchy: the software should be able to building the criteria hierarchy, and it also need to be flexible to make changes about the hierarchy through the building process.

- Number of pairwise comparisons: AHP software should help to provide minimum data needed to perform calculations in the shortest time, and break down complex decision into small judgments.
- Consistency checking: AHP software should be able to check the consistency of entered data and give users warn when the inconsistency is too high.
- Collaborative voting: users should be able to make their own judgments and then the software should allow team to quickly identify areas of disagreement.
- Sensitivity analysis: AHP software should be able to examine the stabilization of the results and ensure the accuracy." (Opydo, 2013)

The existing software for AHP model is AHPproject, MakeItRational, TransparentChoice, and Expert Choice. In this thesis, MakeItRational will be chosen to perform the evaluation.

MakeItRational is a software that developed to incorporate with AHP methodology. It is capable of ranking and choice, prioritization and resource allocation, benchmarking, etc.

MakeItRational proceed the multi-criteria evaluations by splitting it into a set of judgements, which relate to a specific and well-defined excerpt of the performance ranking problem. (MakeItRational, 2009) MakeItRational allow examinations of alternatives at different angles and creates the relative importance of criteria. (MakeItRational, 2009)

Meanwhile, this software fully realises the pairwise comparisons process, which is the core of AHP model. Pairwise comparisons are well supported as a special graphical editor, which can check the consistency of evaluators' comparisons and give alert when potential errors exist. (MakeItRational, 2009)

In addition, the design of this software is user friendly and easy to operate for all evaluators from different levels. The outcomes are visualized and straightforward, as 4 types of charts and tables will be presented in a final report. (MakeItRational, 2009)

Therefore, with the help of AHP software, the evaluation procedure should be more precise, and outcomes are expected to be more reasonable.

5. Empirical analysis

5.1 Sample of ports

As the major container hubs, Port of Rotterdam, Port of Hamburg and Port of Antwerp are considered to be the top 3 container ports in Europe in terms of throughput. With the recovery of European economy and the 8% year-on-year growth of Asia-North Europe, these three top container ports all achieved healthy expansion during recent years. (Wackett, 2014)

However, the soaring growth also comes with many problems such as port congestion. The container terminals at Rotterdam and Hamburg breached to their full capacity occasionally, which pushed several calls to the nearby competitor--Port of Antwerp. (Wackett, 2014) Geographically speaking, Port of Rotterdam, Hamburg and Antwerp are located closely with each other, which means they share overlapping hinterlands and have to compete for the same market.

As the largest container port in Europe, Port of Rotterdam is considered to be the European gateway. In the half-year report 2015, the container throughput of Port of Rotterdam increased by 3.7% compared to the first half of 2014. (Port of Rotterdam, 2015) The recovery of European economy contributes to an increase of 6.6% in transhipment traffic via feeders. (Port of Rotterdam, 2015) With the new terminals at Maasvlakte 2 became operational, Port of Rotterdam expanded their capacity and fully prepared to service the ultra large container vessels in the future. (Port of Rotterdam, 2015)

Figure 4. Gateway of Europe--Rotterdam hinterland map

Source: (Port of Rotterdam Authority)

In the year 2014, the container throughput of Port of Hamburg increased 5.1%, which is recorded as the best-ever result. (Hamburg News, 2015) “With an average container throughput in the North range increase by only 4.2%, Port of Hamburg increased its market share and consolidated its position as Europe’s second largest container port.” (Hamburg News, 2015) The strong growth of throughput is mainly attributable to the 9.8% increase in China-Europe route. (Hamburg News, 2015)

Port of Antwerp achieved a 4.2% growth in throughput in 2014. (Port News, 2014) With a market share of 11.4%, Port of Antwerp is also the largest short sea container port in EU. (Port of Antwerp, 2015) The lowest terminal handling charges in Europe also makes Antwerp a competitive port among its rivals. (Port of Antwerp, 2015)

Under the fierce competition between these 3 ports, a comprehensive port performance evaluation would help port authorities have an insight about their advantages and disadvantages over their arrivals and make corresponding strategies for future development. Therefore, Port of Rotterdam, Hamburg and Antwerp will be chosen as the sample for this thesis.

5.2 Data collection

As is stated in chapter 2, the ideal indicator list consists of 14 indicators, which is considered to be the most comprehensive set of indicator for port performance so far. The definition and calculation formula of each indicator has been standardised by researchers in the PPRISM project. Although pilot project has been launched to test the feasibility of the indicators and availability of data, a complete set of data on the ideal indicator list is not accessible from an individual level. Therefore, only limited indicators with possible access will be included in this thesis.

5.2.1 Selection of data

As is shown in table 5.1, in terms of the availability of data collection, the following 6 indicators will be applied into AHP model: maritime traffic, added value (direct), employment, carbon footprint, quality of customs procedures and reporting corporate and social responsibility. These 6-selected indicators can be fairly representative, as they cross all the 5 categories, and include both quantitative and qualitative ones.

Table 10. Selection of data from ideal indicator list

Category	Name of the indicator	Data availability	Quantitative	Qualitative	Definition
Market Trends indicators	Maritime traffic	✓	✓		The aggregation of seaborne cargo/passengers handled at the sea interface area of the port over a stated period of time
	Call size		✓		The ratio between the total capacity of the vessels (cargo or passenger) that call at the port over a stated period of time and the number of those vessels
Socio-economic indicators	Employment (Direct)	✓	✓		The amount of employment directly sustained and/or created by port activities at a given moment or over a given period, within a given geographical area. Jobs or employment is a measure of the number of jobs required to produce a given volume of sales/production or added value.
	Added value (Direct)	✓	✓		The amount of welfare directly sustained and/or created by port activities at a given moment or over a given period, within a given geographical area
Environmental indicators	Carbon footprint	✓	✓		The carbon footprint is a measure of the total amount of greenhouse gas (GHG) emissions that is directly and indirectly caused by an activity.
	Total water consumption		✓		Identify and report the total volume of water withdrawn. The indicators should be modified to a common ground, normalized by the cargo handled.
	Amount of waste				Identify the amount of waste created by type: Hazardous waste (as defined by national legislation at the point of generation); and Non-hazardous waste (all other forms of solid or liquid

					waste excluding wastewater).
	Environmental management			✓	This indicator aims to track the number of Port Authorities that have implemented a recognized form of EMS
Logistic Chain indicators	Maritime connectivity		✓		The connectivity of a port with container services to overseas destinations, based on frequency, transit time and competing liner shipping companies.
	Intermodal connectivity		✓		The connectivity of a port with intermodal container services to hinterland destinations based on competing terminal operating companies.
	Quality of customs procedures	✓	✓		The time required for customs clearance.
Governance indicators	Integration of port cluster			✓	This indicator expresses the extent that the PA develops initiatives that enhance the integration of the various stakeholders that compose a port cluster
	Reporting Corporate and Social Responsibility	✓		✓	The indicator “Reporting Corporate Social Responsibility” measures the extent that PA undertakes and reports activities in a way that enhances Corporate Responsibility
	Autonomous management			✓	This indicator expresses whether the PA maintains those features that enable it to develop vital initiatives

Source: summarized by author based on PPRISM project (PPRISM, 2010)

5.2.2 Quantitative data

Maritime Traffic

Maritime traffic refers to the aggregation of seaborne cargo or passengers handled by the port, as the main objects of research are container ports, we calculate the aggregation of containers handled. Thus, the unit of measurement is TEU. Frequency of measurement is yearly based. Data include both loaded and empty containers.

Compared with other indicators, the data for maritime traffic is the most standard and can be easily approached. Many organizations and media publish the data from a yearly base, such as port authorities, Lloyds' list, Eurostat, regional associations, etc.

Table 11. Maritime traffic data

Name of Port	Volume of Containers Handled
Antwerp	8.256
Hamburg	9.302
Rotterdam	10.938

Unit: 000 TEU, Data for the year 2013

Source: (EUROSTAT, 2015)

Direct Added Value

As is introduced in the PPRISM project, the Direct Gross Added Value (at current prices) for a company equal to:

"Staff costs + depreciation + downward value adjustments + provisions for liabilities and charges + certain operating expenses + operating result - operating profit - operating subsidies" (PPRISM, 2010)

Direct added value data for Port of Rotterdam can be found in the port authority website, data for Port of Antwerp was published by National Bank of Belgium.

According to the website of Hamburg Port Authority, the total added value (direct and indirect) is 20.000mln Euro. (Port of Hamburg, 2015) The statistics of Port of

Rotterdam and Antwerp shows that the total added values will be doubled after adding the indirect added value. Therefore, 10.000mln Euro was estimated as the direct added value for Port of Hamburg.

Table 12. Direct added value data

Name of Port	Direct Added Value (Current Price)
Antwerp	9.845
Hamburg	10.000*
Rotterdam	12.506

Unit: Value x 1 mln. Euro (current price) Data for the year 2013

Source: (Erasmus University Rotterdam, 2014) (National Bank of Belgium, 2015) (Port of Hamburg, 2015)

** Direct added value for Port of Hamburg is estimated*

Direct & Indirect Employment

The employment figures are crucial for national economics. To emphasize the contribution of port for national employment, many port authorise just publish the sum of direct and indirect employment figures. Because of the complexity of port related industry, the indirect employment may include the jobs in many other port related industry, which means a large number of employment.

According to the data from National Bank of Antwerp, direct employment is 61496 in 2013. When indirect employment been added, this figure is more than doubled (149714 employment in 2013). (National Bank of Belgium, 2015) Same case might be applied to Port of Hamburg and Rotterdam. As no direct employment data available for Port of Rotterdam and Hamburg, total employment (direct and indirect) will be applied into the model.

Table 13. Direct and indirect employment data

Name of Port	Employment (Direct & Indirect)
Antwerp	149.714
Hamburg	151.000
Rotterdam	93.766

Unit: Number of employment, Data for the year 2013

Source: (Erasmus University Rotterdam, 2014) (National Bank of Belgium, 2015) (Port of Hamburg, 2015)

Quality of customs procedures

According to the definition in the PPRISM program, the quality of customs procedures can be represented by the time spend during customs clearance. (PPRISM, 2010) According to the report from World Bank Group, the time and cost during exporting and importing the goods by sea transport are recorded, and the figure include document preparation, customs clearance and inspections, inland transport and handling, port and terminal handling. (World Bank Group, 2014)

Table 14. Quality of customs procedures data

Name of Port	Time to export/import
Antwerp	9.0
Hamburg	9.0
Rotterdam	7.0

Unit: days

Source: (World Bank Group, 2014)

Carbon footprint

Data for greenhouse carbon footprint is not directly available. As is defined by the PPRSIM project, greenhouse gas (GHG) emissions can also be calculated based on the energy use. However, the data collection for energy use is also not easily accessible.

In terms of the data for carbon footprint, Michael Dooms agreed that, there is no accepted definition of carbon footprint for ports. There is a debate on whether people should measure the footprint of the port authority organization or the port cluster as a whole. (Dooms M. , 2015) Port cluster is a joint and even key responsibility of the companies active in the area, and it's not exclusively the port authority. (Dooms M. , 2015) On this port cluster level, extremely high cost for measurement is an obstacle for accessible data. (Dooms M. , 2015) Therefore, in

terms of different definitions and calculation formulas, existing calculation tools cannot provide comparable data, neither.

As there is no or limited data available, some figures are estimated, and might not be able to reflect the real carbon footprint. The idea of this thesis is to involve such an important environmental indicator into performance evaluation. Although data is not accurate, it is still a good example to show how carbon footprint contributes on the evaluation outcomes.

According to the information on port websites, Port of Rotterdam is actively establishing a sustainable port by using clean energy, such as LNG, biomass, wind, and solar. In order to reuse the waste gas, port authority is cooperating with greenhouse growers on a CO_2 capture and storage project. (Port of Rotterdam, 2012) Besides, the waste heat from excess steam is also collected for reutilization. (Port of Rotterdam, 2012) Therefore, based on above information, the GHG Emissions for Port of Rotterdam is estimated to be 18000ktonne/year, which is between Port of Antwerp and Hamburg.

Table 15. Carbon footprint data

Name of Port	GHG Emissions
Antwerp	13280 *
Hamburg	18700 #
Rotterdam	18000 ^

Unit: ktonne/year

** Source: Antwerp Port Authority based on the Flanders energy balance and the Vito study 2011/TEMR/56* (Port of Antewerp, 2012)

 # Source: (Port of Hamburg, 2013)

^ *Data for Port of Rotterdam is estimated.*

5.2.3 Qualitative data

Reporting corporate and social responsibility

The qualitative analysis of corporate and social responsibility of port needs to be done by evaluating the following 6 questions:

- "RAM: the requirement for an annual meeting

- PAR: the public availability of an Annual report
- MWS: whether there are meetings with the community and the stakeholders
- PPM: whether performance metrics are published
- PRSRI: whether there are public reports of socially responsible initiatives
- PFR: whether the PAs financial reports are published" (PPRISM, 2010)

As defined in the PPRISM project, the unit measurement has a base score of 100, from which deduct one point each time when the ports fail to meet one of the 6 requirements. (PPRISM, 2010)

Port of Rotterdam:

As is stated by the Port of Rotterdam authority, corporate responsibility is considered as the key to their successful future. (Port of Rotterdam) The emphasis for Port of Rotterdam is on climate, labour & education, the exchange of knowledge and anchoring sustainability. (Port of Rotterdam)

The assessment of Port of Rotterdam's CSR performance is provided as below:

- RAM: Port of Rotterdam has EPCA annual meeting.
- PAR: The annual report of Port of Rotterdam can be found in its website, and it is free download for public.
- MWS: According to the Port of Rotterdam website, they have EPCA annual meeting hold to build a platform for the global chemical business community. (port of Rotterdam, 2015) "CEOs, CFOs, COOs, Chairmen, Presidents, Vice-Presidents, Business Unit Leaders, Senior Executives, Marketing & Sales Purchasing Directors, Managers, Commercial Coordinators and Products Managers" will get gather for better business and network. (Port of Rotterdam, 2015)
- PPM: Port of Rotterdam doesn't have specialized report of performance metrics. Although part of the performance metrics are involved in its annual report, according to the definition of the PPRISM project, when no total performance metrics available, one point should be deducted from the base score.

- PRSRI: As stated by the port authority, the Port of Rotterdam integrated and published the traditional annual report and the CSR report together. (Port of Rotterdam)

- PFR: the Port of Rotterdam authority published their annual financial report in the annual report.

Therefore, the total score of CSR for Port of Rotterdam should be 100-1=99

Port of Hamburg:

- RAM: The world ports conference of 2015 will be hold by the Hamburg Port Authority to strengthen relationships with the member ports. (Port of Hamburg, 2014)
- PAR: The annual report of Port of Hamburg can be found in its websites, and it is free download for public.
- MWS: Deducting one point, as not information applicable.
- PPM: Port of Hamburg has the energy report for certain years.
- PRSRI: Deducting one point from base score, as no corporate and social responsibility report can be find in the website.
- PFR: the Port of Hamburg authority published their annual financial report in its website, and it is free to download for public.

Therefore, the total score of CSR for Port of Hamburg should be 100-2=98

Port of Antwerp:

Antwerp Port Authority is full aware that to assure company continuity, they must pay attention to the developments in all the local communities. (Port of Antwerp, 2013) Therefore, the port authority strives to build a socially responsible company, and they also participated in the CSR Charter to emphasize their determination to realise their goal for society and the environment. (Port of Antwerp, 2013)

- RAM: Port of Antwerp held the “Cool Logistics Global Conference” in 2012, and occasionally have meeting with different port operators.
- PAR: The annual report of Port of Antwerp can be found in its websites, and it is free download for public.
- MWS: Deducting one point, as not information applicable.
- PPM: Port of Antwerp published their performance metrics in the “Yearbook of Statistics” and “Facts & Figures” report. These reports are available for public to download.
- PRSRI: Port of Antwerp made high quality sustainability report, which was awarded as the best Belgian sustainability report. It is considered to be a good example to take the initiative to communicate about ports sustainability and social responsibility. (Port of Antwerp, 2012)
- PFR: the Port of Antwerp authority involves their annual financial report in its annual report, and it is free to download for public.

Therefore, the total score of CSR for Port of Antwerp should be 100-1=99

Based on the analysis above, the following score of reporting corporate and social responsibility will be figured out:

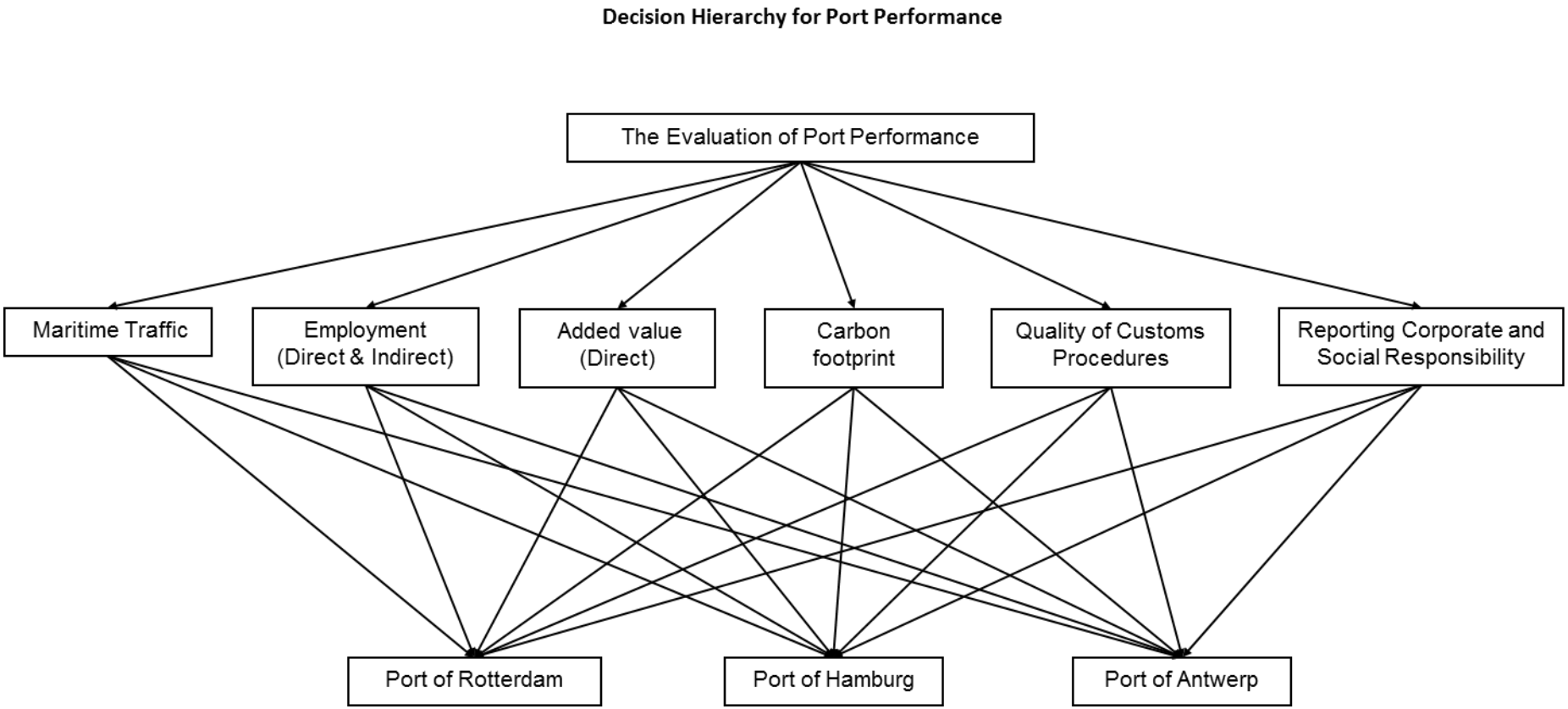
Table 16. Score of reporting corporate and social responsibility

Name of Port	Corporate and social responsibility score
Antwerp	99
Hamburg	98
Rotterdam	99

Source: calculated by author, based on port authority websites

5. 3 AHP applied Analysis

Figure 5. Decision Hierarchy for Port Performance



Source: By author

First step is to identify the objectives and build the hierarchy tree in software. As is shown in figure 5. The top assessment goal is the evaluation of port performance; 6 chosen criterion (indicators) are put in the middle level; the bottom level is where alternatives allocated, so three sample ports are put in the bottom.

The next step is the process of evaluating the importance of objectives. For example: if direct added value is considered to be more important than carbon footprint, then the alternatives evaluation in the former objective should have a greater impact on the final outcomes than the evaluation in the later one. (MakeItRational, 2009) That is the reason why in Figure 6,4 scores was given on direct added value side.

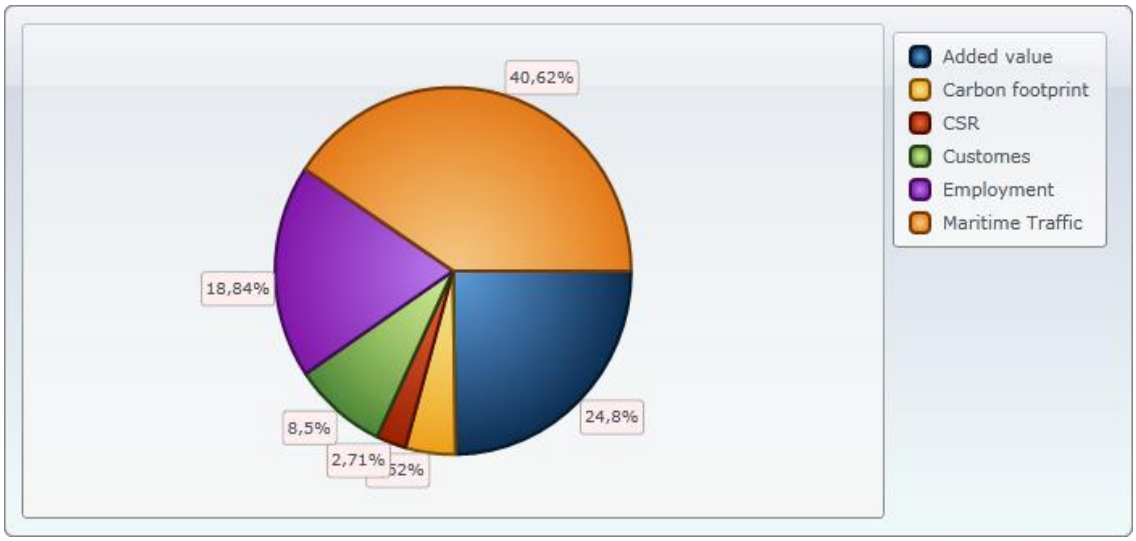
Figure 6. Indicator comparisons with MakeItRational decision-making tool

Source: by author

After the evaluation of the relative importance of indicators, the software provides the outcome of the weight of each indicator and the CR. The weights will be used for calculating total performance score and create the ranking of the ports (alternatives). CR is 4.7%, which is under the 10% limit and can be considered as consistent judgement.

As is shown in Figure 7, maritime traffic, added value, and employment weight higher than other indicators, which means they are considered to be more important when evaluating port performance.

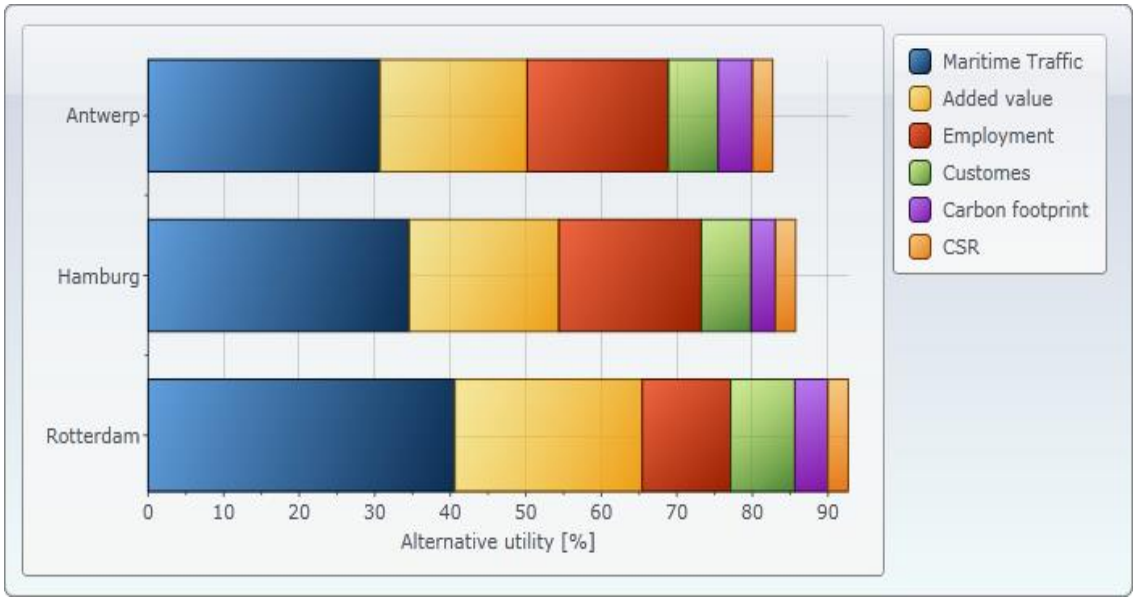
Figure 7. Indicator weights calculated by MakeItRational decision-making tool



Source: by author

The last step is to put the collected data into the software. The software will calculates the total performance score for each port. The ranking of the ports can be seen in Figure 8, and detailed data is presented Table 17. The ranking also contains aggregated information about the importance of indicators. (MakeItRational, 2009)

Figure 8. Final ranking of ports – MakeItRational decision-making tool



Source: by author

Table 17. Chart data for alternatives ranking

Ports	Total	Maritime Traffic	Added Value	Employment	Customs	Carbon Footprint	CSR
Rotterdam	92,69	40,62	24,8	11,7	8,5	4,35	2,71
Hamburg	85,73	34,55	19,83	18,84	6,61	3,21	2,69
Antwerp	82,71	30,66	19,52	18,68	6,61	4,52	2,71

Source: by author

5.4 Discussion of the results

In Figure 8 and Table 17, the final outcomes show that Port of Rotterdam scored at 92.69, which is still at the leading position. Port of Hamburg and Antwerp is at the second and third position, with a total score of 85.73 and 82.71 respectively. This ranking result seems exactly same with the widely used ranking list, which is simply based on throughput.

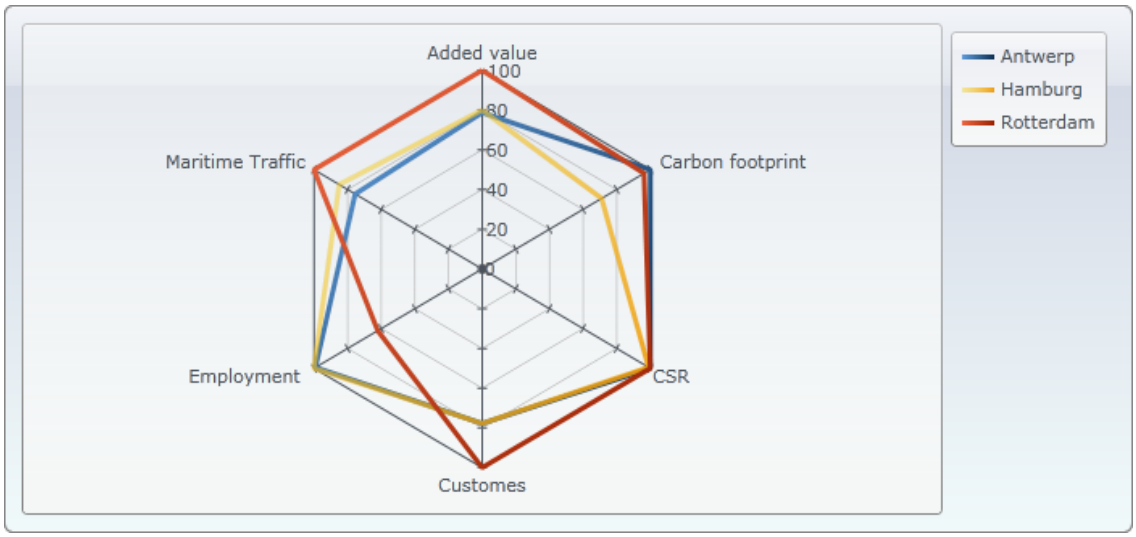
It's not surprising to see an identical result from AHP analysis and normal raking list. Although more indicators are involved in AHP analysis, these indicators are given different weight, which means their value account for different percentage in the final evaluation score. In this thesis, maritime traffic (throughput) is given the largest weight (40.62%) in the evaluation process, consequently, the port with more throughputs would have a higher possibility to get a higher total score. As Port of Rotterdam has the largest throughputs than the other two ports, it is reasonable to see Port of Rotterdam still ranks in the first position among the others.

Although the position of each port in final ranking is same with other existing ranking list, when comparing by total score in Table 17, the difference of each ports is smaller than simply comparing the score under maritime traffic. The smaller gap between sample ports is because of the good performance that Port of Hamburg and Antwerp achieved on other indicators. In terms of the above analysis, the inside meaning of the AHP result is not exactly same with the other existing ranking lists.

The final ranking calculated by AHP model is the most important outcomes, which give the overall image of port performance. However, other outcomes can be valuable as well. For example, the Figure 9 provides the alternatives comparisons in

a radar chart. This is an intuitive way to present the strengths and weaknesses of each port in terms of different indicators.

Figure 9. Alternatives comparisons- MakeItRational decision-making tool



Source: by author

Table 18. Chart data for alternatives comparisons

Criterion	Antwerp	Hamburg	Rotterdam
Added value	78,72	79,96	100
Carbon Footprint	100	71,02	96,26
CSR	100	98,99	100
Customs	77,78	77,78	100
Employment	99,15	100	62,1
Maritime Traffic	75,48	85,04	100

Source: by author

From the Figure 9 and Table 18, we can see that Port of Rotterdam shows a strong advantage over its rivals on maritime traffic, quality of customs procedures, and added value. However, in terms of employment created, Port of Rotterdam is far away behind the others. This result is within our expectation, as Port of Rotterdam has developed many highly automatic terminals, which would reduce the demand

for operational workers. Consequently, fewer vacancies are provided by Port of Rotterdam, which leads to a bad performance in terms of direct employment.

Port of Hamburg scored the best for employment, while relatively weaker in terms of controlling carbon footprint and the quality of customs procedure and added value.

Port of Antwerp shows its strengths in controlling carbon footprint, employment and quality of corporate and social responsibilities. However, Antwerp has the smallest volume of maritime traffic among these three sample ports. Compared with its rivals, added value is also a weak part, which can be improved in the future.

The outcomes show that the AHP model can perfectly applied into port performance evaluation. With the help from MakeItRational software, the result can be calculated easily and precisely.

The AHP model and software is practical. However, because of the limitation of data collection, the result might be less accurate. Besides, only one evaluator determinates the weight of indicators, which makes the result less rational. To be more accurate and precise, a sensitivity analysis can be done to check how port ranking reacts to changes in the weight (relative importance) of indicators. And it's also valuable to add different scenarios by inviting more evaluators, who have different understanding of port performance. The final ranking might be totally different if the evaluators assess the importance of indicators from a port users perspective.

6. Conclusion

6.1 Key findings

An evaluation of port performance should give port authorities and other operators in port industry an insight about the overall strengths and weaknesses of the ports over their rivals. Given the fact that most existing port-ranking lists are simply based on throughputs, which fail to consider other important parameters such as sustainability, social responsibility, governance policy, etc., they are partial and limited to evaluate underlying port performance. This thesis is mainly focused on finding a more comprehensively way to evaluate the port performance with an ideal set of indicators being involved.

By comparing the existing port performance evaluation projects, this thesis found an ideal list of indicators, which was developed by a group of professionals in a EU project called PPRISM. The ideal port performance indicators list consists of 14 indicators, involving 5 categories: market trends and structure, socio-economic, environmental, logistic chain and operational, and governance. These 14 indicators are both quantitative and qualitative, which can help to achieve a more rational port performance evaluation.

This thesis also evaluated the existing multi-criteria decision-making methods and found out that the AHP method is the most appropriate one, which can be perfectly compatible with all the 14 indicators. Unlike many widely used multi-criteria decision making methods, which cannot involve qualitative indicators, AHP method can fully preserve the valuable qualitative information from interviews or evaluators judgement, and convert information into measurable data for further assessment. With the help of AHP-based software, the evaluation procedure was simplified, and the outcomes were presented in a visual and straightforward way through different figures and charts.

In the empirical analysis part, a final port performance evaluation list was developed. Port of Rotterdam still ranked in the first place, with Port of Hamburg and Antwerp following behind. Although the outcomes of new ranking evaluated by AHP model are same with current ranking list, the inside meaning of the new ranking result is richer than simply based on throughput. A smaller difference of total evaluation score of each port also indicated that Port of Hamburg and Antwerp achieved a good performance in terms of indicators other than throughputs.

Additionally, as part of the outcomes, the radar chart of alternatives comparisons provided an insight about the strengths and weaknesses of each port. Port of Rotterdam did not contribute enough regarding to employment. Port of Hamburg should enhance carbon footprint control and contribute more on added value. Port of Antwerp can focus more on attracting maritime traffic and creating added value.

As analyzed above, AHP method combined with ideal indicator list would provide a comprehensive port performance evaluation.

6.2 Limitations and future research

Limited indicators and limited sample ports

In chapter 2, a set of indicators was introduced as an ideal list of port performance indicator. All of the 14 indicators are supposed to be all implied into AHP model. However, because of the extensive efforts needed for data collection, only 6 of them were selected in the end. The absent of a full set of indicators would affect the accuracy of the outcomes.

The selection of port performance indicators is still an ongoing debate. The "ideal" indicator list in this thesis was adopted from the research achievement of PPRISM project. However, actually there are no "ideal" indicators. The selection of indicators can be effected by the role of evaluators in the port industry. For example, from a port users perspective, indicators like employment and added value would have less important than quality of custom procedure. Therefore, it is valuable and interesting to see future research exploring more "ideal" indicator lists from different perspectives.

Additionally, in this thesis, only 3 European container ports were selected as samples. If more sample ports can be involved, a larger view of the image would be presented and the result would be more comparable.

Single perspective:

Regarding to the series of evaluation for the weight of indicators, this thesis gave judgment mainly based on port authorities and local governments' perspectives. Therefore, the indicators like maritime traffic, added value and employment take a large weight and account for a high value in the final result. That is also the reason why the outcome of this thesis is similar to the ranking list, which is simply based on throughput.

If the evaluation of the weight of indicators is from a port user perspective, some indicators (such as intermodal connectivity and quality of customs procedures) would take a larger weight in the final value, which means the ranking and outcome can be totally different.

Therefore, to make a more comprehensive port performance evaluation, the evaluators should come from different areas, stand on different perspectives, and represent their own interest.

Limited evaluators:

As mentioned above, this thesis is based on port authorities and local governments perspective, however, the weight of the criteria is evaluated by author herself. This is an extremely small sample and can easily falls into the mistake of subjective judgment. In order to make comprehensive evaluation, more evaluators' judgments should be collected to set the final value of the weight of indicators.

A questionnaire can be an efficient and convenient way to involve a large number of evaluators. The questionnaire should enable the evaluators make comparisons regarding the relative importance of the indicator. (Sample questionnaire can be seen in Appendix 1) When involving a certain number of evaluators' opinion, the outcomes would be more convincing.

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Appendix 1. Questionnaire

What is your role in port industry?

A. Port Authority B. Government

C. Port user D. Social Communities

Which aspect concerning the port performance evaluation is more important?

How important is it?

Note: please choose from the following scales, which show how much importance one indictor stronger than the other.

1: Equal importance

2: Fair importance

3: Medium importance

4: Strong importance

5: Absolute importance

Carbon footprint	**5 4 3 2 1 2 3 4 5**	**Direct added value**
Carbon footprint	**5 4 3 2 1 2 3 4 5**	**Maritime traffic**
Carbon footprint	**5 4 3 2 1 2 3 4 5**	**Quality of customs procedures**
Carbon footprint	**5 4 3 2 1 2 3 4 5**	**Reporting CSR**
Direct and indirect employment	**5 4 3 2 1 2 3 4 5**	**Carbon footprint**
Direct and indirect employment	**5 4 3 2 1 2 3 4 5**	**Direct added value**
Direct and indirect employment	**5 4 3 2 1 2 3 4 5**	**Maritime traffic**
Direct and indirect employment	**5 4 3 2 1 2 3 4 5**	**Quality of customs procedures**
Direct and indirect employment	**5 4 3 2 1 2 3 4 5**	**Reporting CSR**
Maritime traffic	**5 4 3 2 1 2 3 4 5**	**Direct added value**
Quality of customs procedures	**5 4 3 2 1 2 3 4 5**	**Direct added value**
Quality of customs procedures	**5 4 3 2 1 2 3 4 5**	**Maritime traffic**
Quality of customs procedures	**5 4 3 2 1 2 3 4 5**	**Reporting CSR**
Reporting CSR	**5 4 3 2 1 2 3 4 5**	**Direct added value**
Reporting CSR	**5 4 3 2 1 2 3 4 5**	**Maritime traffic**