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Terminal Planning: The Selection of Relevant KPIs to Evaluate Operations

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Abstract

The European Union is highly dependent on seaports for trade with the rest of the world and within its Internal Market. Approximately, 75% of goods imported and exported and 37% of exchanges within the Union transited through seaports in 2013. To manage this amount of cargo in ports, smooth operations are required. The performance of ports is currently evaluated by using different types of Key Performance Indicators (KPIs). How the indicators are described is dependent on the stakeholders and their organizational interest.

Ports, and the transport sector as a whole, are undergoing drastic changes. To cite a few, demand increases, ship capacity enlargements, shipping line mergers and alliances lead to more concentrated flows and increase of traffic in certain hub ports detrimental to medium size ones, other aspects such new requirements regarding environment protection and security are also relevant. At the same time, ports are usually located in the middle of existing neighborhoods, which limits possibilities to enlarge their area whilst stress is placed to improve the port-city interrelation. Therefore, there is a need to invest in port infrastructure, but expansion or renovation of a port is extremely difficult. The required investments are big and the planning horizon is long. Hence, if the designed structures turn out to be unsuitable due to changes in needs, it is rather expensive to make changes.

Planning tools have developed remarkably during the past 10 years. Different types of planning tools are used in seaport and terminal design to model the completeness. Modelling generates digital representations of physical and functional characteristics of a terminal area, buildings and other infrastructures. With the help of model-based approaches and with suitable KPIs, it is easier to understand and evaluate the effects of certain design solutions for terminal operations in a larger context. By using modelling tools, it is also possible to compare different design options to outline how certain choices in terminal design influences on the completeness.

There is a need to define the objectives of good terminal prior to plan the terminal and its operations. A good terminal would satisfy the stakeholders' expectations in best possible ways in the given preconditions. The achievement of objectives can be evaluated by using suitable indicators. However, the indicators used to plan and model terminal operations may differ from indicators used to evaluate the performance of current ports and terminals. The purpose of this paper is to analyze the indicators required for terminal planning and compare them with existing KPIs used for measuring the performance of ports and terminals.

Keywords: Intermodality; Key Performance Indicators (KPI); Terminal; BIM (Building Information Management)

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1. Introduction

The significance of ports for the European Union is irrefutably high: 75% of all international goods traffic is handled via ports. For inner-EU goods traffic, waterway transport amount to 40% of all cargo. In 2011, the EU ports handled about 3.7 billion tons of goods whereof 70% were bulk, 18% container, 7% Ro-Ro (roll on roll off) and 5% break bulk traffic. (Veregge 2013). Taking 2011 as year of reference, the total goods volume is forecasted to rise by 50% until the year 2030 (European Commission 2013).

In addition to the increased cargo volumes, the port and maritime sector are facing several other new challenges and requirements. For example, due to enlarged vessels and companies merging, cargo volumes are concentrating in a few ports to be handled in a small amount of time. The other topical issues are related to environmental concerns and new security requirements. Obviously, investments are needed to increase capacity, but the problem is that there are limited amount of space for totally new ports, and the current ports are usually in the middle of existing neighborhood limiting possibilities to enlarge their area. Therefore, there is a need to invest in ports, but the planning of new infrastructure is difficult. The required investments are big and the planning horizon is long. So, if the designed structures turn out to be unsuitable due to changes in users' needs, it is expensive to make changes later.

There is a need to define the objectives of a good terminal in order to plan the terminal and its operations. A good terminal would satisfy the stakeholders' expectations in the best possible ways and in the given preconditions. The achievement of objectives can be evaluated by using suitable indicators. Currently, the performance of individual terminals is evaluated by using different types of key performance indicators (KPIs). The involved stakeholders in the decision process and their organizational interest define the way of picking up and describing the indicators.

Planning tools have developed remarkably during the past 10 years. Different types of planning tools are used in seaport and terminal design to model the completeness. The purpose of modelling is to generate digital representations of physical and functional characteristics of the terminal area, its buildings, its processes and other infrastructure and superstructure. With the help of a model-based approach and with suitable set of KPIs, it is easier to understand and evaluate the effects of certain design solutions for terminal operations in a larger context. By using modelling tools, there are also possibilities to compare different design alternatives to outline how certain choices in terminal design influence on the bigger performance-picture.

However, the indicators used to plan and model terminal operations may differ from those indicators used to evaluate the day by day performance of current ports and terminals. Therefore, the purpose of this paper is to analyze the indicators required for terminal planning and compare them with existing KPIs used for measuring the performance of ports and terminals.

This paper is organized as follows: The Introduction section is followed by, the methodology. This is then followed by the results of literature search on currently used KPIs for terminals, current logistics trends and development of BIM (Building Information Modelling) and simulation tools. The empirical material based on the workshop and experts' opinion is presented. The paper concludes with an analysis of different KPIs.

2. Methodology

The methodology for this paper consists of the following three phases: 1) Literature search about current KPIs used for evaluating the performance of the ports and terminals and current trends in port industry and marine transport. 2) Workshop, where experts from different stakeholder groups presented their views on relevant KPIs related to the evaluation of port performance and then discussed these KPIs to decide upon a common list of applicable KPIs. 3) The created list of KPIs was evaluated by experts who are specialized to simulate the operations of ports, terminals and other logistics centres.

Literature search was conducted by using the most common academic journal databases. The search aimed to find which kind of KPIs have been used or have been suggested to be used for evaluating the performance of the ports and terminals. The purpose of the search to find current trends was to evaluate whether the existing KPIs are relevant enough also in the future or is there need for new KPIs.

After the literature search on reported KPIs, the workshop was organized to get practitioners' views on current KPIs and later compare differences between academics' views and practitioners' views. The following participants attended the workshop:

- Port authority
- Logistics service provider
- Port operator
- Railroad operator
- Research organization
- Planner and designer

Based on the workshop, a list of 40 relevant indicators was created. The list consisted of indicators that at least some of the participants considered important from their organization's perspective. After the analysis and discussions, 27 indicators were named as KPIs and other 13 as other performance indicators. The main reasons for naming certain indicators "only" as 'performance indicators' was that either those indicators belonged to the other indicators or they were indicators that in practice measured something similar as another indicator. All the indicators were then grouped to five different categories named as a) Operational, b) Financial, c) Quality, d) Environmental, and e) Safety indicators.

After defining the list of indicators, the list was evaluated by directors and developers of a Dutch software company. The company is specialized to program software models to simulate the operations of ports, terminals and other logistics centres under consideration, or which require major improvements simulations. The software company experts scrutinized all the indicators and divided them in three different categories based on strict justifications. The first category consists of indicators that are possible to consider in simulations and define its value in different parameters. Third category consists of indicators that are very difficult to consider in current simulation models even if the model would be improved significantly. The second category consists of indicators that are between the first and third categories: they are indicators that are not used in current simulation models but, which could be included as a part of the models if someone is ready to invest adequate amount of resources in additional calculation development. This classification was based on expertise of using simulation models in different ports, terminals, and other logistics centres. The first category is rather obvious, but the challenge was to classify the indicators as second or third category. However, by analysing the available input data and used calculation models, the experts has rather well consciousness what would be possible to calculate and what would be very difficult to calculate.

3. Background information

3.1. Currently used KPIs for evaluating the performance of the terminal

Indicators are figures or other measures that enable information on a complex phenomenon, such as environmental impact, to be simplified into a form that is relatively easy to use and understand. The three main functions of indicators are quantification, simplification and communication (ISO, 2010). They can also support decision making by helping to set targets and track and monitor progress on performance (ISO, 2014). As Tanguay et al. (2010) presents, it is essential to clarify the difference between data, a variable and an indicator. Data or variable becomes an indicator only when its role in the evaluation of a phenomenon has been established, meaning that the changes of the data or variable have been defined as negative or positive.

Indicators are used in many sectors and for various purposes. The origin of Key Performance Indicators (KPIs) is in business administration. KPIs provide businesses with a tool for measurement (DEFRA, 2006). KPIs are known for example as measures of organizations', companies' or programs' success. On the other hand, many other sectors, such as buildings or transport, use them to assess the performance of their specific products or processes. Since indicators enable to compare the current state and communicate the evolution of performance in time (when assessed regularly), they are typically used for e.g. target setting, monitoring, benchmarking, ranking purposes - and ultimately, and most importantly, decision making.

Different types of indicators are used for different purposes and have been categorized in several ways. Performance indicators measure the required end performance instead of prescribing the technical solutions to achieve that performance (Gibson, 1982). The latter can be called prescriptive indicators. Another more detailed categorization is to group indicators based on whether they measure inputs, outputs, outcomes or impacts (Segnestam, 2002). Examples of those could be amount of expenditures spent or staff used (input indicators), no of sensors installed (output indicator), extent to which the activities planned in a project took place (process indicator), % of target group reached by the project (outcome indicator) and reduction of CO_2 emissions (impact indicator).

Hundreds of indicator systems or classifications have been developed for different purposes. They structure indicators under a hierarchy of main categories and sub-categories. In sustainability assessment frameworks for example, the main categories are often impacts on people, planet and prosperity (i.e. environmental, social and economic) and the sub-categories can focus for example on sectors such as energy, transport, ICT. Often target values are developed for indicators. If they exist on a uniform scale, e.g. from 1-5, that allows the comparison and scoring of indicators and construction of an overall performance index.

An index is an aggregate of many indicators. Still, it aims to provide a coherent and multidimensional, though simplified, view of a system. Usually indices provide a snapshot of the current situation and are used to compare e.g. cities, but they can also be calculated regularly and provide in one figure, an indication if the system is moving in a certain direction (Mayer, 2008).

Sometimes weighting factors are also used to indicate the relative importance of the indicators from e.g. the viewpoint of different stakeholders. Different stakeholders naturally view the relevance and importance of indicators from their viewpoint reflecting their needs and targets and therefore the needed indicators often differ between actors, even if the assessed process is the same.

Different ports use different kinds of indicators to assess their own performance. Morales-Fusco et al. (2016) analysed 61 Mediterranean ports and found that those ports use altogether 77 different KPIs. By analysing found KPIs in more detail, they were able to reduce the numbers of KPIs to 27 and classify the indicators into six different categories: traffic, financial, operational, customs procedures, sustainability and security, and human resources. (Morales-Fusco et al., 2016).

Ha et al. (2017) reviewed 259 relevant papers from 1970 to 2016 on Web of Science to find different performance indices used in ports. Based on the review, they concluded that port stakeholders used 16 principal port performance indices and 60 other indices. These indices could be divided in six different dimensions: core activities, supporting activities, financial strength, user satisfaction, terminal supply chain integration, and sustainable growth. (Ha et al., 2017).

Performance indicators help to get information about the port performance. An extensive analysis of port performance helps managers to make better decisions on port operations. Consciousness of port performance indicators can raise transparency on port performance with respect to various dimensions and hence managers in port can raise their port attractiveness by considering important corners from a certain key stakeholder. This offers diagnostic instruments to port managers, aiming to meet the different needs of port stakeholders. Additionally, information related to port performance indicators enables port managers to better understand and value the opinions of various stakeholders and offers diagnostic instruments to manage stakeholder relations. (Ha et al., 2017).

3.2. The effect of megatrends in logistics and port management on terminal requirements

Different port governance models have been under discussion decades, and ‘public versus private’ has been the biggest debate (Brooks and Cullinane, 2007). Even if the debates have ended up promoting private sector involvement in ports, only a few countries with limited number of ports have been privatized during the past decade (Brooks et al., 2017). Since 2007, European Union has recommended to use landlord model for port governance (Verhoeven, 2009), and this model has become the most common and dominant model during the early twenty-first century (Brooks et al., 2017). In a landlord model, a public port authority acts as both landlord and regulatory body, while private companies carry out port operations (e.g. Bischou and Gray, 2005). Due to the changing nature of port governance, the port authority no longer has an integrated and holistic role within port activities; instead, it has given the control of operations to separate organizations and at least the ownership of superstructure and equipment if it has retain the ownership of infrastructure assets (Brooks et al., 2017).

Private organizations' involvement in port governance have an effect on ports' competitive position and investments are required to develop competitiveness and cargo volumes. Earlier, the ports competed against each other, but due to the involvement of private organizations operating in several ports, cooperation between ports has increased. This tendency has both good and counterproductive effects on the development of individual port. The terminals may achieve higher productivity and get additional investments by international terminal operators (Parola et al., 2017), while sometimes the operators may share the competencies and customers between the ports in a way that an individual port may end up for serving dying cargo segment and therefore it loses the interest of private investors (Shinohara, 2017).

The increased size of container vessels has affected container terminals in several ways. First, big vessels require particular investments in terminals such as the need for bigger cranes, deeper sea routes, etc. Secondly, the operations of big vessels concentrate on certain terminals, as the operations require particular investments and the big vessels operate most economically in long-distance lines. Therefore, the ports that serve mega vessels strengthen their role as transshipment port while the other ports nearby become as feeder ports (Rodrique and Ashar, 2016). Third, due to the high volumes and operating costs of the big vessels, the big vessels visit the terminals for longer intervals but they require rapid loading and unloading operations. This requirement forces terminals to arrange the needed capacity for unloading and loading and for quayside operations whenever the vessels arrive, as the vessel may choose another terminal if the quay were not available and waiting time would be too long (Fransoo and Lee, 2013). (Notteboom, 2004).

Port work has been very labor intensive and dangerous work, but well paid. Therefore, there are many incentives to automate port operations to decrease the number of required workers. However, automation requires large investments, and in order to gain cost savings and increased efficiency, there should be information about the type and volumes of handled cargo when designing the proper automation system. (Hinkka et al., 2016).

3.3. The use of Building Information Modelling (BIM) for terminal design

The design phase aims the development of a solution that is possible to be constructed. Traditionally various Computer Aided Design (CAD) applications are used to plan different functional areas and related technical domains and disciplines. Building Information Modeling (BIM) is a methodology to manage construction projects in an intelligent and collaborative manner (Cheng et al., 2016). Succar (2009) describes BIM as 'a set of interacting policies, processes and technologies generating a methodology to manage the essential building design and project data in digital format through the building's lifecycle. It has been used already for some time in the building industry, and since the past decade, the methodology has been increasingly utilized to also manage other industry sectors such as infrastructures (Chong et al., 2016). BIM continues to be used more and more in civil engineering and freight terminals and ports have a great potential to utilize BIM. (Pärn et al., 2017).

In a large terminal development project, there is a tremendous need for advanced tools that enable using information together to address problems from the engineering perspective. These kind of actions could potentially save money and time. The purpose of BIM depends on the need of the project phase. With an integrated approach, all operations and maintenance of terminals during the life cycle can be better examined. Moreover, model-based work practices help to manage construction process and supports documenting end result into 'as built model'.

The fact that the 4th (time) and 5th (cost) dimensions can be added to BIM has boosted efficiency and quality in infrastructure projects (Bradley et al., 2016). Capabilities such as checking of space conflicts (Moon et al., 2014), use of satellite images for monitoring construction (Han, 2013), and incorporation of cost and schedule model for evaluation (Kim et al., 2014) is a great asset when utilizing BIM. Such models help detect collisions in advance (clash detection) in e.g. equipment space reservations or storage areas. Traditionally undetected clashes are very costly to repair later, because the change causes a chain reaction to design and construction work.

Communication stands as a critical element in all project teams. A shared information and knowledge resource enables informed decisions and their communication to everyone. In many cases, traditional paper work is partially or completely avoided since the necessary designs are completed with the help of BIM (The National BIM Standard-United States, 2016). The need for BIM can also be explained by the need for better integration, cooperation and coordination within construction teams (Cicmil and Marshall, 2005) and having an inter-organizational information sharing system avoids situations where information is 'fuzzy, unformatted or difficult to interpret" (Ajam et al., 2010). By adopting BIM, information can be shared across the supply chain. This also means one source of input will facilitate many outputs, discouraging silo working and encouraging data-driven management strategies to be created (Beaumont and Underwood, 2015).

Model-based working can be used for designing both schematic massing models and detailed construction-ready models. Rather than having to create and document designs for each new phase, all the necessary information is stored in a database, which can be regularly updated and easier to manage. Thus, BIM is not just about geometrical modelling and the input of information, but also a way to improve collaboration between stakeholders and time required for documenting the work (Bryde et al., 2013). BIM allows project managers to reengineer the ways to involve all actors (Bryde et al., 2013). There are also opportunities to provide a more accurate visualization and track changes automatically. This is an added value to traditional 2D drawings or 3D renderings resulting in better designs (Bachman, 2009).

Simulation models are widely used in terminal design (Dragovic et al, 2017). Efficient logistic operations can only be achieved by a proper and robust terminal design, as it establishes the foundations for operational choices. Design choices typically cannot be easily changed, without extensive financial repercussions, or significant impact on the terminals operational performance. If these are in any way hampering the operations, the capacity assumptions might not be met. Design volume (desired throughput capacity) is closely connected with space requirements, transport modes, and possible container handling equipment and cannot be considered in isolation. Improper design cannot only underestimate the needs, but also overestimate them, ending up in too high capital and/or operational costs. Any layout considerations not taking into account the needs for adequate operations are insufficient, and may cause serious negative functional implications. Nevertheless, a proper infrastructure design is only the first step in reaching efficient logistics. It needs to be followed by suitable planning of the functional areas (such as stack ground spot plan), supporting equipment (e.g. number of automated guided vehicles), operational procedures, appropriate planning of arrivals (especially vessel calls), suitable Terminal Operating System (TOS), good coordination, and others.

Currently design, operational simulation and performance indicators are separated from each other and there is no interfaces available to export and import information. However, this is a very interesting topic for a holistic terminal development and it will elevate the terminal development to a next level in the future.

4. Empirical material

As explained earlier, the workshop defined a list of 27 relevant KPIs and 13 performance indicators to evaluate the performance of terminal. Then these indicators were grouped to five different categories named as a) Operational, b) Financial, c) Quality, d) Environmental, and e) Safety indicators. The indicators can be found in Table 1. Table 1 also shows the results of evaluation of indicators in a simulation point of view. I.e. which indicators can be evaluated by using a simulation model, which can be evaluated if some additional calculation model is programmed, and which of the indicators are very difficult to obtain even if there would be a reasonable amount of resources to program additional calculation model.

Table 1. A list of indicators for evaluating terminal performance. The indicators written in normal text are KPIs while the indicators written in italic are performance indicators. The values for indicators coloured in green are rather easily possible to obtain from simulation models, indicators coloured in yellow are possible to get from simulation if additional calculation model is programmed, but indicators coloured in red are very difficult to obtain from simulation despite the additional improvements for the model.

Operational	Financial	Quality	Environmental	Safety
Intermodal terminal throughput (volume)	Return on investment (ROI)	Turnaround time	Energy consumption per handled unit	Number of road accidents
Equipment utilization	Terminal's profitability	Waiting time	Carbon footprint per unit	Number of railway accidents
Gate utilization	Operating efficiency	Easiness of entry and exit from highways	CO, NOX, SOC, PM emissions	
Labour utilization rate	Operating revenues per unit	Easiness of entry and exit from rail network	Population exposed to high level traffic noise	
Storage area utilization	Operating benefits per unit	Delays produced (reliability) - road		
Rail track utilization	Direct jobs sustained from terminal activities	Delays produced (reliability) - railway		
Berth utilization	Indirect jobs sustained from terminal activities			
	Road and rail track maintenance cost			
Manoeuvring time	*Capital expenditures (CAPEX)*	*Unproductive time*	*Use of alternative fuels from total consumption*	*Accidents related to hazard cargo*
Service time	*Operational expenditures (OPEX)*			
Berthing time	*Corrective maintenance cost (equipment)*			
Idle time (equipment)	*Preventive maintenance cost (equipment)*			
	Corrective concrete structures maintenance cost			
	Preventive concrete structures maintenance cost			

5. Analysis of KPIs

The purpose of KPIs is to evaluate the companies' success and performance. Even if the targets for KPI values can be set in advance, usually KPIs are used to monitor and evaluate the performance afterwards, when the exact figures of the monitored period are available. When KPIs are used in the terminal planning phase, the figures are, of course, estimates. However, because of modern BIM tools, rather detailed models for alternative solutions are made already in the planning phase providing economic indicators whereas simulation tools are used to evaluate the efficiencies of different alternatives, but also how certain details affect the performance of an entire terminal and port. Therefore, there is a need to define suitable KPIs for a port and terminal already in the planning phase to help in the planning decision process.

In Table 1, we have collected a list of indicators for evaluating terminal performance. For the purpose of this paper, the list does not need to be unanimous with everyone with a say during terminal planning; indeed, some of the listed KPIs could be replaced by better defined, already benchmarked, ones, but the overall content of the KPIs is probably fair. Hence, when different listed indicators in same category are colored similarly, the question whether certain single indicator is obtainable, defined correctly or whether it is relevant at all, becomes insignificant.

Table 1 also shows that operational and quality performance indicators are rather well achievable using simulation models. Many of these indicators, indicated with green colour, are calculated as part of a simulation model or rather easily calculated based on its results. The list of easily collectable indicators includes the key measures in terminal functional areas, such as volume move, utilizations and various operational and waiting (queueing) times. It also seems that environmental performance indicators are possible to be included into simulations, although their calculation was quite neglected up to date, since they were not considered the goal of such simulations. Especially energy consumption and various emissions per handled unit need further information for e.g. about the equipment used.

Even if many of the stakeholder workshop participants considered financial indicators as the most important set of indicators, most of these are not yet calculated through in simulations. Based on the discussions with a company making operational simulations, it is possible to make assumptions for some of the financial indicators based on operational and quality indicators data from the overall transport chain. In existing terminals where minor changes are made the reliability of assumptions can be improved with financial information from TOS. Based on Table 1, it seems that safety indicators are not simulated in models, even if improved safety is named as an important justification for many terminal automation enlargements. Currently terminals have stated that they aim at improving safety and collect information on accidents and close to situations. Up until this date, safety indicators come from global and average statistics that can roughly relate with volumes moved, productivity and intensity of use, but not linked with specific terminal layouts, which is not yet achieved through simulation, thus making it hard to be calculated beyond average values correlating with performance issues already.

Recent trends in maritime transport and port sector have changed the position of ports in a global supply chain. Ports and terminals are currently important intermodal nodes, but the location of any intermediate node in a supply change can quickly change along the supply chains as a whole and the continuously changing transport needs. Therefore, ports need to be adaptable in order to attract customers to include the port as a part of their transport chain. However, the flexibility of adapting the port to the needs of its current potential users is rather difficult to measure by using KPIs even when the port’s ability to comply with the requirements of the market can be a more important factor during the design of the supply chain over than any single operational performance value. From a review on KPIs found and the literature, as reflected when looking at Table 1, it seems that flexibility factors have minor role when defining KPIs or there are not established ways to measure flexibility.

6. Conclusions

Currently, financial performance indicators were seen as the most relevant indicators when evaluating the performance of a terminal or port. However, when planning a new terminal, its owner aims at improve its economic performance and typically financial indicators are not included in the simulation of a terminal operation. However, some of such indicators could be calculated as a part of the simulation already, even if it seems to be very difficult to include the some of the most relevant indicators such as return on investment (ROI) as a part of the simulation.

Terminal simulation software since it aims at physical performance, seems to concentrate on operational and quality indicators. They are, of course, relevant indicators, but only show one of the facets of the terminal’s competitiveness and performance. Based on the expert opinion, it is feasible to include environmental indicators to the simulation model along with some financial indicators. Including those indicators as a part of the model would offer a more comprehensive view on terminal performance and provide additional insights during a terminal’s design decision process.

In addition, it is found that terminal’s flexibility is not well covered with existing indicators in used, both based on the literature and conducted workshop. Therefore, there is a need to develop indicators considering the flexibility and adaptability factors and their trade off with the optimization (standardization) of some of the operational indicators like equipment productivity may decrease the terminal’s responsiveness to varying customer needs.

As a summary, the paper shows some development requirements for terminal simulation models. Even if the expert opinion was that especially financial and safety KPIs are difficult to include in current models, this is not perhaps the final truth. Models are developing all the time and can cope with added complexity. Financial KPIs are difficult to measure as costs and other related factors differ greatly between different countries and ports.

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