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Nordic Container Port Sustainability Performance—A Conceptual Intelligent Framework

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Abstract

There is a lack of both integrative frameworks for container ports and dedicated ones to the Nordic region as observed in the literature. The purpose of this paper is to fill that gap by proposing a conceptual intelligent sustainability performance management framework for Nordic container ports. First a description of such framework is given where the application of artificial intelligence is vital. Then, scanning the literature for performance measurement, features of ports in the Nordic region and port sustainability is undertaken. A dedicated list of key performance indicators is suggested. Finally, a prototype based on hypothetical data is developed for demonstration purposes.

Keywords

Conceptual Framework, Sustainability Performance, Nordic Container Ports, Prototype

1. Introduction

Ports are complex systems as they are composed of different companies, dealing with different activities and offering a wide range of services. A port can be viewed as an industrial cluster, or as a virtual enterprise, or as a hub for different supply chains connecting *in-situ* three mode of transport: rail, road and sea. Depending on the view, different metrics are relevant and one should strike the balance between all these views while choosing the Key Performance Indicators (KPIs). This complexity implies diversified sources of pollution which constitute a damaging factor for business and society as a whole.

Integrated supply chains in a holistic view are a natural result of the ever increasing focus, across several industries, on customer satisfaction, efficiency, quality improvement, and cost reduction. Specifically, the tre-

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mendous pressure on ports and shipping industry to streamline the transportation processes with regards to the ecological challenges, improve the quality, and cut costs has led to the necessity for mega-ships and mega-container terminals in order to benefit from the economy of scale. Considering the supply chain as a complex system, measuring its KPIs can help its management and improve its competitiveness. The development of information and communication technology and especially its increasing use in companies, whatever their size, facilitate data collection on a broader scale and could lead to more extensive performance measurement [1]. However, this overwhelmingly available data still need be transformed into meaningful information. A lack of integrative framework has already been stressed in the literature, e.g. [2], and this paper intends to address this issue. Which KPIs to measure and what kind of sustainable performance framework to adopt for Nordic container ports are the fundamental questions this paper aims to answer. These ports have clearly some special characteristics that will certainly influence the type of relevant KPIs. The choice of Nordic ports stems from their sizes, the geographical properties of the region and its market logistical structure.

The next section addresses a proposed conceptual intelligent framework dedicated to Nordic Container port sustainability performance. This is followed by a literature review in order to establish a reference and gain an insight in what has been done in the fields of port sustainability and performance measurement. This ends with a list of KPIs devoted to Nordic container ports. Implementation issues of the proposed framework and modeling details are then presented subsequently while a conclusion sums up this work.

2. The Proposed Framework

Figure 1 below gives an overview of the proposed conceptual framework. This holistic framework will monitor port sustainability performance along the economic, environmental, and social dimensions over a predefined time horizon (e.g. yearly). An input box is linked to the port performance system which is delimited by the dashed rectangle. This is complemented by two equivalent systems for port cluster and port supply chains. All these systems give a feedback to the input box. Several other factors are also part of this input, namely, surveys, expert opinions, processed system feedback, and some business intelligence (and data mining) conclusions deducted from gathered ERP system data, RFID data if any, sensors data, and the system itself. This input can be supplemented with periodical reports from other ports and dedicated organizations, e.g. ESPO ranking of environmental issues according to ports' concerns [3] or the top ten port environmental issues as identified by the ESPO (Sea Ports Organization) Survey [4] compared with the main environmental needs identified by PEARL [5] Other techniques like Life Cycle Analysis or Cost-Benefit Analysis might help as input in tuning or stressing the importance of certain KPIs as well.

The role of this input is to help identify and restructure the relevant KPIs. The weighing and ranking of theses KPIs is then carried out through the application of artificial intelligence techniques.

This step can be regarded as a black box with relevant KPIs and expertise as input and a sustainable performance monitoring capability as output to the next step. Here, three value driven dimensions are visualized and help monitor the port sustainability performance. A manager can see what kind of actions that have a better impact on the port performance, which parameters and according to which dimension this would be possible or, on the other hand which combination gives rise to the best outcome. It would be possible to drill down to a parameter level if required. What is needed is firstly, to transform human-like answers, from surveys for instance,

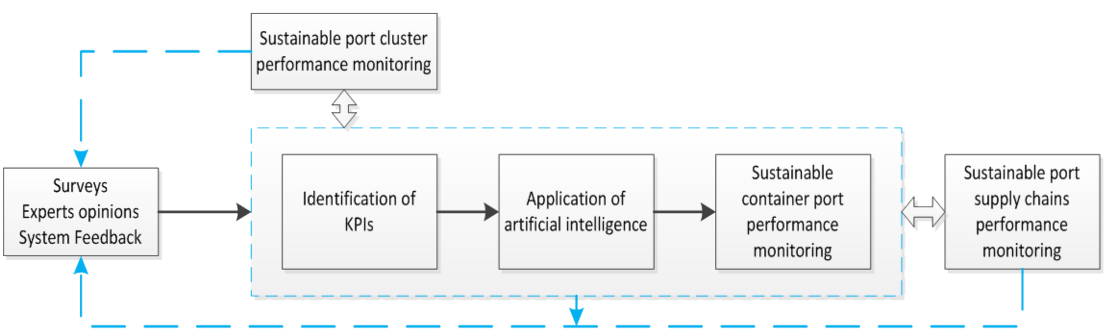

Figure 1. A conceptual intelligent framework for Nordic ports sustainability performance management.

into crispy values that can be computed. Secondly, ranking of the KPIs is required so that comparison with other ports would be possible. Therefore, the most adequate techniques might be fuzzy logic for the former and Analytic Hierarchy Process (AHP) for the latter.

The father of fuzzy logic is Lotfi A. Zadeh who proposed it in 1965 [6]. Fuzzy logic is based on “degrees of truth” where 0 and 1 as extreme cases of truth as opposed to the Boolean logic. It is the most appropriate technique here because it has the capabilities of mapping non-linear relationships, dealing with both quantitative and qualitative criteria, and handling system vagueness and complexity in a robust way. Fuzzy set approach has been employed, among others, in evaluating the greenness of major Korean ports [7].

As for AHP, it was developed by Thomas L. Saaty in the 1970s and is today a widely used and effective multi-criteria decision making method that permits decisions to be structured hierarchically and integrating quantitative and qualitative data, logical reasoning, and expert experience in the decision-making process [8] [9]. For instance, it has been applied, together with the graph model for conflict resolution technique, in investigating the Canadian West coast port congestion conflict [10]. By means of pairwise comparison, AHP will help choosing and ranking a set of relevant KPIs from a potential list. Most importantly, it will be useful in comparing (on a yearly basis) the performance of a set of Nordic ports (four or five best performing ones) and choosing the best alternative that should be used as a benchmark. The strongest performance points of each port might be drafted and used as part of the benchmark.

Finally, the full system will be connected to a database where data mining algorithms will be applied and visualization tools will help establish interesting correlations and visualize the results in a meaningful way. This can, in turn, enhance the system and help decision makers. Therefore, the sustainability performance of a container port will be managed along the economic, environmental and social dimensions putting a port in a strong position to streamline and optimize the flow internally, for its cluster and for its supply chains. It is possible to establish which sustainability dimension along which the port is best performing, *i.e.* determining the dominant value driver that will improve the ports performance with a minimum investment. One can as well provide an overall port sustainability index where the three dimensions are equally or differently weighed based on local experience.

3. KPIs’ Identification

3.1. Measuring Performance

Performance measurement illustrates the information or feedback on actives relating to meeting strategic objectives and customer expectations [11]. The goal is control, communication, and improvement of business performance [1]. Both the Total Quality Management (TQM) and Toyota’s (Lean) Production System philosophies helped spreading the development and implementation of performance measurement systems in modern companies. Kaplan and Norton introduced a balanced scorecard framework covering four perspectives, namely “Financial”, “Customer”, “Internal Business Processes”, and “Learning and Growth” each of which is mapped to five or six measures and covering all together both qualitative and quantitative data [12]. Through interaction with the industrials and academics, many of the implementation challenges were adequately tackled by Kaplan and Norton in 1996, 2001 and then 2004 with the introduction of the concept of a strategy map ([13], [14], and [15]) followed by a fourth generation introduced by Hannabarger, Buchman and Economy in 2007. The latter has the ability to focus on evaluation system measures so that organizations can balance the day-to-day operations and long-term tactical goals [16]. The Balanced Scorecard is mostly used to translate the strategy of organizations into a set of objectives and measures which support the future improvement with targets and strategic initiatives. Although balanced scorecard framework is widely accepted in the industry yielding satisfying results in practice, it has no theoretical foundations.

When it comes to performance measurement in the supply chain, the SCOR model offers an insight into indicators and metrics of supply chains developed for manufacturing processes [17]. Therefore, even if it might not be directly applicable to logistics service provision [18], it could certainly be adapted. References [19] and [20] suggested a list of performance indicators and a comprehensible and in-depth literature examination of logistics service provision. Supply chains are thought of as either efficient or responsive [21], or similarly, either lean or agile [22], and most of them are based on strong partnerships. However, [23] claims that it is neither feasible nor profitable to strongly cooperate with all partners in the supply chain and a selection of key customers and/or suppliers is more adequate. Reference [24] suggests that the balanced scorecard can be used successfully to deal with multiple performance metrics in supply chain management. Finally the use of information systems is vital in coordinating in the supply chain within its actors. Even if collaboration is not an easy task, IT investment can have a positive impact on market performance as a result of better coordination in the value chain [25].

Reference [26] relates performance to the investigation of effectiveness and efficiency in the achievement of a specified activity. Efficiency seeks to make things faster, with less waste, and in the most economical way (most optimally possible input to output ratio). In contrast, effectiveness seeks to do the right thing at the right time and place, at the right cost in order to achieve a predetermined desired effect (an overall goal). Despite the widespread of financial and utilization metrics in port industry, and due to the lack of standardization, the focus of performance measurement has moved away from the effectiveness and utilization measures to the efficiency perspective [2]. Efficiency is a fundamental criterion for ports' survival in today's market environment. Reference [27] defined a port's total productivity indicator as the port throughput per profit dollar (the shadow price variable) while [28] suggested an appropriate weighting of partial productivity measures. The data envelopment analysis (DEA) and Stochastic Frontier Analysis (SFA) approaches were already developed and applied in other fields for decades before [29] applied DEA approach to evaluate the efficiency within port settings. These approaches gained since then a wide acceptance in the field due to the fact that it is a non-parametric approach not requiring a pre-defined explicit functional formulation and allows for ports' benchmarking and ranking. Reference [2] proposed a conceptual integrative framework based on an operational logistics and strategic supply chain management (SCM) perspective. However, despite the fact that it is tested on a number of ports, it is still an illustrative and none conclusive method. Reference [30] proposed a two-stage, internal and external, integration approach to measuring port performance with emphasis on the qualitative aspects in order to increase visibility within the port settings and along the transport chain, thus a better supply chain and logistics actors' integration. This lean methodology extends to the port networking environment and requires increasing flexibility which will subsequently increase the port's sustainability [31].

On the one hand, [32] designed a system of sustainable management indicators transferable to other ports through an exhaustive environmental analysis of port activities. Sixty three indicators were identified among which seventeen multi-dimensional ones were chosen for port environmental policy. However, these indicators are too difficult to implement for small ports and are rather adapted for large ports. On the other hand, [33] developed a set of twelve environmental indicators specific for industrial ports by integrating procedures from ISO14001 and focusing on five environmental management perspectives, namely, success, awareness, determination, preparedness, and environmental policy coverage. They concluded that ports must play a proactive role and stressed the importance of ISO 14001 standards. Moreover, within the framework of the port environmental information collector project (PEARL), [5] conducted a survey on environmental monitoring requirements of European ports and the use of Earth Observation (EO) data among them. As a result, a better insight into port environmental challenges was gained. A comprehensive review on performance measurement in a port context is given in [34].

3.2. Sustainability of Container Ports

ISO 14001 and EMAS are generic management system standards comprehensive, extensive and not specific to port organization. However, these standards are so general that it becomes impractical for small ports to implement them directly. The European EcoPorts framework came to fill up this gap by developing some port dedicated tools serving as step stones towards achieving these certifications. The Self Diagnosis Method (SDM) is a tool for port environmental management performance review developed within this framework. The main advantages of this tool is that it is port specific, can be implemented in a matter of a one-day work maximum, and offers a European benchmark [35] for comparison [3]. The Self Diagnosis Method (SDM) results constitute basic requirements for a second EcoPorts tool called the Port Environmental Review System (PERS). This tool helps ports implement the recommendations set in the new ESPO Environmental Code of Practice [4]. Both SDM and PERS are basic steps towards the accomplishment of the port's Environmental Management System (EMS) which in turn helps in the achievement of ISO 14001/EMAS certifications. For more detailed on this subject, it is referred to [37].

3.3. Sustainability of Container Ports

The Nordic region can often be characterized by its arctic or sub-arctic climate, sparse population and long distance to main markets [37]. This is accompanied by a full usage of Electronic Data Interchange (EDI) systems, a qualified labor and a relatively low automation level. This puts a considerable pressure on the logistics networks as volumes are often low. Furthermore, the living standard in Nordic regions is high which implicates high costs of labor, facilities, and operations as well. Therefore, ports in such areas tend to be of small to medium to medium size with limited number of employees. Meteorological aspects and weather conditions are, of vital importance as it can have a significant negative effect on their activities and their infrastructures. The waterway access to some ports might be frozen for a number of months per year while the quays might be re-dimensioned to cope with the change in the waves' height, *i.e.* dredging and maintenance work on quays are inevitable. Moreover, although the ports are of small to medium size, their impact on the environment can be catastrophic if not carefully monitored, as the arctic area is manifold more sensitive than other areas. Environmental monitoring is therefore critical in such areas.

Often these ports serve small communities and they have an important influence on the social network of their regions, hence the significance of these ports social factor. However, the level of automation, ICT and the environmental awareness are good enablers to the implementation of dedicated performance frameworks in such areas. Consequently, the type of metrics to be monitored should be adapted to reflect all these facts. For more on the identification of KPIs, please refer to [34]. **Table 1** below gives an overview of the proposed KPIs.

Table 1. Detailed list of the proposed KPIs for Nordic container ports.

Sustainability Index	
A_1 = **Economical Index** (%) B_{11} = **Operational Index** (%) C_{111} = Average ship turn-around time: Total hours the vessel stays in port divided by Total no. of vessels (Hrs/Vessel) C_{112} = Berth efficiency Index (%) D_{1121} = Average Berth throughput: Total tonnage of cargo handled at berths divided by Total no. of berths (Hrs/Vessel) D_{1122} = Berth occupancy rate (%): Total time of shipsat berths x 100 divided by Total no. of berths x (1 or 30 or 360) days D_{1123} = Berth utilization rate (%): Total time that ships actually work x 100 divided by Total time of ships alongside D_{1124} = Average vessel time at berth: Total hours alongside berths divided by Total no. of berthed vessels (Hrs/Vessel) C_{113} = Dwell time: the average time a container remainsstacked on the terminal (Days or Hrs) C_{114} = TEUs per crane hour: Total no. of TEUs handled divided by Total no. of cranes used x total no. of hourscranes worked. C_{115} = Tons per gang hour: Total tonnage handled dividedby Total no. of gangs x total no. of hours worked. C_{116} = Soil occupation efficiency (e.g. no. of TEUs per yardsquare meter) C_{117} = Interface efficiency D_{1161} = Waiting time from one interface to another D_{1161} = Lead time to service delivery per interface D_{1163} = Service level per interface B_{12} = **Financial Index** (%) C_{121} = Rate of return on turnover: Operating surplus divided by Operating income C_{122} = Total contribution C_{123} = Contribution per ton of cargo C_{124} = Berth occupancy revenue per ton of cargo C_{125} = Cargo handling revenue per ton of cargo C_{126} = Capital equipment expenditure per ton of cargo C_{127} = Labor expenditure B_{13}= **Innovation index**: a percentage of innovation comparedto a given reference B_{14} = **Customer Satisfaction Index** (CSI) (%) C_{141} = Customer experience C_{142} = Customer service level B15 = **Supplier Performance Index** (SPI): Supplier training level in percent (%)	A_2 = **Environmental Index** (%) B_{21}= **Energy efficiency** (%) C_{211} = Fuel consumption (%) C_{212} = Electric consumption (%) C_{213} = Water consumption (%) B_{22} = **Pollution Index** (%) C_{221} = Air quality Index (%) D_{2211} = Atmospheric contaminant emissions: CO, NO_x, SO_x & PM10 particles (%) D_{2212} = Greenhouse effect (Carbon footprint):CO_2, CH_4, N_2O (%) D_{2213} = Dust Index (%) D_{2214} = Odor Pollution Index (%) C_{222} = Water quality Index (%) D_{2221} = Ballast water D_{2222} = Bilge (ship discharge) C_{223} = Soil Index (%) D_{2231} = Dredging sludge D_{2232} = Sea floor contamination C_{224} = Noise Index (%) C_{225} = Waste Index (%) D_{2251} = Waste creation (Kg (m3)/TEU (ton)) D_{2252} = Waste disposal D_{2253} = Oil, chemical, and hazardous spills B_{23} = **Safety and security Index** (%) B_{24} = **Emergency plan readiness** (%) A_3 = **Social Index** (%) B_{31} = **Port social impact factor**: The impact of the port on the development of the region (%) C_{311} = Percentage of own employees per active population in the region (%) C_{312} = Percentage of employees' working partners peractive population in the region (%) C_{313} = Percentage of employees' children per total children in the region (%) C_{314} = Percentage of the port yearly investmentscompared to the total investments in the region (%) B_{32} = **Employee Satisfaction Index** (ESI) (%) C_{321} = Employee training level in percent (%) C_{322} = Employee's experience (%) B_{33} = **Esthetic Index** (%)

4. Prototyping and Implementation Issues

In this section, the implementation of the proposed framework will be discussed. However, only the first part of the framework will be implemented (the middle rectangle of **Figure 1**) and a prototype will be given solely for demonstration purposes. The target is small and medium Nordic container ports (e.g. Narvik container port) where a sustainability index is developed along the economic, environmental and social dimensions in order to monitor the port sustainability performance. Nevertheless, accidents that results in a loss of life cannot be covered by this index. This constitutes a boundary restriction of the applicability of this framework.

An initial information about the container port is obtained from surveying the different aspects of this port and its actors, using existing relevant surveys, input from experts, and ranking the pertinent parameters. Now the in this information about the KPIs is gathered, it needs to be treated as it is heterogeneous of quantitative or qualitative nature or both. Preprocessing these parameters by applying fuzzy logic makes then all quantitative. Using Matlab's fuzzy logic toolbox, Mamdani-type fuzzy inference is well suited for this task.

A benchmark is set for the container port based on results of the best in class adapted to the port's strategic objectives, realities, constraints and limitations. All the parameters will then be a percentage from this benchmark as presented in **Table 1** (SI, A_r, B_{ri}, C_{rij}, and D_{rijk} are decimals from 0 to 1). The KPIs list has a tree structure where parent parameters are calculated from the combination of all its children applying normalized weights (α_r, β_{ri}, γ_{rij}, δ_{rijk} and θ_{rijk} are decimals from 0 to 1). The input will be constituted of all the lowest leaves or last children in the tree structure (D_{rijk}, most of C_{rij}, B_{13}, B_{23}, B_{24}, and B_{33}) and an initial set of weights estimated based on expert knowledge and experience (port's experts, managerial team and operators).

The weights of the KPIs will be optimized through the use of Artificial Intelligence techniques and the relationship between parameters is described by the equations below:

The Sustainability index SI:

$$\text{SI} = \sum_{r=1}^{l} \alpha_r A_r; \quad \forall \alpha_r \in [0,1] \tag{1}$$

where:

$$A_r = \sum_{i=1}^{m} \beta_{ri} B_{ri}; \quad \forall \beta_{ri} \in [0,1] \tag{2}$$

$$B_{ri} = \sum_{j=1}^{n} \gamma_{rij} C_{rij}; \quad \forall \gamma_{rij} \in [0,1] \tag{3}$$

$$C_{rij} = \sum_{k=1}^{p} \delta_{rijk} D_{rijk}; \quad \forall \delta_{rijk} \in [0,1] \tag{4}$$

And:

$$\sum_{r=1}^{l} \alpha_r = \sum_{i=1}^{m} \beta_{ri} = \sum_{j=1}^{n} \gamma_{rij} = \sum_{k=1}^{p} \delta_{rijk} = 1 \tag{5}$$

Then,

$$\text{SI} = \sum_{r=1}^{l} \sum_{i=1}^{m} \sum_{j=1}^{n} \sum_{k=1}^{p} \theta_{rijk} D_{rijk} \quad \text{where} \quad \theta_{rijk} = \alpha_r \beta_{ri} \gamma_{rij} \delta_{rijk} \tag{6}$$

In our case:

$l = 3$; $m = 3$, 4, 5; $n = 2$, 3, 4, 5, 7 and $p = 2$, 3, 4.

Equations (1) to (4), represent how the parameters are aggregated while Equation (5), expresses the normalization of the weights, and Equation (6) shows how the sustainability index is aggregated from all the list.

Once the application is run, the output will be an optimized set of weights θ_{rijk}, a sustainability index SI, all A_r and most of B_{ri} parameters. Similarly, if a set of sustainable indices SI is available, it is possible to forecast of the next period's sustainability index using a neural network with back propagation (two or three layers). Here Matlab's neural network toolbox is well adapted for this task. A demo version is developed using C# and a SQLite database.

Figures 2-4 show respectively, the graphical user interface of the prototype, its database showing the SI stored values while running the application, and the SI forecast for 2014. Of course all these results are based on hypothetical data. The sustainability index (SI) constitutes a value tailor-made for the given port. It reflects how the local and regional efforts and intelligence come together to improve the port's sustainability performance. Equation (1) gives its general form, however Equation (6) shows that it is highly dependent on the chosen parameters and how the weights are assigned to them. Therefore, the sustainability index is not comparable across ports. Comparison can be achieved only if both the parameters and weights are standardized.

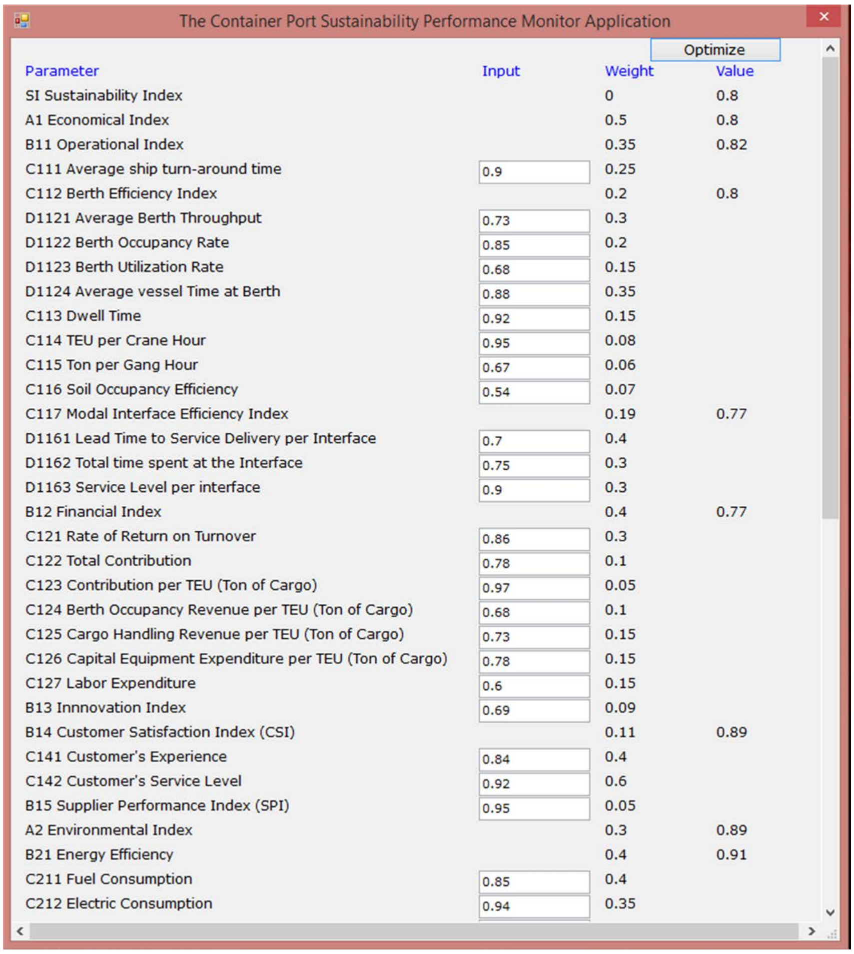

Figure 2. The GUI of the prototype and an example of forecasting the SI.

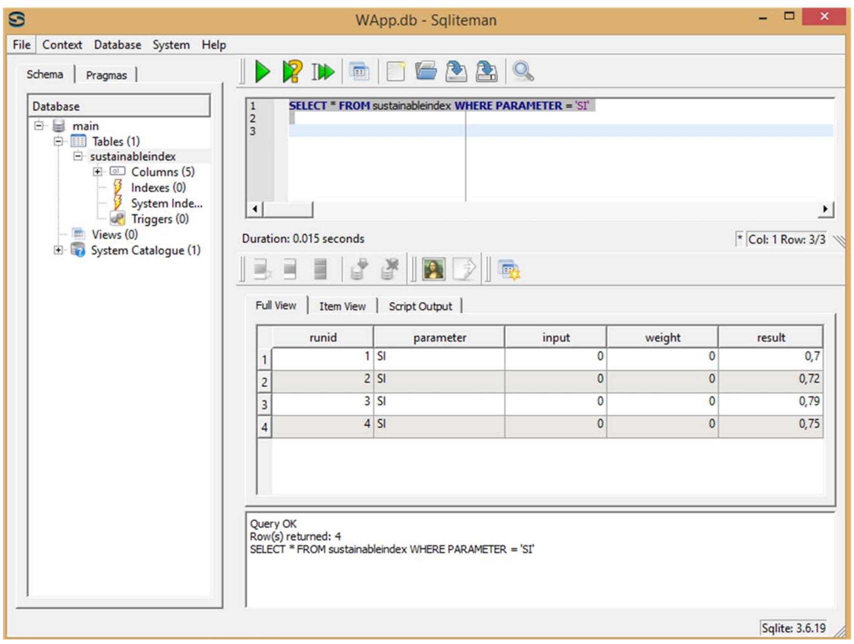

Figure 3. A snapshot of the prototype's database.

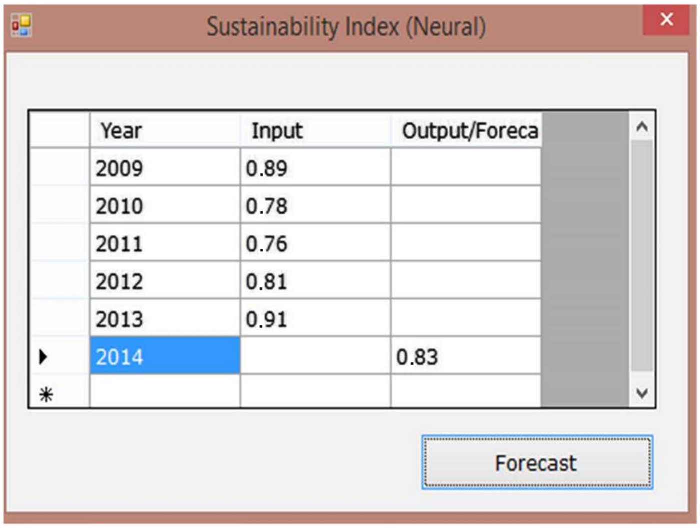

Figure 4. An example of forecasting the SI for 2014.

The main advantage of this cognitive framework is that it provides, in the long run, unique KPI values for the port and mostly a tailor-made unique weights that store most of the intelligence relevant to the port in question. It allows for monitoring its sustainability performance and visualizes potential scenarios to reach the desired performance.

There are several technologies to visualize the data, namely database technologies, MS SharePoint or MS Excel pivot tables. These will help make more sense out of the data and uncover potential business intelligence.

This prototype can be extended to include both the ports cluster and supply chains. The next logical step is a real implementation at a Nordic container port, and then to its clusters and supply chains. A full deployment will lead to tuning this framework, finding out about its strengths, exposing its weaknesses, and building up confidence around it.

5. Conclusion

A conceptual intelligent integrative sustainability performance management framework for container ports is proposed where relevant key performance indicators are identified. The target ports are small to medium size Nordic container ports (e.g. Narvik container port). By using fuzzy logic and neural networks, this framework monitors the sustainability performance along the economic, environmental and social dimensions and results, in the long run, in a dedicated set of weights for the given port. The sustainability index can be comparable across ports only if the parameters and their weights are standardized. This framework can be extended to both its cluster and its supply chains as a future research. A prototype is developed for demonstration purposes. However, a full deployment at Nordic container port level constitutes a further improvement alley.

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