Enhancing port's competitiveness thanks to 5G enabled applications and services

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***Abstract*—This work aims to evaluate a set of Critical Success Factors (CSF) that are important for port operations optimization. Furthermore, a set of 5G enabled applications is evaluated based on their importance for two typologies of companies located in the port of Hamburg, Athens and Luka Koper. More specifically, the importance of CSFs and 5G enabled applications and services is assessed based on the point of views of respondents working for technological companies and companies involved in the port's operations, using Multi Criteria Analysis. Finally, the relationship between the CSFs and 5G applications and services is considered based on the χ^2 test of hypothesis. Then, the possibility to promote 5G applications and services as CSF for port operations optimization which will in turn increase port competitiveness, is discussed.**

***Index Terms*—5G networks, Critical Success Factors, Multi Criteria Analysis, maritime port, competitiveness, logistics, value chain**

I. Introduction

The current work aims to evaluate the importance of a set of Critical Success Factors (CSF) for port operations optimization and a set of 5G applications and services for the companies involved in operational or technological activities. The CSFs and the 5G applications and services considered in this study are relevant for the use cases demonstrated in the context of the *5G creating opportunities for LOGistics supply chain INNOVation* (5G-LOGINNOV) project. It is a European-funded project that aims to design an innovative framework addressing integration and validation of modern technologies related to the industry 4.0 and ports domains by creating new opportunities for Logistics value chain innovation [1]. More in detail, 5G-LOGINNOV will promote the development of new products and services based on 5G technologies, that will support the entrance in the market of new start ups and SMEs. Thanks to the integration and validation of Connected Automated Mobility (CAM) and 5G technologies, new services will be created to handle the increase of traffic, the need for larger port capacity and more efficiency. The introduction of 5G applications or services will allow to deploy new types of Internet of Things (IoT) devices and Artificial Intelligence (AI) with Machine Learning (ML) analytics, traffic management services can be implemented to optimize port operations and reduce the impact on the environment in the city and the disturbance to the local population. Finally, 5G-LOGINNOV will open SMEs' and Start-Ups' door to these new markets using its three Living Labs as facilitators and ambassadors for innovation on ports. In this context, the analysis performed in this work is the first step to understand which are the needs of the actors that already participate in the port logistics chain.

CSFs has been defined as "those characteristics, conditions or variables that when properly sustained, maintained, or managed can have a significant impact on the success of a firm competing in a particular industry" [11]. Thus, it is interesting to understand if there is a relationship between the most important CSFs for port operations optimization and the 5G applications and services that are important for the companies involved in the 5G-LOGINNOV project. The final aim is to be able to promote 5G applications and services in the framework of a set of CSFs which will finally increase the port competitiveness. Although, [11] suggest collecting the information through interviews, in this work an online survey delivered to all stakeholders involved in the project was organized. The results of the current work could be useful to understand which are the most important 5G applications and services for companies working in maritime port and in the context of which CSF for port operations optimization these technologies could be promoted for.

The paper is structured as follows. Section II reviews the literature on port competitiveness and its evaluation. Section III presents the methodology adopted, based on Multi Criteria Analysis. Sections from IV to VI discuss the evaluation of CSFs and of the importance of different 5G applications and services, respectively, and their relations. Finally, Section VII concludes the paper.

II. Literature review

Port competitiveness is a broad concept that can be tackled from different points of views. For this reason, the evaluation of port competitiveness can be a complex task. In this section, the literature review has been broken down in two parts. The first reports different definitions of port competitiveness, the second reviews the main approaches to evaluate ports competitiveness.

A. Port competitiveness

Port competitiveness is difficult to define because it implies to consider several aspects. Indeed, as [19] point out, port competitiveness is a multidimensional concept. This multifaceted nature makes difficult the reaching of a univocal conceptualization in the literature. Thus, different contributions consider a limited set of factors that can affect port competitiveness. According to [18], the definition of competitiveness depends on the type of port involved and on the type of commodity it handles. Furthermore, [7] points out that it is the terminal that determines the competitiveness of a port. This last approach evidences that there are a variety of actors that participate in the system. Given the complexity of the port environment, [16] analysed the relationships between port operators by considering their objectives to identify the factors that affect port competitiveness. [22] enlarged the definition of port competitiveness based on eight key determinants, including: i) terminal operation efficiency level; ii) port cargo handling charges; iii) reliability; iv) port selection preferences of carriers and shippers; v) the depth of the navigation channel; vi) adaptability to the changing market environment; vii) landside accessibility; viii) product differentiation. Other authors [14] defined the port competitiveness according to hard components (e.g., infrastructures) and soft components (e.g., ICT systems, safety and security, services). Indeed, the deployment of new technologies to improve overall performance and competitiveness is found in current practices adopted by port authorities. An example is the Port of Livorno (Italy) that within the "Port of the Future" initiative, has built smarter and digital infrastructure (based on 5G technology), where digitization and innovation are key pillars for the port's competitiveness [5]. Finally, as [24] point out, a framework in the literature concentrates the port competitiveness on port selection criteria [15], [24].

B. Evaluation of port competitiveness

An evaluation of the most important factors of port competitiveness for the users has been presented by [25] using the Multi Criteria Analysis (MCA). The authors focused on the point of views of shipping liners, forwarders and shippers and found that costs is the most important factor for shipping liners, while forwarders and shippers considered the location of the port the most important aspect. This work was focused on the competitiveness and considered success factors such as the capacity of the port and sea-land connection. MCA has been deployed by [12] to rank transshipment ports based on service attributes. The authors found that costs, proximity to main navigation routes and proximity to main import/export areas and the condition of the infrastructure were the most important aspects for ports competitiveness. Similarly, [21] used MCA to rank Chinese ports based on their competitiveness. They found that the location of the port is one of the most important factors for the success of a port. The focus on digital transformation of port operations and its impact on port competitiveness has been studied by [10] and found a positive relationship between e-transformation, customer satisfaction and port competitiveness. The model proposed by [6] aimed at evaluating port competitiveness thanks to the MCA. The authors evaluated twelve ports based on volume (location, facilities, cargo volume, service level, port fees) and investment (price, institution structure, legal framework, financial resources, and port reputation) factors. They found that volume is more important than investment, although these two factors should be considered simultaneously. An evaluation of the ports' performance using MCA has been proposed [20]. The authors found that transport costs and time along the transportation chain were the most important factors.

Several authors [13], [23] point out that competitiveness measurement of ports can provide valuable suggestions for managers of ports to deploy development strategies. In doing so, [13] used a factor analysis model and they ranked five ports on different factors of competitiveness. The paper by [23] used a factor analysis method and fuzzy equivalence relationship clustering method to select evaluation indicators related to the port hardware and software levels. With this approach, they aimed at making clear the positioning of the port logistics competitiveness of Qingdao Port. Finally, [9] developed an evaluation index system about the port logistics competitiveness. They also employed factor analysis and cluster analysis to evaluate and enhance the logistics competitiveness of Ningbo - Zhoushan port. In 2018, this port has hosted a pilot project for the adoption of 5G technology to improve automation.

III. Methodology

The CSFs and 5G applications and services will be ranked based on the evaluation provided by experts working for the companies located in one of the three maritime ports where the 5G-LOGINNOV demonstration will take place (Athens, Hamburg or Luka Koper). In this context, respondents are employees of companies involved in daily operations and services aimed at sustaining port activities. To identify 5G applications and services more correlated to important CSFs we have i) ranked CSFs (and 5G applications and services) using Multi Criteria Analysis, then ii) we tested for independence each couple of CSF and 5G application or service, and lastly iii) we discussed the interrelation between the CSFs and 5G applications and services that resulted associated with a confidence level ($\alpha \leq 0.05$). The CSFs and the 5G applications and services are evaluated based on two different perspectives, the point of view of respondents working for companies involved in port operation activities and respondents working for technological companies.

The final output of the methodology is a list of 5G applications and services that are related to the most important CSFs. The information on which 5G applications and services to set up to implement specific CSFs will turn very handy to port operations managers to increase competitiveness.

A. Dataset

A preliminary list of CSFs for port operations has been identified based on the work of [19]. The list of CSFs has been preliminary reviewed and integrated by the experts of the 5G-LOGINNOV project. The degree of importance of each CSF for port competitiveness was collected through a survey delivered to the stakeholders involved in 5G-LOGINNOV Use Cases demonstrations and Living Labs. Thanks to the answers of 44 participants, it was possible to analyse the respondents' preferences on a list of 23 different CSFs. The questions were aimed at assessing how much each CSF will ensure the greatest performance of the port and to what extent each will contribute. The participants expressed their preference on an ordinal scale based on five classes ordered from *strongly disagree* to *strongly agree*. Similarly, another set of questions aimed to collect information on the degree of importance of a set of 5G applications and services for the company's respondent.

We decided to select *Company Specialization* of the respondent to evaluate the CSFs and the 5G applications and services from different point of views. The motivation for grouping respondents by these two features, was that we expected to see different CSF and 5G applications and services preferences and ranks depending on the characteristics of company.

For clarity, in the case of the company specialization feature, the answers are split in two groups: one group of answers (27 answers) have been provided by employees working on technology providers' companies (i.e., Technology provider, Telco, IT) and the other group is formed by companies working on port operations (i.e., Shipping, Receiver, Warehouse) that account for 17 answers. Each group will be used as criterion of a Multi Criteria Analysis that will allow to rank CSFs and 5G applications and services.

B. Data preprocessing

To generate and rank CSFs and 5G applications and services for each scenario we have first cleaned the dataset from those respondents who did not provide an answer to the questions related to the assessment of the CSFs or 5G applications and services importance. After, we cleaned the data to be computer readable by converting the answers of the respondents from categorical data type to numerical. For this purpose, we use an ordinal scale of values in the range from -2 to +2, where negative values encode disagreement with the statement and the positive one agreement.

C. Multi Criteria Analysis

The Multi Criteria Analytical tools used to rank CSFs and 5G applications and services are the *Weighted Sum*, the *Weighted product*, *Technique for Order of Preference by Similarity to Ideal Solution (Topsis)*, *Reference Point Approach of MOORA* and *Full multiplicative form of MOORA* implemented in the Python package scikit-criteria [4]. The *Weighted Sum* is the simplest MCA approach and it can be deployed when data are expressed using the same unit. The *Weighted Product* is similar to the *Weighted Sum* but, instead of addition, the weighted terms are multiplied. *Topsis* has been proposed by [8] and it consists of the couple comparison of alternatives based on the geometric distance. More specifically, each alternative is compared to an ideal alternative, that is the one that has obtained the highest score with reference to a criterion. *MOORA* is a multi-objective approach and it has been proposed by [2]. It consists of calculating the normalized performance of each alternative, for each criterion, against all the other alternatives. In case of the *Reference Point Approach of MOORA* proposed by [3], the performance of each alternative is determined based on a reference point. The minimum is the deviation from the reference point, the highest is the ranking of one alternative. In the *Full multiplicative form of MOORA* proposed in [17], the utility function of an alternative is obtained by multiplying the performance in relation to each criterion. This approach does not take into account the weights assigned to each criterion. The main advantage of using a MCA approach in this context is the possibility to represent the different point of views of the respondents with different experiences or working for different types of companies on the importance of CSFs for ports operation optimization or 5G enabled applications and services. Each subgroup of respondents will be considered as a criteria of the Multi Criteria Analysis. Criteria are defined using the characteristics of the company in terms of operations performed within the logistic supply chain (i.e., company specialization).

D. Scenarios Analysis

The methodology for generating different scenarios is articulated as follows. First, we select a relevant feature that characterize the respondents (i.e., Company specialization). In our application, the criteria *Company Specialization* has two Micro-Criteria (i.e., technology providers and operations). For each criterion we assign different weights to account for different point of views. We call scenario the combination of one set of criteria with a set of weights.

Table I shows the different scenarios that will be considered. There are three scenarios in total and they encompass a wide variety of settings considering both equal weights among criteria as well as criteria outweighing one and the others.

TABLE I
SCENARIOS BASED ON COMPANY SPECIALIZATION

Scenario / Criteria Weights	Technology provider, Telco, IT	Shipping, Receiver, Warehouse
Scenario 1 *Equal Weights*	0.50	0.50
Scenario 2 *Operational*	0.10	0.90
Scenario 3 *Technological*	0.90	0.10

The role of the weights is to simulate the point of views of the respondents based on the type of company they work for. In case of the criteria *Company specialization*, the respondent could consider the operational point of view more important if he/she works in that field. In this case, higher weights are assigned to the *Operational* scenario (i.e., Scenario 2). Since it is possible to generate several scenarios by changing the weights, to reduce the space of the solutions, we decided to produce only a limited set of scenarios with large differences among weights. Once the scenarios are set up, meaning that we have the two sets of information needed for the analysis (a matrix with mean preferences for each criterion and the weights), we compute the rank for each scenario using the Multi Criteria Analytical tools. The output of the methodology is a set of ranks of CSFs (or 5G applications and services) based on their importance for the port's competitiveness. The output will allow to compare the settings where the subgroups are alternatively more relevant than the others.

IV. Evaluation of Critical Success factors

In this section, we present the evaluation of CSFs based on their importance for port operations optimization. Successively, a scenario analysis is performed thanks to the implementation of MCA, where each scenario represents the point of view of respondents grouped based on the type of company they work for.

A. Scenario analysis with MCA

Once the data has been processed, the weights for each scenario are set up, we finally compute the ranks with all the five selected MCA methods described in section III-C. The result is one rank for each scenario. Table II shows the ranks for each scenario associated with Company Specialization (Scenario 1-3).

TABLE II
RANKING OF CRITICAL SUCCESS FACTORS

Rank	Scenario 1 *Equal Weights*	Scenario 2 *Operational*	Scenario 3 *Technological*
1	Synchronization of sea-land operations	Synchronization of sea-land operations	Development of joint-projects on R&D
2	Respect of international green regulations	Respect of international green regulations	Green innovations in processes and facilities
3	Development of joint-projects on R&D	Presence of dedicated terminals ensuring a stable cargo base	Encourage digital innovation and collaboration throughout the port.

The two subgroups of respondents (Shipping, Receiving, and Warehouse versus Technology Provider, IT, and Telco) have different, almost opposite, perspectives on what the top three CSFs are. Indeed, from the comparison between Scenario 2 *Operational* and Scenario 3 *Technological*, we can clearly see that the Synchronization of sea-land operations, the respect of international green regulations and the presence of dedicated terminals ensuring a stable cargo base are the most important CSFs for respondents working in the operational area. The development of joint projects on R&D, the green innovations in processes and facilities as well as to encourage digital innovation and collaboration are instead more important for respondents working on the technological area (Scenario 3).

In conclusion, the two most different scenarios among those considered in the study are Scenario 2 and Scenario 3; while Scenario 1 and Scenario 2 are quite similar. Another interesting difference is also the position within the rank of the two CSFs that appear in both lists. While synchronization of sea-land operations is ranked first in scenario 1 and 2, it is not as important in Scenario 3 where it is not even among the first three positions.

V. Evaluation of 5G applications and services

In this section, we present an evaluation of the importance of different 5G applications and services based on the type of company the respondent works for (Technological or Operational). Initially, the analysis is focused on the level of knowledge of the respondents on 5G applications and services. Furthermore, the intention of the companies to invest on 5G applications and services is reported. Finally, a scenario analysis of the importance of a set of 5G applications and services based on the company type is discussed.

A. 5G enabled applications and services in 5G-LOGINNOV

The 5G applications and services will be demonstrated in three 5G-LOGINNOV Living Labs. The test bed consists of several 5G use cases. The trucks' precise positioning will allow to obtain more accurate information on emissions for monitoring purposes and will be utilized to expedite and optimize the workflow of yard truck daily operations. Furthermore, the Green Light Optimal Speed Advisory (GLOSA) will advice the drivers about the optimal speed and will be tested with the Automated Truck Platoons (ATP). A predictive maintenance tool will be developed to analyse telemetry data collected from the fleet of 5G-connected trucks to potentially predict possible breakdowns, reduce downtime for repairs and optimise stock of spare parts. Finally, several surveillance cameras will be deployed for computer vision techniques for the detection of container seals and human presence in specified areas of the port.

B. Knowledge about 5G applications and services and willingness to invest

According to the survey results, the 89% of the respondents knows about 5G while 11% of the respondents do not know. The employees working for technological companies are more informed about 5G, while respondents from companies involved in the port operations are less informed (24% of respondents never heard about 5G). As expected, technological companies are more keen to invest on 5G applications and services (62%), compared to the companies involved in the operational activities of the port. The 72% of the respondents who know about 5G would be interested in investing or they are planning already to implement the technology within a short period of time. A relevant number of the respondents interested in investing are planning to invest soon (46%), while others are waiting to see the outcomes of the use cases (26%). The 28% of the respondents are not aware of the importance of these technologies for their companies. Finally, the majority of technological companies (62%) are planning to invest on 5G applications and services or are already starting a 5G project, while only a small share of companies (15%) involved in the port operations plan to invest on 5G. Furthermore, the respondents split by propensity to invest are all in agreement about the most important 5G applications and services and they are: the ability of storing and accessing data from the cloud, and the possibility of performing simulations in real time. Of the group that is planning or already investing on 5G, other important technologies are related to building predictive models (for machinery failures and delivery time) and to monitor real time information on supply chain. Other applications that respondents find important for their companies are related to recording and sharing information on specific activities.

C. Evaluation of the importance of 5G applications and services

After having analysed the knowledge and attitudes of the respondents with reference to the 5G applications and services, we use MCA to evaluate the importance of different 5G applications and services based on two different point of views (technological and operational). Table III shows that Real time to perform simulations ranks second in all scenarios; while real time information on supply chain is ranked first when the point of view is operational. The technological scenario, instead, considers the possibility of accessing and using data from the cloud the most important aspect that 5G applications can bring to the company. While 5G applications and services for prediction models for delivery time are of interest for both point of views, although technological companies favor also predictive models for maintenance purposes. Finally, within the operational group there is a consensus that technologies that allow information sharing can help in building trust.

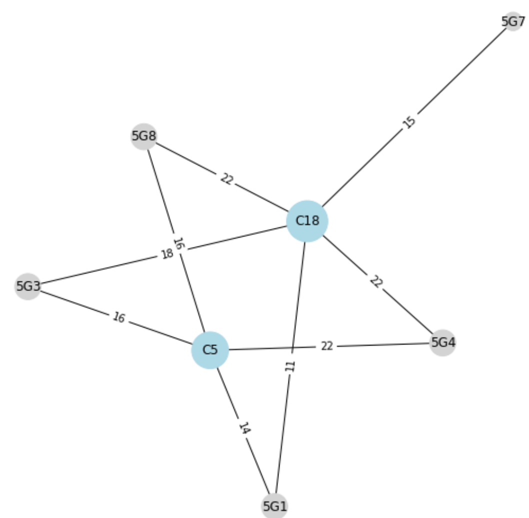
TABLE III
RANKING OF 5G APPLICATIONS AND SERVICES

Rank	Scenario 1 *Equal Weights*	Scenario 2 *Operational*	Scenario 3 *Technological*
1	Data stored in Cloud	Real-time information on supply chain	Data stored in Cloud
2	Real-time data to perform simulations	Real-time data to perform simulations	Real-time data to perform simulations
3	Real-time information on supply chain	Data stored in Cloud	Predictive maintenance (failure)

VI. ANALYSIS OF THE RELATION BETWEEN CSFS AND 5G APPLICATIONS AND SERVICES

After having obtained the ranking of the CSFs and 5G applications and services based on the point of views of operational and technological companies, we analyse the relation between 5G applications and services and the CSFs. The objective is to determine if some 5G applications and services can be promoted as enablers of CSFs of port operation optimization. For this purpose, we test the hypothesis of independence between all couples of CSFs and 5G applications and services using a χ^2 test of hypothesis for categorical variables. More specifically, we test the hypothesis H_0 that the CSF is not associated with the 5G application, against the alternative hypothesis (H_1) that the two couples are associated. We selected a significance level α of 0.05. We found that for the 30% of the couples the hypothesis H_0 is rejected. This means that there exists a sort of relationship between the CSF and the 5G applications and services. We therefore considered the most important CSFs (the CSFs that were ranked first with the MCA in Scenario 2 and 3) and analysed their relation with the 5G applications and services by also considering the value of the χ^2 statistic that quantifies how much the two are associated. Table IV shows the results of the test of hypothesis between the two highest ranked CSFs and 5G applications and services. Figure 1 shows that the two CSFs Development of joint-projects on R&D (C5) and Synchronization of sea-land operations (C18) are both related to four 5G applications and services: predictive analytics of future failure of vehicle (5G3), predictive analytics to predict the impossibility to deliver an order on time (5G4), sharing information with different actors in the supply chain to improve and build trust (5G8) and exploit real time data to perform simulations (5G1). Furthermore, C18 is related to the possibility to share information with different actors to better planning and schedule activities (5G7).

Fig. 1. Relations between CSFs and 5G applications and services



Overall, it can be noticed that the two most important CSFs from the point of view of technological and operational companies are all related to three types of 5G applications and services: predictive maintenance, use of data in real time and sharing of information. Therefore these 5G applications and services should be promoted as enablers of port operations optimization and thus to increase the port competitiveness.

VII. CONCLUSION

In this work we have presented an evaluation of the Critical Success Factors for port operations optimization and of 5G enabled applications and services. A MCA was performed using five different approaches and a final ranking has been created based on the majority votes. It turned out that employees more involved in operational activities of the port considered the

TABLE IV
RESULTS OF THE χ^2 TO ASSESS THE RELATION BETWEEN CSFS AND 5G APPLICATIONS AND SERVICES

5G enabled applications and services	C5		C18	
	χ^2	$P-value$	χ^2	$P-value$
5G1: Possibility to exploit the real-time data to perform simulations on the processes	14	0.01	11	0.02
5G3: Predictive analysis, on the data collected, aimed at indicating the future date of failure of vehicles	16	0.00	18	0.00
5G4: Predictive analysis, on the data collected, aimed at reporting the impossibility of delivering an order on time	22	0.00	22	0.00
5G8: Sharing information with the different actors in the supply chain to improve and build trust	16	0.02	22	0.00
5G7: Sharing information with the different actors in the supply chain to better planning and schedule activities			15	0.01

synchronization of sea-land's operations the most important factor for the success of the port. While, employees with a more technological background considered more important to develop joint-projects on R&D. The same approach has been adopted to rank the most important 5G applications and services for each company type. It turned out that companies involved in the port operations and the technological ones are interested on 5G applications and services that allow to handle information in real time and on data storage on the cloud.

Finally, the analysis of the associations between the CSFs and the 5G applications and services revealed that the 30% of CSFs are related to the 5G applications and services. More specifically, the two most important CSFs for technological and operational companies, synchronization of sea-port operations and development of joint-projects on R&D, are associated to 5G applications and services that deal with the exchange of real time and sharing of information and predictive maintenance.

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