14th ITS European Congress, Toulouse, France, 30 May-1 June 2022

Paper ID #26

Analytic Hierarchic Process in the 5G-LOGINNOV project

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Abstract

The Analytic Hierarchic Process (AHP) is a type of analysis that allows finding, given a certain objective, the best option considering different criteria (Saaty T.L., 1990). However, it is not always possible to collect proper data for AHP: it is often only conceivable to use data collected for other purposes. Using the available data through a new methodology, this paper identifies the 5G services proposed in the *5G creating opportunities for LOGistics supply chain INNOVation* (5G-LOGINNOV) project that are important for the competitiveness of the port, answering to the following research question: which use case proposed in the 5G-LOGINNOV project best meets the real needs of the ports? The AHP proposed in this paper can be re-used in European projects to rank the use cases, understanding which are more in line with the defined objectives. Moreover, this AHP helps to reduce the number of criteria by considering the stakeholders' knowledge.

Keywords: Evaluation methodology, data analysis, AHP, European projects, 5G services, 5G networks, maritime port, logistics, competitiveness.

Introduction

The current work aims to perform an AHP to understand which 5G applications and services – relevant for the use cases (UC) that will be demonstrated in the context of the 5G-LOGINNOV project - are considered more urgent and needed for port operation optimisation. The importance of these applications and services will be evaluated considering the point of views of respondents that work for technological companies and for companies involved in the port's operations.

The paper is structured as follows:

- In section 1 the 5G-LOGINNOV project and the related 5G applications and services will be briefly introduced in order to give the reader a proper overview of the research focus.
- Section 2 will show how the available data have been utilized to perform the AHP. The idea is to propose a new methodology that can allow to perform the AHP using a specific data set.
- Section 3 will present how the AHP has been implemented, explaining all the steps that have been followed.
- Finally, Section 4 will present the conclusions and the ideas for future research.

1. The 5G-LOGINNOV project

5G-LOGINNOV[1] aims to use new innovative concepts, applications and devices supported by

[1] More information can be found on the 5G-LOGINNOV official website: https://5g-loginnov.eu

disruptive 5G technologies as Internet of Things (IoT), data analytics, next generation traffic management and the Cooperative, Connected and Automated Mobility (CCAM). The final goal of the 5G-LOGINNOV project is, therefore, to pave the way towards efficient freight and traffic operations at ports and logistics hubs, designing an innovative framework and addressing integration of modern technologies related to the industry 4.0 and ports domains by creating new opportunities for logistics value chain innovation.

Within this ambition, the project will further develop and deploy next generation ports & logistics hubs operation system architecture integrated in 5G networks in three ports: Athens (Greece), Hamburg (Germany) and Luka Koper (Slovenia). In these ports, three different living labs have been established as facilitators and ambassadors for innovation on ports: the analysis presented in this paper aims to be a first step to understand the most urgent needs of the actors in the port logistics chain. The use cases considered in this paper are:

- UC1: Management and Network Orchestration platform, developed in the Luka Koper living lab;
- UC5: Automation for Ports: Port Control Logistics and Remote Automation, developed in the Luka Koper and Athens living labs;
- UC6: Mission Critical Communications in ports, developed in the Luka Koper living lab;
- UC8: Floating Truck & Emission Data, developed in the Hamburg living lab;
- UC10: 5G GLOSA & automated truck platooning (ATP), developed in the Hamburg living lab;
- UC11: Dynamic control loop for environment sensitive traffic management actions developed in the Hamburg living lab.

2. Methodology to use the available data to perform the AHP

The data used for the analysis presented in this paper was collected during 5G-LOGINNOV, through an online survey delivered to all stakeholders involved in the project, including all the experts working for companies situated in the three living labs. In particular, the respondents are employees of companies directly involved in daily operations and services aimed at sustaining port activities (Porelli, A. et all, 2021).

The data used for the analysis presented in this paper were the answers to the following questions:

1. Can you order the importance of the evaluation criteria of the UCs from the 1st to the 15th place? This question aimed to understand the scale of importance that each interviewee assigned to the pre-defined criteria.
2. How much do you agree that a certain criterion is important for the relative UC? In this case, the scale used included 5 options: 1 = strongly disagree; 2 = disagree; = 3 = somehow agree; 4 = agree; 5 = strongly agree.

As it can be noticed, these questions were not set purely to have immediately usable data to proceed with the AHP. In fact, they did not use the Saaty scale (Saaty, T.L., 1990), and they were not set up to include a comparison between elements. For this reason, before being able to proceed with the AHP, a

further step was necessary to allow the different reference scales to dialogue.
As regards the answers to the first question, it was decided to give a score inversely proportional to the ranking: the criteria placed in the first place was assigned a score of 15, while to the criteria positioned in the last place was assigned a score of 1. Within each use case, for each criterion, the average of the scores given by the individual interviewees was considered to have a single value for each criterion as shown in Table 1.

Table 1: Score for the criteria according to the respondents of UC1 and their average

	RESPONDENTS	20	21	24	26	Total	Average
	USE CASE	1	1	1	1		
CRITERIA	PROVIDE ACCURATE COMMUNICATIONS AND RECOMMENDATIONS FOR OPERATIONS	15	6	15	8	44	11
	INCREASE SAFETY WITHIN PORT	2	10	11	11	34	8,5
	INCREASE SECURITY IN PORT AREAS	3	9	14	12	38	9,5
	INCREASE EFFICIENCY OF THE OPERATIONS	14	15	13	15	57	14,25
	DECREASE COSTS FOR OPERATION	13	3	12	14	42	10,5
	DECREASE TRAFFIC AND INCIDENTS	5	11	10	13	39	9,75
	IMPROVE CONNECTIONS INSIDE AND OUTSIDE THE PORT	6	8	5	3	22	5,5
	INCREASE NUMBER OF ITC SERVICES	4	14	4	2	24	6
	DEGREE OF CENTRALIZATION OF DATA AND INFORMATION SOURCES	11	13	2	1	27	6,75
	DEGREE OF DATA-DRIVEN AND DIGITALLY AUTOMATED PROCESSES	12	12	3	4	31	7,75
	IMPROVE QUALITY OF WORKING ENVIRONMENT	7	7	6	10	30	7,5
	INCREASE ECONOMIC WEALTH	10	2	8	7	27	6,75
	INCREASE BUSINESS COOPERATION	9	1	7	9	26	6,5
	DECREASE HEALTH RISKS FOR WORKERS	1	5	9	6	21	5,25
	INCREASE RESILIENCY TO CLIMATE CHANGE	8	4	1	5	18	4,5

It was therefore possible to find the highest and the lowest score given to the criteria and for each UC. Then the relative differences (i.e. the highest score given to a criteria minus the lowest score given to a criteria) were found. Having found all the variances, the highest difference was divided by 5 (like the number of scores in the Saaty scale: 1, 3, 5, 7, 9) as shown in Table 2. Thanks to this procedure, it was possible to obtain the size of the sets of each value included in the Saaty Scale. In this way, it was achievable to define five ranges to be matched with the Saaty scale value, as shown in Table 3.

Table 2: Differences among the highest score and the lowest score given to a criterion from the respondents

	Highest score given to a criteria	Lowest score given to a criteria	Difference (highest score given to a criteria - lowest score given to a criteria)	Size of the sets of each value included in the Saaty Scale
UC1	14,25	4,5	9,75	
UC 5	14,5	3,75	10,75	
UC 6	13,83	2,83	**11**	= 11/5 = **2,2**
UC 8	12,55	4,45	8,1	
UC 10	12,09	4	8,09	
UC 11	13	4,17	8,83	

Table 3: Definition of ranges and their correspondent Saaty Scale value for the criteria

Range of difference when comparing different criteria	Saaty Scale (values to be used to perform the AHP)
0 → 2,2	1
2,21 → 4,41	3
4,42 → 6,62	5
6,63 → 8,83	7
+ 8,84	9

The same procedure was followed to recalculate the AHP scores based on the answers to the second questions, arriving to define the range as shown in Table 4.

Table 4: Definition of ranges and their correspondent Saaty Scale value for the choices

Range of difference when comparing different criteria	Saaty Scale (values to be used to perform the AHP)
0 → 0,50	1
0,51 → 1,01	3
1,02 → 1,52	5
1,53 → 2,03	7
+ 2,04	9

3. The AHP implementation

After having obtained the rights data format, in order to proceed performing the AHP, the steps presented in Figure 1 were defined.

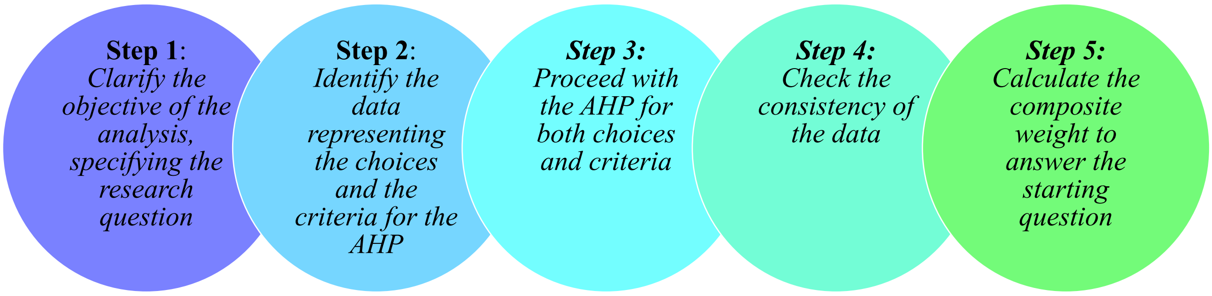

Figure 1: The AHP steps

Step 1: Clarify the objective of the analysis, specifying the research question

This analysis aims to provide a specific answer to the question: "what is the impact of the use cases, based on different evaluation criteria and the different weights that the respondents have assigned to these criteria?". Starting from this question it became clear that the best analysis to find the answers that took into consideration all the proposed criteria and their relative weights was the two-level AHP (Saaty, 2000).

Step 2: Identify the data representing the choices and the criteria for the AHP

In order to perform the two-level AHP included in this analysis, the methodology followed was the one proposed by Kardi Teknomo (2006), inspired by Thomas L. Saaty (1990). The AHP aims to derive a ratio scale from paired comparisons. The idea behind this analysis is to assess how much a *choice* is better than the other one according to the different established *criteria* and their corresponding weights.

In particular, in this analysis, the *choices* (or alternatives) were the 6 UCs developed within the 5G-LOGINNOV project (UC1, UC5, UC6, UC8, UC10 and UC11), while the 15 *criteria* were: provide accurate communications and recommendations for operations, increase safety within the port, increase security in port areas, increase the efficiency of the operations, decrease costs for operation, decrease traffic and incidents, improve connections inside and outside the port, increase the number of ITC services, degree of centralization of data and information sources, degree of data-driven and digitally automated processes, improve quality of the working environment, increase economic wealth, increase businesses cooperation, decrease health risks for workers, increase resiliency to climate change.

According to the methodology of the two levels AHP, the steps to be performed to obtain a ranking of UCs based on their importance involves a double AHP:

- one in which all the *criteria* were compared with each other;
- one in which all the *choices* (in this case represented by the UCs) were compared with each other, based on each criterion.

The AHP foresees a pairwise comparison of choices (or alternatives) by assigning to them a specific assessment based on the Saaty scale, as reported in Table 5.

Table 5: Saaty Scale (Saaty, 1990)

Assessment	Reciprocal value	Meaning
1	1	Equal
3	1/3	Slightly better / slightly worse
5	1/5	Strongly Better / Strongly worse
7	1/7	Very strongly better / very strongly worse
9	1/9	Extremely better / extremely worse

The total number of pairwise comparisons to be made depends on the number of elements to be compared and it is equal to: n (n-1) / 2, where "n" is the number of elements to compare. In this analysis:

- for the *criteria*, the total number of pairwise comparisons are: 15(15-1)/2 = 105;
- for the *choices* (the UCs) the total number of pairwise comparisons for each criterion are: 6(6-1)/2 = 15.

Step 3: Proceed with the AHP for both choices and criteria

Thanks to this method it was possible to proceed with the creation of the different comparison matrices, first by comparing the criteria with each other, then by comparing the use cases on the basis of each criterion.

To better explain how the AHP has been performed, this third step has been divided in 3 sub steps:

- sub step 3.1: Compute criteria priority vectors for each use case (AHP level 1);
- sub step 3.2: Select relevant criteria;
- sub step 3.3: Compute ranking of choices/use case (AHP level 2).

Let's see them in detail.

Sub Step 3.1: Compute criteria priority vectors for each use case (AHP level 1)

Table 6 is reported as an example that shows the AHP process: in yellow, there are the diagonal elements that are always equal to 1 because they compare the same element in the row-column, in blue the judgments of the comparison in pairs row-columns are highlighted and in orange there are corresponding elements that complete the matrix with reciprocal values.

Table 6: Comparison of the different Use Cases considering the increased security in port areas

	UC 1	UC 5	UC 6	UC 8	UC 10	UC 11
UC 1	1,00	1,00	0,33	5,00	5,00	5,00
UC 5	1,00	1,00	0,33	3,00	3,00	5,00
UC 6	3,00	3,00	1,00	7,00	7,00	9,00
UC 8	0,20	0,33	0,14	1,00	1,00	1,00
UC 10	0,20	0,33	0,14	1,00	1,00	1,00
UC 11	0,20	0,20	0,11	1,00	1,00	1,00

For each comparison matrix, the normalized relative weight was calculated, dividing each element of the matrix with the sum of its column. Then it was necessary to calculate the priority vector by averaging across the rows. The results are shown in the Table 7.

Table 7: comparison matrix, normalized relative weight and priority weight

	UC 1	UC 5	UC 6	UC 8	UC 10	UC 11	normalized relative weight	priority weight
UC 1	0,18	0,17	0,16	0,28	0,28	0,23	0,22	**21,56**
UC 5	0,18	0,17	0,16	0,17	0,17	0,23	0,18	**17,85**
UC 6	0,54	0,51	0,48	0,39	0,39	0,41	0,45	**45,31**
UC 8	0,04	0,06	0,07	0,06	0,06	0,05	0,05	**5,31**
UC 10	0,04	0,06	0,07	0,06	0,06	0,05	0,05	**5,31**
UC 11	0,04	0,03	0,05	0,06	0,06	0,05	0,05	**4,67**

Sub Step 3.2: Select relevant criteria

Table 8 shows the results deriving from all the comparison matrices, presenting the priority weight of each criterion, according to each UC and on average.

Table 8: Priority weight for each criterion as defined from the UCs and on average

	UC1	UC5	UC6	UC8	UC10	UC11	**Average among Ucs**
Provide accurate communications and reccommendations for operations	11,10	9,95	6,17	7,92	11,08	16,83	**10,51**
Increase safety within port	5,21	6,58	20,80	2,85	3,78	2,04	**6,88**
Increase security in port areas	7,57	6,94	14,83	2,96	3,53	2,11	**6,32**
Increase efficiency of the operations	24,52	25,45	14,83	14,25	13,62	15,01	**17,95**
Decrease costs for operation	12,80	14,02	6,17	3,76	11,08	7,48	**9,22**
Decrease traffic and incidents	8,40	4,17	10,37	15,45	14,10	12,08	**10,76**
Improve connections inside and outside the port	2,54	1,66	3,69	10,22	5,51	5,19	**4,80**
Increase number of ITC services	2,75	2,51	4,23	2,61	2,60	2,18	**2,81**
Degree of centralization of data and information sources	3,41	6,94	2,87	4,67	4,47	7,19	**4,93**
Degree of data-driven and digitally automated processes	4,79	6,94	2,95	6,75	4,02	4,71	**5,03**
Improve quality of working environment	4,04	4,07	3,96	2,96	3,90	3,04	**3,66**
Increase economic wealth	3,41	2,87	2,87	3,76	3,78	3,15	**3,31**
Increase businesses cooperation	3,08	2,51	2,03	2,13	1,86	1,76	**2,23**
Decrease health risks for workers	4,48	2,80	2,95	2,08	1,72	2,22	**2,71**
Increase resiliency to climate changee considered successful?	1,89	2,57	1,27	17,64	14,94	15,01	**8,89**

The priority vectors show different weights for different use cases (table 8). This means that each use case has different relevant criteria. Furthermore, the average values of the weights for each one of the 15 criteria shows that some have greater values than others and their average values range from 2,2 to 17,95. Given the wide range, it is important to select only the relevant criteria to be passed on to level 2 where they are used to compute the rank among different choices. To select the criteria, it was decided to use:

i) the mean value as an estimator of the importance at the project level;
ii) the standard deviation as an expression of the accordance among priority weights of different use cases.

Figure 2 shows a plot of the two statistics and it presents two different behaviors. One on the top right quadrant characterized by high mean and standard deviation, and another one in the bottom left with low mean and standard deviation. By setting the threshold at criteria with values greater than 6 and 3 respectively for the mean and the standard, 7 relevant criteria were identified. These will be weighted in to compute the ranking in the AHP level 2.

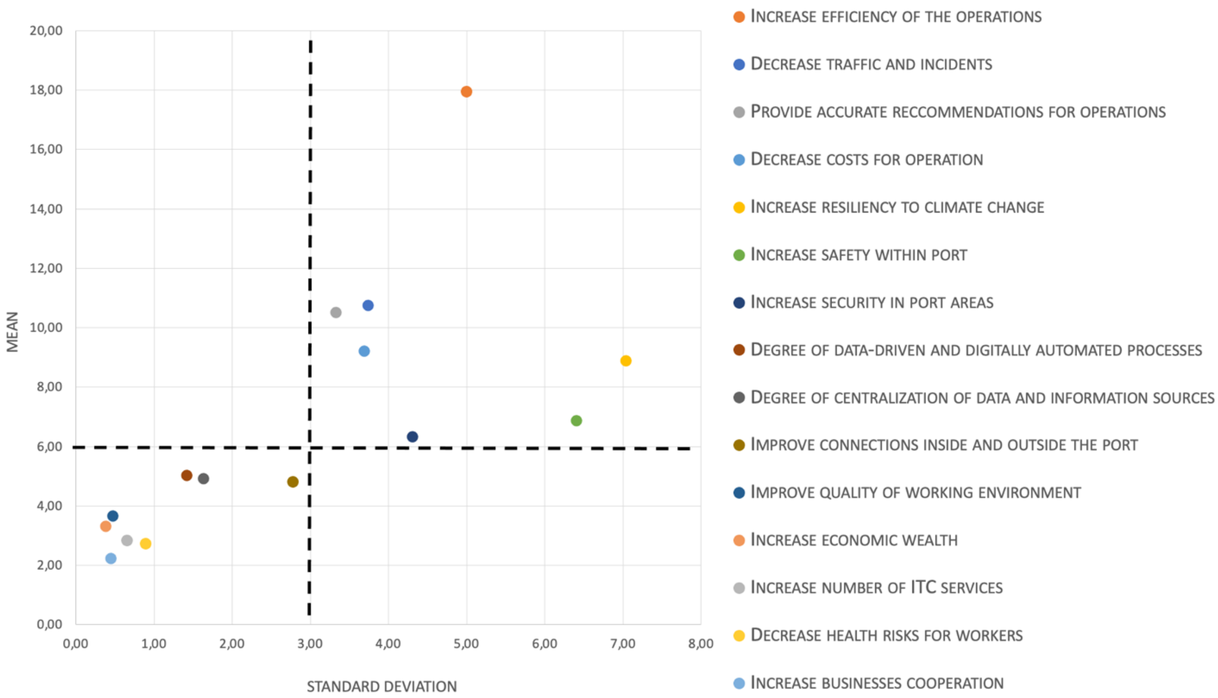

Figure 2: Standard deviation to find the most relevant criteria

Sub Step 3.3: Compute ranking of choices/use case (AHP level 2)

The final step for the AHP required to compute ranking of choices per use case: Table 9 shows the priority weight for each UC according to the different considered criteria.

Table 9: Priority weight for each UC according to the different considered criteria

	USE CASE 1	USE CASE 5	USE CASE 6	USE CASE 8	USE CASE 10	USE CASE 11
PROVIDE ACCURATE COMMUNICATIONS AND RECOMMENDATIONS FOR OPERATIONS	16,07	13,69	13,69	16,07	16,07	24,4
INCREASE SAFETY WITHIN PORT	17,1	19,55	48,56	6,72	4,48	3,59
INCREASE SECURITY IN PORT AREAS	21,56	17,85	45,31	5,31	5,31	4,67
INCREASE EFFICIENCY OF THE OPERATIONS	20,49	16,32	14,24	16,32	16,32	16,32
DECREASE COSTS FOR OPERATION	15,97	28,47	13,19	13,19	13,19	15,97
DECREASE TRAFFIC AND INCIDENTS	7,52	7,52	10,5	21,01	29,11	24,35
IMPROVE CONNECTIONS INSIDE AND OUTSIDE THE PORT	39,84	4,83	13,83	13,83	13,83	13,83
INCREASE NUMBER OF ITC SERVICES	34,03	12,5	18,75	12,5	9,72	12,5
DEGREE OF CENTRALIZATION OF DATA AND INFORMATION SOURCES	22,21	22,21	11,34	9,26	16,1	18,88
DEGREE OF DATA-DRIVEN AND DIGITALLY AUTOMATED PROCESSES	16,67	16,67	16,67	16,67	16,67	16,67
IMPROVE QUALITY OF WORKING ENVIRONMENT	14,24	16,32	20,49	16,32	16,32	16,32
INCREASE ECONOMIC WEALTH	12,78	32,78	16,11	12,78	12,78	12,78
INCREASE BUSINESS COOPERATION	26,28	18,78	22,11	13,22	10,84	8,76
DECREASE HEALTH RISKS FOR WORKERS	10,55	14,31	44,03	9,03	10,55	29,32
INCREASE RESILIENCY TO CLIMATE CHANGE	3,77	7,19	4,76	29,32	29,32	25,63

Step 4: Check the consistency of the data

Before proceeding further, it was important to calculate the consistency index and the consistency ratio, using the Random Consistency Index (Saaty, 2000). All values analyzed passed the consistency test (all values resulted <0.1).

Step 5: Calculate the composite weight to answer the starting question

Having developed the AHP both by comparing the *criteria* and by comparing the *choices*, it was possible to arrive to the final calculation that allows answering the question that guided the whole analysis. The calculation foresees that the overall weight of each UC is the normalization of a linear combination of multiplication between weight and priority vector as follow:

UCX = (adjusted weight for criteria A) (priority vector of UCx for criteria A) +

(adjusted weight for criteria B) (priority vector of UCx for criteria B) ...

Finally, Table 10 shows the results of the AHP analysis, demonstrating that UC6 is the best choice, followed by UC1 and UC 11.

Table 10: Final results: the composite weights

Use Cases	Composite Weight
Use Case 1	17,14
Use Case 4	15,92
Use Case 6	18,52
Use Case 8	15,37
Use Case 10	16,33
Use Case 11	16,72

Through a quantitative method, this analysis allowed to reduce the subjectivity in the choice of criteria. Consequently, the selected criteria equipped the evaluation to better understand which use case best responds to the objective of the project.

4. Conclusion

In this paper, the aim was to present an AHP applied on a particular data set coming from the 5G-LOGINNOV project.

The methodology proposed in this paper allows using data not strictly collected to implement the AHP. The original methodology proposed by Saaty (Saaty T.L.,1990), in fact, foresees a specific data collection methodology. On the contrary, with the methodology presented in this paper, the aim is to propose a new precious path for European projects as it allows to carry out the AHP using data collected for other purposes - through interviews or questionnaires. This innovation in the evaluation methodology allows to carry out an important analysis - the AHP - without overloading the stakeholders involved in the project.

The AHP developed within the methodology proposed in this paper allows:

- to periodically check - during the project lifetime - if the objectives and criteria used are still current;
- to understand the strengths of the use cases, prioritizing certain actions and allowing a better dissemination and exploitation of the results.

After developing the innovative methodology, the AHP was implemented by following five steps:

1. Clarify the objective of the analysis, specifying the research question;
2. Identify the data representing the choices and the criteria for the AHP;
3. Proceed with the AHP for both choices and criteria. This step included three sub-step:
   3.1 *Compute criteria priority vectors for each use case (AHP level 1);*
   3.2 *Select relevant criteria;*
   3.3 *Compute ranking of choices/use case (AHP level 2).*
4. Check the consistency of the data.
5. Calculate the composite weight to answer the starting question.

The AHP is an important decision-making technique that has revealed to be a significant strategy to resolve conflicts and incertitude. As pointed out also from Zhu (Zhu et all, 2005), even if the AHP can clearly help in providing an overall ranking of specific alternatives – as shown in the analysis proposed in this paper - the ranking produced can be very sensitive: the smallest change in the priority weights can completely alter the final order of the alternatives.

The AHP presented in this paper has given a final result: considering the 15 criteria, the best 5G services and application are the ones developed within thew use case 6: Mission Critical Communications in ports, developed in the Koper living lab. However, it must be noticed that the use case 6 is just a few steps away from the other use cases.

An interesting future research dedicated to finding the most urgent and most needed 5G services and applications for the ports should try to understand if more/different criteria are needed and if a different (or wider) sample of respondents should be considered.

Another interesting research should re-propose the analysis presented in this article to different ports in Europe and in the world: it would be interesting to see if the priorities are common regardless from the peculiarities of the port or if they change according to the reality in which the port itself is located.

Acknowledgment

The data presented in this paper is part of the 5G-LOGINNOV project that is co-funded by the European Commission, Horizon 2020 research and innovation programme under grant agreement No. 957400 (innovation action). The content reflects only the authors' view and European Commission is not responsible for any use that may be made of the information it contains.

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