Performance Assessment for Intermodal Transportation Systems: a Case Study

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***Abstract*—This paper proposes a methodology to evaluate an Intermodal Transportation System (ITS). These systems are very complex and a lot of different actors are involved. The evaluation process should take into account concurrent needs and goals. Moreover, the data and the importance of different indicators are strictly related to the judgments of individual experts. Then it is necessary to have a methodology able to collect all the independent judgments and merge them in order to evaluate the whole system performances. The paper proposes a general methodology based on the Analytic Hierarchy Process to evaluate the behavior of the ITS system. Moreover, the hierarchy including the typical factors that compose a logistic system has been identified. In order to show the effectiveness of the proposed methodology, we present a real case study consisting of the port of Trieste (Italy), the intermodal terminal and the highway connecting them. Several Key Performance Indicators are evaluated to provide assessment procedure.**

Keywords—Intermodal Transportation System, evaluation, Key Performance Indicators, Analytic Hierarchy Process.

I. INTRODUCTION

The freight transport is a key element for the welfare of society and for the economic competitiveness of the countries. Despite the benefits that it brings, such as stocking the shelves of our corner shops and local supermarkets, it does have its downside. There is a partial solution which is operationally feasible, economically viable and, most importantly, environmentally sustainable. It is the concept of Intermodal Transportation Systems (ITSs). This is a system in which two or more different modes of transport, such as road and rail, road and waterway or rail and shipping are combined, or integrated, to enable goods contained within a single loading unit, to be moved from their place of origin to their final destination [1], [2].

The aim of this paper is to provide a performance assessment procedure to evaluate an ITS. The term assessment is referred to a cognitive activity, carried out intentionally, aimed at providing a judgment on an action or complex of actions (i.e. a project). The assessment of a system means understanding its impacts and quantifying its benefits. Understanding the impacts of the system and its benefits is a key element for further implementation of cooperative services, as positive results are crucial to convincing politicians and decision-makers about the need to implement ITSs. In order to be able to choose between different investment alternatives and to compare the costs and benefits of different solutions, it is useful to develop a Cost-Benefit Analysis (CBA), which is the consideration of a decision in terms of consequences or costs and benefits [3], [4]. However, due to the complexity of the system and the amount of data to take into account, a simple CBA analysis is not enough. Indeed, the stakeholders may be interested in different indicators: public authorities are more interested in the social impacts respect to business actors that are interested in the efficiency and productivity of the system. For this reason, it is necessary to propose a methodology able to take into account all the differences between the involved aspects.

An effective method to evaluate an ITS is that of Analytic Hierarchy Process (AHP) [5]. The AHP is a theory of measurement through pairwise comparisons and relies on the judgments of experts to derive priority scales.

The core of the AHP was originally a method for converting subjective assessments of relative importance to a set of overall scores or weights [6]. The most commonly used techniques are simple weighting methods or evaluation methods and the theory of multi-attribute utility [7], [8].

This paper proposes a general methodology based on the AHP in order to identify a hierarchy, which includes the typical factors composing a logistic system. The presented methodology aims at evaluating the performances related to the implementation of innovative technology services and assessing the overall impact of the Information and Communication Technology (ICT) tools on the ITSs. The considered strategy is applied to a real case study consisting of the port of Trieste (Italy), the intermodal terminal and the highway connecting them, within the EU 7th FP project CO-GISTICS (cf. www.cogistics.eu).

To evaluate the system, a set of criteria is defined on the basis of typical logistics Key Performance Indicators (KPIs). The importance of the KPIs can be different for the different stakeholders, so we propose the use of the AHP methodology to obtain a general ranking referred to the whole ITS. To this aim different weights are determined, based on defined criteria per service and involved stakeholders.

The paper is organized as follows. Section II specifies the assessment of ITSs. Section III presents the case study. Finally, Section IV summarizes the results.

II. Assessment of Intermodal Transportation Systems

ITSs utilize two or more 'suitable' transport modes, to form an integrated transport chain aimed at achieving operationally efficient and cost-effective delivery of goods in an environmentally sustainable manner from their point of origin to their final destination. Each mode of transport has its own advantages: potential capacity, high levels of safety, flexibility, low energy consumption, low environmental impact. Intermodal transportation allows each mode to play its role in building transport chains, which overall, are more efficient, cost effective and sustainable [9]. In the logistic infrastructures, there is the need to improve the efficiency of logistics through machine to machine communication, cooperative system technologies, effective redaction of fuel consumption and CO_2 emission. Such objectives are pursued focusing on services that can optimize freight delivery plan, synchronize different transport modes, reduce the pollution and improve fuel consumption [1], [2].

A. The Main Phases of the AHP method

In this section, the AHP method is described and the main phases necessary to perform the AHP ranking is considered. The method was originally proposed by Saaty [6] and it is one of the more widely applied multicriteria analysis methods [10].

According to [11], the formulation of AHP develops a linear additive model. In the hierarchical structure, alternatives are located at the last level of the hierarchy, but are accounted for the exact same way as the elements at all other levels by means of pairwise comparisons. AHP uses procedures for deriving the weights and the scores achieved by alternatives, which are based, respectively, on pairwise comparisons between criteria and between options. Thus, in assessing weights, the decision maker is asked a series of questions, each of which asks how important one particular criterion is relative to another for the decision being addressed.

AHP can be applied by following four steps: 1) problem structuring, 2) weights evaluation, 3) summary of priorities and 4) sensitivity analysis. Starting from a decision problem, the first step consists in structuring the problem according to a hierarchical scheme, in order to provide a detailed, simple, systematic and structured decomposition of the general problem into its basic components. To this aim, the goal of the AHP is identified and the related criteria, sub-criteria and alternatives to reach the goal are determined.

The second step of weight evaluation is the core of the method, and provides the weights that are necessary for generating the ranking. More precisely, it is possible to individually analyze each aspect of the decision problem. Considering n ordered criteria of comparison (i.e., criteria, sub-criteria or alternatives in relation with criteria or sub-criteria), a $n \times n$ judgments matrix A is defined, where each upper diagonal element $a_{ij}>0$ is generated by comparing the i-th element with the j-th one through the fundamental scale of absolute numbers. The inferior triangular part of matrix A is completed with the reciprocal values of the upper triangular part, by obtaining reciprocal matrix elements: $a_{ji}=1/a_{ij}$. Moreover, if $a_{ij} \cdot a_{jk}=a_{ik}$, then matrix A is said to be perfect consistent and its principal eigenvalue is $\lambda_{max}=n$.

In AHP, the weights are obtained by solving the following eigenvector problem:

$$A\, w = \lambda_{max}\, w \tag{1}$$

where w is the priority eigenvector associated with the principal eigenvalue λ_{max}. If slight inconsistencies are introduced, then it holds $\lambda_{max} \neq n$.

In the field of decision-making, the concept of priority is quintessential and how priorities are derived influences the choices one makes. Priorities should be unique and not one of many possibilities, they must also capture the dominance of the order expressed in the judgments of the pairwise comparison matrix.

In the AHP methodology, a judgments matrix A is obtained for each set of criteria, sub-criteria and alternatives that are considered in each criterion and sub-criterion. Operatively, approximate formulation methods are used in order to calculate the weights from the judgments matrix [12].

First, the elements of matrix A are normalized as follows:

$$x_{ij} = \frac{a_{ij}}{\sum_i a_{ij}} \tag{2}$$

Second, the weight w_i are calculated as the average of the elements of the rows of the normalized matrix:

$$w_i = \sum_{j=1}^{n} x_{ij}/n. \tag{3}$$

The third step consists in evaluating the reliability of the obtained weights, by measuring the inconsistency of matrix A: the inconsistency increases if the judgments are badly posed. In the approximate method, the principal eigenvalue is approximately evaluated as follows:

$$\lambda_{max} = \frac{1}{n}\sum_{i=1}^{n} \frac{a_{ij} \times w_j}{w_i}. \tag{4}$$

Now, the consistency index CI is defined according to Saaty and it increases proportionally with the inconsistency of the matrix:

$$CI = \frac{\lambda_{max} - n}{n-1}. \tag{5}$$

In order to provide a measure of the inconsistence that is independent of the matrix order, Saaty proposed the Consistency Ratio (CR) defined as follows:

$$CR = CI/RI(n). \tag{6}$$

This is obtained by considering the ratio between *CI* and its expected value (Random Consistency Index - *RI*) determined over a large number of positive reciprocal matrices of order n, whose entries are randomly chosen in the set of values $n \in \{1,2,..., 10\}$ (Table I).

TABLE I. RANDOM CONSISTENCY INDEX (RI)

n	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.46	1.49

On the basis of several empirical studies, Saaty concludes that the value of $CR < 0.10$ is acceptable.

In the next step the summary of priority is performed to determine the rankings and the global weights for each alternative: to this aim the weights of each criterion and of each sub-criterion are combined with the weights of the alternatives (weights aggregation).

Finally, the procedure is verified by conducting a sensitivity analysis of the results in order to evaluate the stability of the solution with respect to possible excursions of the values associated to the judgments. The study of the methods to modify the input data in order to observe the impact on the results is an important research topic of the related literature.

B. *First Step of the AHP applied to ITS*

The potential of ITS depends on freight mode decisions to maintain linkage in the chain of movements. All decisions are made in some kinds of environmental context and therefore involve many factors beyond the control of the decision maker.

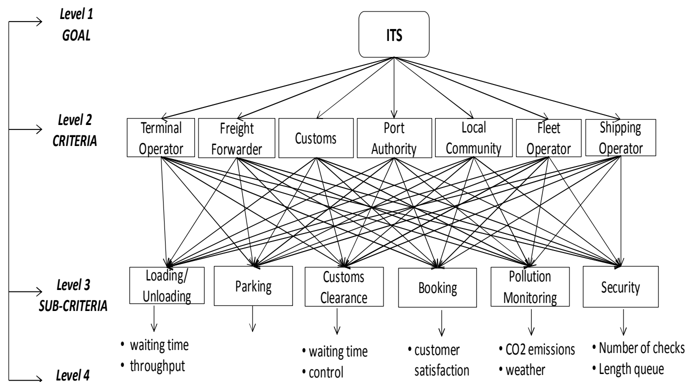

Fig. 1. AHP for ITS: hierarchy

Fig. 1 shows a general four-level structure of the criteria that can be applied for ITS evaluation.

The first level is the final goal, which is the ITS evaluation. The second level considers all the actors involved in the system. Indeed, the stakeholders' point of view represents the criteria to evaluate the system. The third level presents the sub-criteria, which are the typical services provided by an ITS. The connection between the second and the third level describes the importance rate of all services for each actor. In the last level we list the possible alternatives that include the KPIs such as Waiting Time, Throughput, Customer Satisfaction, satisfactions, etc..

III. THE CASE STUDY

A. *The ITS Services*

In recent years, increasing attention has been paid to the utilization of latest technological advances towards the development of innovative freight transport services. Indeed, such services can facilitate and enhance the daily operational efficiency of the freight road transport sector and reduce their environmental footprint. In this context, in the Port of Trieste cooperative freight transport services are being currently deployed, piloted and evaluated. In particular, great effort is devoted to increase energy efficiency by reducing fuel consumption and CO_2 emission, for sustainable mobility of goods. The services concern the following:

1) Intelligent Truck Parking (ITP), i.e., a service providing information about parking availability spots and places for trucks and vans;
2) Priority and Speed advice (PSA), i.e., a service supporting drivers with information on optimal speed they should adopt in order to reach a destination on time and pass through a traffic-light controlled intersection without stopping;
3) Eco-Drive Support (EDS) and CO_2 Footprint Estimation and Monitoring (CFEM), i.e., a service supporting drivers in adopting a more energy efficient driving behavior thus reducing fuel consumption and CO_2 emissions;
4) Cargo Transport Optimization (CTO), i.e., a service including the following sub-services: a) proof of cargo delivery and b) monitoring of cargo.

B. *The Key Performance Indicators*

To evaluate an ITS, it is useful to define some concise numeric indicators through which it is possible to calculate an overall score about the goodness of the system.

The KPIs are defined as quantitative or qualitative indicators, derived from one or several measurements, agreed on beforehand, expressed as a percentage, index, rate or other value, which are monitored at regular or irregular time intervals and can be compared to one or more criteria.

The definition of the criteria depends on the field of research and the goals it intends to achieve. It should be noticed that the KPIs need a denominator (per time/per distance/per trip) in order to make a measure comparable. For qualitative KPIs the "denominator" is represented by the time and circumstances on which the data are acquired (e.g. before 39 and after the use of a specific technology proposed in the project, etc.).

Moreover, KPIs can not be considered homogeneous because the nature of the collected data (qualitative/quantitative), the process of data acquisition, the type of data considered determine the presence of KPIs diverse in nature.

According to [3], evaluation criteria and KPIs are defined taking into account the stakeholders' needs and the basis of the businesses models in order to determine which data need to be collected during the operation of each pilot from infrastructure and transport network operators/managers, public authorities, service providers, fleet operators and drivers. The evaluation criteria identify the macro performance areas affected by the implementation of the innovative services. In particular, such areas are: network efficiency, environmental impact, economic sustainability, traffic network management and driver-specific metrics.

Table II reports in the first column the KPI name, in the second column the KPI measure unit, in the third column the name of the corresponding alternative in the AHP application.

TABLE II. KEY PERFORMANCE INDICATORS

KPI	Unit	Alternative
Average waiting time	hh/mm/ss	A1
Average throughput of the system	Trucks/day	A2
Perceived system usefulness	Six-point rating scale ranging from "never" to "always"	A3
Customer satisfaction	Five-point rating scale ranging from "never" to "always	A4
Average vehicle speed	Km/h	A5
Average travel time	hh/mm/ss	A6
Average distance driven	Km	A7
Average fuel consumption	MJ	A8
Average CO2 emissions	kgCO2/tkm	A9
Weather Condition Index	Probability of adverse weather conditions per route	A10

C. AHP Application

In order to apply the AHP to the Trieste case study, three criteria Ci (i=1,2,3) are defined by the following stakeholders (Fig. 2): Fleet Operator, Public Authority and Inland terminal. Moreover, five sub-criteria Si with i=1, …,5 are identified, corresponding to the services, for each of which the relevant measurable KPIs (Table II) are indicated as 'alternatives' denoted by Ai with i=1,…,10. Fig. 2 shows the hierarchy resulting from the AHP's first phase applied to the Port of Trieste.

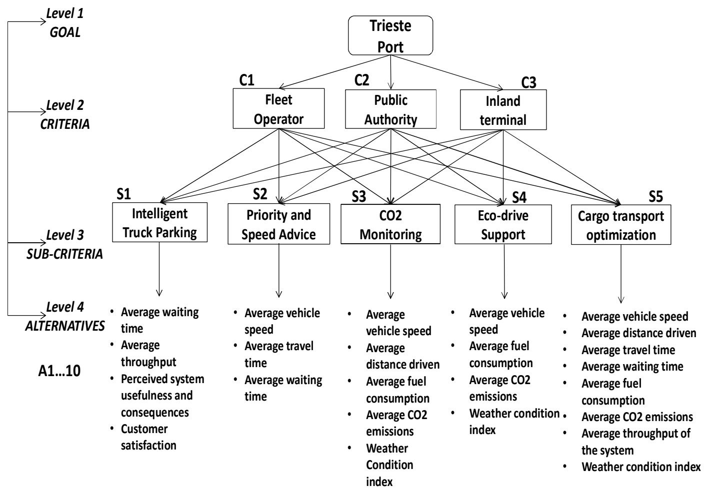

Fig. 2. Port of Trieste's hierarchy

TABLE III. SAATY'S FUNDAMENTAL SCALE

Intensity of importance	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	Absolutely more important
2,4,6,8	Intermediate values

In the second step, for each level of the hierarchy, the relative importance of the criteria has been determined respect to the top level decision element by pairwise comparison, using the Saaty's fundamental scale reported in Table III.

Starting from the hierarchy shown in Fig. 2, we get nine judgments matrices by comparing firstly the alternatives Ai for i=1,…,10 to each sub-criterion Si for i=1,…,5 (5 matrices), then the sub-criteria with respect the three criteria Ci for i=1,…,3, obtaining three matrices, and finally the criteria Ci for i=1,…,3 with respect the top level.

The results of the comparison are reported in each judgments matrix A and are used to obtain absolute local weights. In particular, for the sake of brevity, we report one judgments matrix for each level of the hierarchy. More specifically, Table IV reports the matrix resulting from the pairwise comparison between the 4 KPIs corresponding to the service Intelligent Truck Parking (S1).

TABLE IV. JUDGMENTS MATRIX A FOR ALTERNATIVES OF ITP SERVICE

	A1	A2	A3	A4
A1	1	6	7	7
A2	1/6	1	2	2
A3	1/7	0.5	1	1
A4	1/7	0.5	1	1

After the normalization of each matrix A, the weights w_i are calculated according to equation (3) and are reported in Table V. The output of this step is the absolute local rankings of the alternatives to each sub-criterion.

TABLE V. WEIGHTS EVALUATION OF ALTERNATIVES OF THE ITP SERVICE

w_1	0.678
w_2	0.158
w_3	0.086
w_4	0.086

TABLE VI. AHP CONSISTENCY INDICES

CR	0.0136
RI	0.9
CI	0.0122

TABLE VII. JUDGMENTS MATRIX A FOR THE FLEET OPERATOR CRITERION

	S1	**S2**	**S3**	**S4**	**S5**
S1	1	3	7	6	8
S2	1/3	1	3	2	3
S3	1/7	1/3	1	1/2	2
S4	1/6	1/2	2	1	2
S5	1/8	1/3	1/2	1/2	1

TABLE VIII. WEIGHTS EVALUATION FOR THE FLEET OPERATOR CRITERION

w1	0.5729
w2	0.1684
w3	0.0788
w4	0.0928
w5	0.0795

TABLE IX. AHP RESULTS FOR THE FLEET OPERATOR CRITERION

CR	0.01805
RI	1.12
CI	0.0202

TABLE X. JUDGMENTS MATRIX A FOR THE TOP LEVEL

	C1	**C2**	**C3**
C1	1	1/4	2
C2	4	1	6
C3	1/2	1/6	1

Moreover, the reliability of the obtained weights is evaluated, by measuring the inconsistency of matrix *A* and are shown in Table VI: the indices *CR* and *CI* are determined according to equations (5) and (6), respectively, and the values of *RI* are determined according to Table I. Since we obtain $CR=0.0136<0.10$, we conclude that matrix *A* is consistent and the reliability of the AHP application is guaranteed.

As for the higher level, we report the judgments matrix *A* in Table VII obtained from the pairwise comparison between the 5 sub-criteria Si for i=1,…,5 with respect to criterion C1 (Fleet Operator). The corresponding weights are reported in Table VIII.

The results of the AHP corresponding to the Sub-criteria level are shown in Table IX: since CR<0.10, we conclude that matrix *A* is consistent.

Finally, the judgments matrix resulting from the pairwise comparison between the criteria C1, C2 and C3 with respect to the top level 'Trieste Port' is reported in Table X. After normalizing the previous judgments matrix, the obtained weights are reported in Table XI and the AHP consistency indices are shown in Table XII. The values are satisfactory since the judgments matrix results are consistent (also in this case CR<0.10).

TABLE XI. WEIGHTS EVALUATION FOR THE TOP LEVEL

w1	0.6335
w2	0.1999
w3	0.1665

TABLE XII. AHP CONSISTENCY INDICES FOR THE TOP LEVEL

CR	0.0079
RI	0.58
CI	0.0046

The same 3 steps procedure of the AHP is applied to each alternative of each level and the corresponding obtained weights are reported in Fig. 3 for each alternative corresponding to a KPI.

By adding the resulting weighted KPI for each sub-criterion and criterion, it is possible to get a ranking of the KPIs as shown in Table XIII, which reflects the measure of each KPI impact on the logistic system.

TABLE XIII. KPIS RANKING

KPI	**Alternatives**	**Weight**
Average waiting time	A1	0.38
Average vehicle speed	A5	0.26523108
Average throughput of the system	A2	0.086856145
Customer satisfaction	A4	0.045083291
Perceived system usefulness	A3	0.045083291
Average travel time	A6	0.043264706
Average distance driven	A7	0.038982118
Average fuel consumption	A8	0.035705709
Average CO2 emissions	A9	0.029489296
Weather Condition Index	A10	0.026227772

Criteria	Criteria Weight	Sub-Criteria	Sub-Criteria Weight	Alternatives	Alternatives Weight	Weighted Score
C1	0.63	S1	0.57	A1	0.68	0.245191873
				A2	0.15	0.054769673
				A3	0.09	0.030813697
				A4	0.09	0.030813697
		S2	0.17	A5	0.73	0.080376455
				A6	0.18	0.020094114
				A1	0.09	0.010047057
		S3	0.08	A5	0.49	0.026231767
				A7	0.24	0.012703936
				A8	0.10	0.005493743
				A9	0.09	0.004631336
				A10	0.08	0.004492462
		S4	0.09	A5	0.59	0.0325846
				A8	0.18	0.009710308
				A9	0.13	0.007245332
				A10	0.10	0.005718573
		S5	0.08	A5	0.30	0.015511696
				A7	0.14	0.007233107
				A6	0.14	0.007233107
				A1	0.11	0.00589819
				A8	0.08	0.004139294
				A9	0.08	0.004139294
				A2	0.08	0.004139294
				A10	0.08	0.003980084
C2	0.19	S1	0.50	A1	0.68	0.064417536
				A2	0.15	0.014389251
				A3	0.09	0.008095466
				A4	0.09	0.008095466
		S2	0.13	A5	0.73	0.018637397
				A6	0.18	0.004659349
				A1	0.09	0.002329675
		S3	0.13	A5	0.49	0.011782244
				A7	0.24	0.005706092
				A8	0.10	0.002467566
				A9	0.09	0.002080208
				A10	0.08	0.002017831
		S4	0.13	A5	0.59	0.014183947
				A8	0.18	0.004226858
				A9	0.13	0.003153864
				A10	0.10	0.002489272
		S5	0.12	A5	0.30	0.006857747
				A7	0.14	0.003197769
				A6	0.14	0.003197769
				A1	0.11	0.0026076
				A8	0.08	0.001829989
				A9	0.08	0.001829989
				A2	0.08	0.001829989
				A10	0.08	0.001759602
C3	0.17	S1	0.41	A1	0.68	0.049128996
				A2	0.15	0.010974177
				A3	0.09	0.006174128
				A4	0.09	0.006174128
		S2	0.21	A5	0.73	0.027052903
				A6	0.18	0.006763226
				A1	0.09	0.003381613
		S3	0.21	A5	0.49	0.018220418
				A7	0.24	0.008824073
				A8	0.10	0.003815919
				A9	0.09	0.003216896
				A10	0.08	0.003120435
		S4	0.11	A5	0.59	0.010967242
				A8	0.18	0.003268271
				A9	0.13	0.002438615
				A10	0.10	0.001924743
		S5	0.05	A5	0.30	0.002824665
				A7	0.14	0.001317142
				A6	0.14	0.001317142
				A1	0.11	0.001074055
				A8	0.08	0.000753761
				A9	0.08	0.000753761
				A2	0.08	0.000753761
				A10	0.08	0.000724769

Fig. 3. AHP levels

IV. CONCLUSIONS

This paper presents a performance assessment procedure to evaluate an Intermodal Transportation System. We have evaluated the performance related to the implementation of innovative technology services and the overall impact of these on the port of Trieste (Italy), the intermodal terminal and the highway connecting them. To pursue this aim, we have defined some Key Performance Indicators and we have attribute them a weight through the AHP methodology. The results point out that the most important KPIs for all the stakeholders are the Average waiting time and the Average vehicle speed. Hence, the performances concerning the time have a more important impact on the system with respect to the weather and the emissions.

In the future research, a weight sensitivity analysis study could be deployed through altering criterion weight values calculated by AHP, even if corresponding weight sensitivity on multi-criteria evaluation results is generally difficult to be quantitatively assessed [13].

REFERENCES

[1] Fanti M.P., Iacobellis G., Nolich M., Rusich A., Ukovich W., “A Decision Support System for Cooperative Logistics”, T-ASE, Vol. X, No. X, October 2015.

[2] Fanti M.P., Iacobellis G., Nolich M., Rusich A., Ukovich W., “A decision support system for multimodal logistic management,” in Automation Science and Engineering (CASE), 2015 IEEE International Conference on, August 2015.

[3] Salanova Grau J. M., Fanti M.P., Iacobellis G., Nolich M., Rusich A., Ukovich W., Mitsakis E., Aifadopoulou G., Scala E., Papadopoulos C., “Evaluation framework in Cooperative Intelligent Transport Systems (C-ITS) for freight transport: the case of the CO-GISTICS speed advice service”, 2016.

[4] Jean D., Stern N., “The Theory of Cost-Benefit Analysis. “In Handbook of Public Economics”, vol. 2, edited by Alan J. Auerbach and Martin Feldstein, 909-89. Amsterdam: North-Holland, 1987.

[5] Saaty T.L., “Decision-making with the AHP” Int. J. Services Sciences, Vol. 1, No. 1, 2008.

[6] Saaty T.L., “Decision-making with the AHP: Why is the principal eigenvector necessary?” European Journal of Operational Research, 2003.

[7] Saaty T.L., Hu G., “Ranking by the eigenvector versus other methods in the analytic hierarchy process, Applied Mathematical Letters” 11 (4) 121–125, 1998.

[8] Kunadhamraks P., Hanaoka S., “Evaluating the logistics performance of intermodal transportation in Thailand”, Asia Pacific Journal of Marketing and Logistics, 2008.

[9] Lowe D., “Intermodal freight transport”, Oxford, UK, 2005.

[10] Fanti M.P., Iacobellis G., Hadjidimitriou S., Stamos I., Mininel S., Dell’Amico M., Ukovich W., “A Methodological Approach for a Cost-Benefit Analysis of Cooperative Freight Transport Services”, 2017.

[11] Hanaoka S., Kunadhamraks P., “Multiple criteria and fuzzy based evaluation of logistics performance for intermodal transportation. Journal of Advanced Transportation”, 2009.

[12] Ishizaka, A., and Lusti, M.. “How to derive priorities in AHP: a comparative study.” Central European Journal of Operations Research, 14(4), 387-400, 2006.

[13] Chen, Y., Yu J., Khan S., “The spatial framework for weight sensitivity analysis in AHP-based multi-criteria decision making” Environmental modelling & software, - Elsevier, 2013.