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PREFACE

This monograph appears as a result of our intention to extend the scope of LOGIC conference by promoting specific logistics related topics in an more dedicated and comprehensive way.

The book is devoted to quantitative methods which are, without any doubt, essential for both logistics an logisticians. It is well known that this fact is even stated in ancient Greek root of the word logistics - *logistikos* means skilled in calculation.

The monograph presents different quantitative methods and approaches covering mathematical programming methods, DEA, heuristics and metaheuristics approaches, big data analytics, elements of possibility theory, multicriteria decision making, etc. Those methods and techniques cover different problem areas: location problems, vehicle routing, supply chain management, freight transportation, intermodality, reverse logistics, risk in transportation, logistic systems performances, energy consumption, and other related areas. Those topics are organized in 11 chapters which include numerous tables and illustrations.

Although concise, the monograph, in our opinion, gives broad range of information from different areas and therefore we do believe that could be beneficial to those who need to widen their perspective on quantitative methods and its potentials for application in logistics. Selected chapters cover the most relevant methods, techniques and approaches which are of particular importance for logistics systems planning, control and analysis. Hence, we do hope that the monograph could be of interests not only to academic community but also to industry professionals. To academic community as useful source of information both through the chapters content itself and through the included lists of references, while for industry professionals as a potential source of ideas which could help in enhancing their excellence and innovations potentials.

Belgrade, January 2020

Editors

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RESOURCE CONSTRAINED PROJECTS PRIORITIZATION WITH MCDM METHOD – CASE STUDY: SERBIAN RAILWAY INFRASTRUCTURE PROJECTS

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Abstract: *Transport infrastructure development is one of the most important factors for a country's progress. Problem of transport projects prioritization is complex task due to many facts relevant in this process, such as: the need for large capital investments; the national budget constraints; a long period of project preparation; etc. Also, in this process numerous stakeholders are involved who often have different interests. The challenge that is considered in this paper is to develop an investment plan for railway projects realization in accordance with limited budget.*
The proposed model has two stages: a projects' ranking and a projects' selection. Based on multi-criteria decision making method, the weights of railway projects are defined. The projects are ranked using the Analytic hierarchy process. The next stage, the projects' selection is done by the Excel Solver. The selection of projects is made in accordance with the available budget and projects' weights.
All data are taken from the Serbian National Programme of Public Railway Infrastructure for the period 2017-2021, as the last official national document and Master Plan for Railways for 2012-2021 for the Republic of Serbia.
The main contribution is developed MCDM methodology for single resource constrained projects prioritization that can be applied in any industry, not just transport.

Keywords*: Multi-criteria decision making; Analytic hierarchy process; Project prioritization; Railway infrastructure projects*

1. INTRODUCTION

Development of quality transport infrastructure is a precondition and one of the most important factors for a country's progress around the world. It has been confirmed by so many cases how transport infrastructure has added a momentum and efficiency to the world economies. Also, transport infrastructure facilitates the development of connections between regions within a country and between countries, and thus supports the formation of mutual economic, social and cultural relations. The transport

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infrastructure investments are driven by the policies of public authorities and ministry in charge. These entities are highly involved in decisions making processes about transport infrastructure development. In all European countries, the infrastructure manager is either the state or a public company, whereby the public authorities support financially all the capital investments.

The railway transport has been seen as a backbone for sustainable transport system. It has an essential role for the economies and the quality of life worldwide. It is the most environmentally-friendly, but also economically-cost effective, mode of transport. However, many years of the neglect and the lack of investments into railway network have led to the poor conditions' of railway infrastructure which is one of the reasons for decreasing of railway transport demands on the transport market. So, in order to increase the volume of railway transport and to take advantage of all benefits offered by the railway transport it is necessary to prepare sustainable national investment plans for improving railway infrastructure.

The main challenge considered in this paper is to define an investment plan for realization of railway infrastructure projects when the objective is to maximize the effects of these projects, but with limited budget. The model for the resource constrained projects prioritization is developed. The proposed methodology is made in two stages: a projects' ranking that is done with the AHP approach, and a projects' selection that is done with the Excel Solver.

The model is tested and verified with the real data from planned railway projects on Serbian railway infrastructure network. All data are real data from Serbian National Programme of Public Railway Infrastructure for the period 2017-2021[2], as the last official national document (hereafter: NP) and Master Plan for Railways for 2012-2021 for the Republic of Serbia (hereafter: MPR).

The paper is organized as follows. After Introduction, the second section is dedicated to the problem description. The elements of the model, i.e. alternatives and criteria, are thoroughly defined. The third section presents the model for the resource constrained projects prioritization. This section also gives more details about applied approaches. The last section is dedicated to the final conclusion and future research.

2. THE PROBLEM DESCRIPTION

The rail infrastructure can function for a very long time without any investment in its maintenance because it has a long service life. Without regular investment in its maintenance, trains can run, but at the same time the maintenance costs, as well as the costs of the procurement of materials, increase, whereas the quality of rail services simultaneously decreases. Consequently, there is a need for huge and expensive investments that cannot be avoided (Macura and Bojović, 2013).

In the Republic of Serbia, there were no significant capital investments in the rail infrastructure or even in its regular maintenance until 2013 although rail lines are about 45 years old on average.

Unfortunately, it is evident that the rail sector has not been in focus for a certain time. In accordance with this, there are some facts published in the Business plan of Serbian

[2]Official Gazette of the Republic of Serbia, No. 53/2017

infrastructure manager: only in 34 km of the whole rail network in Serbia is it possible for trains to run at a speed higher than 100km/h, which is only 1.4% of the whole network (Serbian Railways Infrastructure, 2018).

In period from 2013 to the end of 2018 were finished several railway projects where about 223 km of main railway lines are reconstructed and modernized. Aim of two railway projects was doubling of single tracks railway line so in this period was constructed 35 km of new railway tracks. Besides that, in period of 2017 to the end of 2018 the first phase of the renewal of the regional railways was carried out, within which about 271 km was renewed. Works which are currently underway are works on two sections of Belgrade-Budapest railway line from Belgrade to Novi Sad and work on renewal of 192 km of regional lines.

The plan presented in the NP relevant for the 2017-2021 period considers the construction of new rail lines, the recovery and maintenance of the existing rail lines; priorities, as well as a schedule for their implementation, the costs and the sources for their financing are defined.

Public investment is the field of the public finance management in the Republic of Serbia which has been paid great attention to. Strengthening the framework for public investments management intensifies new infrastructure projects and raises the quality of the existing infrastructure (Ministry of Finance of the Republic of Serbia, 2019). Capital projects, i.e. loans for projects, have become an integral part of the Budget of the Republic of Serbia by adoption the Regulation on the content, method of preparation and evaluation, as well as monitoring of the implementation and reporting on the implementation of capital projects (Ministry of Finance of the Republic of Serbia, 2017).

In order to keep the achieved fiscal stability, the financing of new capital projects will primarily be possible by freeing the fiscal space, which means that in the process of proposing projects, budget users should present the proposed, the existing and new projects within the limits proposed by the Budget Law (Ministry of Finance of the Republic of Serbia, 2018).

In the case when a budget beneficiary proposes several different capital projects for their inclusion in the priority areas of financing, the beneficiary should prioritize those projects according to their significance.

In order to perform the prioritization of rail projects, all of the considered railway infrastructure projects in the NP are presented in Table 1, together with their main characteristics, i.e. their length and the number of tracks.

Table 1. Considered alternatives

	Alternative	Length	No. of tracks
A1	Niš – Preševo – North Macedonia border	92	1
A2	Resnik – Klenje – Mali Požarevac – Velika Plana	84	2
A3	Velika Plana – Gilje	49	2
A4	Paraćin – Stalać	22	2
A5	Stalać – Djunis	17.7	1
A6	Djunis – Niš	40	2
A7	Golubinci – Šid – Croatia border	81	1
A8	Pančevo – Vršac – Romania border	75	1
A9	Stalać – Kraljevo – Rudnica	149	1
A10	Valjevo – Vrbnica – Montenegro border	209.4	1

Figure 1 shows the railway network in the Republic of Serbia with considered alternatives, i.e. railway projects. All projects are on the railway Corridor 10, except A8, A9 and A10.



Figure 1. Serbian railway network with considered alternatives

All relevant criteria are presented in Table 2. Here are given the measure of each criterion and type of criterion (whether it has to be minimized ↘ , or maximized↗).

Table 2. Considered criteria

	Criteria	Measure	Type of criterion
X1	Investment cost	EUR/km	↘
X2	The part of Corridor 10	Yes/No [1,2]	↘
X3	Rail infrastructure capacity utilization	The percent of rail line capacity utilization [%]	↗
X4	Maturity of the project	None, Initial, Intermediate, Final Stage [0,1,2,3]	↗
X5	Traffic volume	[train/day]	↗
X6	Social aspect	[population/km]	↗
X7	Cost per minute saved for passenger traffic	[EUR]	↘

Criterion X1 – Investment cost

Capital investment costs are taken from the NP and they are presented as unit cost per kilometer of a single track railway line. This criterion varies across the projects because of planned scope of the projects which depends of types of improvement (renewal, reconstruction, modernization or construction of new railway lines).

Criterion X2 – The part of Corridor 10

The Pan-European Rail Corridor 10 is a very important corridor that has a total length of 872 km on the territory of the Republic of Serbia, which presents about 23% of the railway network. Considering the significance of this corridor, which is the main transit route and the shortest route between Greece, the Middle East and Western Europe, the revitalization of railway sections along this corridor has a higher priority for providing capital investments.

Criterion X3 –Rail infrastructure capacity utilization

The capacity of the railway infrastructure is defined as the number of trains that can run on a particular railway section over a certain period of time (usually 24 hours) taking into account the characteristics and all limitations of that section. The data related to the infrastructure capacity utilization for the presented alternatives were taken from the MPR, except for the Stalac-Kraljevo-Rudnica project were received from the consultants working on the preparation of the Conceptual Design with a Pre-Feasibility Study.

Criterion X4 – Maturity of the project

Maturity of the project is presented as a stage of completion of necessary technical documentation. The term *None* represents that an alternative does not have any technical documentation. The alternatives in *Initial stage* are alternatives with at least provided funds for preparation of a Preliminary Design or with prepared Conceptual Design. *Intermediate stage* is stage where process of preparation of Preliminary Design is underway. Alternatives in *Final stage* are alternatives with at least prepared Preliminary design.

Criterion X5 – Traffic volume

Criterion of traffic volume is measured in trains per day. Data for this criterion are taken from the MPR, except for project Stalać-Kraljevo-Rudnica. This data is received from the consultants working on the preparation of the Conceptual Design with Pre-Feasibility Study.

Criterion X6 – Social aspect

Criterion Social aspect is measured in population per kilometer and represents a number of direct beneficiaries on micro level (on level of alternative). Data are taken from the Statistical book of Republic of Serbia (Statistical Office of the Republic of Serbia, 2018).

Criterion X7 – Cost per minute saved for passenger traffic

Upgrading of railway infrastructure has a direct benefit for rail user in way of time savings. In this paper only passenger traffic is taken into account because goods manly transported by train are not affected with travel time. The criterion Cost per minute saved for passenger traffic represents a cost-benefit ratio for which the data for time savings are taken from the MPR, except for the project Stalać-Kraljevo-Rudnica. This data is received from the consultants working on the preparation of the Conceptual Design with Pre-Feasibility Study.

3. PROPOSED MCDM MODEL

The proposed model for resource constrained projects prioritization includes the AHP approach for projects' ranking, i.e. for the projects' weights obtaining, and also the application of the Excel Solver for the projects' selection. The final product is the multiyear investment plan.

After determining the alternatives of the model and all relevant criteria in Section 2, the AHP approach will be briefly described below.

3.1 The AHP approach

The AHP approach was developed by Thomas Saaty (Saaty, 1980). Usually, the structure of the AHP model has three levels: the goal, criteria and alternatives (a model could have more levels; for instance, there can be subcriteria level, etc.). Since its founding in 1980s, this approach has been widely used in the scientific literature as well as in practice, due to many its advantages: the AHP structures the problem as a hierarchy, which is more compatible with the natural cognitive process; both qualitative and quantitative attributes can be considered; allows checking the consistency index of evaluators; group decision making is very well facilitated; there is an user-friendly software; etc.

The AHP approach is widely used in various fields (Macharis and Bernardini, 2015; Vaiday and Kumarb, 2006), here are some of them:

- Transportation (Chin et al. 2019; Macura and Bojković, 2016; Lai et al. 2015; Dhir et al. 2015; Barić and Starčević, 2015; Podvezko et al., 2014; Bojković et al., 2011; Islam and Saaty, 2010; Modarres and Zarei, 2002; Saaty, 1995);
- Logistics (Jain and Khan, 2017; Gurcan et al., 2016; Stević et al., 2015; Büyüközkan et al., 2008; Alberto, 2000);
- Marketing (Erbiyik et al., 2012; Yang and Lee, 1997);
- Project management (Quadros and Nassi 2015; Vargas, 2010; Al-Harbi, 2001)
    - Railway projects: Hamurcu and Eren 2018; Stoilova and Nikolova 2018; Polat and Eray 2015; Macura and Šelmić 2015; Nyström and Söderholm 2010.

To the best of our knowledge the AHP approach with Excel Solver tool for railway projects' evaluation has not been introduced as such so far. That is why this research is believed to be one of the first steps towards the development of MCDM models with Excel Solver tool for resource constrained projects prioritization in railway industry.

There are some researches (Macharis and Bernardini, 2015; Hüging et al., 2014; Macura et al., 2011) that emphasize the validity of the Multi-Criteria Decision Making methods' for the transport project appraisal. In the paper (Macharis and Bernardini, 2015) authors gave an overview of the Multi-Criteria Decision Analysis (MCDA) applications for the transport project appraisal. The aim of this paper is to check whether or not there is an increasing of the MCDA methods' applications in the evaluation of transport projects. The main conclusion of this research was that there is a certain increase of the MCDA methods' applications, and the most used approach in this field is the AHP.

Here is presented the AHP approach through several steps.

First step

Definition of the goal, criteria and alternatives.

Second step:

The pair-wise comparison matrix development.

In order to compute the weights for the criteria, the pairwise comparison matrix A is developed. The matrix A is a $m \times m$ matrix, where m is the number of criteria. Each element of matrix A, a_{ij} represents the importance of ith criterion relative to the jth criterion. Whereby, a_{ji}, the importance of jth criterion relative to the ith criterion, is:

$$a_{ji} = 1/a_{ij}$$

This rule is known as an axiom of reciprocity.

The relative importance between two criteria is measured in accordance with Table 1.

Table 3. The Saaty scale

Value	Importance
1	Equal
3	Weak
5	Strong
7	Demonstrated
9	Absolute
2,4,6,8	Intermediate values

Third step

The normalized pairwise comparison matrix development.

The normalized pairwise comparison matrix A_{norm} is developed by using the following equation:

$$a'_{ij} = a_{ij} / \sum_{l=1}^{m} a_{lj} \quad (1)$$

Fourth step

The criteria weight vector calculation.

The criteria weight vector w is built in following way:

$$w_i = (1/m) \times \sum_{l=1}^{m} a'_{il} \quad (2)$$

There is a matrix S, $n \times m$ (where n and m are the numbers of alternatives and criteria, respectively) with elements s_{ij} which represents the value of the ith alternative with respect to the jth criterion.

Fifth step

The matrix B^j, $n \times n$ with elements b_{ih} which represents the evaluation of ith alternative compared to the hth alternative with respect to the jth criterion.

The normalized matrix B_{norm} should be developed, in the same way as the normalized matrix A_{norm}.

Sixth step

There is the score vectors s_j, j=1,…,m. The vector s_j contains the scores of the alternatives with respect to the jth criterion.

Finally, the matrix S is obtained.

Seventh step

Once the weight vector w and the matrix S have been computed, the vector v is obtained as follows:

$$v = S \times w \quad (3)$$

The vector v presents the final priorities among alternatives.

At the end, the consistency of evaluators can be checked using the eigenvector method.

The factor λ_{max} is used for calculation of the consistency index, CI (Saaty, 1980).

$$\lambda_{max} = \sum_{j=1}^{m} \left(w_j \times \left(\sum_{j=1}^{m} a_{ij} \right) \right) \quad (4)$$

$$CI = (\lambda_{max} - m)/(m-1) \quad (5)$$

After the consistency index is calculated, the consistency ratio, CR, can be considered as a relation of the consistency index and the random index, RI. Table 6 presents the values for RI, where m is the number of elements in a pairwise matrix.

$$CR = CI / RI \quad (6)$$

Table 4. The values of RI

m	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

For CR < 0.1, the degree of consistency is satisfactory. Otherwise, the judgment of an evaluator should be revised.

3.2 The structure of the model and results

An algorithm for considered problem is presented in Figure 2. At the start, there are alternatives and criteria, as the elements of the model. These values are input for the AHP approach. The results of the AHP are the weights of alternatives and criteria.

Besides these values, projects costs and available budget per year are input for the Excel Solver. Some projects will not be implemented in the planned year because of the limited national budget, and they will be deferred for the next year. Every time, when there is a lack of the financial resource, the Excel Solver is used to select the projects for implementation, i.e. to determine those projects that will be postponed. When the year of the start for all considered projects is defined, the algorithm is finished.

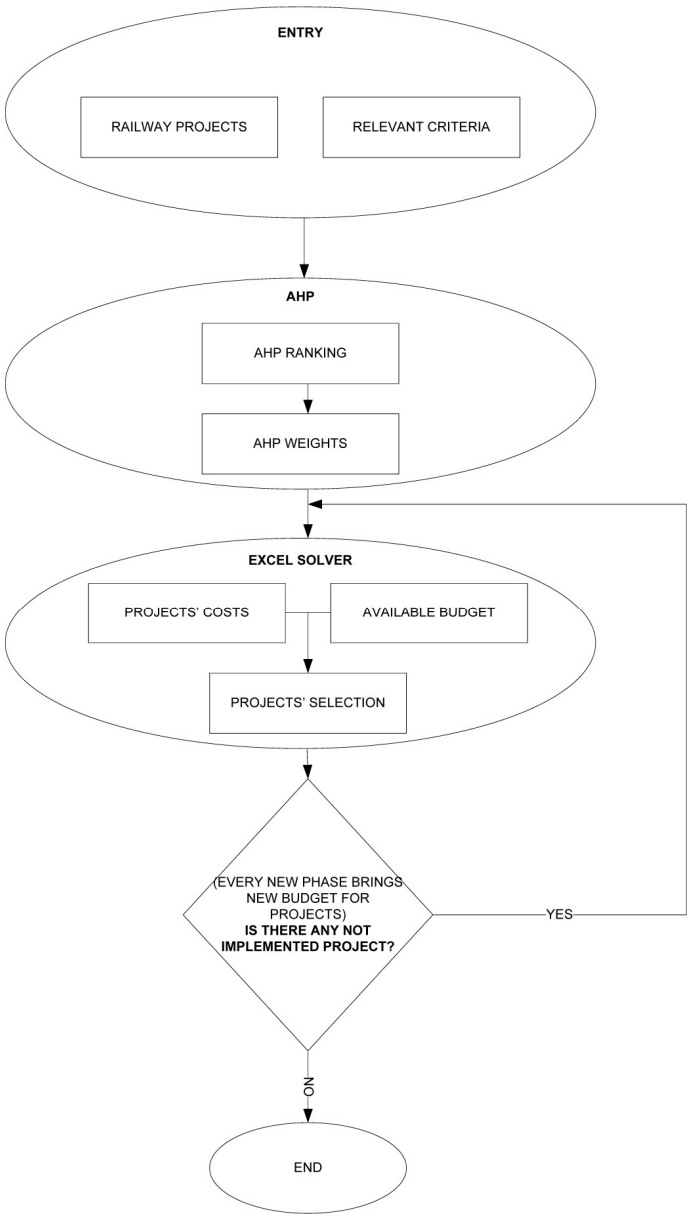


Figure 2. The algorithm of the proposed model

The proposed model can be considered through two stages.

1) The first stage means the projects' ranking, i.e. the projects' weights obtaining. This calculation is made with the AHP approach (Dimitrijević, 2017). The elements of the model are 10 railway projects (Table 1) and 7 relevant criteria (Table 2). The input for the AHP model are data from Table 5. Based on these values, the pair-wise comparison matrices, presenting the comparison of alternative related to each criterion, are made.

Table 5. Input data

	X1 (mil.EUR/km)	X2 [1,2]	X3 [%]	X4 [0,1,2,3]	X5 [train/day]	X6 [population/km]	X7 [EUR]
A1	1.7	1	55	1	27	6300	3.67
A2	2.05	1	69	1	27	21782	8.82
A3	2	1	21	2	65	2359	22.05
A4	1.8	1	29	2	34	2730	25.48
A5	3.1	1	80	3	38	7410	9.08
A6	2	1	23.8	2	38	10684	28.88
A7	1.54	1	32	1	28	2782	47.17
A8	1.2	2	71	0	48	2518	6.83
A9	1.34	2	31	1	22	2220	2.47
A10	1.1	2	71	1	54	1241	1.91

Table 6 presents the pair-wise comparison matrix for criteria. Based on this matrix, the criteria weights are defined.

Table 6. Pair-wise comparison matrix for criteria

	X1	X2	X3	X4	X5	X6	X7
X1	1	3	5	0.3333	5	7	5
X2	-	1	3	0.2	3	5	2
X3	-	-	1	0.14286	0.5	3	0.3333
X4	-	-	-	1	5	7	5
X5	-	-	-	-	1	3	2
X6	-	-	-	-	-	1	0.3333
X7	-	-	-	-	-	-	1

The final weights for all alternatives and criteria are obtained and presented in tables 7 and 8.

Table 7. The alternatives' weights and rank

	Alternative	Weight	Rank
A1	Niš – Preševo – North Macedonia border	0.0897	7
A2	Resnik – Klenje – Mali Požarevac – Velika Plana	0.0771	10
A3	Velika Plana – Gilje	0.1160	3
A4	Paraćin – Stalać	0.0987	4
A5	Stalać – Djunis	0.1388	1
A6	Djunis – Niš	0.0983	5
A7	Golubinci – Šid – Croatia border	0.0804	8
A8	Pančevo – Vršac – Romania border	0.0949	6
A9	Stalać – Kraljevo – Rudnica	0.0795	9
A10	Valjevo – Vrbnica – Montenegro border	0.1265	2

Table 8. The criteria weights and rank

	Criteria	Weight	Rank
X1	Investment cost	0.2660	2
X2	The part of Corridor 10	0.1468	3
X3	Criteria of rail infrastructure capacity utilization	0.0557	6
X4	Maturity of the project	0.3334	1
X5	Criteria of traffic volume	0.0882	4
X6	Social aspect	0.0251	7
X7	Cost per minute saved for passenger traffic	0.0849	5

2) The second stage is the projects' selection, i.e. the multiyear investment plan development.

Relevant input for this stage are: the assumed budget per year (Table 9), the start date and estimated duration for all projects (Table 10), presented through the Gantt chart (Figure 3). The suggestion for decision makers, when a certain project should start (Figure 5), is provided by the Excel Solver.

Let us assume that there is a certain amount of the money for each year, as it is shown in Table 9.

Table 9. Data for the budget

Year	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Budget limit per year (mil.EUR)	350	250	200	200	200	300	300	200	120	120

Table 10 presents several data: when certain project starts and estimated project's duration, as well as the total costs for each project.

Table 10. Duration time and total costs for all alternatives

	Start [quarter and year]	Duration [months]	Total costs (mil.EUR)
A1	Q4 2022	36	160
A2	Q1 2023	54	340
A3	Q1 2022	30	200
A4	Q1 2022	18	80
A5	Q1 2021	48	150
A6	Q1 2022	30	150
A7	Q4 2022	48	250
A8	Q1 2023	36	96
A9	Q1 2024	60	200
A10	Q2 2022	48	230

* Q1, Q2, Q3, Q4 as the first, second, third, fourth quarter of a year

Gantt chart is a type of a bar chart that presents a projects' schedule. Here are presented all projects with their start times and how long they will be implemented (Figure 3).This chart is made before the proposed algorithm is applied.

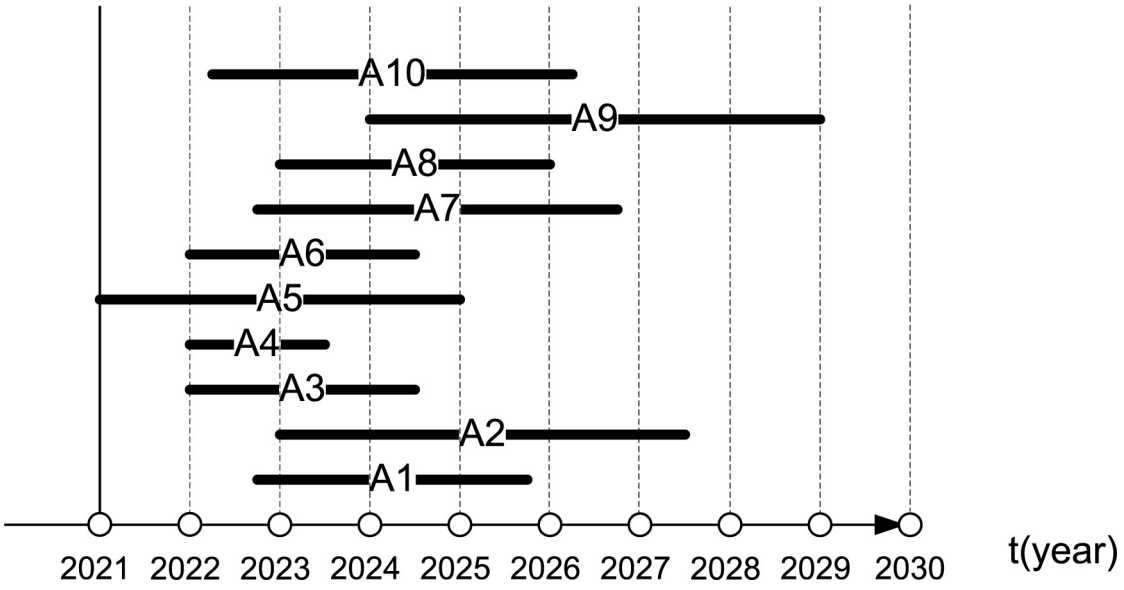


Figure 3. Gantt Chart at the beginning

Let us assume that the budget is limited. At the beginning of each year there is a certain amount of the money, which presents the available budget for all projects planned for that year. So, some projects will be implemented in the planned year, but some of them will not be finished, because of the limited budget. Which project will be finished or not is the answer that the Excel Solver should give to the decision makers.

Following figure presents how the Excel Solver provided the decision about projects' implementation, i.e. postponement. Here is shown example for 2022, with six planned projects: A1, A3, A4, A6, A7 and A10. Total requested budget is 1070 mil.EUR (160+200+80+150+250+230=1070). The available budget is 250+200=450 mil.EUR, where 250 mil.EUR is planned budget for 2020 (Table 7) and 200 mil.EUR is the rest from 2021 (the planned budget for 2021 is 350 mil.EUR, but after the implementation of the project A5, which costs 150 mil.EUR, there is the rest of 200 mil.EUR). Considering that there is no enough money for all planned projects, some projects will be postponed. For the considered example, the Excel Solver gave the suggestion that the projects A3, A4 and A6 should be implemented, but A1, A7 and A10 should be postponed (Figure 4: Column "Decision", variable 0/1 means postponement/implementation, respectively). This is also presented in Table 11, the third row.

Activity	Total	Cost/Project	Effectiveness	Decision	Cost	Performance
	(from AHP Ratings)	(in '000 000's)	(Normalized)*100	Variable	(in 000's)	(effectiveness)
A1	0.0897	160	8.9700	0	0	0
A3	0.1160	200	11.6000	1	200	0.116
A4	0.0987	80	9.8700	1	80	0.0987
A6	0.0983	150	9.8300	1	150	0.0983
A7	0.0804	250	8.0400	0	0	0
A10	0.1265	230	12.6500	0	0	0
SUM	0.6096			Allocated	430	0.313 Performance
				Available	450	Score

Figure 4. Excel Solver results for the 2022

Table 11 presents the multiyear railway investment plan that is developed based on the proposed algorithm (Figure 2).

Table 11. Multiyear railway investment plan

Year	Available budget (planned+rest)	Planned projects	Budget requested	Implemented projects	Postponed projects
2021	350	A5	150	A5	/
2022	250+200	A1,A3,A4, A6,A7,A10	1070	A3,A4,A6	A1,A7,A10
2023	200+20	A1,A2,A7,A8,A10	1076	A8	A1,A2,A7,A10
2024	200+124	A1,A2,A7,A9,A10	1080	A10	A1,A2,A7,19
2025	200+94	A1,A2,A7,A9	980	A1	A2,A7,A9
2026	300+134	A2,A7,A9	820	A7	A2,A9
2027	300+184	A2,A9	570	A2	A9
2028	200+144	A9	230	A9	/

Following figure presents the new Gantt chart, based on the previous table. This chart is made after the proposed algorithm is applied.

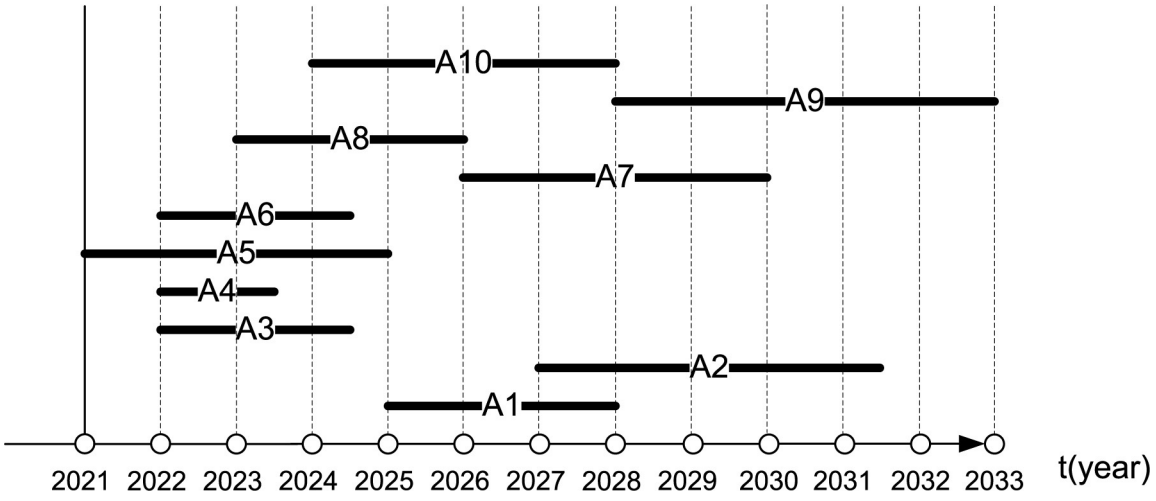


Figure 5. Gantt Chart at the end

Some projects will be postponed even for few years due to lack of the financial resources for their implementation. In the presented example, without budget limitation all projects would be implemented and finished until 2030, but with budget limitation this period is moved to the 2033.

According to the latest European Union guidelines for the development of the trans-European transport network, deadline for Member states for development finalization of all transport projects of the Core network is 2030 (Regulation 1315/2013, 2013). Although the Republic of Serbia is not yet a member of the European Union, the developed investment plan for the railway infrastructure shows that even under the limited budget, there is a possibility of meeting the EU's target.

4. CONCLUSION

Transport system is crucial factor for the economy growth and the level of standard of living. An adequate infrastructure is a precondition for a good transport system. The railway transport has been seen as a backbone for sustainable mobility, so the investments in this transport mode are of the high importance.

In this paper, the model for a sustainable investment plan related to the railway projects' prioritization is developed. Firstly, all relevant projects are ranked with the AHP approach, and then based on the Gantt chart linked to these railway projects, the multiyear investment plan is developed.

Future research will be dedicated to analysis of the investment plan development under the uncertain conditions, such as uncertainty in financing of the projects, or how to develop a multiyear investment plan with some imprecise or missing data. Also, the sensitivity analysis should be done in order to check the robustness of the model.

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METHODS FOR CROSS-NATIONAL PERFORMANCE EVALUATION IN LOGISTICS

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Abstract: *The efficient movement of freight across countries is the backbone of world global trade. To keep track of gaps between national logistic systems, different approaches for comparison are developing. In this chapter, we provide a review of various monitoring tools with the focus to the Logistic Performance Index (LPI) developed by the World Bank, as the most known national measure. The need and possibility to improve an index-based approach for cross-national performance comparison is analyzed. We emphasize the functionality of LPI as a benchmarking tool and argue that in order to learn from more successful peers, comparability and similarity of countries needs to be entailed. Accordingly, we analyze the usability of two conceptually different approaches, one drawn from multi-criteria decision analysis and other grounded in statistics. Using a sample of OECD (Organization for Economic Cooperation and Development) countries, we explore the performance evaluation outputs of ELECTRE (ELimination Et Choix Traduisant la REalité; Elimination and Choice Corresponding to Reality) multi-level outranking (ELECTRE MLO) benchmarking approach and hierarchical clustering on the basis of Ward's method. The results are discussed in relation to LPI ranking scores to show that alternative approaches can supplement to LPI results by giving more insight to policy-makers on how countries stand relative to each other.*

Keywords*: cross-national performance evaluation, benchmarking, logistic performance index, ELECTRE MLO, hierarchical clustering, OECD countries*

1. INTRODUCTION

Logistic industry is proven to be the most important 'trade facilitator' bringing significant growth in trade flows at national level (Marti et al., 2014; Puertas et al., 2014). In the era of intensified global flows of freight and capital it is nearly unattainable to trade internationally unless logistic companies monitor their performances in a flow of functions i.e. in macro level context (Brar et al., 2010; Çakır, 2017). This invoked researchers to give more attention to the international dimensions of logistics and research logistic performance in cross-national context. Still, majority of evaluation approaches in logistics are focusing on micro (firm) level while the literature aiming to

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benchmark the logistics performances of countries worldwide is rather scarce (Cakir, 2017; Rashidi and Cullinane, 2019).

From methodological point of view, composite indicators (CIs) or indexes are far the most exploited. In the centre is Logistic Performance Index (LPI) devised by World Bank, along with other logistic indexes built up around some specific topics of interest, as for example Green Logistic Performance Index (GLPI) constructed by Hung Lau (2011) or index of sustainable operational logistics performance (SOLP) introduced in Rashidi and Cullinane (2019). All indexes are referred as benchmarking tools but with rather modest justification. Namely, as it is generally the case with benchmarking on the basis of CIs, comparing is a central issue with little or no consideration of 'cross-national learning' and tracking relevant best practice exemplars as the principal aim of international benchmarking. Benchmarking is envisioned as powerful policy tool, set to support exchanging knowledge and experience in contrast to regulatory posed pressures associated with sharing the same policy goals.

In this chapter we argue that some alternative approaches to cross-national performance evaluation should be revisited to make macro level logistic assessment more about learning than comparing. Following some fresh ideas of international benchmarking for policy, we demonstrate the importance of similarity among compared peers as well as the notion of incomparability. We propose to rely on an outranking approach and hierarchical levels of performance, instead of ranking them without sufficient knowledge of the arguments for which someone was declared better. Accordingly, we emphasize the feature of corresponding benchmarks, which allows to reveal an appropriate peers to learn from.

Among numerous issues that scrutinize Composite indicators (see Jeremić et al., 2016) is the collinearity of variables underlying particular CI which might generate biased CI (Fusco, 2015; de Freitas et al., 2019). Also, issues such as weighting scheme and aggregation methods still raise a concern among researchers (Jeremić et al., 2011; Dobrota et al., 2012: Dobrota et al., 2016; Milenković et al., 2016; Maričić et al., 2019). In line with learning from the similar within benchmarking framework, applications of hierarchical clustering (HC) can also offer an added value. HC represents an exploratory technique, aiming at creating groups of similar countries, and in following steps merging the clusters according to level of similarity (Seddon and Currie, 2017). It is often used when evaluating various CIs (Đurović et al., 2016; Kostoska and Hristoski, 2017; Roszko-Wójtowicz and Białek, 2018; Akande et al., 2019).

To be able to highlight the added value of proposed alternatives against mainstream index approach, we rely on the data used to construct LPI for 34 OECD countries.

The chapter is organized in the following manner. In section 2, we first elaborate existing approaches for cross-national performance evaluation in logistics. Afterwards we expose arguments in support to the need for alternatives to index approach. The fundamentals of the proposed methods are presented in section 3. Empirical examples which are illustrating the added value of the proposed LPI complements are presented in section 4. Chapter ends with summary of findings along with limitations and future research directions.

2. CROSS-NATIONAL STUDIES IN LOGISTICS - WHY AND HOW

2.1. The need for macro level analysis in logistics

Organised and synchronised international transport flows are the key factor of effective global trade. World Bank reports that on average logistics costs make up some 13 percent of GDP but with distinct variations among countries - ranging from around 8 percent in United States and the Netherlands to even 25 percent in least efficient countries (World Bank, 2017). Besides providing low costs in more competitive imports and exports, logistics enables better using of national transportation assets and increases the employment opportunities (Hayaloglu, 2015).

Logistics is associated with the 'trade facilitation' concept, introduced by World Trade Organisation (WTO) entailing ''simplification and harmonisation of international trade procedures''(Hollweg and Wong, 2009; Puertas et al., 2014; Marti et al., 2014). Guner and Coskun (2012) offer a comprehensive review of facilitating impact of logistics on international trade flow and argue that logistics is one of the most important elements of national competitiveness. In the core is the ability to move goods expeditiously, reliably and at low cost. This is highly dependable on country's logistics capacity and gains importance with globalization and growth of international trade volume. Poor infrastructure, complex customs procedures, excessive bureaucracy are just some of the factors leading to varying level of logistics performance from country to country that hinders the efficient movement of goods across borders and brings the assessment of trade facilitation measures to the forefront (Marti et al., 2014). To come up with so-called trade facilitation measures, researchers and practitioners are in search for adequate tools that will enable tracking performance of each link (country) in international trade chain. These measures refer to both policy and also trade and logistics procedures with high impact on trade competitiveness.

Recognizing the cross-cutting nature of logistics and the need to facilitate countries worldwide in framing their own policies, in 2007 World Bank began to be involved in a process of constructing a measure of country-specific logistic performance. The result was global index of logistic performance – LPI, devised to motivate consistent approaches to intervention and reforms at the national level (World Bank, 2018). It was a breakthrough that also invoked researchers and scholars to engage more in cross-national studies in logistics.

2.2. LPI and beyond - A review of methods for cross-national performance evaluation in logistics

As previously pointed out, macro level studies in logistics are relatively scarce compared to micro level analysis. In cross-national performance evaluation context, Logistic Performance Index (LPI) is the most known national measure. It is published by World Bank every two years ever since 2007 year. LPI is built up around six categories of enquiring: customs, infrastructure, international shipments, logistics competence, tracking and tracing and timeliness (Figure 1).

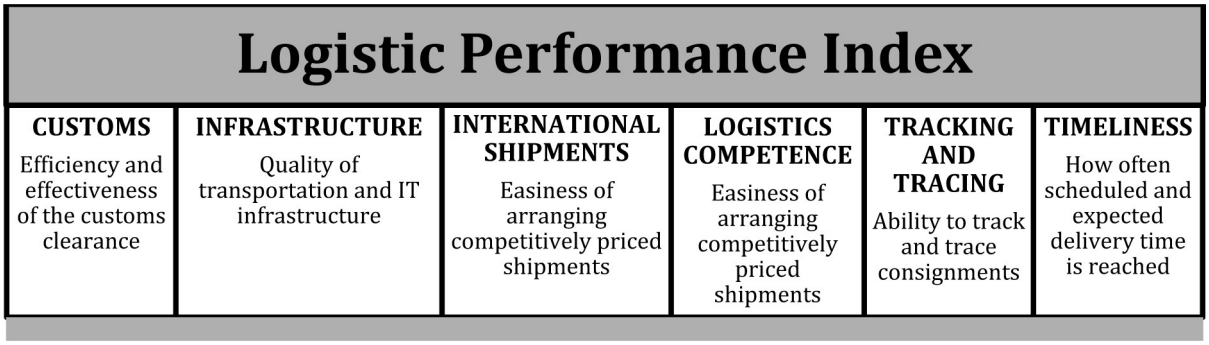


Figure 1. LPI dimensions

LPI underlying data are gathered using standardized online questionnaire, which contains two parts – first used to collect data for international LPI, and second for domestic LPI. The latest edition of LPI (from 2018) covers 160 countries in case if international LPI, and 100 countries for domestic LPI, entailing nearly 6,000 country assessments. In the case of domestic LPI, respondents (logistic professionals) provide opinions and data on the logistics environment in the country where they work using values from 1 to 5 that indicate worst and best performance respectively. Different is for international LPI where each respondent is asked to evaluate eight countries i.e. trading partners on each of the six dimensions of LPI also using five-step qualitative scale. Countries to be evaluated are selected on the basis of data on most important export and import partners of the country where the respondent is located, or from neighbouring land-bridge countries in the case of landlocked respondents. Starting from 2012, respondents are selected following the predefined sampling procedure - Uniform Sampling Randomized (USR) to avoid under-representing countries with lower trade volumes (World Bank, 2018).

To come up with a single aggregated score of international LPI, first z-scores procedure is used to normalize data followed by Principal Component Analysis (PCA). Kaiser Criterion and eigenvalue screen plot results are used to indicate that the single principal component value encapsulates all six LPI dimensions (with 92 percent of the variation in the six components for data from 2018 as well as from 2016). Normalized data for six dimensions are multiplied by component loadings obtained by PCA and summed to obtain international LPI. Component loadings are in fact weights of six LPI indicators and calculations from previous years indicate that they remain steady over years and with close values for each of six components. It implies that LPI dimensions are close to equal weighting. This allows to compare results over years and also to come up with an aggregated LPI which is a new feature first published in 2018 report. It is calculated in a way that scores from years 2012, 2014, 2016 and 2018 are aggregated with different weights for each year, giving higher weights to more recent data. The novelty of 2018 LPI report is insight on cyber security threats in logistics and the use of electronic trading platforms by shippers.

It is undoubtedly that LPI represents a comprehensive national logistic measure and broad database that allows cross-national performance evaluation in logistics. As pointed out in a recent study by Rezaei et al. (2018), LPI is the only available tool to measure worldwide logistics performance and it is respected everywhere. However there are several concerns raised by scholars. Rashidi and Cullinane (2019) elaborate the lack of insights on operational level, i.e. lack on guidelines for countries with

acceptable level of infrastructure and on how to improve their operational outcome. Rezaei et al. (2018) questioned the reliability of data gathered from poorer countries as they rely on traditional smaller operators with specific characteristics. The other concern they highlight and that is also addressed by Petrović et al. (2017) is about landlocked countries. As they are dependable on the infrastructure and customs of neighbouring countries their rating may be not adequately presented in terms of international trade.

Regardless the concerns, LPI gave an impetus to macro level studies in logistics which are drawing attention over last years (from 2011). Some of representative macro level studies in logistics are listed in Table 1. We can see that many of them are built up around LPI (Burmaoglu and Sesen, 2011; Hung Lau, 2011; Guner and Coskun, 2012; Jane and Laih, 2012; Marti et al., 2014; Puertas et al., 2014; Popescu and Sipos, 2014; Yildiz, 2014; Hayaloglu, 2015; Civelek et al., 2015; d'Aleo, 2015; Uca et al., 2016; Yu and Hsiao, 2016; Çakır, 2017; Petrović et al., 2017; Rezaei et al., 2018; Sezer and Abasiz, 2017, Rashidi and Cullinane, 2019).

Besides leaning on LPI as information base, several other conclusions can be drawn on the basis of presented macro level studies in logistics.

The relationship between logistic performance and other aspects (social, economic, environmental) is in the focus of majority of macro level studies (Guner and Coskun, 2012; Popescu and Sipos, 2014; Yildiz, 2014; Marti et al., 2014; Puertas et al., 2014; Hayaloglu, 2015; Civelek et al., 2015; d'Aleo, 2015; Uca et al., 2016; Çakır, 2017; Sezer and Abasiz, 2017). Guner and Coskun (2012) performed correlation analysis to analyse social and economic factors of logistics performance in OECD countries measured by LPI and ended up with results in favour of social influences (reflected by index measures as Human Development Index - HDI and Democracy Index - DMC). The relationship between economic and logistic performance was also studied by Popescu and Sipos (2014) who found positive correlation between two measures (GDP and LPI) for analysed EU countries. Similar, but more thorough research was done by Yildiz (2014) who besides GDP and LPI also included World Bank's "doing business" scores which were as well as GDP found to be highly positive correlated with LPI dimensions. They have also created world maps distinguishing countries by their logistics performance. Marti et al. (2014) relied on 5-year LPI data and a gravity model and found out that each LPI component has a significant impact on trade flows in developing countries especially those from Africa, South America and Eastern Europe. The same analysis was performed by this group of authors using EU countries as a case study (Puertas et al., 2014). Research of Hayaloglu (2015) follows this stream and uses eight different models for panel data analysis to study the relation between economic growth and developments in logistic sector measured by predefined proxy indicators. Three studies (Civelek et al., 2015; d'Aleo, 2015 and Uca et al., 2016) used hierarchical regression analysis to deal with a so called mediator role of LPI and examined how is LPI related to GDP as well as some other global measures as Global Competitiveness Index (Civelek et al., 2015; d'Aleo, 2015), Corruption Perception Index (CPI) and Foreign Trade Volume (FTV) (Uca et al., 2016). The LPI was used as a mediator criterion to examine its effects on other indexes. Not all studies dealing with impact of logistics development on economic growth use LPI. For example, Sezer and Abasiz (2017) exploited various WBs logistics variables of transportation and communications.

Table 1. Macro level studies in logistics

Authors	Method	Units	Data	Outcome
Burmaoglu and Sesen (2011)	Cluster and Discriminant Analysis	World	LPI and WEF data	Clustering countries Discriminating variables
Hung Lau (2011)	Composite indicators (LPI approach)	Japan and China (total 107 companies)	questionnaire survey	Green Logistics Performance Index (GLPI)
Guner and Coskun (2012)	Correlation analysis	OECD countries	Data from WB (including LPI), OECD, Political Risk Services, Economist Intelligence Unit and United Nations	Correlation between LPI and social and economic factors
Jane and Laih (2012)	hybrid between the polynomial time capacity-scaling and decomposition algorithm	World	LPI data	New logistic performance index
Marti et al. (2014)	Gravity model (Two-stage Heckman's model)	developing countries grouped into five regions	LPI data, UN Comtrade database	Impact of logistic performance on trade flows of country over the 5-year period
Puertas et al. (2014)	Gravity model (Two-stage Heckman's model)	EU countries	LPI data, UN Comtrade database	Impact of logistic performance on trade flows of country over the 5-year period
Popescu and Sipos (2014)	Linear regression model	EU countries	LPI and GDP data from WB	Correlation between LPI and GDP, plotting countries in two dimensional space
Yildiz (2014)	Best fitted regression model Cluster analysis	World	World bank data (including LPI)	Correlation between LPI and GDP, Mapping countries according to clusters
Hayaloglu (2015)	Panel data analysis	OECD countries	World bank and ITF	relation between logistics and economic growth
Civelek et al. (2015)	hierarchical regression analysis	/	World bank data (including LPI) World Economic Forum	Relationship between LPI, Global Competitiveness Index (GCI) and GDP
d'Aleo (2015)	hierarchical regression analysis	EU countries	World bank data (including LPI)	Relationship between LPI, GCI and GDP
Uca et al. (2016)	hierarchical regression analysis	92 countries	World bank data (including LPI) various data bases for FTV Transparency International for CPI	Relationship between LPI, Corruption Perception Index (CPI) and Foreign Trade Volume (FTV)
Yu and Hsiao (2016)	Meta-Frontier Data Envelopment Analysis with Assurance Regions	OECD countries	LPI data questionnaire survey	DEA-based LPI providing directions of improvement
Çakır (2017)	Combination of CRITIC, SAW and Peters' fuzzy regression methods.	OECD countries	LPI data	Ranking countries
Petrović et al. (2017)	I-distance	World	LPI data	I-distance based ranking
Rezaei et al. (2018)	Best Worst Method (BWM)	World	LPI data	New weights for LPI
Sezer and Abasiz (2017)	Panel Data Analysis	OECD countries	World bank data	Impact of logistics development on economic growth
Rashidi and Cullinane (2019)	Data Envelopment Analysis	OECD countries	LPI data	Ranking countries on the basis of new index SLPI

Another study worth mentioning is done by Jhawar et al. (2014). Although not about cross-national performance evaluation (and thus not included in Table 1) it is about LPI. The authors analysed the impact of development of skilled work force on logistic performance in India, measured by LPI. The variables around HR and skills

developments are termed as enablers and within system dynamics model their influence on results reflected by six LPI aspects is analysed. The result was in a form of Causal loop diagram.

We now proceed with conclusions from methodological point of view. Above mentioned studies dealing with relationship between logistics and social and economic aspects mostly rely on different statistical approaches like Correlation analysis (Guner and Coskun, 2012), Regression models (Popescu and Sipos, 2014; Civelek et al., 2015; d'Aleo, 2015 and Uca et al., 2016), Panel Data Analysis (Hayaloglu, 2015; Sezer and Abasiz, 2017) or Gravity model (Marti et al., 2014; Puertas et al., 2014).

If we move to cross-national analysis, i.e. comparing performance of countries, various approaches are evident. Majority of them rely on a new index derived from LPI data. Yu and Hsiao (2016) offered an alternative to LPI on the basis of Meta-Frontier Data Envelopment Analysis with Assurance Regions. Using a sample of OECD countries they compare World Bank LPI and proposed DEA-based LPI rankings and highlight that their approach is more useful in revealing the directions of improvement. A hybrid approach (including CRITIC, SAW and Peters' fuzzy regression methods) was used by Çakır (2017) to rank OECD countries on the basis of LPI data. The results were compared with LPI rankings and other Multi-Criteria Decision Making (MCDM) approaches with conclusion that variations in the rankings are evident and come as a consequence of distinct mathematical foundations of different methods. A specific study is done by Hung Lau (2011) aimed at international benchmarking of green logistics using composite indicator. Based on the concept of LPI (questionnaire for logistics companies, 5-point scale, PCA analysis) they have developed Green Logistics Performance Index (GLPI) and demonstrated its development process and usage for two countries China and Japan. New cross-national measure was also proposed by Rashidi and Cullinane (2019). It is named sustainable operational logistics performance (SOLP) score. The authors proposed to merge it with LPI and come up with a new index for ranking countries - SLPI. It was created on the basis of Data Envelopment Analysis and LPI data and calculated for OECD countries. Rezaei et al. (2018) and Petrović et al. (2017) dealt with methodological issues of LPI in terms of weights and presented alternatives to PCA used to construct LPI. The first study exploited Best Worst Method (BWM) while the later used I-distance. Both studies report matching rankings with LPI (with small differences), but highlight that offered solutions better encapsulate LPI dimensions. Another research about methodological construct of LPI is done by Jane and Laih (2012), who used a specific algorithm to devise new logistic performance index.

Some authors present their indexes as the alternative to LPI (Jane and Laih, 2012; Yu and Hsiao, 2016; Petrović et al., 2017; Rezaei et al., 2018) while others see them as the complementary measures. Rashidi and Cullinane (2019) compared their SOLP and LPI and argued that, due to different criteria included, two indices should be seen as complementary measures rather than alternatives. Also, regardless the name (GLPI) and underlying building procedure similar to LPI, index proposed by Hung Lau (2011) is not seen as an alternative to World's Bank index, because it solely includes environmental variables (15 in total, in three categories green purchasing, green packaging and green transportation) and relies exclusively on self-assessment.

Although ranking countries is prevailing there are examples of clustering approach. Such is work done by Burmaoglu and Sesen (2011) who performed hierarchical clustering analysis to distinguish between low and high competitive countries in logistics. They

further moved to discriminant analysis to track the most effective discriminatory variables and found that infrastructure and ICT (tracking and tracing) to be the most influential in separating country into groups.

We want also to highlight that LPI is a global measure and although main stream informational base, a great deal of studies tend to focus on specific country groups - mostly OECD countries due to large data sets available for researchers.

2.3. Moving from comparing to learning - The motivation and the scope of the study

Composite indicators are far the most used tool for international comparison and benchmarking. This includes logistics to. By being able to accommodate various aspects and accompanying indicators, they provide a practical measure of development, which is easy to interpret and addresses rising public awareness. There are two basic approaches in the context of macro level analysis - global indices developed by relevant international organizations and indexes proposed by scholars. The first ones are more popular, reachable for a wider audience, but also sometimes poor in their construct as a result of a so-called 'trade-off between breadth and depth in the selection of indicators' (Vicente and Lopez, 2006). Namely in order to cover as many countries, proxy indicators need to be included, as in case for example with ITUs 2010 version of Information and communication technology development index - IDI (Petrović et al., 2012). On the other hand, scholarly devised indexes are more sophisticated in methodological terms but often covering limited set of countries. Examples are above discussed logistic indexes - GLPI and SOLP.

Opting for an average/aggregated score also referred as "super criterion" is logical, having that there is no entity (organization or country) that is a best performer in all aspects analysed (Laise, 2004). The outcomes are rankings or league tables that distinguish leaders from laggards. The natural question that has been previously elaborated (see for e.g. Laise, 2004 or Petrović et al, 2012, 2013, 2018a, 2018b) is - what can CIs base approach offer to decision/policy makers?

If we recall macro level studies presented in the section above, we can argue that majority of them is about comparing countries' performance with lack of insight on learning from leading peers. As argued by Cakir (2017), the performance metrics should be designed as a system to allow countries to complement and support one another. LPI itself is promoted as a benchmarking tool but it fails to fulfil the principal aim of benchmarking i.e. tracking relevant best practice exemplars to support cross-national learning (see also Yu and Hsiao, 2016 for discussion). Moreover, although devised as a tool for international benchmarking, GLPI lacks of insights on how can laggards use it to emulate performance of the more successful counterparts. Namely, it is all about comparing instead of learning because the question of a relevant or corresponding benchmark is neglected. The feature of corresponding benchmark is well accommodated by Data Envelopment Analyses. In its principal formalization, DEA provides a "reference set" which pinpoints to the similar (in terms of its inputs and outputs) but more successful units. They are labelled as corresponding benchmarks and form the frontier (see Petrović et al., 2018c for more thorough discussion). Simply, to become efficient, a laggard needs to reach the performance of its corresponding benchmark. Rashidi and Cullinane (2019) exploited DEA to come up with a new macro level measure in logistics

and addressed the issue of benchmarks - they proposed 'development matrix' (Diagrammatic representation of SOLP rankings vs. LPI) as a tool for tracking benchmarks for lagging logistic industries. However, it is not in a spirit of corresponding benchmark because it rather groups countries by performance than to directly relate laggards to relevant benchmarks. Detecting directions for improvements on the basis of DEA approach is also offered by Yu and Hsiao (2016). The authors address the issue of benchmarking on the basis of their DEA-based LPI, arguing that the income effects on the logistics production frontier of countries with similar characteristics must be included to move from ranking/comparing to benchmarking. In line, they benchmark countries against peers that operate under similar technologies and relative to the frontier that is drawn from the groups of OECD countries formed on the basis of income level. This allowed them to come up with efficiency differences within each group, technology gap between groups as well as the global logistics frontier, which than led to suitable managerial implications for each country. However, although comprehensive in background calculations, similar to the diagrammatic representation offered by Rashidi and Cullinane (2019), the model ends up with a 2D grid that classifies OECD countries in four group without direct linking those failing behind to the ones to look up to.

Following the idea of moving from comparing to learning, we propose to use ELECTRE based benchmarking tool (introduced in Petrović et al., 2012) for cross-national performance evaluation in logistics. Beside resolving the above elaborated issue of corresponding benchmark, this approach has additional advantage over DEA. Namely, it has broader scope of application since it does not require input/output typology of performance indicators as is the case with DEA based efficiency measuring. Rashidi and Cullinane (2019) see the input-output structure of the DEA methodology as an issue in logistics performance evaluation because the size of units under evaluation is excluded from the performance evaluation process.

What is also in favour of the ELECTRE MLO is the outcome in a form of hierarchical levels of performance instead of index based ranking. Opting for classifying countries into the level of performance is more reasonable as its accommodates decision makers appraisal of superior performance as well as the notion of incomparability - i.e. sharing the same level of performance if there is not enough argument to declare that someone is better (Petrović et al., 2012, 2014, 2018a, 2018b). It is important to stress that due to compensatory effect posed by CIs, incomparability may be neglected, leading to 'mechanical' ranking of incomparable units.

To place this approach under scrutiny we have also explored another way to hierarchically classify countries according to their performance. Clustering is conceptually in line with hierarchical grouping of countries on the basis of ELECTRE MLO. It is also about similarity of cases which is maximized within the cluster while at the same time the resemblance to folders outside of the group is minimized. We opted for hierarchical clustering on the basis of Ward's method. Cluster analysis for cross-national evaluation in logistics was exploited by Burmaoglu and Sesen (2011) as well as in Yildiz (2014). Burmaoglu and Sesen (2011) ended up with two clusters which they further analysed in terms of factors discriminating countries into these two groups. Yildiz (2014) used k-means (partitioning clustering) to cluster countries according to all six dimensions of LPI as well as overall LPI score. Hierarchical clustering, proposed in our paper, is superior to partitioning clustering in terms of coherence of clustering (Bindra et al., 2018). Also, the hierarchical relationship among clusters is easily detected,

and it provides relatively high scalability (Xu and Tian, 2015). Moreover, hierarchical clustering approaches produce clusters of higher quality (Bouguettaya et al., 2015).

3. METHODOLOGY

3.1. Benchmarking with ELECTRE MLO

ELECTRE MLO is a relatively new idea envisaged in support of the international benchmarking. As argued by the authors who devised it, the aim is twofold. First is to classify countries into hierarchical levels of performance instead of ranking them. This kind of grouping countries offers more perceptible output, than ranking according quantitative performance gaps whose magnitude may be less explicable. Second, ot enables to go beyond searching for a 'mythical' best practice and to discover the relevant practice exemplars which could help for achieving countries' own distinct objectives. In this way, benchmarking procedure is closer to the desired nature of benchmarking - tool for learning.

The procedure entails classification of countries into performance groups and arranging them in hierarchical levels, visualized in the form of specific output labelled as 'relation tree'. It is an easy to follow output where countries are graphically interpreted as nodes and organized in a descending manner (the first level consists of the best performing countries). The countries from adjacent levels are connected by arrows. An arrow directed towards a country shows that this country is outperformed by the one from upper adjacent level. The better performing country is than seen as a corresponding benchmark for the one bellow. It is termed ′corresponding′ since it is from a nearby performance level and with the smallest performance gap compared to the outperformed one. The alternatives at the same hierarchical level are seen as mutually incomparable.

In detail explanation of mathematical formalisation of ELECTRE MLO, can be found in Petrović et al. (2012) and Stamenković et al. (2016). Here we will present in short the main postulations. Some basic notations typical for ELECTRE are listed below:

1. $A = \{a_1, a_2, \dots, a_n\}$is the set of m alternatives.

2. $G = \{g_1, g_2, \dots, g_n\}$ is the coherent set of criteria used to evaluate alternatives with their corresponding weights $\omega_1, \omega_2, \dots, \omega_n$.

3. $I_1, I_2, \dots, I_n$ are the sets of scores for each of the criteria. Every set of scores has a finite number of elements, and let $|I_1|, |I_2|, \dots, |I_n|$ denote diameter of these set of scores, i.e. $|I_k| = maxI_k - minI_k$.

4. sets G_{ij}^{+}, G_{ij}^{-} and $G_{ij}^{=}$ represent all the criteria where the performance score of alternative a_i is higher (G_{ij}^{+}), lower (G_{ij}^{-}) or equal ($G_{ij}^{=}$) to the performance score of the alternative a_j.

5. $g_k(a_i) \epsilon I_k$ is the score of alternative a_i with respect to criterion g_k for all alternatives $a_i \in A$ and all criteria $g_k \in G$, which creates the performance matrix M_{mxn}.

ELECTRE MLO is grounded in modified ELECTRE I, a well known MCDM technique that classifies alternatives in core and non-core, where the first ones are those that are not outranked by any of the later. It relies on the computation of two indexes - Concordance and Discordance, used to apprise the dominance relations. Namely, if for two

alternatives (a_i and a_j) Concordance index is above and at the same time the Discordance is below the thresholds set by decision maker (p and q), the a_i is outperforming a_j.

ELECTRE MLO entails specific iterative procedure including repeated identification of preferable alternatives (i.e. core alternatives). The modification comes from the fact that ELECTRE MLO uses the cutting level of the modified Concordance index (Equation 1) above the so called Absolute Significance Threshold (AST) to create a hierarchical order for each step of the procedure.

$$C_{ij}^{*} = \frac{\sum_{\{k|g_k \epsilon G_{ij}^{+}\}} \omega_k}{\sum_{\{k|g_k \epsilon G_{ij}^{+} \cup G_{ij}^{-}\}} \omega_k} \quad (1)$$

In this way cycles are omitted, meaning that it will not allow the core subset of alternatives to be empty in each step of iterative procedure. This is known as problem of intransitivity in outranking relation resulting in so called cycles - a situation when: an alternative a_1 outranks alternative a_2 alternative a_2 outranks alternative a_3 ,..., alternative a_{k-1} outranks alternative a_k and alternative a_k outranks alternative a_1. More about modified concordance index and AST can be found in Anić and Larichev (1996) and Bojković et al. (2010) while application in ELECTRE MLO (i.e. omitting cycles in relation graph) is in detail explained in Stamenković et al. (2016).

As stated above, the creation of hierarchical levels entails specific iterative procedure for creating hierarchical levels of performance. First, core alternatives are selected and placed at the first level. The same procedure is applied for the remaining alternatives, i.e. a new core is created. These alternatives will be the second-level alternatives, and they are outperformed only by some of alternatives from the first level. The procedure proceeds until all alternatives are exhausted. Generally, the alternative a_i that is outside the core belongs to the hierarchical level L_k, $(k \geq 2)$ when the condition from the Eq. 2 is satisfied:

$$max\,\{t|(\exists a\,j\ \in\ Lt)\,aj\ \succ\ ai\,\}\ =\ k\ -\ 1. \quad (2)$$

The computation is performed using a designed software solution and output entails relation graph (relation tree) as well as concordance and discordance matrices.

3.2. Hierarchical clustering with Ward's method

Ward hierarchical clustering method is one of the agglomerative clustering methods that is based on a classical sum-of-squares criterion. The method is interesting because it looks for clusters in multivariate Euclidean space (Murtagh and Legendre, 2014). It essentially starts with the *n* clusters (each with the size of 1 entity) and eventually group all the observations into one cluster. Results of the hierarchical clustering are depicted as a tree or dendrogram. Ward's method forms the distance between two clusters, *M* and *N*, and calculates how much the sum of squares will increase when we merge those clusters following Eq. 3.

$$\Delta(M,N) = \sum_{i\in M\cup N}\|\overrightarrow{x_i} - \overrightarrow{m_{M\cup N}}\|^2 - \sum_{i\in M}\|\overrightarrow{x_i} - \overrightarrow{m_M}\|^2 - \sum_{i\in N}\|\overrightarrow{x_i} - \overrightarrow{m_N}\|^2 \quad (3)$$

Where $\overrightarrow{m_j}$ is the centre of cluster *j*, and n_j is the number of entities in it. Initially, sum of squares equal zero and grows as the merging of clusters occur. Idea of the Ward's method is to keep the growth of sum of squares as small as possible (Strauss and von Maltitz, 2017).

4. EMPIRICAL EXAMPLE

4.1. Data set

To illustrate the added value of ELECTRE MLO and hierarchical clustering on the basis of Ward's method we have evaluated the performance of 34 OECD countries on the basis of their LPI results from 2018 (available at World Bank internet site). In ELECTRE MLO procedure, countries are considered as alternatives and six LPI dimensions are the criteria, while in Ward's method we group countries by considering how similar they are in terms of six LPI dimensions. First of all, we decided on this data set because LPI is a comprehensive data base and OECD countries have been exploited in a number of studies. Second and more important, LPI data was chosen for comparison purposes i.e. to make a distinctions between of ELECTRE MLO and hierarchical clustering on the basis of Ward's method on one side and CIs based approach on the other. OECD countries are chosen in respect to the one of the premises of using benchmarking as a policy tool - the selection of benchmarking partners (here countries that are to be benchmarked). As elaborated by several authors (e.g. Ros 1991, Dolowitz and Marsh, 2000; Petrović et al., 2012, 2013, 2018c; Evans, 2017) policy transfer based on cross-national learning is a questionable issue and it cannot be assured that benchmarking will lead to policy transfer - as it can go from inspiration to coping. Moreover, if it is expected that countries steer their agendas according to benchmarking results, it is important that there is an institutional support for this - an organization which gathers these countries and can serve as a facilitator in exchanging knowledge and practice.

4.2. Benchmarking OECD countries with ELECTRE MLO

Following ELECRE MLO procedure, in the first step scores are assigned to performance indicators for each country. We decided on nine step scale as to offer finer differentiation in performance (see Bojković et al., 2010 and Petrović et al., 2012 for additional discussion). As all of the observed countries are far from the theoretical benchmark (five for LPI dimensions) maximum value in the sample is associated with the highest score. Criteria and alternatives with associated scores are presented in Table 2.

The weights are drawn from PCA loadings in LPI construct.

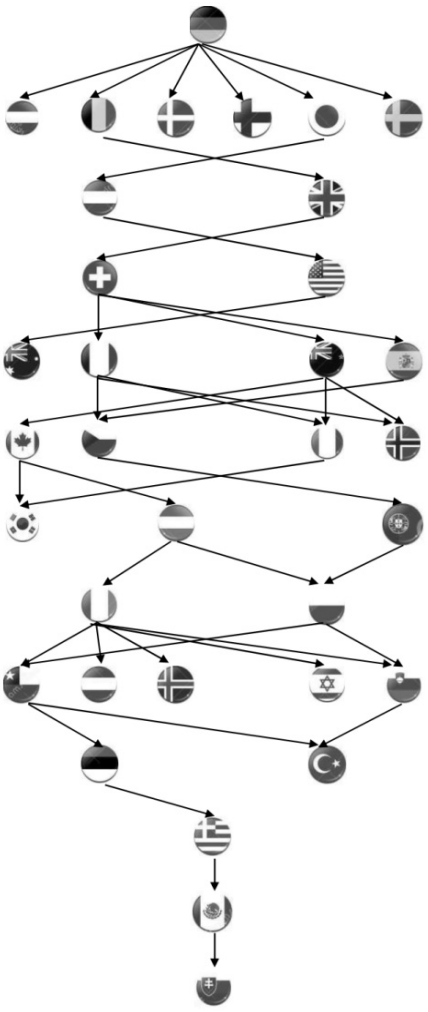
Table 2. Criteria and alternatives with associated scores

		Customs	Infrastructure	International shipments	Logistics competence	Tracking and tracing	Timeliness
	w	17	17	16	17	17	17
	Ik	1-9	1-9	1-9	1-9	1-9	1-9
	|Ik|	9	9	9	9	9	9
	w*	0,16832	0,16832	0,15842	0,16832	0,16832	0,16832
Australia	AUS	8	7	4	5	6	6
Austria	AUT	7	8	9	8	8	8
Belgium	BEL	7	7	9	8	8	8
Canada	CAN	6	6	5	7	6	6
Chile	CHL	4	3	4	1	2	5
Czech Republic	CZE	4	4	8	5	5	8
Denmark	DNK	8	7	6	7	9	9
Estonia	EST	4	2	4	1	2	5
Finland	FIN	8	7	6	7	9	9
France	FRA	6	7	6	6	7	8
Germany	DEU	9	9	9	9	9	9
Greece	GRC	1	2	4	1	2	4
Hungary	HUN	5	3	4	2	5	2
Iceland	ISL	4	3	1	5	3	4
Ireland	IRL	5	3	5	5	5	5
Israel	ISR	4	3	1	3	4	4
Italy	ITA	5	6	6	5	6	8
Japan	JPN	9	9	7	8	8	8
Korea, Rep.	KOR	5	6	5	4	6	6
Luxembourg	LUX	6	5	5	6	5	6
Mexico	MEX	1	1	3	1	1	3
Netherlands	NLD	8	9	7	8	7	8
New Zealand	NZL	7	7	5	7	7	8
Norway	NOR	6	5	5	5	7	6
Poland	POL	4	3	7	4	4	6
Portugal	PRT	4	3	8	5	5	8
Slovak Republic	SVK	1	1	3	1	1	1
Slovenia	SLO	5	3	4	1	2	4
Spain	ESP	6	6	8	6	6	7
Sweden	SWE	9	9	9	7	7	9
Switzerland	CHE	7	7	6	7	8	8
Turkey	TUR	1	3	3	1	2	4
United Kingdom	GBR	7	7	7	8	8	9
United States	USA	7	8	6	6	8	7

The concordance (p) and discordance (q) threshold are set to 0.80 and 0.30 respectively. The first threshold is the sum of the criteria weights and in this case if it is greater than 80% of the total weight of all criteria, the dominance can be declared. In choosing p we followed recommendation drawn from AST value. If the lower values are chosen, it would mean that decision-maker is less strict when asserting that a country's performance is preferable. The tolerance of inferior performance (discordance threshold) is set to 0.3 meaning that country will not be considered as 'better performing' if, under any criteria where a country's performance level is worse, the

difference in scores is three or more. Based on the Concordance and Discordance indices (see Appendix A) as well as the above defined threshold values, and following the level construction procedure (described in Section 3.1.), the relation tree is obtained and presented in Fig. 2.

Relation tree



EMLO level	Country Code	LPI Rank
I	DEU	1
II	SWE	2
	BEL	3
	AUT	4
	JPN	5
	DNK	8
	FIN	10
III	NLD	6
	GBR	9
IV	CHE	13
	USA	14
V	NZL	15
	FRA	16
	ESP	17
	AUS	18
VI	ITA	19
	CAN	20
	NOR	21
	CZE	22
VII	PRT	23
	LUX	24
	KOR	25
VIII	POL	28
	IRL	29
IX	HUN	31
	CHL	34
	SLO	35
	ISR	37
	ISL	40
X	EST	36
	TUR	47
XI	GRC	42
XII	MEX	51
XIII	SVK	53

Figure 2. Relation tree vs. LPI rankings

As seen from relation tree (Fig. 2) 34 OECD countries are classified into 13 levels (groups) of performance. First level occupies best performing country, Germany in this case. It dominates all countries from the second level – which is illustrated by arrows connecting Germany and second-level countries. Looking at second and third level we can observe that not all countries from these adjacent levels are connected. Four countries from the second level (Austria, Sweden, Finland and Denmark), although better performing, and thus placed on higher level, are not dominating Netherlands and Great Britain (third-level countries in relation tree and with lower rank according to LPI as well). This implies that these countries are incomparable and therefore they are eliminated as potential benchmarks for Netherlands and Great Britain. The same can be found among other performance levels, for example Korea and Portugal relative to Ireland. This is why ELECTRE MLO provides a more sophisticated ranking scheme

compared to index based rankings where every better ranked country is a potential benchmark for lower ranked ones.

If we move to comparing ELECTRE MLO results with LPI rankings (Fig. 2) we can see that in general, considerable level of correspondence exists between hierarchical status and LPI rankings. However there are some differences - cases when LPI levels do not match performance level obtained by ELECTRE MLO. For example, Netherlands is classified at lower level than Denmark and Finland although with higher rank according to LPI. This is the consequence of a kind of unbalanced performance of Netherlands that is masked due to compensatory effect posed by CIs approach. Although Netherlands achieves a good performance on majority of criteria, it falls behind in 'Tracking and tracing' and 'Timeliness' (e.g. compared to Denmark). Unlike in CIs based approach pair wise comparison accommodated by ELECTRE MLO allows this kind of observation. It is also important to stress that Denmark and Finland are recognized by ELECTRE MLO as with rather specific performance and thus excluded as potential benchmarks for Netherlands. Relation tree pinpoints to Japan to be a corresponding benchmark for Netherlands. This means that Japan is better by sufficient number of criteria (according to pre-defined threshold) and among second level countries has the smallest performance gap compared to Netherlands (hence the term 'corresponding').

Also it can be observed that some countries have more than one corresponding benchmark (e.g. Czech Republic may chose between Spain and France). In this case it is up to decision maker to make the final decision following some additional criteria. Regarding development paths a country may also opt for more ambitious strategy i.e. instead of adjacent level countries to focus on those from upper levels (and skip some intermediate goals). As discussed in Petrović et al. (2012) this entails choosing a 'revolutionary' over 'evolutionary' development path. Namely although ELECTRE MLO favours gradual development paths ('climbing up the relation tree' in a stepwise manner as explained in Petrović et al. (2014, 2018)) using concordance and discordance matrices decision maker may track benchmarks with higher performance gain.

4.3. Hierarchical clustering of OECD countries with Ward's method

Method generated five clusters presented on Figure 3: A (Denmark, United Kingdom, Finland, France, Switzerland, United States, New Zealand, Austria, Belgium, Japan, Netherlands, Sweden and Germany), B (Canada, Luxembourg, South Korea, Norway, Italy, Australia, Spain), C (Czech Republic, Portugal, Ireland, Poland), D (Chile, Estonia, Slovenia, Hungary, Israel) and E (Greece, Turkey, Mexico, Slovak Republic, Iceland). Clusters D and E are far from the rest of the field, and they are joined with other clusters in the final stage. Cluster A represents the best performing countries and they are joined in second stage with cluster B and C (which are joined together before this stage). Added value of hierarchical clustering is possibility to visualize not only the cluster membership, but relationship with similar clusters and the stages in which similar clusters are aggregated.

The advantage over LPI ranking is that countries are grouped by similarity in their performance implying that corresponding more successful peers i.e. the ones to 'look up to' can be tracked more easily in twofold manner. First the most similar (by performance) counterparts can be tracked within the same cluster, similar to opting for "evolutional" development strategy on the basis of ELECTRE-MLO results. Secondly, due

to the hierarchical relationship between clusters, decision maker may opt for more ambitious goals and chose a relevant benchmark from a set of better performers within the cluster connected with the one containing the country under observation. For instance, some of the countries which are represented by the cluster C (Portugal and Czech Republic) might strive to meet the performance of Norway or Canada.

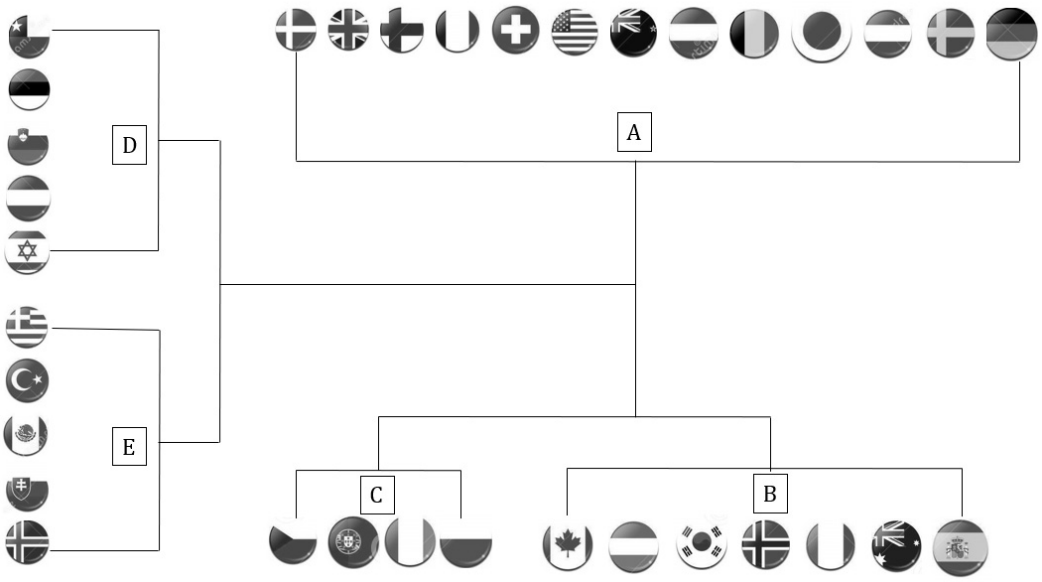


Figure 3. Cluster membership of countries represented via dendrogram

Relating clustering results with LPI rankings (Table 3.) we can observe that there is a significant degree of matching (i.e. clusters "follow" LPI rankings). The only difference can be observed in the case of clusters B and C. Some of the countries in the cluster C (Portugal and Czech Republic) have better LPI rank than some countries from cluster B (South Korea and Luxembourg). One of the issues that composite indicators (such as LPI) suffer from, is the compensability among the variables, meaning the possibility to offset certain poor performance of particular variable with strong performance from the other one(s) (Munda and Nardo, 2009; Mazziotta and Pareto, 2016). As the consequence, certain country might be propelled to better rank while being more similar to lower ranked countries based on all remaining variables (which is in this case being presented in the results of Ward's method). As authors (Otoiu et al., 2014) pointed out, cluster analysis helps overcome problems that may occur due to the distribution of variables and therefore, validation results achieved through cluster analysis are more robust and help to achieve a good check of the validity of the composite indicators.

Table 3. Clusters and LPI rankings

Cluster	Country	LPI rank
A	Germany	1
	Sweden	2
	Belgium	3
	Austria	4
	Japan	5
	Netherlands	6
	Denmark	8
	United Kingdom	9
	Finland	10
	Switzerland	13
	United States	14
	New Zealand	15
	France	16
B	Spain	17
	Australia	18
	Italy	19
	Canada	20
	Norway	21
	Luxembourg	24
	South Korea	25
C	Czech Republic	22
	Portugal	23
	Poland	28
	Ireland	29
D	Hungary	31
	Chile	34
	Slovenia	35
	Estonia	36
	Israel	37
E	Iceland	40
	Greece	42
	Turkey	47
	Mexico	51
	Slovak Republic	53

5. CONCLUSION

This chapter reviews existing approaches for cross-national evaluation in logistics and highlights the advantages of grouping countries (to levels or clusters) according to their performance instead of ranking them on the basis of index value. Two conceptually different methods are explored: benchmarking with ELECTRE-MLO and hierarchical clustering with Ward's method. To illustrate the added value of these potential methodological substitutes we relied on data included in the most known national measure in logistics, Logistic Performance Index (LPI) for 34 OECD countries.

The advantage of ELECTRE MLO approach is in addressing the comparability between countries along with the selection of suitable benchmark countries for the outperformed ones. Compared to CIs approach, ELECTRE MLO gives more respect to the essence of benchmarking - discovering the 'relevant practice to follow' in reaching own specific objectives. Also the visualisation of results in a form of 'relation tree' provides decision makers with an easy to follow output. As showed in empirical example, both ELECTRE MLO and Ward's method revealed a fair level of correspondence with LPI results making these approaches valid options for cross-national performance evaluation in logistics. However, we argue that they are more complements than alternatives to LPI. As for ELECTRE MLO, there are two limitations. Firstly, it is not to be exploited as a global performance evaluation tool (like is LPI) because if a large number of countries is included, the outcome i.e. 'relation tree' may be blurry and unreadable. Secondly, the 'relation tree' is in fact a network of benchmarking partners implying that it includes countries with a kind of institutional support for sharing knowledge and practice (e.g. members of cooperation organizations like OECD or EBRD which will facilitate eventual policy transfer). On the subject of future applications of this tool in logistics we propose to move to stepwise benchmarking, tracking set of intermediate benchmarks that a country can follow on the road to the top performer (ultimate benchmark). Methodological foundations can be drawn from Petrović et al. (2014, 2018a) but additional research is needed to make it more suitable for cross-national performance evaluation in logistics.

Regarding hierarchical clustering on the basis of Ward's method we have demonstrated how to obtain clusters by similarity of performance and the procedure to aggregate them. It can serve as a valuable input for decision making process, since countries can observe peers of similar LPI performance and peers who can serve as the benchmark. In future research, applications of k-medoids (such as partitioning around medoids) might bring additional value (Patel and Thakral, 2016) to the research since the particular countries are being defined as the cluster centre (best representative of the group).

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Appendix A - Concordance and Discordance Matrices

Table A1: Concordance Matrix

	AUS	AUT	BEL	CAN	CHL	CZE	DNK	EST	FIN	FRA	DEU	GRC	HUN	ISL	IRL	ISR	ITA	JPN	KOR	LUX	MEX	NLD	NZL	NOR	POL	PRT	SVK	SLO	ESP	SWE	CHE	TUR	GBR	USA
AUS		0,17	0,20	0,51	1,00	0,61	0,00	1,00	0,00	0,20	0,00	1,00	1,00	1,00	0,81	1,00	0,51	0,00	0,76	0,61	1,00	0,00	0,20	0,51	0,81	0,61	1,00	1,00	0,40	0,00	0,20	1,00	0,20	0,17
AUT	0,83		0,50	1,00	1,00	1,00	0,50	1,00	0,50	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,32	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,40	1,00	1,00	0,66	1,00
BEL	0,80	0,50		1,00	1,00	1,00	0,49	1,00	0,49	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,49	1,00	1,00	1,00	1,00	0,60	1,00	1,00	1,00	1,00	1,00	1,00	0,50	1,00	1,00	1,00	0,75
CAN	0,49	0,00	0,00		1,00	0,67	0,00	1,00	0,00	0,20	0,00	1,00	1,00	1,00	1,00	1,00	0,51	0,00	1,00	1,00	1,00	0,00	0,00	0,67	0,81	0,67	1,00	1,00	0,34	0,00	0,00	1,00	0,00	0,17
CHL	0,00	0,00	0,00	0,00		0,00	0,00	1,00	0,00	0,00	0,00	1,00	0,25	0,49	0,00	0,49	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	1,00	0,50	0,00	0,00	0,00	1,00	0,00	0,00
CZE	0,39	0,00	0,00	0,33	1,00		0,16	1,00	0,16	0,19	0,00	1,00	0,80	1,00	0,75	1,00	0,24	0,19	0,50	0,39	1,00	0,19	0,19	0,39	1,00	1,00	1,00	0,83	0,20	0,00	0,19	1,00	0,16	0,33
DNK	1,00	0,50	0,51	1,00	1,00	0,84		1,00	0,00	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,34	1,00	1,00	1,00	0,40	1,00	1,00	0,84	0,84	1,00	1,00	0,84	0,25	1,00	1,00	0,51	0,80
EST	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	1,00	0,20	0,39	0,00	0,39	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	1,00	0,33	0,00	0,00	0,00	0,75	0,00	0,00
FIN	1,00	0,50	0,51	1,00	1,00	0,84	0,00	1,00		1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,34	1,00	1,00	1,00	0,40	1,00	1,00	0,84	0,84	1,00	1,00	0,84	0,25	1,00	1,00	0,51	0,80
FRA	0,80	0,00	0,00	0,80	1,00	0,81	0,00	1,00	0,00		0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	1,00	0,00	0,32	1,00	0,84	0,81	1,00	1,00	0,76	0,00	0,00	1,00	0,00	0,25
DEU	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00		1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
GRC	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,20	0,19	0,00	0,19	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,48	0,00	0,00
HUN	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,60	0,00	0,60	0,00	0,00	0,00	0,00	0,83	0,00	0,00	0,00	0,40	0,25	1,00	0,67	0,00	0,00	0,00	0,80	0,00	0,00
ISL	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,50	0,00	0,00	0,00	0,17	0,00	0,84	0,00	0,00	0,25	0,00	0,84	0,51	0,00	0,00	0,00	0,00	0,76	0,00	0,00
IRL	0,19	0,00	0,00	0,00	1,00	0,25	0,00	1,00	0,00	0,00	0,00	0,00	1,00	1,00		1,00	0,00	0,00	0,00	0,25	0,00	1,00	0,00	0,00	0,61	0,34	1,00	1,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00
ISR	0,00	0,00	0,00	0,00	0,00	0,51	0,00	0,00	0,00	0,00	0,00	0,00	0,81	0,40	0,50		0,00	0,00	0,00	0,00	0,84	0,00	0,00	0,00	0,00	0,00	0,84	0,51	0,00	0,00	0,00	0,76	0,00	0,00
ITA	0,49	0,00	0,00	0,00	0,49	1,00	0,76	0,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00		0,00	1,00	0,66	1,00	0,00	0,19	0,60	0,84	0,76	1,00	1,00	0,25	0,00	0,00	1,00	0,00	0,20
JPN	1,00	0,68	0,51	1,00	1,00	0,81	0,66	1,00	0,66	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00		1,00	1,00	1,00	1,00	1,00	1,00	1,00	0,81	1,00	1,00	0,84	0,51	1,00	1,00	0,67	1,00
KOR	0,24	0,00	0,00	0,00	1,00	0,50	0,00	1,00	0,00	0,00	0,00	1,00	1,00	0,83	0,75	1,00	0,00	0,00		0,50	1,00	0,00	0,00	0,00	0,76	0,50	1,00	1,00	0,00	0,00	0,00	1,00	0,00	0,00
LUX	0,39	0,00	0,00	0,00	1,00	0,61	0,00	1,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	1,00	0,00	0,34	0,00	0,50		1,00	0,00	0,00	0,50	0,81	0,61	1,00	0,00	0,00	0,00	1,00	0,00	0,00
MEX	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,17	0,16	0,00	0,16	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
NLD	1,00	0,51	0,40	1,00	1,00	0,81	0,60	1,00	0,60	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	1,00		1,00	1,00	1,00	0,81	1,00	1,00	0,84	0,25	0,80	1,00	0,50	0,83
NZL	0,80	0,00	0,00	1,00	1,00	0,81	0,00	1,00	0,00	0,68	0,00	1,00	1,00	1,00	1,00	1,00	0,81	0,00	1,00	1,00	1,00	0,00		1,00	0,84	0,81	1,00	1,00	0,84	0,00	0,00	1,00	0,00	0,40
NOR	0,49	0,00	0,00	0,33	1,00	0,61	0,00	1,00	0,00	0,00	0,00	0,00	1,00	1,00	1,00	1,00	0,40	0,00	0,75	0,50	1,00	0,00	0,00		0,81	0,61	1,00	1,00	0,20	0,00	0,00	1,00	0,00	0,00
POL	0,19	0,00	0,00	0,19	1,00	0,00	0,16	1,00	0,16	0,16	0,00	1,00	0,60	0,75	0,39	1,00	0,16	0,00	0,24	0,19	1,00	0,00	0,16	0,19		0,00	1,00	0,80	0,00	0,00	0,16	1,00	0,00	0,16
PRT	0,39	0,00	0,00	0,33	1,00	0,00	0,16	1,00	0,16	0,19	0,00	1,00	1,00	1,00	0,66	1,00	0,24	0,19	0,50	0,39	1,00	0,19	0,19	0,39	1,00		1,00	0,80	0,20	0,00	0,19	1,00	0,16	0,33
SVK	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,16	0,00	0,16	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00
SLO	0,00	0,00	0,00	0,00	0,00	0,50	0,17	0,00	0,67	0,00	0,00	0,00	0,33	0,49	0,00	0,49	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,20	0,20	1,00		0,00	0,00	0,00	1,00	0,00	0,00
ESP	0,60	0,00	0,00	0,66	1,00	0,80	0,16	1,00	0,16	0,24	0,00	1,00	1,00	1,00	1,00	1,00	0,75	0,16	1,00	1,00	1,00	0,16	0,16	0,80	1,00	0,80	1,00	1,00		0,00	0,16	1,00	0,16	0,24
SWE	1,00	0,60	0,50	1,00	1,00	1,00	0,75	1,00	0,75	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,49	1,00	1,00	1,00	0,75	1,00	1,00	1,00	1,00	1,00	1,00	1,00		0,80	1,00	0,60	0,83
CHE	0,80	0,00	0,00	1,00	1,00	0,81	0,00	1,00	0,00	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,00	1,00	1,00	1,00	0,20	1,00	1,00	0,84	0,81	1,00	1,00	0,84	0,20		1,00	0,00	0,67
TUR	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,25	0,00	0,00	0,00	0,52	0,20	0,00	0,24	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00	0,00	1,00	0,00	0,00	0,00	0,00		0,00	0,00
GBR	0,80	0,34	0,00	1,00	1,00	0,84	0,49	1,00	0,49	1,00	0,00	1,00	1,00	1,00	1,00	1,00	1,00	0,33	1,00	1,00	1,00	0,50	1,00	1,00	1,00	0,84	1,00	1,00	0,84	0,40	1,00	1,00		0,75
USA	0,83	0,00	0,25	0,83	1,00	0,67	0,20	1,00	0,20	0,75	0,00	1,00	1,00	1,00	1,00	1,00	0,80	0,00	1,00	1,00	1,00	0,17	0,60	1,00	0,84	0,67	1,00	1,00	0,76	0,17	0,33	1,00	0,25	

Table A2: Discordance Matrix

	AUS	AUT	BEL	CAN	CHL	CZE	DNK	EST	FIN	FRA	DEU	GRC	HUN	ISL	IRL	ISR	ITA	JPN	KOR	LUX	MEX	NLD	NZL	NOR	POL	PRT	SVK	SLO	ESP	SWE	CHE	TUR	GBR	USA
AUS		0,56	0,56	0,22	0,00	0,44	0,33	0,00	0,33	0,22	0,56	0,00	0,00	0,00	0,11	0,00	0,22	0,33	0,11	0,11	0,00	0,33	0,22	0,11	0,33	0,44	0,00	0,00	0,44	0,56	0,22	0,00	0,33	0,22
AUT	0,11		0,11	0,00	0,00	0,00	0,00	0,00	0,11	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,11	0,00
BEL	0,11	0,11		0,00	0,00	0,00	0,11	0,00	0,11	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,11
CAN	0,22	0,44	0,44		0,00	0,33	0,33	0,00	0,33	0,22	0,44	0,00	0,00	0,00	0,00	0,00	0,22	0,33	0,00	0,00	0,00	0,33	0,22	0,11	0,22	0,33	0,00	0,00	0,33	0,44	0,22	0,00	0,33	0,22
CHL	0,44	0,78	0,78	0,67		0,44	0,78	0,00	0,78	0,56	0,89	0,00	0,33	0,44	0,44	0,22	0,44	0,78	0,44	0,56	0,00	0,78	0,67	0,56	0,33	0,44	0,00	0,11	0,56	0,67	0,67	0,00	0,78	0,67
CZE	0,44	0,44	0,33	0,22	0,00		0,44	0,00	0,44	0,33	0,56	0,00	0,11	0,00	0,11	0,00	0,22	0,56	0,22	0,22	0,00	0,56	0,33	0,22	0,00	0,00	0,00	0,11	0,22	0,56	0,33	0,00	0,33	0,44
DNK	0,00	0,33	0,33	0,00	0,00	0,22		0,00	0,00	0,00	0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,22	0,00	0,00	0,11	0,22	0,00	0,00	0,22	0,33	0,00	0,00	0,11	0,11
EST	0,56	0,78	0,78	0,67	0,11	0,44	0,78		0,78	0,56	0,89	0,00	0,33	0,44	0,44	0,22	0,44	0,78	0,44	0,56	0,00	0,78	0,67	0,56	0,33	0,44	0,00	0,11	0,56	0,78	0,67	0,11	0,78	0,67
FIN	0,00	0,33	0,33	0,00	0,00	0,22	0,00	0,00		0,00	0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,22	0,00	0,00	0,11	0,22	0,00	0,00	0,22	0,33	0,00	0,00	0,11	0,11
FRA	0,22	0,33	0,33	0,11	0,00	0,22	0,22	0,00	0,22		0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,33	0,00	0,00	0,00	0,22	0,11	0,00	0,11	0,22	0,00	0,00	0,22	0,33	0,11	0,00	0,22	0,11
DEU	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
GRC	0,78	0,78	0,78	0,67	0,33	0,44	0,78	0,33	0,78	0,56	0,89		0,44	0,44	0,44	0,33	0,44	0,89	0,44	0,56	0,00	0,78	0,67	0,56	0,33	0,44	0,00	0,44	0,56	0,89	0,67	0,11	0,78	0,67
HUN	0,44	0,67	0,78	0,56	0,33	0,67	0,78	0,33	0,78	0,67	0,78	0,22		0,33	0,33	0,22	0,67	0,67	0,44	0,44	0,11	0,67	0,67	0,44	0,44	0,67	0,00	0,22	0,56	0,78	0,67	0,22	0,78	0,56
ISL	0,44	0,89	0,89	0,44	0,33	0,78	0,67	0,33	0,67	0,56	0,89	0,33	0,33		0,44	0,11	0,56	0,67	0,44	0,44	0,22	0,67	0,44	0,44	0,67	0,78	0,22	0,33	0,78	0,89	0,56	0,22	0,67	0,56
IRL	0,44	0,56	0,44	0,33	0,00	0,33	0,44	0,00	0,44	0,44	0,67	0,00	0,00	0,00		0,00	0,33	0,67	0,33	0,22	0,00	0,67	0,44	0,22	0,22	0,33	0,00	0,00	0,33	0,67	0,44	0,00	0,44	0,56
ISR	0,44	0,89	0,89	0,44	0,33	0,78	0,56	0,33	0,56	0,56	0,89	0,33	0,33	0,22	0,44		0,56	0,67	0,44	0,44	0,22	0,67	0,44	0,44	0,67	0,78	0,22	0,33	0,78	0,89	0,56	0,22	0,67	0,56
ITA	0,33	0,33	0,33	0,22	0,00	0,22	0,33	0,00	0,33	0,11	0,44	0,00	0,00	0,00	0,00	0,00		0,44	0,00	0,11	0,00	0,33	0,22	0,11	0,11	0,22	0,00	0,00	0,22	0,44	0,22	0,00	0,33	0,22
JPN	0,00	0,22	0,22	0,00	0,00	0,11	0,11	0,00	0,11	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00		0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,00	0,00	0,11	0,00	0,00	0,00	0,11	0,00
KOR	0,33	0,44	0,44	0,33	0,00	0,33	0,33	0,00	0,33	0,22	0,56	0,00	0,00	0,11	0,11	0,00	0,22	0,44		0,22	0,00	0,44	0,33	0,11	0,22	0,33	0,00	0,00	0,33	0,44	0,33	0,00	0,44	0,22
LUX	0,22	0,44	0,44	0,11	0,00	0,33	0,44	0,00	0,44	0,22	0,44	0,00	0,00	0,00	0,00	0,00	0,22	0,44	0,11		0,00	0,44	0,22	0,22	0,22	0,33	0,00	0,00	0,33	0,44	0,33	0,00	0,33	0,33
MEX	0,78	0,78	0,78	0,67	0,33	0,56	0,89	0,33	0,89	0,67	0,89	0,11	0,44	0,44	0,44	0,33	0,56	0,89	0,56	0,56		0,89	0,67	0,67	0,44	0,56	0,00	0,44	0,56	0,89	0,78	0,22	0,78	0,78
NLD	0,00	0,22	0,22	0,00	0,00	0,11	0,22	0,00	0,22	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,00	0,00	0,00		0,00	0,00	0,00	0,11	0,00	0,00	0,11	0,22	0,11	0,00	0,11	0,11
NZL	0,11	0,44	0,44	0,00	0,00	0,33	0,22	0,00	0,22	0,11	0,44	0,00	0,00	0,00	0,00	0,00	0,11	0,22	0,00	0,00	0,00	0,22		0,00	0,22	0,33	0,00	0,00	0,33	0,44	0,11	0,00	0,22	0,11
NOR	0,22	0,44	0,44	0,22	0,00	0,33	0,33	0,00	0,33	0,22	0,44	0,00	0,00	0,00	0,00	0,00	0,22	0,44	0,11	0,11	0,00	0,44	0,22		0,22	0,33	0,00	0,00	0,33	0,44	0,22	0,00	0,33	0,33
POL	0,44	0,56	0,44	0,33	0,00	0,22	0,56	0,00	0,56	0,44	0,67	0,00	0,11	0,11	0,11	0,00	0,33	0,67	0,33	0,22	0,00	0,67	0,44	0,33		0,22	0,00	0,11	0,33	0,67	0,44	0,00	0,44	0,56
PRT	0,44	0,56	0,44	0,33	0,00	0,11	0,44	0,00	0,44	0,44	0,67	0,00	0,11	0,00	0,11	0,00	0,33	0,67	0,33	0,22	0,00	0,67	0,44	0,22	0,00		0,00	0,11	0,33	0,67	0,44	0,00	0,44	0,56
SVK	0,78	0,78	0,89	0,67	0,44	0,78	0,89	0,44	0,89	0,78	0,89	0,33	0,44	0,44	0,44	0,33	0,78	0,89	0,56	0,56	0,22	0,89	0,78	0,67	0,56	0,78		0,44	0,67	0,89	0,78	0,33	0,89	0,78
SLO	0,44	0,78	0,78	0,67	0,11	0,44	0,78	0,11	0,78	0,56	0,89	0,00	0,33	0,44	0,44	0,22	0,44	0,78	0,44	0,56	0,00	0,78	0,67	0,56	0,33	0,44	0,00		0,56	0,67	0,67	0,00	0,78	0,67
ESP	0,22	0,22	0,22	0,11	0,00	0,11	0,33	0,00	0,33	0,11	0,33	0,00	0,00	0,00	0,00	0,00	0,11	0,33	0,00	0,00	0,00	0,33	0,11	0,11	0,00	0,11	0,00	0,00		0,33	0,22	0,00	0,22	0,22
SWE	0,00	0,11	0,11	0,00	0,00	0,00	0,22	0,00	0,22	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,11	0,00	0,00	0,00	0,11	0,00	0,00	0,00	0,00	0,00	0,00	0,00		0,11	0,00	0,11	0,11
CHE	0,11	0,33	0,33	0,00	0,00	0,22	0,11	0,00	0,11	0,00	0,33	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,22	0,00	0,00	0,11	0,22	0,00	0,00	0,22	0,33		0,00	0,11	0,11
TUR	0,78	0,78	0,78	0,67	0,33	0,56	0,78	0,33	0,78	0,56	0,89	0,11	0,44	0,44	0,44	0,33	0,44	0,89	0,44	0,56	0,00	0,78	0,67	0,56	0,44	0,56	0,00	0,44	0,56	0,89	0,67		0,78	0,67
GBR	0,11	0,22	0,22	0,00	0,00	0,11	0,11	0,00	0,11	0,00	0,22	0,00	0,00	0,00	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,22	0,00	0,00	0,00	0,11	0,00	0,00	0,11	0,22	0,00	0,00		0,11
USA	0,11	0,33	0,33	0,11	0,00	0,22	0,22	0,00	0,22	0,11	0,33	0,00	0,00	0,00	0,00	0,00	0,11	0,22	0,00	0,00	0,00	0,22	0,11	0,00	0,11	0,22	0,00	0,00	0,22	0,33	0,11	0,00	0,22	

MANAGING RISKS IN LOGISTICS USING FMEA-DEA APPROACH

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Abstract: *Modern logistics markets, characterized by complex structure and tough competition, are all exposed to various risks. These can cause different problems and disturbances. In recent years, increasing attention has been paid to managing risks in logistics. There are different systematizations of risks, as well as methods used for risk identification, analysis and evaluation. One of the most important and most frequently used methods is Failure Mode and Effects Analysis (FMEA) approach. Due to its simple application and usable results, the FMEA method has been widely used. However, this method also has some disadvantages. One of the most frequently mentioned in the literature is the calculation of Risk Priority Number (RPN). In this paper, for improving the RPN calculation for risks in different logistics processes, Data Envelopment Analysis (DEA) approach is proposed. The approach has been tested in two real examples. The first relates to 58 logistics risks in international commodity flows, while the second concerns risks for 37 activities in product distribution. In the first example, the most important risks are identified as congestion (border, customs offices, incomplete documentation, wrong addresses (loading/unloading), etc.) In the distribution process, the risks with dominant priority are delay in transportation process, goods control (low quality, short expiration date) and order-picking process (goods extraction and putting on pallets). According to the results, the proposed approach has great applicability for managing risks in logistics.*

Keywords*: Risks management, Logistics, Failure Mode and Effects Analysis, Data Envelopment Analysis*

1. INTRODUCTION

Recently, risk management has been the focus of academics and practitioners. There are different definitions of risks in the literature. Risk, in general, is defined as "the probability of variance in an expected outcome" or "the chance, in quantitative terms, of a defined hazard occurring" (Spekman and Davis, 2004). The risks are investigated in different areas and there are differences between term definition and observed aspects across different sectors.

In logistics, risks are related to negative consequences, such as danger, damage, injury, or any other undesired consequences (Harland et al., 2003). Supply chain risk is often specified into operational risks and disruption risks, built upon the characteristics of the risks (Tang 2006). In this sense, operational risks refer to inherent uncertainties from

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supply, demand and cost, whose frequency is high while impact is low. On the contrary, disruption risks indicate major natural and man-made disasters whose impact is much greater than operational risks, though the likelihood is slim (Kwak, 2014).

Different approaches are used for risk management in logistics (Kwak, 2014). One of the most frequently used approaches generally, but also in logistics, is Failure Mode and Effects Analysis (FMEA). In this paper, the possibilities of improving the application of the traditional FMEA approach in logistics have been explored. A special emphasis is given to the Data Envelopment Analysis (DEA) approach. The aim of the paper is to develop an efficient risk management tool for logistics processes available in different systems and at different levels. The proposed approach takes into account relative importance weights of risk factors, yet without subjectivity.

The paper is organized as follows. The next section provides the description of risks in logistics, as well as a review of different approaches for risks management in logistics. The proposed FMEA-DEA approach for risks management in logistics is presented in third section. In fourth section, the proposed approach is tested on two numerical examples. At the end of the paper, concluding remarks and directions for future research are specified.

2. PROBLEM DESCRIPTION

In this chapter, main risks in logistics are explored. Furthermore, approaches for risk management are investigated and shortly described.

2.1 Risks in logistics

As already mentioned, generally, risk management in recent years has gained significance. The same situation is in logistics. Logistics is crucial for linking upstream and downstream parties. In this sense, any logistics disruption can cause a number of negative consequences. At the end, everything is projected to the customer and their dissatisfaction. Regardless the size and structure of the logistics system, the risks can be divided into internal and external, or exogenous and endogenous (Trkman and McCormack, 2009). More complex logistics systems and processes have the higher likelihood of risk occurrence.

It is very important to emphasize that a disruption in a process or a system will affect performances of the entire system or chain. All activities and processes need to be planned in advance. Risk management should be an important part of the enterprise risk management. When an unwanted event occurs, it is very important to solve the problem successfully, quickly, and with fewer consequences. For this reason, flexible and adaptive logistics is very important.

In accordance with a point of event occurrence, risk management strategy can be divided into two approaches: mitigation strategy and contingency strategy. Mitigation strategy represents pre-actions to avoid or minimize the likelihood of a risk attacking or its impact. Contingency strategy refers to post-actions to handle damage in a quick and short time with minimal expense (Wee and Blos, 2012). Mitigation action is used for managing the risk sources and contingency action for handling the risk consequences.

As mentioned before, mitigation strategy is a set of planning activities before the event happened. Mitigation strategy should prepare the system or process for a specific disturbance or threat. In addition, certain costs will be incurred in order to avoid the disruption or lower the losses. Chopra and Sodhi (2004) defined the threats in the supply chains, seven mitigation approaches and their tailored strategies. Tang (2006) identified robust strategies for mitigating supply chain disruptions. Pettit et al. (2010) identified a zone of resilience defined by the supply chain capability and vulnerability. Contingency strategy is aiming to rapidly respond to the disruption event and also to recover quickly from that event with minimum expenses (Wee and Blos, 2012). Mitigation strategy and contingency strategy are highly interconnected. Mitigation strategy should reduce likelihood of risk occurrence and lower the costs of contingency actions.

There are five risk categories in an enterprise; these include strategic, financial, operational, human capital, and hazard categories to assess and manage risks. According to Wee and Blos (2012), all logistics risks relate to physical and information flow, as shown in Figure 1.

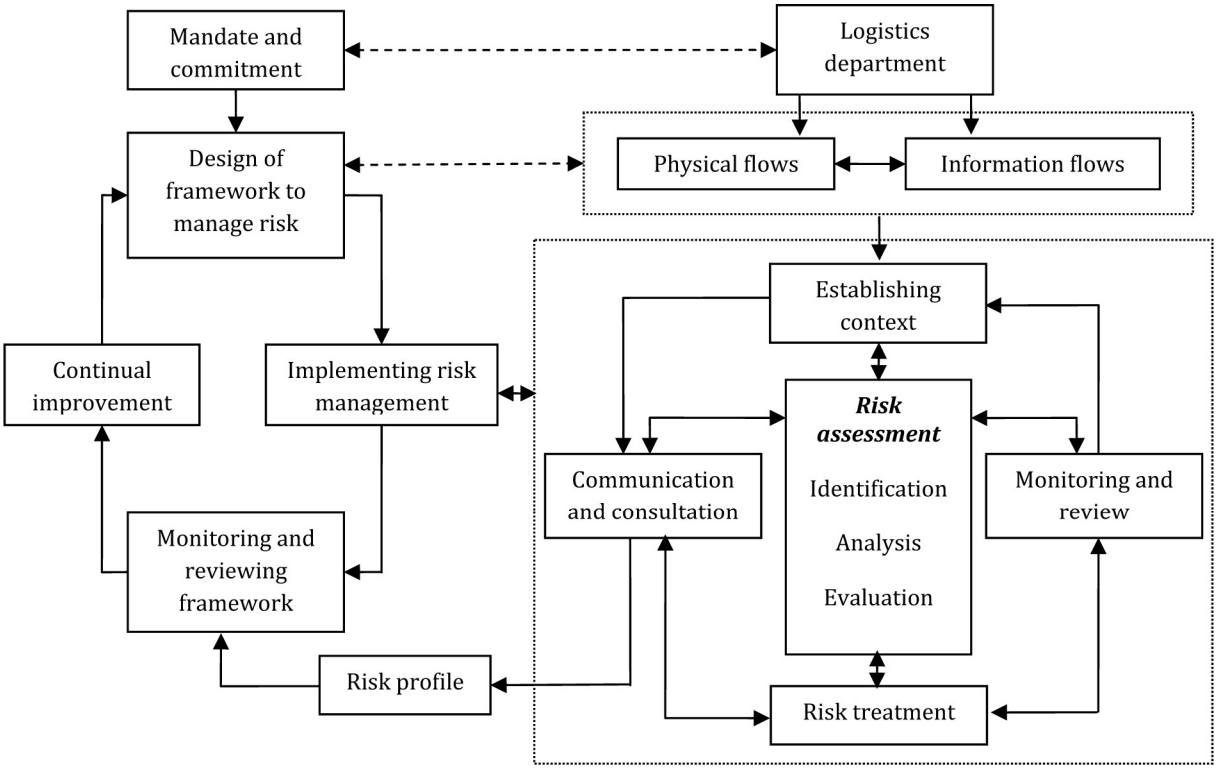


Figure 1. Risk management in logistics (Wee and Blos, 2012)

The basic processes for risk management in logistics are risk identification, evaluation, mitigation, implementation, and monitoring. Logistics management functions are largely affected by certain risks. In that manner, each sector will focus on, for them, the most important risks (Table 1).

In the literature, there are different risks in logistics systems. According to Kwak (2014), the most important risks in intercontinental commodity flows are delay, natural disasters, space shortage, freight rate fluctuation, miscommunication, cargo damage, inaccurate documents, strike, etc. In recent years, one of the most important categories

in logistics is the risk of poor quality. Bearing that in mind, there is a need for the continuous monitoring of potential risks, as well as measuring the quality level of the delivered services (Kilibarda et al. 2016).

Table 1: Risks in different logistics management functions (Wee and Blos, 2012)

Risks/Functions	Transportation management	Warehousing management	Material handling	Inventory management	Order management	Purchasing management	Customer service	Information management
Environment	*	*	*	*				*
Suppliers				*	*	*		*
Operational	*		*			*	*	*
Control		*		*	*			*
Planning				*	*	*	*	*
Customers					*		*	*
Information	*	*	*	*	*	*	*	*

2.2 Different approaches for risk management in logistics

For managing risks there is a number of approaches, classified in different ways. According to Wee and Blos (2012), there are different techniques for different stages of risks management (Table 2).

Table 2. Assessment techniques in different stages (adapted: Wee and Blos, 2012)

Stage	**Assessment techniques**
Identification	Brainstorming, Structure or Semi-Structure Interview, Delphi, Check-list, Primary hazard analysis, HAZOP, HACCP, Environment risk assessment, Structure-What if-SWIFT, Scenario analysis, FMEA, Cause-and-effect analysis, Human reliability analysis, Reliability-centered maintenance, Consequence/probability matrix, Multiple FMEA, MCGDM
Analysis	HAZOP, HACCP, Environment risk assessment, Structure-What if-SWIFT, Scenario analysis, Business impact analysis, Root cause analysis, FMEA, Fault tree analysis, Event tree analysis, Cause and consequence analysis, Cause-and-effect analysis, LOPA, Decision tree, Human reliability analysis, Bow tie analysis, Reliability-centered maintenance, Markov analysis, Bayesian statistics and Bayes Nets, FN curves, Risk indices, Consequence/probability matrix, Cost/Benefit analysis, Multi-criteria decision analysis, FMEA-DEA, FMECA, KANO-FMEA
Evaluation	HACCP, Environment risk assessment, Structure-What if-SWIFT, Root cause analysis, FMEA, Reliability-centered maintenance, Monte Carlo simulation, Bayesian statistics and Bayes Nets, FN curves, Risk indices, QFD - FMEA

There is also ASSE (American Society of Safety Engineers) classification into Qualitative methodology (Preliminary risk analysis, HAZOP, FMEA), Tree-based technology (Failure tree analysis, Event tree analysis, Cause - Consequences analysis, Management oversight risk tree, Safety management organization review technique), and Techniques for dynamic system (Go method, Diagraph/Fault graph, Markov modeling, Dynamic event logic analytic methodology, Dynamic event tree analysis method).

One of the most important and most frequently used engineering technique methods is FMEA. FMEA is a decision-making tool for defining, identifying and eliminating potential failures, problems and errors from the system, design, process, or service before they reach the customer. In literature, FMEA is combined with different approaches and methods. In order to determine risk priority number, some authors used DEA. FMEA-DEA also provides corrective information regarding the failure factors – severity, occurrence and detection (Chin et al. 2009; Chang and Sun, 2009).

The Fault Tree Analysis is mainly applied as an addition to the FMEA to enhance the analysis or to replace the FMEA completely in order to cover the failure combination possibilities (Pickard et al. 2005). The proposed procedure allows considering multiple failures while keeping all elements of FMEA (Xiao et al. 2011). FMEA is also extended with Criticality Analysis (CA). In that manner, Failure Modes, Effects and Criticality Analysis (FMECA) may also rank each failure according to the criticality of a failure effect and its probability of occurrence. Some benefits of FMECA approach are the following: contribution to the improved designs for products and processes (greater reliability, better quality, enlarged safety); improvement in consumer satisfaction (contributes to cost savings, decreases development time, warranty costs, waste, etc.); and contribution to the development of control plans, testing requirements, optimum maintenance plans, reliability growth analysis and related activities (Lipol and Haq, 2011).

The risk priorities of failure modes are almost crisp, which has been criticized due to several limitations. Some authors used multi-criteria group decision making (MCGDM) approach in order to use linguistic variables and to obtain better solution. Nazam et al. (2015) applied fuzzy technique for order performance by similarity to ideal solution (TOPSIS) integrated with fuzzy analytical hierarchy process (AHP) in the food retail chain.

FMEA is also integrated with Kano model. Shahin (2004) combined FMEA and Kano in order to enhance FMEA capabilities through its integration with Kano model. The main reason is that the severity is being determined from the designers' point of view, not from the customers' side. It supports the nonlinear relationship between frequency and severity of failure. Likewise, a new index called "correction ratio" (Cr) is proposed to assess the corrective actions in FMEA (Shahin, 2004).

Almannai et al. (2008) used quality function deployment (QFD) technique and the failure mode and effects analysis (FMEA) technique. The main reason for this combination is the ability of QFD to identify the most suitable alternative and the ability of FMEA to identify the associated risk.

3. FMEA-DEA APPROACH

In this chapter, FMEA-DEA approach for risk management in logistics is described in more details. The advantages of applying this approach are also highlighted.

Failure Mode and Effects Analysis (FMEA) Approach

As mentioned before, FMEA was developed for the failure analysis in different systems and processes. The procedure of this method is based on the failure characteristics and structure of observed systems and processes. The main objective of FMEA is to analyze potential defects/faults in the observed system and corrective measures that can reduce the risks. Benefits of failure detection are numerous: increasing the safety of functions and service reliability, reducing warranty and service costs, shortening the development process, obtaining better compliance of the planned terms, increasing process efficiency, increasing customer satisfaction, etc. FMEA discovers and prioritizes failures by computing the risk priority number (RPN) which is a product of several risk factors: severity (S), occurrence (O) and detection (D) (Andrejić and Kilibarda, 2017).

Severity describes the seriousness (effects) of the failure. Each effect is given a severity number from 1 (no danger) to 10 (critical). In this paper, severity ratings proposed in (Chin et al., 2009b) are used (Table 3). Occurrence describes the probability of failure appearance. Traditional ratings for failure occurrence proposed in (Chin et al., 2009) are used in this paper (Table 3). The ability to detect the failure before it reaches the customers can be defined as detection. The assigned detection number measures the risk that the failure will escape detection. A high detection number indicates that the chances are high that the failure will escape detection, or in other words, that the chances of detection are low (Andrejić and Kilibarda, 2017). Detection ratings used in this paper are presented in Table 3.

Table 3. Ratings for Severity of a failure (adapted: Chin et al., 2009)

Rating	Severity - S	Probability of occurrence- O	Detection - D
10	Hazardous without warning	Very high: failure is almost inevitable	Absolute uncertainty
9	Hazardous with warning		Very remote
8	Very high	High: repeated failures	Remote
7	High		Very low
6	Moderate	Moderate: occasional failures	Low
5	Low		Moderate
4	Very low		Moderately high
3	Minor	Low: relatively few failures	High
2	Very minor		Very high
1	None	Remote: failure is unlikely	Almost certain

RPN is calculated after the determination of three mentioned components. The RPN can be easily calculated by multiplying three mentioned components:

$$RPN = S \times O \times D \quad (1)$$

The failure modes with the highest RPN should have the highest priority for monitoring and corrective actions. The main problem with standard FMEA approaches is the

calculation of RPN. As mentioned before, according to a traditional approach, RPN is calculated as the product of severity, detection and occurrence. However, with DEA approach, a frontier is established considering the less critical failure modes. The mentioned approach also provides useful information about how much each failure mode has to be improved to become relatively acceptable.

Data Envelopment analysis (DEA)

DEA is a mathematical programming technique which enables the comparison of efficiencies of different Decision Making Units (DMUs), based on multiple inputs and outputs. The efficiency is relative and relates to the set of units within the analysis. Charnes et al. (1978) proposed a non-parametric approach for efficiency estimation, where they reduce multiple inputs to a single virtual input and multiple outputs were reduced to a single virtual output using weighting coefficients. In the set of homogeneous units, the DEA finds the most efficient DMUs and according to them, it defines the efficiency of other units. This method is also used for obtaining information about corrective actions of inefficient DMUs. Obtained efficiencies are relative since they relate only to a set of observed DMUs and they cannot be considered as absolute (Andrejic et al., 2013).

The basic CCR (Charnes, Cooper, Rhodes, 1978) model presents the basis of all present models. In the original form, this model presents the problem of fractional programming. According to the appropriate transformations, the model is reduced to the linear programming problem. In order to estimate DMU efficiency, it is necessary to have data of consumed input and realized output variables. The following notation is most frequently used in the DEA terminology. A set of DMUs has n DMU (j = 1, 2,..., n), where each input is characterized by m input (i= 1, 2,..., m) and s output variables (r = 1, 2,..., s). The value of i input variable is denoted as x_{ij}, while y_{rj} denotes the value of r output variables of DMU_j. Weighting coefficients are related to all inputs and outputs and they are denoted with v_i and u_r respectively. They present decision variables. In order to estimate DMU efficiency of the observed set, it is necessary to perform n independent estimations where DMU_k (k=1,...,n) presents the failure/risk whose efficiency is measured. In that case, the primal CCR (multiplier form) model has the following form: μ

$$Max\sum_{r=1}^{s} u_r y_{rk} \tag{2}$$

$$\sum_{i=1}^{m} v_i x_{ik} = 1 \tag{3}$$

$$\sum_{r=1}^{s} \mu_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \le 0,\ j = 1,2,\ldots,n \tag{4}$$

$$v_i \ge 0, i = 1,..,m \tag{5}$$

$$u_r \ge 0, r = 1,..,s \tag{6}$$

In the process of DEA method application, the CCR model is preferable as the initial model. As in linear programming problems, the CCR model also has two formulations: primal and dual. Dual formulation (envelopment form) of the original CCR model was

used in this paper. There are several benefits of solving the dual problem. Considering the fact that the number of DMUs is higher than the number of inputs and outputs, in practice, due to a computational effort, the dual model is mostly solved. *Max-slack* solution cannot be obtained by solving the primal model. The interpretation of the dual model is more straightforward because the solutions are characterized as inputs and outputs that correspond to the original data, whereas the multipliers provided by solutions to the primal model represent evaluations of these observed values. CCR dual model is usually solved in two stages:

Stage I

$$Min\ \theta \tag{7}$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j y_{rj} - y_{rk} \geq 0,\ r = 1,2,...,s \tag{8}$$

$$\theta x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0,\ i = 1,2,...,m \tag{9}$$

$$\lambda_j \geq 0,\ j = 1,2,...,n \tag{10}$$

Stage II

$$Max\ e\left(\sum_{r=1}^{s} s_r^+ + \sum_{i=1}^{m} s_i^- \right) \tag{11}$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j y_{rj} - y_{rk} - s_r^+ = 0, r = 1,2,...,s \tag{12}$$

$$\theta^* x_{ik} - \sum_{j=1}^{n} \lambda_j x_{ij} - s_i^- = 0, i = 1,2,..., m \tag{13}$$

$$\lambda_j, s_r^+, s_i^- \geq 0,\ i = 1,2,...,m, r = 1,2,...,s, j = 1,2,...,n \tag{14}$$

The main problem with standard FMEA approaches is the calculation of RPN. As mentioned before, according to a traditional approach, RPN is calculated as a product of severity, detection and occurrence. However, with DEA approach, a frontier is established considering the less critical failure modes. The mentioned approach also provides useful information.

The variable θ is called the intensity factor, and it shows how it is possible for DMU_k to proportionally reduce all output variables. The optimal value θ is obtained in the first phase, after which it is used for estimating the efficiency in the second phase. Variables s_r^+ and s_i^- show how it is possible that DMU_k individually reduces *i* input variable and increases *r* output variable in order to become efficient. These values are called slack variables. If from the set of dual weighting coefficients λ_j (*j* = 1, 2, ..., *n*) only λ_k has a

positive value, then the intensity factor is $\theta = 1$, which means that DMU_k engaged the minimum amount of input variables and it is the marginal point. If that is not the case, DMU_k is inefficient. DMUs with a positive value for the dual weighting coefficients λ_j are called peers for DMU_k. Therefore, if $\theta < 1$, then DMU_k is relatively inefficient and it should proportionally reduce all input variables for $(1-\theta)*100$ percentage in order to become efficient with the existing level of output variables.

In order to use FMEA and DEA, it is important to define inputs and outputs. According to DEA characteristics, it is deemed a good alternative tool to enhance the assessment capability of FMEA. The common features of DEA and FMEA are (Chin et al. 2009):

- Determination of risk ranking for failure modes in FMEA as to efficiency ranking of DMUs in DEA;
- Both deem to have inputs and outputs (in FMEA the inputs are severity, occurrence and detection and the output is RPN).

RPNs are presented as relatively risky among failure modes. Prioritized corrective actions are tackled based on the RPN derived from the inputs. The failure modes used in FMEA are equivalent to DMUs in DEA; the inputs (severity, occurrence, detection) of FMEA can be identically seen as multiple inputs of DEA (Chin et al. 2009). The application of DEA in FMEA achieves a number of benefits: risk rankings among failure modes are in terms of cardinal order; information about corrective actions for risk elements (severity, occurrence, detection) are available; resource allocations management is improved, etc.

4. NUMERICAL EXAMPLES

In this section, the proposed model is tested on two different examples. The first example relates to risks in organization of international commodity flow, while the second example investigates risks in distribution processes.

4.1 Applying FMEA-DEA approach for risks analysis in international commodity flows

The importance of global logistics in international trade flows is recognized. In the network of processes and participants, there are numerous risks for logistics providers. Potential risks can greatly disrupt flows and make a number of problems for all participants. The organization of international commodity flows is a complex and often uncertain process (Kilibarda et al., 2016). The freight forwarders and logistics providers as architects of international goods flows have to design, organize and realize all processes and activities. The structure of activities is shown in Figure 2. The first is the purchasing contract between the seller (exporter) and the buyer (importer). The exporter or importer, as users of logistics services, gives a request to freight forwarding companies. After that, they present an appropriate logistic offer. The result of the offer acceptance is a contract for freight forwarding which starts the process of organizing and realizing the international trade flow. Preparation, packaging and loading of goods is the first step. Freight forwarder and customs officer are involved in issuing the export clearance. Documentation preparation (CMR, EUR1, invoice, customs declaration, insurance policy, etc.) and exchange are very important. The next process in the

organization of international flows is transport. Import clearance, unloading, cost calculation, and payment are realized at the end of the international commodity flow.

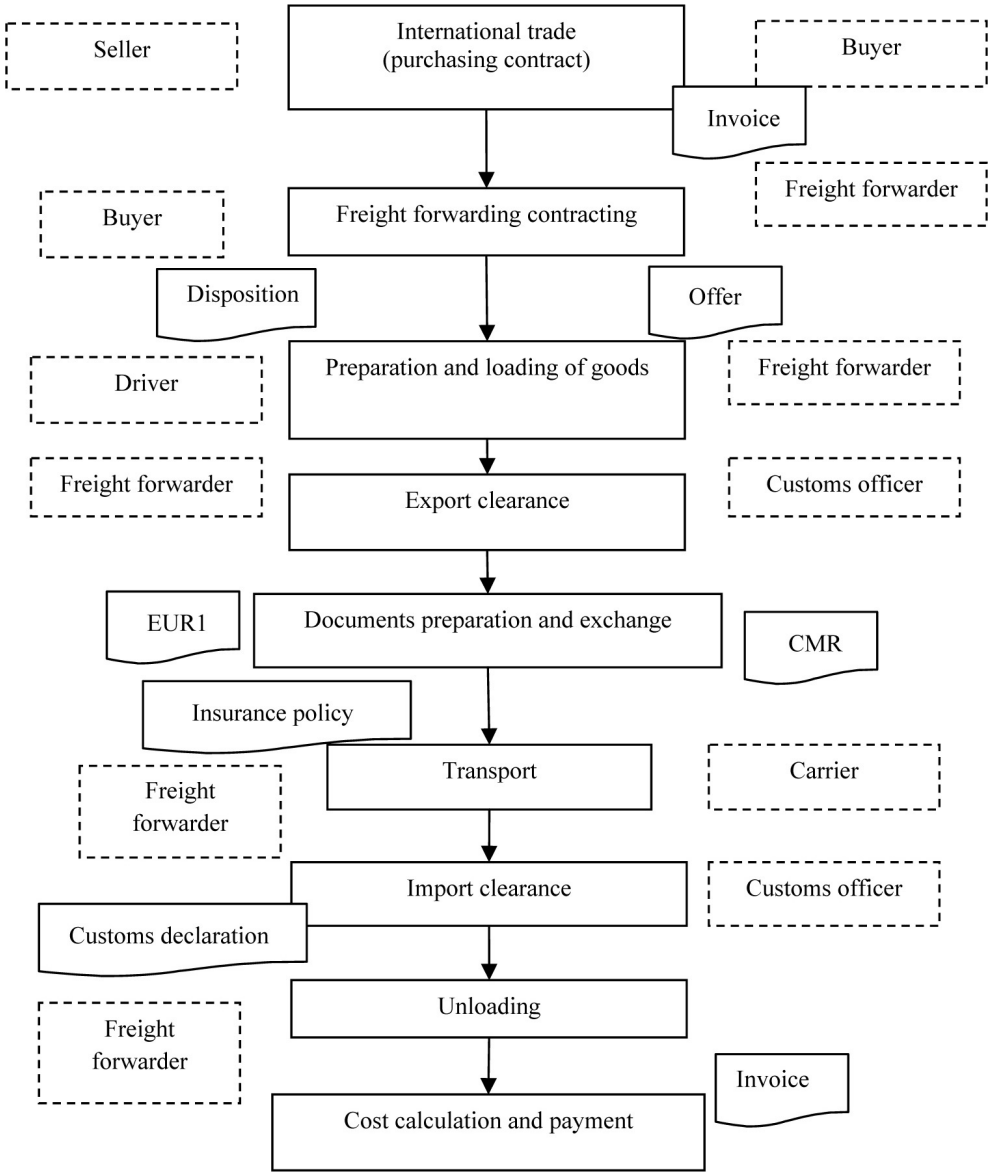


Figure 2. Basic processes in the organization of international flows (Andrejić and Kilibarda, 2018)

For the analyzed system, seven processes with 58 potential failures (risks) are identified (Andrejić and Kilibarda, 2018). In order to improve the calculation of the RPN number and gain a more reliable result, FMEA-DEA approach is applied. As inputs in this model O, S, and D are used, while 1 is the artificial output for all DMUs. The O, S, D values are results of the assessment of experts with years of experience in the organization of international commodity flows. Results are presented in Table 4. Unlike the traditional RPN number, in this case, the efficiency scores are calculated. In FMEA-DEA approach, larger efficiency scores refer to less RPN, while less efficiency scores mean larger RPN. In this paper, CCR DEA input-oriented model is used.

Table 4. Analysis of risks in international commodity flows

Process	Failure	Consequence	O	S	D	FMEA-DEA scores
Preparation and loading of goods	Delay due to retention on previous loading	Delay in delivery (out of term); Problems in customs procedures	8	4	8	0.84
	Wrong loading address (official and real addresses are different)	Empty driving - deadhead (unexpected costs)	9	8	9	**0.64**
		Time losses (delay - penalties)	9	9	9	**0.62**
	Inappropriate handling equipment	Manual loading; Engagement of third parties; time losses-delay with delivery	7	7	7	0.80
		Additional costs of engaging the vehicle	7	6	6	0.90
	Overload (the weight of the shipment exceeds the maximum load)	Problems with law	5	9	4	1.00
	Congestion on loading area	Time losses; Delay in delivery (out of term)	7	7	8	1.00
		Additional costs of engaging the vehicle	7	8	8	0.85
	Lack of reference / loading number	Problems with loading (inability)	5	4	7	1.00
	Inadequate manipulation of goods while loading	Damage to goods and unexpected costs	6	8	8	0.75
	Loading the wrong goods to the vehicle (returning the vehicle to the place of loading)	Empty driving - deadhead (unexpected costs)	6	6	8	0.75
		Time losses; Delays	5	8	8	0.86
Documents preparation and exchange	Driver takes incomplete (unchecked) documentation	Return to the place of loading due to the lack of documentation (empty drive and unexpected costs)	8	7	8	**0.72**
	Lack of stamps and signatures on the invoice	Customs officer consider subject incomplete	7	9	6	0.79
	Discrepancies in values and quantities in invoice, CMR and other documents	Customs officer consider subject incomplete	7	9	7	**0.74**
	Lack of declaration of preferential origin of goods (for the value of goods <6000€	The importer is not exempt from paying import duties	6	8	7	0.80
		Time losses to the arrival of new (changed) invoice	6	8	7	0.80
	The supplier did not send the instructions/ documentation for the creation of EUR 1 form	The importer is not exempt from paying import duties	6	8	5	0.92
		Time losses for waiting instructions for creating EUR 1 form	6	7	5	0.96
Export clearance	Lack of information - exact place of customs clearance	Additional km unexpected costs	7	9	8	0.80
	The customs procedure longer than 24 hours	Additional costs of engaging the vehicle	7	8	8	**0.63**
		Delay of delivery	7	8	8	**0.63**
	The supplier has not provided a service-the task assigned to the carrier; poor communication	Vehicle retention; Additional costs of engaging the vehicle	7	8	6	0.81
	Non-working day	Waiting for the first working day - additional costs of engaging the vehicle	4	8	5	1.00
	Documents authentication – forwarder error	Inability to leave the country; Time losses	6	8	9	0.73

Table 4. Analysis of risks in international commodity flows (continued)

Process	Failure	Consequence	O	S	D	FMEA-DEA scores
	The freight forwarder does not prepare and does not send EUR 1 - regardless receiving the announcement	The importer is not exempt from paying import duties	6	7	7	0.83
		Import clearance is delayed – waiting for EUR 1; Additional costs of engaging the vehicle	6	8	7	0.80
	Poor communication seller-freight forwarder-importer	Delay of delivery	8	8	10	**0.72**
		Additional costs of engaging the vehicle	8	8	10	**0.72**
Transport	Vehicle malfunction	Delay in delivery (out of term); penalties	6	9	9	0.73
	Traffic congestion		9	9	9	**0.62**
	Construction zone		7	6	6	0.90
	Inadequate infrastructure		6	6	5	1.00
	Bad weather conditions		6	8	6	0.85
	Traffic accident		6	7	10	0.77
	Congestion at the border		8	9	9	**0.64**
	Theft of goods	Unwanted costs and losses	6	8	6	0.85
	Poor security of goods in transport	Unwanted costs and losses	7	8	7	0.76
	Damaged goods in transport					
	Inappropriate temperature	Damaged goods and unwanted costs	7	7	8	0.75
	Improper packaging; non palletized goods	Damaged goods and unwanted costs	7	8	8	**0.72**
Import clearance	Delayed arrivals	Delay in delivery (out of term)	8	8	7	**0.74**
	Congestion in customs offices	Delay in delivery (out of term)	9	9	8	**0.65**
	Freight forwarder failure in declaration filling	Vehicle retention at the customs office, delay in delivery	6	8	7	0.80
	The importer is not able to pay the customs duties; vehicle is captured	Additional costs of engaging the vehicle	6	3	7	1.00
		Delay in delivery (out of term)	6	3	7	1.00
	Customs officer consider subject incomplete	Delay in delivery (out of term)	7	3	9	1.00
	Lack of labor in providing freight forwarding services	Delay in delivery (out of term)	6	3	8	1.00
	Customs account delays	Inability to deliver on the same day - delays	7	3	9	1.00
Unloading	Wrong unloading address (official and real addresses are different)	Empty driving - deadhead (unexpected costs)	9	8	9	**0.64**
		Time losses (delay - penalties)	9	9	9	**0.62**
	Vehicle arrival after working time	Unloading is postponed for the next day; Vehicle retention	8	8	7	0.74
	Inappropriate handling equipment	Vehicle retention; Additional costs	7	7	6	0.85
	Inadequate manipulation of goods while loading	Damage to goods and unexpected costs	6	8	8	0.75
	Congestion on loading area	Vehicle retention; Additional costs	6	5	8	0.85
Cost calculation and payment	Bad costs calculation and inappropriate offer	Income loss	8	8	7	0.74
	Bad anticipation of unexpected costs		9	9	7	**0.70**
	Inappropriate customer assessment	Inability to charge	7	8	8	**0.72**
	Inappropriate banking service	Problems in transfer and realization of payments	6	7	7	0.83

The first process in the observed case is the preparation and loading of goods. According to the efficiency scores for the observed process, the most important failure is wrong loading address (Table 4). The address of the factory is not the place where the goods are stored. Mentioned failure is the result of poor communication between importers and suppliers, as well as misunderstanding in the business of both parties. This occurrence is high, especially during the first purchase from an unknown supplier. Production warehouse in some cases can be located nearby, so losses are less in such cases. However, it often happens that the warehouse is located hundreds of kilometers away from the address that is entered on the order. Therefore, the truck travels the same distance twice, and thus additional costs are doubled. These errors are rarely detected before the vehicle arrives at the wrong address, especially when the address of the loading is found in the internet databases. Timely error detection can be prevented by contacting the supplier directly. The consequences are also time losses and penalties. There are also risks with medium importance like inadequate manipulation of goods while loading and inappropriate handling equipment. Risks from this group have to be monitored. In the end, there are risks with lowest importance (overload, lack of reference/loading number, etc). Risks in this group do not require special attention.

In the process of documents preparation and exchange, the most important risk is taking incomplete documentation with the score 0.72 (Table 4). The problem usually occurs due to lack of time. This failure can also be caused by previous delays, which are often in practice. The consequences may include returning to the place of loading due to the lack of documentation, empty drive, unexpected costs, etc. In order to overcome the mentioned failure, it is necessary to provide additional instructions to the driver regarding the verification of documents. The driver needs to inform freight forwarder when the document validation is complete. The next risk relates to discrepancies in values and quantities in the invoice, CMR and other documents with the score 0.74. Due to insufficient attention in the process of form filling, inconsistencies in the documents may appear. Consequences include problems in customs procedures.

According to the results in Table 4, the most important risks are related to the customs procedure longer than 24 hours and poor communication between seller-freight and forwarder-importer with the scores 0.63 and 0.72 respectively. Both risks have same consequences in additional costs of engaging the vehicle and delay of delivery. Communication among all participants is essential for the smooth organization of commodity flows. Poor communication causes additional costs, time losses, and in some cases damage and loss of goods, dissatisfaction of all participants, etc. Transporters, freight forwarders, and logistics providers are not able to detect failures that have a direct impact on their operations. The task of a logistics provider is to contact the seller directly with the approval of the importer and try to obtain the necessary information, as well as anticipate and solve the problem that directly threatens a certain trade flow. Regardless the INCOTERMS (International Commercial Terms) rules, in some cases communication between the supplier and freight forwarder is very important.

According to the results, the most important risk in the process of transport is traffic congestion. Congestions on the road are frequent and it is not easy to predict and avoid them (Table 4). In such situation, clients are often dissatisfied and often intolerant due to delays. In some cases, the delay of goods delivery can result in production stopping. The inability to detect or find alternative solutions is the core of this problem.

Congestion on the border has similar consequences as previous failure. This failure is also impossible to anticipate and avoid. The potential solution is the choice of another border crossing. However, the vehicle is often conditioned to cross border in a certain place defined in instructions of the importer. In the case of holidays and non-working days, the congestion is additionally increased. In addition to the above mentioned, there are also the following risks: traffic accident, vehicle malfunction, damaged goods in transport, improper packaging, inappropriate temperature, etc.

In the process of import clearance, the most important failure is congestion in customs offices with the score 0.65. The delays in the arrival of the vehicle to the customs office mean the impossibility of starting the customs clearance procedure, so the clearance procedure is postponed for the following day. Defined terms of delivery cannot be realized in this case. Retention can be on loading, during the road, at the border, as well as in the customs office. The late arrival of the vehicle has a negative impact on all participants. In addition, there are also the following risks: the customs officer considers subject incomplete, lack of labor in providing freight forwarding services, the importer is not able to pay the customs duties, etc.

As mentioned, in the process of loading, the dominant failure by FMEA-DEA approach is wrong loading address (Table 4). The main problem is the fact that it is not easy to detect this failure. The consequences are also time losses and penalties. The next failure in the process of unloading refers to vehicle arrival after working time. The consequences are postponing the unloading for the following day. Other failures (inappropriate handling equipment, inadequate manipulation of goods while loading and congestion on loading area) have less impact. The process of calculating costs and payments is very important and it is necessary to consider it, especially in the initial part. As shown in Table 4, the most common problem is inadequate calculation and anticipation of costs with the score 0.70. The consequence is the loss of revenue. Before contracting, it is necessary to verify and evaluate the client. Problems with inability to charge services can be overcome by inspecting the client. Inappropriate banking services can cause problems in transfer and realization of payments. According to the previous comments, it can be concluded that a large number of risks affects international commodity flows. Risk management is the key to overcoming potential problems. Setting priorities in risk management is one of the main contributions of the proposed approach.

4.2 Applying FME-DEA approach for risks analysis in product distribution

In this part of the paper, the risks in product distribution are analyzed in more details. The proposed approach is applied in order to determine the priorities of risks in a reliable way. Distribution process analyzed in this paper is presented in Figure 3. One of the first processes is the product ordering with two segments: ordering from suppliers and customer ordering. Warehousing is the next process with two groups of activities: activities related to goods receiving and being stored, and activities related to order processing and preparing for delivery. Order picking, as the work intensive process with a large number of potential failures, is the crucial process in warehouses (Andrejić et al, 2013). Packaging process is realized through merging goods from different segments, forming transport units, goods inspection, as well as loading goods in vehicles. The transport is the key process in the product distribution process and largely affects customer satisfaction (Andrejić et al, 2016). Inventory management is the process that is

related to all mentioned processes. At the end is the unloading process in the retail stores.

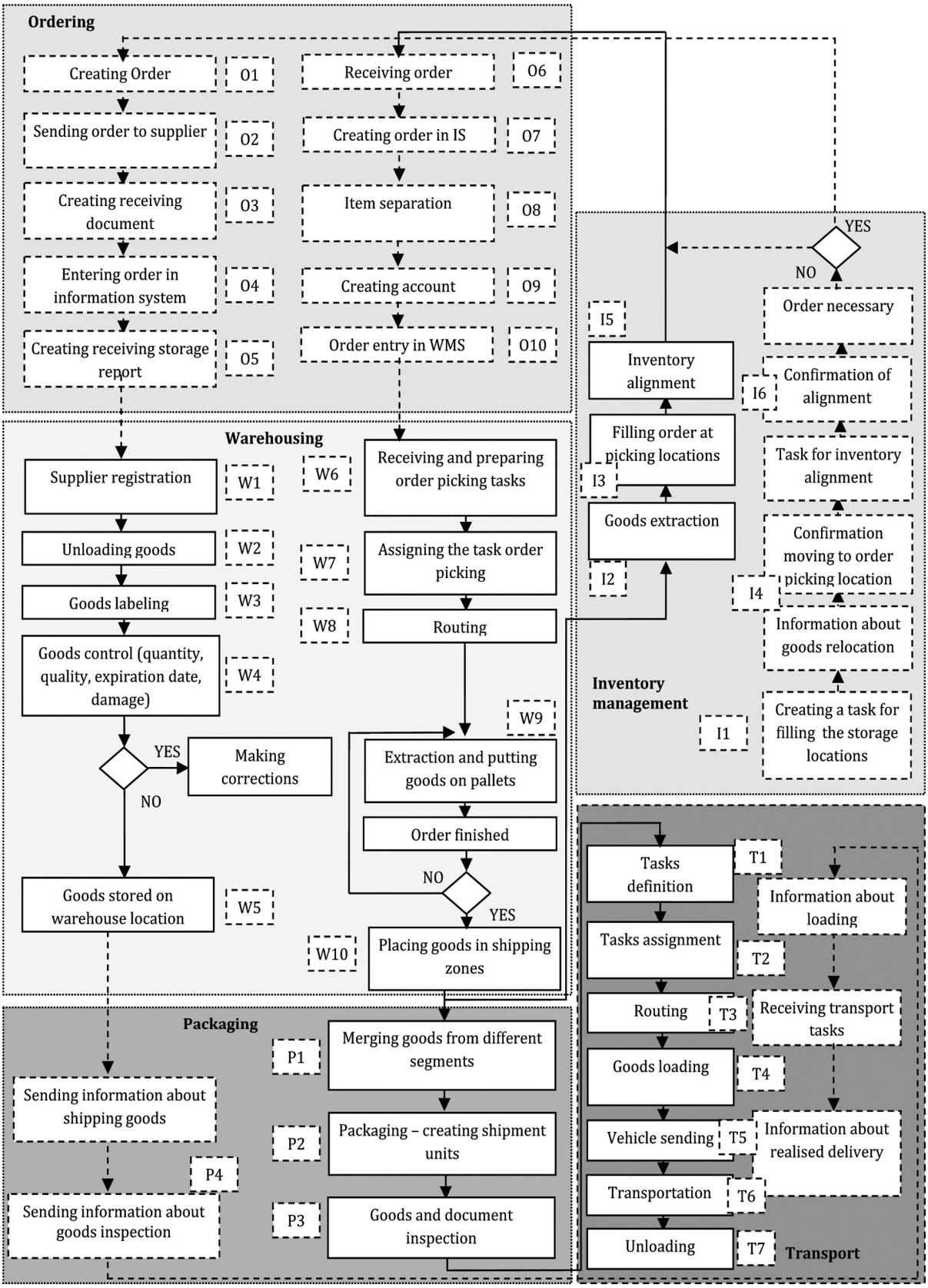


Figure 3. Distribution process decomposition (Andrejić and Kilibarda, 2017)

In order to gain more reliable results for RPN numbers, in this paper, FMEA-DEA approach is used. Results for all 37 activities are shown in Table 5. As mentioned before, in FMEA-DEA approach larger efficiency scores refer to less RPN, and contrary.

Table 5: Analysis of risks in product distribution

Process	*R*	*P*	*N*	*FMEA- DEA RPN*	*Process*	*R*	*P*	*N*	*FMEA - DEA RPN*
O1	6	5	3	0.67	W10	4	3	3	0.67
O2	3	3	3	0.67	P1	8	5	5	0.40
O3	4	5	4	0.50	P2	3	4	3	0.67
O4	6	7	5	0.40	P3	6	5	5	0.40
O5	4	5	4	0.50	P4	2	3	4	1.00
O6	2	2	3	1.00	I1	3	4	4	0.67
O7	6	5	5	0.40	I2	6	6	5	0.40
O8	5	6	3	0.67	I3	4	3	4	0.67
O9	7	5	4	0.50	I4	4	4	4	0.50
O10	4	5	4	0.50	I5	7	6	5	0.40
W1	2	2	2	1.00	I6	4	5	4	0.50
W2	8	5	4	0.50	T1	6	5	5	0.40
W3	5	5	4	0.50	T2	4	3	4	0.67
W4	7	6	7	**0.33**	T3	7	6	5	0.40
W5	4	5	6	0.50	T4	7	7	4	0.50
W6	5	4	4	0.50	T5	4	3	3	0.67
W7	3	3	3	0.67	T6	8	7	7	**0.29**
W8	8	6	5	0.40	T7	7	7	4	0.50
W9	6	6	7	**0.33**					

According to the results, the most critical is the transportation process with the efficiency score 0.29. There are numerous potential risks and failures in transportation process. Transport failures greatly affect delivery process and customer complaints. There are different aspects of transport failures in literature. Delayed shipping is the most important and the most frequent. The potential reasons for this mistake include the driver, congestion, wrong route calculation, etc. Damage of goods in transportation process is also important.

The next process is goods control with the score 0.33. These are problems in the warehousing process when the supplier supplies the goods of low quality and short expiration date. One of the basic steps is to define the level of quality and dimensions (specific checklists) of each unit of goods for each supplier. A relatively small number of employers in this process limit the level of control. Putting away is a very important activity in a warehouse. A large number of mistakes are generated in this process. In real systems, order pickers realize this activity. Frequently, the relocation of order pickers from picking to putting away and control process greatly affects the occurrence of failures and reduces the level of customer service. They realize this process with insufficient attention. Assigning a smaller number of employees to realize only putting away and control processes should reduce failures to minimum. Inappropriate organization of space may affect failures as well. One of the main aims is to reduce the effort in the order picking process. However, a large number of similar items at very short distances can cause failures (Andrejić et al. 2015).

The same situation is with the process of goods extraction and putting on pallets with the efficiency score 0.33. This part of order picking process is the most critical, which

confirms the value of risk priority number. There are different criteria for identification of failures in the order–picking process. According to the place of identification, there are internal (in house) and external (outside) failures. In the literature, there are four basic categories of failures: typing failures (addition, confusion, etc.), failures in amount (shortage, excess, etc.), omission failures, and condition failures (damage, lack of packaging, labeling). On the other side, there are processes with the efficiency score 1 (supplier registration, sending information about the goods inspection, etc).

4. CONCLUSION

Logistics as very complex industry with a large number of entities is threatened by numerous risks. Risks in logistics vary by system type and level of observation. For risk management in logistics, it is important to have appropriate tools and approaches. In this paper, FMEA-DEA approach for risks in logistics is proposed. The proposed approach has improved the process of calculating the RPN number in a more reliable way, since it does not require specifying the risk factor weights subjectively. The proposed approach is tested on two real cases. In organizing international commodity flows, 58 risks are identified. According to the calculated priorities, the most important risks are congestion (border, customs offices, incomplete documentation, wrong addresses (loading/unloading), etc.) In the set of 37 activities, the risks with the highest priority are: delay in transportation process, goods control (low quality, short expiration date) and order-picking process (goods extraction and putting on pallets), etc. Future research should be directed in several directions. The first direction refers to the testing of multiple, simultaneous and conditioned risks influencing the logistics. The second direction relates to determining the costs of risk management and the cost of correcting the resulting consequences. In future research, it is necessary to pay more attention to real systems and concrete cases rather than theoretical models with numerous limitations in practical application.

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DEFINING THE TYPICAL STRUCTURES OF THE INTERMODAL TERMINALS

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Abstract: *Intermodal transport enables energy, costs and time savings, improves the quality of services and supports sustainable development. The basic element of the intermodal transport system is the intermodal terminal (IT) whose efficiency largely depends on its' structure defined by a combination of different characteristics and modalities of elements, such as the structure of functions and services, sub-system technologies, size, location, layout, etc. Accordingly, the subject of this paper is the development of a methodology for defining typical IT structures based on a wide range of structural elements and factors that affect elements and define their significance. The methodology also included the multi-criteria decision-making (MCDM) model that combines the fuzzy Delphi method, used for evaluating the strength of the factor's influence on the elements, and the fuzzy VIKOR (VišeKriterijumska Optimizacija i kompromisno Rešenje, srb) method, used for ranking and selecting the key elements for defining the IT structure. The aim of this paper was to identify typical IT structures as a prerequisite for their further analysis and selection of those that would represent benchmarks for other terminals with mutually comparable characteristics. The following are identified as the key elements for defining the IT structure: modes of transport connecting the IT, place and role of the IT in the network/chain, size of the IT and the structure of the functions and services that IT performs. Based on the possible combinations of their modalities and research which included over 180 real-life ITs in Europe, 36 typical IT structures are defined.*

Keywords*: intermodal transport, intermodal terminal, typical structure, fuzzy Delphi, fuzzy VIKOR.*

1. INTRODUCTION

Economic globalization and market liberalization have led to the separation of the places of production and consumption, which has resulted in the significant growth of the world trade and intercontinental goods flows. The realization of these flows mainly involves the use of different transport modes, as well as the need to interconnect them. On the other hand, the transport sector faces serious problems as it generates negative economic, social, environmental and other impacts, mainly due to the intensive growth of the road freight transport (Krstić et al., 2019a; Zečević et al., 2017a). Given that the

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traditional methods of development and improvement of individual modes of transport are not able to tackle with these problems (Barysienė, 2012), the solution is sought in the integration of different transport modes through the intensified development of the intermodal transport, with the aim of shifting freight flows from road to the alternative transport modes (EC, 2011). Intermodal transport represent the transport of goods in one and the same loading unit or vehicle using multiple transport modes, where there is no transshipment of goods between the transport modes (ECMT, 1993). The main goal is the application of the different transport modes in order to reduce the overall costs and improve the quality of services. Energy, cost and time savings, less environmental pollution and other positive effects of intermodal transport have been attracting the growing attention in the developed European countries (Caris et al., 2013). The European Union (EU) set the objectives to shift the 30% of the road freight transport at distances over 300 km to the more environmental friendly transport modes (rail, water) by 2030, and 50% by 2050 (EC, 2011). These goals can only be achieved through more intensive development of the intermodal transport.

One of the basic intermodal transport subsystems are intermodal terminals (IT), which represent places for storing and transporting intermodal transport units (ITU) between the different transport modes (UNECE, 2009). ITs represent very important nodes of the transport network that serve as the links between the different transport modes and can have different structures obtained by combining different elements such as the structure of functions, services and subsystems, the place and role in the network, subsystem technology, location, size and layout, etc. In the literature, there are papers in which attempts have been made to define the typical terminal structures (e.g. Kutin et al., 2017; Park & Medda, 2010; Roso et al., 2009; Woxenius, 2007, Sirikijpanichku & Fereira, 2005). However, in these papers the terminal structures are predominantly defined only in relation to one or a few elements. Theoretically, by combining different modalities and characteristics of structural elements, large number of different terminal structures can be formed, but in practice exist typical structures, largely depending on several key elements. The subject and main contribution of this paper is the development of a methodology for defining typical IT structures that involves identifying a wide sets of structural elements and factors that influence these elements, as well as the multi-criteria decision-making (MCDM) model based on which the evaluation and selection of the key elements have been performed. The developed MCDM model is based on the integration of the Delphi and VIKOR (*VišeKriterijumska Optimizacija i kompromisno Rešenje*, srb) methods in the fuzzy environment, where the fuzzy Delphi method was used to define the strength of the factor's influence on the elements, and the fuzzy VIKOR method for ranking and selecting the key elements on the basis of which the typical terminal structures are defined. The goal of defining the typical IT structures is to create preconditions for comparing their basic characteristics, performance, efficiency, etc., in order to identify those that can serve as the benchmarks for other ITs that have the potential to develop into these structures or as a model for the development of future ITs.

The paper is organized as follows. First, the elements for defining the IT structure, as well as the factors influencing these elements and their significance, are identified and described. Afterwards, the MCDM model is described, based on which the structural elements are ranked and the key elements selected. By combining the various characteristics and modalities of the identified key elements and by researching 180 ITs

across Europe, typical IT structures are defined. Finally, concluding remarks and future research directions are provided.

2. ELEMENTS AND FACTORS FOR DEFYNING THE IT STRUCTURE

As already mentioned, the IT structure is defined by a combination of different elements. The combinations are affected by many factors which define and shape the basic requirements that a terminal of a certain structure must perform. Factors may affect one or more elements of the structure and may have a different significance. The following lists and explains the elements for defining the structure, as well as the factors affecting them.

2.1 Elements for defining the IT structure

The elements for defining the IT structure can be classified into four levels (Krstić et al., 2019b): organizational, operational, physical/spatial and technological. Organizational level consists of elements such as: founders and owners (E_1), organizational structure (E_2) and place and role in the network chain (E_3). ***The founders and owners*** represent the investors, i.e. the owners of the capital used for the construction of the IT. In the literature there are various classifications of financing models (Beth, 1985; Alderton, 1999) and according to the ownership of the capital, financing can be (Cullinane & Song, 2002): public, privat or public-private partnership (PPP). In practice, ITs are most often established on the basis of the PPP (Tadić & Zečević, 2010). ***The organizational structure***, i.e. the management model implies distribution of responsibilities, allocation of resources and management of relationships, behavior and activities in the IT in order to achieve the desired business outcome. This topic was elaborated by Vieira & Neto (2016), Bichou & Gray (2005), Monios (2015), and others, while the particularly interesting is the classification of management models based on the relationship between the owner and operator of the terminal, i.e. who employs the personnel, who owns the infrastructure and superstructure and who manages them, i.e. who makes operational decisions (Krstić et al., 2019b). Transport systems are characterized by the movement of goods through the networks where ITs represent nodes of the logistics, i.e. transport networks, in which processes of transshipment, changes in transport means and modes, storage, consolidation, sorting, and others are realized depending on ***the place and role in the network*** (Tadić & Zečević, 2012). According to this element the ITs can be classified in different ways (Park & Medda, 2010; Woxenius, 1997), and the basic classification is on the maritime and inland ITs (Krstić et al., 2019b).

Operational level consists of the following elements: type of cargo/transport unit (E_4), structure of functions and services (E_5) and IT users (E_6). Although by the definition only ITUs are being manipulated in the IT, in practice different ***types of cargo and transport units*** may appear (Notteboom & Rodrigue, 2009; Middendorf, 1998). IT, depending on the size, volume and intensity of flows, user requests and other influences, may have different ***structure of functions and services***. In the literature there are different classifications of the IT functions (e.g. de Villiers, 2015; Wiegmans et al., 1999), and according to Zečević (2006) ITs can be divided into four categories: A, B, C and D, expanding the range of services from basic (receiving, transshipping, loading and shipping of transport means and ITUs) to VAL (Value Added Logistics) services. ***IT users***

are the customers of the services which can be physical or legal entities (more often legal entities), owners or organizers of freight and transport flows passing through the IT (Zečević, 2006). They can be divided into those whose core business is logistics and organization of goods transport, and those to whom this is not the core business (Krstić et al., 2019b; Wiegmans et al., 1999).

Physical/spatial level includes the following elements: location (E_7), size (volume and intensity of flows) (E_8), territory coverage (E_9) and spatial organization - layout (E_{10}). The successful functioning of IT depends to a large extent on its ***location*** (Zečević et al., 2017a), which should be considered in terms of the macro (Teye, 2017) and the micro environment (Zečević, 2006). Considering ***the size*** different classifications of the ITs may appear, based on different measuring units: the volume of flows that pass through the IT, the land area of the IT, the number of present transport modes, etc. (Notteboom & Rodrigue, 2009; ITIP, 2001; Wiegmans et al., 1999). IT can have different ***territory coverage***, i.e. ***catchment areas*** . Catchment area is the space of origin/destination of the goods and-transport flows which at one stage pass through the IT (Zečević, 2006). One IT can have different catchment areas for different goods and transport flows, transport chain technologies and different service types (Zečević, 2006). IT can appear in different variations in relation to the ***spatial organization*** of subsystems. While planning the IT layout, a number of parameters, potential constraints and potential stochastic interactions between the subsystems, potential technologies, volume and flow structure, present modes of transport, etc. must be taken into account. (Zhang et al., 2016; de Villiers, 2015; Roy & de Koster, 2013). The basic IT layout classification can be done according to the present modes of transport (Krstić et al., 2019b).

Technological level includes the elements: connection of transport modes and transport chain technologies (E_{11}), subsystems structure (E_{12}) and basic subsystems technologies of the IT (E_{13}). IT can connect different ***modes of transport*** (water, rail, road and much less air) and ***technologies for the realization of transport chains*** (Notteboom & Rodrigue, 2009; Nazari, 2005). ***IT subsystems*** are functionally rounded units within the systems that are responsible for the partial or complete realization of one or more functions. Various examples of the subsystems structure can be found in the literature (Kemme, 2013; Brinkmann, 2011; Steenken et al., 2004), and each subsystem enables the realization of certain requirements, i.e. terminal services, by using the technological elements. However, the ***technologies of the basic subsystems*** of transport (Steenken et al., 2004), storage (Kalmar, 2011) and transshipment (Krstić et al., 2019a) have the greatest influence on the other structure elements.

2.2 Factors influencing the definition of the IT structure

Based on the character and type of influence, the factors can be classified as: internal factors, factors of logistics flows requirements and environmental factors. The above factors influence the structural elements of IT, and these influences, as well as the links between the factors and elements are shown in Table 1. Based on the literature review (Heljedal, 2013, Bergqvist et al., 2010; Roso, 2008; Zečević, 2006) the following lists and explains all factors.

Table 1. Relations between the factors and the elements for defining the IT structure

	Founders /owners	Organizational structure	Place/role in network	Type of cargo/ITU	Functions and services	Users	Location	Size	territory coverage	Layout	Transport modes	Subsystems structure	Subsystems technology
Technological performance				●	●					●	●	●	●
Spatial performance							●	●		●		●	●
Financial performance	●	●	●		●	●	●	●	●		●		●
Location performance			●			●	●	●	●	●	●		
Ownership/organizational performance	●	●	●			●							
Logistics strategies	●	●	●		●	●	●		●		●		
Flow features			●				●	●	●		●		
Quality requirements			●		●	●	●	●	●	●	●	●	●
Cargo features				●	●	●	●	●		●	●	●	●
Network and transport chains features			●		●	●	●	●	●		●	●	●
Spatial and business plans							●	●	●	●	●		
Economic/organizational features	●	●	●			●	●	●	●				
Laws	●	●					●				●		
Social factors				●			●				●		●
Geographical features							●	●		●	●		●
Infrastructure features							●	●	●	●			●
Traffic and logistics features			●		●	●	●	●	●		●		●
Geological features							●	●		●			
Climatic features				●			●			●	●		●
Environmental factors				●			●			●	●		●

Internal factors include certain IT performances (technological, spatial, financial, location and ownership/organizational) which define the requirements for arrangement of the certain structure functioning. ***Technological performances*** (F_1) define the requirements in terms of the efficiency of processes and activities and achieving the appropriate values of performance indicators (storage capacity, speed and intensity of transshipment, time of holding the vehicles in the system, etc.), as well as the basic characteristics of IT subsystems technologies. ***Spatial performances*** (F_2) define the requirements for the surface sizes of the IT, as well as their basic characteristics in terms of shape, geometry, position, connectivity, availability, etc., so that all physical components of the IT are adequately fitted and efficiently functioning. ***Financial performances*** (F_3) refer to defining the requirements regarding the necessary finances, sources and method of financing, profitability of investments, i.e. fund return possibilities, etc. Each terminal subsystem requires certain investments, generates costs and allows revenues, and its justification interacts with a large number of variables from the environment (Zečević et al., 2006). The financial justification performances affect the majority of the IT structural elements (Table 1). ***Location performances*** (F_4) refer to the definition of requirements for the macro and micro location of the IT, as its position in relation to important economic, traffic, social and other content. ***Ownership/organizational performances*** (F_5) define the basic characteristics, requirements, advantages and disadvantages of different models of establishment, management and organization of ITs, in order to select the appropriate model in the planning process. Adequate definition of these performances for different IT structures is aimed at achieving a high level of their efficiency.

Factors of logistics flows requirements include the requirements generated by goods and transport flows that pass through the IT, as well as the requirements of the participants in these flows. Logistics strategies, flow features, quality requirements, goods features, networks and transport chains features belong to this group of factors. ***Logistics strategies*** (F_6) define the requirements for realization of logistics activities and may affect founders and owners, organizational structure, structure of functions and services, terminal users, but also the place and role of the IT in the network/chain, location, territory coverage and transport modes and transport chain technologies (Table 1). ***Flow features*** (F_7), i.e. rules of flows creation, place and time of the beginning/end of flows, main features, i.e. whether flows are stationary or non-stationary, deterministic or stochastic, continuous or discontinuous, homogenous or heterogeneous, etc. affect the place and role of the terminal in the network/chain, location and size of the terminal, territory coverage, transport modes and transport chain technologies (Table 1). ***Quality requirements*** (F_8) refer to requirements regarding the features of the IT services, such as reliability, flexibility, availability, accuracy, information exchange, etc., thus directly affecting multiple structural elements of the terminal (Table 1). ***Cargo features*** (F_9) such as: type of cargo, package options, quantity, physical state, degree of cargo danger, deterioration, sensitivity, etc., mostly affect the definition of IT structure in terms of the type of cargo/transport units, but also on other structural elements. ***Networks and transport chains features*** (F_{10}), i.e. the size and structure of the logistics network, available transport modes, etc., set the requirements that terminals have to fulfill in order to enable their efficient functioning in the network and servicing different transport modes. This factor has the greatest impact on the place and role of the terminal in the network/chain, and transport modes and transport chain technologies.

Environmental factors represent various external factors which, according to their character, can be regulatory/social (spatial and business plans, economic/organizational features, laws and social factors), and physical (geographical, infrastructure, traffic and logistic, geological, climatic and ecological features). ***Spatial and business plans*** (F_{11}) refer to urban plans, spatial planning plans, general and detailed regulation plans, economy development strategies etc., which can have a significant impact on the various elements of the IT structure, above all on the location, size and layout of the terminal (Table 1). ***Economic/organizational features*** (F_{12}), refer to the presence of economic systems in the field of logistics, management, information technologies, etc. which affect the organizational structure, founders and owners, coverage of the territory, users, location, place in the network and size. ***Laws*** (F_{13}) in the field of traffic and transportation, spatial planning, financing and management of economic entities, environmental protection, etc. can significantly affect the IT structural elements, above all founders and owners, organizational structure, location and layout of the terminal, etc. ***Social factors*** (F_{14}) refer to the influence of the local population on defining the structure of the terminal. Residents have certain requirements related to the realization of goods and transport flows, i.e. on the effects of their realization, which can significantly affect the location, type of cargo, transport modes and transport chain technologies, subsystems technologies and other elements of the IT structure (Table 1). ***Geographical features*** (F_{15}) refer to the relief of the land, the topology and slope of the terrain, the proximity of river flows and other features that may have an impact on the IT structural elements, primarily on the location, size and layout of the terminal, transport modes and transport chain technologies, as well as subsystems technologies..

Infrastructure features (F_{16}) refer to the presence, level of construction and state of the utility infrastructure (water supply, sewage, gas pipeline, etc.), which can significantly affect primarily the location, size and layout of the terminal, as well as the subsystems technologies ***Traffic and logistics features*** (F_{17}) refer to the characteristics of the transport infrastructure, such as the degree of construction, density of the traffic network, condition or the quality of the infrastructure, etc. which affects the possibility of using different transport modes and accessing the significant transport routes. This factor has the greatest impact on transport modes and transport chain technologies, but also on the place and role in the network, subsystems technologies and users. ***Geological features*** (F_{18}) refer to basic soil characteristics such as the soil composition, erosion, landslides, groundwater, etc., which may affect terminal structure elements such as: location, size, and layout. ***Climatic features*** (F_{19}) refer to the effects of temperature, humidity, average rainfall, water flows of nearby rivers (i.e. flood risk), etc. which may affect the IT structural elements, primarily location and layout (Table 1). ***Environmental features*** (F_{20}) include influences that can lead to the negative effects on the environment and are caused by the goods and transport flows. This factor mostly affects the location, transport modes and transport chain technologies, as well as the layout, type of cargo and subsystems technologies.

3. SELECTION OF THE KEY ELEMENTS FOR DEFINING THE IT STRUCTURE

In the previous section, the elements for defining the IT structure and the factors that influence these elements are explained. Not all the elements have the same significance and influence on the definition and design of the IT structures, therefore it is necessary to distinguish the most important, key elements. To accomplish this task, a hybrid model based on the fuzzy Delphi and the fuzzy VIKOR method is proposed. These are MCDM methods, but in this paper instead of criteria, factors will be evaluated, and instead of alternative elements for defining the IT structure. The basic characteristics of the methods, the reasons and steps of their application, as well as the process of ranking the elements are explained below.

3.1 Hybrid fuzzy Delphi-VIKOR model for ranking the elements of the IT structure

The first part of the model uses fuzzy Delphi method in order to gather the information and from a broader set factors extract those which are, according to the decision makers (DM), i.e. members of the stakeholders, relevant for ranking the structure elements. The traditional Delphi method was first proposed by Dalkey & Helmer (1963), and it has been widely applied in various areas. The aim of the method is to collect data from the field of expertise of the participants. The method is defined as a process of group communication through which the convergence of thoughts about a particular real problem is achieved. It is suitable for achieving the consensus through a series of questionnaires by which the data from a group of selected participants (DMs) are collected in multiple iterations. The Delphi method is characterized by the anonymity, iteration, controlled feedback, statistical group response, and stability in responses among the DMs on a specific issue (Shen et al., 2011). However, although the Delphi method provides a chance to completely integrate diverse DMs' opinions, it is time-consuming, costly, and has a lower questionnaire return rate because it tries to obtain converged results through repetitive surveys. In addition, the problems of imprecise,

vague and ambiguous evaluations of the DMs, due to incomplete information or inability of their treatment in a decision environment, are also present. As one of the possible ways to overcome the problems and limitations of the Delphi method, Murry et al. (1985) suggested the involvement of the fuzzy set theory (Zadeh, 1965) which can efficiently deal with the vagueness in thinking and expressing preferences of DMs. Since its first application, fuzzy Delphi method has been applied in many MCDM problems from various fields, either alone or in a combination with other methods (e.g. Tadić et al., 2019; Tadić et al., 2018; Zečević et al., 2017a; Tadić et al., 2016b; Mikaeil et al., 2013; Daim et al., 2012, Shen et al., 2011). The fuzzy Delphi method can obtain converged responses of the DMs with fewer survey rounds, or even in a single round, and effectively conduct the ambiguity and uncertainty of the DMs' evaluations (Klir & Folger, 1988). In the process of the group decision-making it integrates the opinions of all DMs with the aim of achieving the consensus with significant time and cost savings (Mikaeil et al., 2013).

The second part of the model refers to the application of the fuzzy VIKOR method for the evaluation and ranking of the elements for defining the IT structure in relation to the impact factors. The VIKOR method is chosen due to its advantages over some other methods (Caterino et al., 2008). The VIKOR method (Opricovic, 1998) is an MCDM method that can help the DMs to optimize the complex systems, i.e. to solve discrete decision-making problems with conflicting criteria. The method performs ranking of the alternatives on the basis of criterion functions and the selection of a compromise solution that is closest to the ideal alternative. The solution is considered to be a compromise because it is obtained by mutual concessions, i.e. it provides a maximum group utility and a minimum individual regret of the opponent. In order to solve the problem of imprecision in expressing DMs' preferences, Opricovic (2007) extended the VIKOR method in fuzzy environment, and since then it has been successfully applied in many fields, alone or in combination with other methods (e.g. Zečević et al., 2017a; Zečević et al., 2017b; Tadić et al., 2017; Tadić et al., 2016a; Tadić et al., 2015; Tadić et al., 2014; Zečević et al., 2014; Chang, 2014, Opricovic, 2011). The following explains the application steps, and the schematic representation is given in Figure 1.

Step 1: Define the structure of the evaluation model. It is necessary to identify the problem and the stakeholders interested in its solution, define the sets of IT structural elements and the factors for their evaluation.

Step 2: Define the fuzzy scale for the evaluation of the factors and elements by the DMs. Nine-point linguistic scale with the corresponding triangular fuzzy numbers is defined in this paper and shown in Table 2.

Table 2. Linguistic terms and corresponding fuzzy values

Linguistic term	Abbreviations	Fuzzy scale
None	N	(1, 1, 2)
Very Low	VL	(1, 2, 3)
Low	L	(2, 3, 4)
Fairly Low	FL	(3, 4, 5)
Medium	M	(4, 5, 6)
Fairly High	FH	(5, 6, 7)
High	H	(6, 7, 8)
Very High	VH	(7, 8, 9)
Extremely High	EH	(8, 9, 10)

Step 3: Evaluate and select the factors for the evaluation of the elements by applying the fuzzy Delphi method (Hsu & Yang, 2000).

Step 3.1: Obtain the evaluations of the factors by the DMs and transform them in the triangular fuzzy numbers by applying the relations given in Table 2.

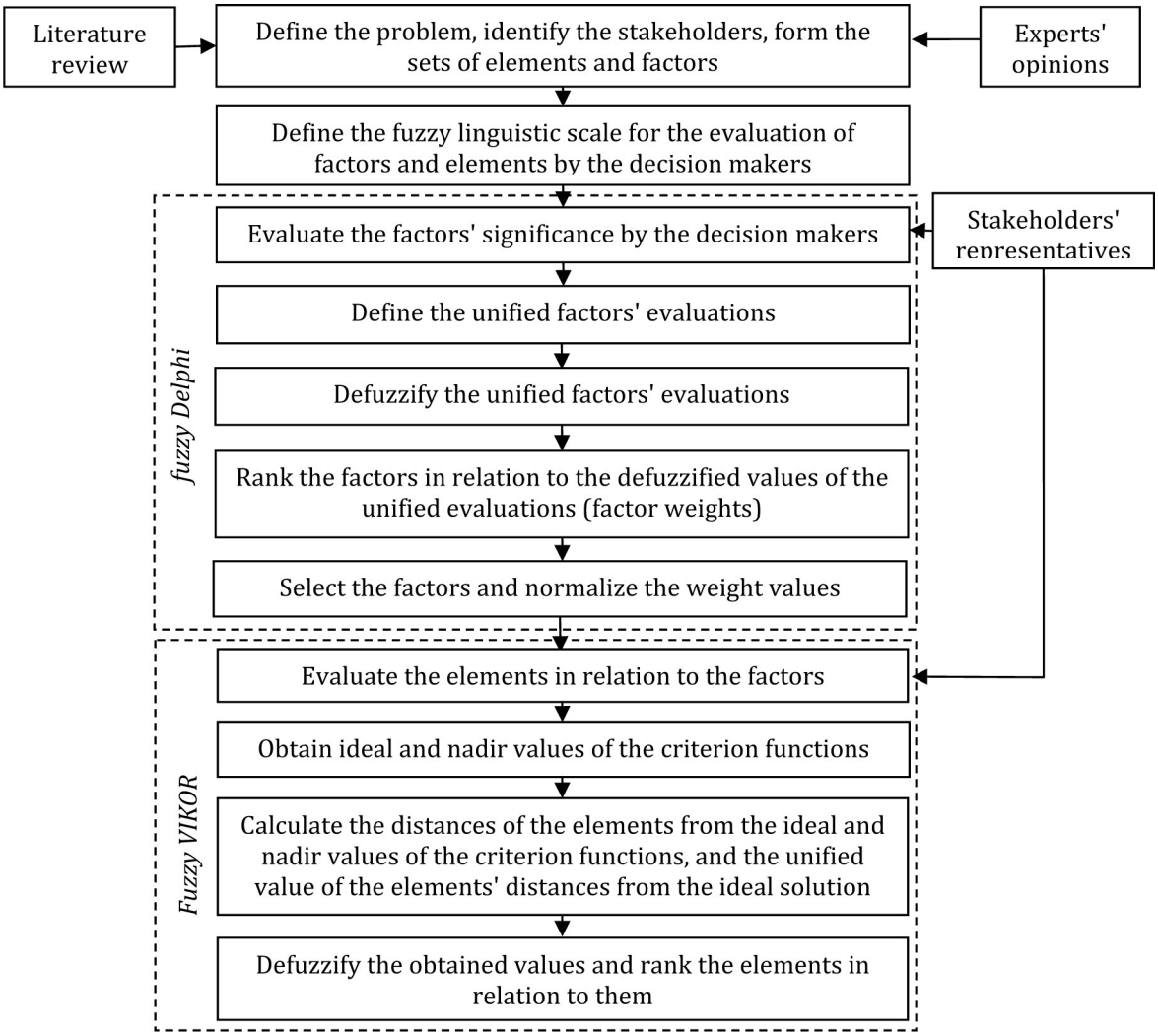


Figure 1. Schematic representation of the proposed fuzzy Delphi-fuzzy VIKOR model

Step 3.2: Define the unified evaluations of the factors. The general approach for establishing unified evaluations is as follows:

$$\tilde{\delta} = (\alpha, \beta, \gamma) \tag{1}$$

$$\alpha = Min(l_k), \;\; k = 1, \dots, n \tag{2}$$

$$\beta = \left(\prod_{k=1}^{n} m_k\right)^{1/n}, \;\; k = 1, \dots, n \tag{3}$$

$$\gamma = Max(r_k), \;\; k = 1, \dots, n \tag{4}$$

where α, β and γ are the left, medium and right values of the unified fuzzy value $\tilde{\delta}$, respectively, and $\alpha \leq \beta \leq \gamma$. l_k, m_k and r_k are the left, medium and right values of the triangular fuzzy evaluation which indicates the importance of the factor in relation to the stakeholder k. n is the number of the considered stakeholders.

As it is necessary in this step to unify the evaluations of the sub-criteria with respect to each stakeholder, by applying the equations (1-4) for the fuzzy evaluations $\tilde{b}_{jk} = (l_{jk}, m_{jk}, r_{jk})$ of the importance of the factor *j* with respect to the stakeholder *k*, unified fuzzy evaluations $\tilde{\delta}_j = (\alpha_j, \beta_j, \gamma_j)$ for the factors *j*, *j=1,..,f*, are obtained, where *f* is the number of factors.

Step 3.3: Defuzzify the values. For the defuzzyfication of the triangular fuzzy values, in this paper is used the equation with the general form (Kutlu & Ekmekcioglu, 2012):

$$crisp(P) = (\alpha + 4\beta + \gamma)/6 \tag{5}$$

where *crisp(P)* represents the defuzzyfied value of some fuzzy value $\tilde{P} = (\alpha, \beta, \gamma)$. Accordingly, defuzzyfied value of the unified evaluation *crisp(δ_j)* s obtained by applying equation (5) for the unified fuzzy evaluation $\tilde{\delta}_j = (\alpha_j, \beta_j, \gamma_j)$. These defuzzyfied values represent the weights of the factors (w_j) as well as the values based on which the selection of the factors that require further consideration is performed.

Step 3.4: Select the factors. The appropriate set of factors for the evaluation of elements is obtained by setting the threshold θ. The sifting principles are as follows:

$if\ crisp(\delta_j) > \theta$ factor *j* is acceptable,

$if\ crisp(\delta_j) < \theta$ factor j is unacceptable.

The threshold depends on the way the questionnaire is formed, and the scale used for the evaluation (Shen et al., 2010).

Step 3.5: Normalize the weight values. The obtained factor weights need to be normalized by applying the following equation:

$$w_j^N = \frac{w_j}{\sum_{j=1}^{s} w_j},\ \ j = 1, \dots, s \tag{6}$$

where w_j^N is the normalized factor weight, and s is the total number of selected factors.

Step 4: Evaluate the elements and rank them by applying the fuzzy VIKOR method. DMs evaluate the elements (*i*) in relation to the factors (*j*) and their evaluations are then converted into the triangular fuzzy numbers using the relations given in table 2. The values of the elements are obtained by applying the fuzzy VIKOR method. The procedure is adapted from Opricovic (2011), and computational steps are described below.

Step 4.1: Form the fuzzy performance matrix ($\widetilde{D}$) members of which are the triangular fuzzy numbers representing the unified evaluations of the elements, in relation to the factors:

$$\widetilde{D} = \begin{array}{c} \\ E_1 \\ E_2 \\ \vdots \\ E_o \end{array} \begin{array}{c} \begin{array}{cccc} F_1 & F_2 & \dots & F_s \end{array} \\ \begin{bmatrix} \tilde{e}_{11} & \tilde{e}_{12} & \dots & \tilde{e}_{1s} \\ \tilde{e}_{21} & \tilde{e}_{22} & \dots & \tilde{e}_{2s} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{e}_{o1} & \tilde{e}_{o1} & \dots & \tilde{e}_{os} \end{bmatrix} \end{array} \tag{7}$$

where E_i denotes the element *i*, *i = 1,...,o*, *o* represents the total number of elements; F_j represents the factor *j*, *j = 1,...,s*; $\tilde{e}_{ij} = (l_{ij}, m_{ij}, r_{ij})$ denotes the triangular fuzzy evaluations of the element E_i in relation to the factor F_j.

Step 4.2: Obtain the ideal $\tilde{e}_j^* = \left(l_j^*, m_j^*, r_j^*\right)$ and the nadir $\tilde{e}_j^\circ = \left(l_j^\circ, m_j^\circ, r_j^\circ\right)$ values of the criterion functions, i.e. of the evaluations of the elements in relation to the factors:

$$\tilde{e}_j^* = \max_i \tilde{e}_{ij}, \quad \tilde{e}_j^\circ = \min_i \tilde{e}_{ij}, \quad za\ j \in J^b \tag{8}$$

$$\tilde{e}_j^* = \min_i \tilde{e}_{ij}, \quad \tilde{e}_j^\circ = \max_i \tilde{e}_{ij}, \quad za\ j \in J^c \tag{9}$$

where J^b and J^c are the sets of factors representing benefits (higher evaluations by these factors lead to higher ranking of the element) and costs (lower evaluations lead to higher ranking), respectively.

Step 4.3: Calculate the normalized fuzzy difference $\tilde{d}_{ij}$:

$$\tilde{d}_{ij} = \frac{\tilde{e}_j^* \ominus \tilde{e}_{ij}}{r_j^* - l_j^\circ} \quad za\ j \in J^b \tag{10}$$

$$\tilde{d}_{ij} = \frac{\tilde{e}_{ij} \ominus \tilde{e}_j^*}{r_j^\circ - l_j^*} \quad za\ j \in J^c \tag{11}$$

Step 4.4: Calculate the values $\tilde{S}_i = \left(S_i^l, S_i^m, S_i^r\right)$, which represent the fuzzy weighted distance of the element E_i from $\tilde{e}_j^*$ and the values $\tilde{R}_i = \left(R_i^l, R_i^m, R_i^r\right)$, which represent the fuzzy weighted distance of the element E_i from $\tilde{e}_j^\circ$, by applying the following equations:

$$\tilde{S}_i = \sum_{j=1}^{s} w_j \otimes \tilde{d}_{ij} \tag{12}$$

$$\tilde{R}_i = \max_j w_j \otimes \tilde{d}_{ij} \tag{13}$$

Step 4.5: Calculate the values $\tilde{Q}_i = \left(Q_i^l, Q_i^m, Q_i^r\right)$, i.e. the overall distances of the elements from the ideal solution, by the equation:

$$\tilde{Q}_i = v \frac{\tilde{S}_i \ominus \tilde{S}^*}{S^{\circ r} - S^{*l}} \oplus (1 - v) \frac{\tilde{R}_i \ominus \tilde{R}^*}{R^{\circ r} - R^{*l}} \tag{14}$$

where $\tilde{S}^* = \min_i \tilde{S}_i$, S^{*l} is the lower value of the triangular fuzzy number $\tilde{S}^*$, $S^{\circ r} = \max_i S_i^r$, $\tilde{R}^* = \min_i \tilde{R}_i$, R^{*l} is the lower value of the triangular fuzzy number $\tilde{R}^*$ i $R^{\circ r} = \max_i R_i^r$. The value v is introduced as a weight for the strategy of "the majority of criteria" (or "the maximum group utility"), whereas $1 - v$ is the weight of the individual regret.

Step 4.6: Defuzzify the values $\tilde{S}_i$, $\tilde{R}_i$ and $\tilde{Q}_i$ by applying the equation (5).

Step 4.7: Rank the elements according to the increasing crisp values. The results are three ranking lists $\{E\}_S$, $\{E\}_R$ and $\{E\}_Q$ obtained by the values *crisp(S)*, *crisp(R)* and *crisp(Q)*, respectively.

Step 4.8: Propose as a compromise solution the element $E^{(1)}$ which is the best ranked by the value of Q, if the following two conditions are satisfied: Co.1. "Acceptable Advantage": $Adv \geq DQ$ where $Adv = \left[Q\left(E^{(2)}\right) - Q\left(E^{(1)}\right)\right] / \left[Q\left(E^{(o)}\right) - Q\left(E^{(1)}\right)\right]$ is the advantage rate of the element $E^{(1)}$ in relation to the element ranked as the second $E^{(2)}$ in the list $\{E\}_Q$, and $DQ = 1/(o - 1)$ is the threshold from which the advantage rate (Adv) has to be higher. Co.2. "Acceptable stability in decision making": The element $E^{(1)}$ must also be the best ranked by S or/and R. If one of the conditions is not satisfied, then a set of compromise solutions is proposed, which consists of: CS1. The elements $E^{(1)}$ and $E^{(2)}$ if only the condition Co.2 is not satisfied, or CS2. The elements $E^{(1)}, E^{(2)}, \ldots, E^{(0)}$ if the

condition Co.1 is not satisfied; $E^{(0)}$ is determined by the relation $\left[Q\left(E^{(O)}\right) - Q\left(E^{(1)}\right)\right] / \left[Q\left(E^{(o)}\right) - Q\left(E^{(1)}\right)\right] < DQ$ for maximum E - the total number of the elements (the positions of these elements are "in closeness"), where $E^{(0)}$ is the last ranked element in relation to Q, and $E^{(o)}$ is the element with the highest index value.

3.2 Application of the hybrid fuzzy Delphi-VIKOR model for ranking and selection of the key elements of the IT structure

The proposed hybrid fuzzy Delphi-VIKOR model is used to rank the elements of the IT structure based on the previously described factors. The first step in applying the model is to evaluate the importance of factors by the DMs belonging to different stakeholder groups (founders/owners and operators - Fo., users - Us., and administration and residents - Ad.). The founders/owners and operators as the main goal have the maximization of profit as a result of successful IT operation, users goal is to get the quality service at a reasonable price, and administration and residents goal is the economic development of the region (city, state) and the preservation of the environment. The relations given in Table 2 are used for the evaluations of the factors. Using the equations (1 - 4) evaluations of the DMs are unified, after which they are defuzzyfied using the equation (5). Defuzzyfied values are then used for factor ranking and selection of those that have a significant effect on IT structure elements. Value of 4.5 for the θ is adopted. Defuzzyfied values of the selected factors were then normalized using the equation (6) and these values were used in the second part of the model as the weights of the factors for the evaluation of the structural elements. The evaluations of the DMs, unified evaluations, defuzzyfied factor values, and the final normalized weights of the factors are given in Table 3. From Table 3 it can be seen that 6 factors are labeled as unacceptable, which means that they will not be considered when ranking the elements for defining the IT structure.

Table 3. Evaluation and selection of the factors for IT structure elements ranking

Factor	Fo.	Us.	Ad.	Unified	Defuzzified	Selection	Normalized
F_1	(7,8,9)	(6,7,8)	(2,3,4)	(2.00,4.82,9.00)	5,047	Selected	0,063
F_2	(7,8,9)	(5,6,7)	(2,3,4)	(2.00,4.58,9.00)	4,886	Selected	0,061
F_3	(8,9,10)	(4,5,6)	(2,3,4)	(2.00,4.48,10.00)	4,988	Selected	0,062
F_4	(6,7,8)	(6,7,8)	(5,6,7)	(5.00,6.26,8.00)	6,338	Selected	0,079
F_5	(8,9,10)	(2,3,4)	(1,2,3)	(1.00,3.00,10.00)	3,833	Unacceptable	/
F_6	(6,7,8)	(7,8,9)	(3,4,5)	(3.00,5.52,9.00)	5,679	Selected	0,071
F_7	(6,7,8)	(6,7,8)	(1,2,3)	(1.00,3.66,8.00)	3,940	Unacceptable	/
F_8	(3,4,5)	(8,9,10)	(2,3,4)	(2.00,4.16,10.00)	4,773	Selected	0,059
F_9	(5,6,7)	(5,6,7)	(3,4,5)	(3.00,4.76,7.00)	4,841	Selected	0,060
F_{10}	(8,9,10)	(7,8,9)	(4,5,6)	(4.00,6.60,10.00)	6,736	Selected	0,084
F_{11}	(6,7,8)	(3,4,5)	(7,8,9)	(3.00,5.81,9.00)	5,873	Selected	0,073
F_{12}	(6,7,8)	(4,5,6)	(7,8,9)	(4.00,6.26,9.00)	6,338	Selected	0,079
F_{13}	(7,8,9)	(4,5,6)	(7,8,9)	(4.00,6.54,9.00)	6,528	Selected	0,081
F_{14}	(2,3,4)	(2,3,4)	(8,9,10)	(2.00,4.16,10.00)	4,773	Selected	0,059
F_{15}	(3,4,5)	(2,3,4)	(5,6,7)	(2.00,3.91,7.00)	4,110	Unacceptable	/
F_{16}	(7,8,9)	(6,7,8)	(5,6,7)	(5.00,6.54,9.00)	6,695	Selected	0,083
F_{17}	(7,8,9)	(7,8,9)	(5,6,7)	(5.00,6.84,9.00)	6,893	Selected	0,086
F_{18}	(2,3,4)	(2,3,4)	(3,4,5)	(2.00,3.00,5.00)	3,167	Unacceptable	/
F_{19}	(1,2,3)	(1,2,3)	(4,5,6)	(1.00,2.52,6.00)	2,847	Unacceptable	/
F_{20}	(1,1,2)	(1,1,2)	(8,9,10)	(1.00,2.00,10.00)	3,167	Unacceptable	/

The next step is to rank the elements of the structure using the VIKOR method. First, the elements of the structure are evaluated in relation to the factors using the relations given in Table 2. These evaluations are given in Table 4.

Table 4. Evaluations of the IT structure elements in relation to the factors

	E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}
F_1	N	N	N	VH	VH	N	N	N	N	VH	VH	FH	EH
F_2	N	N	N	N	N	N	FH	VH	N	EH	N	FH	VH
F_3	VH	FH	VH	N	VH	L	L	VH	L	N	H	N	M
F_4	N	N	EH	N	N	FH	EH	VH	EH	M	EH	N	N
F_6	VL	VL	EH	N	VH	FL	FL	N	VL	N	M	N	N
F_8	N	N	VH	N	EH	EH	L	H	VL	VL	FH	FH	VH
F_9	N	N	N	EH	H	FL	FL	FH	N	M	L	M	VH
F_{10}	N	N	EH	N	VH	M	FH	VH	H	N	FH	L	L
F_{11}	N	N	N	N	N	N	H	VH	L	VL	FH	N	N
F_{12}	VH	L	EH	N	N	FL	L	FH	M	N	N	N	N
F_{13}	M	M	N	N	N	N	M	N	N	N	FL	N	N
F_{14}	N	N	N	FL	N	N	L	N	N	N	FH	N	L
F_{16}	N	N	N	N	N	N	H	H	M	VH	N	N	VH
F_{17}	N	N	EH	N	H	VH	H	H	M	N	EH	N	H

Evaluations shown in Table 3 are transformed into triangular fuzzy numbers and based on them the ideal $\tilde{e}_j^* = (l_j^*, m_j^*, r_j^*)$ and the nadir $\tilde{e}_j^\circ = (l_j^\circ, m_j^\circ, r_j^\circ)$ values of the criterion functions are obtained by applying the equation (8), whereas all factors are taken as the "benefit" factors. After that the values of the normalized fuzzy differences $\tilde{d}_{ij}$ are calculated using the equation (10). The values of the maximum group utility $\tilde{S}_i = (S_i^l, S_i^m, S_i^r)$ and the minimum individual regret $\tilde{R}_i = (R_i^l, R_i^m, R_i^r)$ are obtained by applying the equations (12) and (13), respectively. The overall distances of the elements from the ideal solution $\tilde{Q}_i = (Q_i^l, Q_i^m, Q_i^r)$ are obtained by applying the equation (14) whereas the value v=0.5 is taken for the coefficient of the weight of the maximum group utility. The obtained values for $\tilde{S}_i$, $\tilde{R}_i$ and $\tilde{Q}_i$, are then defuzzyfied by applying the equation (5). Based on these defuzzyfied values three ranking lists are formed $\{E\}_S$, $\{E\}_R$ and $\{E\}_Q$, and presented in Table 5.

Table 5. Ranking of the elements in relation to the S, R and Q values

		E_1	E_2	E_3	E_4	E_5	E_6	E_7	E_8	E_9	E_{10}	E_{11}	E_{12}	E_{13}
$\widetilde{S}$	S_l	0.435	0.494	0.095	0.486	0.250	0.367	0.127	0.102	0.339	0.378	0.039	0.477	0.289
	S_m	0.686	0.745	0.346	0.737	0.501	0.618	0.378	0.353	0.590	0.629	0.290	0.727	0.540
	S_r	0.852	0.911	0.540	0.888	0.681	0.809	0.622	0.561	0.793	0.809	0.525	0.889	0.731
	Crisp(S)	0.672	0.731	0.337	0.720	0.489	0.608	0.377	0.346	0.582	0.617	0.287	0.713	0.530
	Rank	10	13	2	12	5	8	4	3	7	9	1	11	6
$\widetilde{R}$	R_l	0.057	0.057	0.046	0.057	0.056	0.057	0.042	0.047	0.042	0.057	0.053	0.057	0.057
	R_m	0.076	0.076	0.065	0.076	0.074	0.076	0.056	0.065	0.065	0.076	0.070	0.076	0.076
	R_r	0.086	0.086	0.081	0.086	0.083	0.086	0.070	0.081	0.081	0.086	0.079	0.086	0.086
	Crisp(R)	0.075	0.075	0.064	0.075	0.072	0.075	0.056	0.065	0.064	0.075	0.069	0.075	0.075
	Rank	8	9	4	13	6	7	1	3	2	11	5	12	10
$\widetilde{Q}$	Q_l	-0.05	-0.03	-0.21	-0.03	-0.14	-0.08	-0.20	-0.20	-0.10	-0.08	-0.23	-0.04	-0.12
	Q_m	0.172	0.197	0.018	0.194	0.090	0.142	0.028	0.021	0.125	0.147	-0.01	0.190	0.108
	Q_r	0.367	0.393	0.229	0.383	0.292	0.348	0.260	0.238	0.339	0.349	0.222	0.384	0.314
	Crisp(Q)	0.167	0.193	0.016	0.188	0.086	0.139	0.030	0.020	0.123	0.143	-0.01	0.184	0.105
	Rank	10	13	2	12	5	8	4	3	7	9	1	11	6

As the key elements for defining the IT structure, transport modes (E_{11}), place and role in the network/chain (E_3), terminal size (E_8) and structure of functions and services (E_6) are selected. They are ranked as the first, second, third and fifth, respectively. Terminal location (E_7) and subsystems technologies (E_{13}), although ranked as the fourth and sixth, as well as the lower ranked elements, have not been selected as the key ones for the following reasons. For the terminal location (E_7), founders and owners (E_1) and management models (E_2), the rule of appearing in the combination with the other key elements was not determined. Further classification in relation to these elements would lead to an excessive number of IT structures, therefore they could not be referred to as the typical structures. On the other hand, by combining the remained elements with the key ones would not lead to further division and classification. These are the elements with strong dependence on some of the key elements, such as: territory coverage (E_9) (depends on the location and role of the terminal in the network), layout of the terminal (E_{10}) (depends on the present modes of transport), subsystems structure (E_{12}) (depends on the structure of functions and services) and subsystems technologies (E_{13}) (mainly depends on the terminal size and the subsystems structure, or indirectly on the structure of functions).

4. TYPICAL STRUCTURES OF THE INTERMODAL TERMINALS

Based on the identified key structural elements and research that included over 180 real-life ITs in Europe, typical structures (TS) of the intermodal terminals have been identified in this paper. The basic classification of the TS group was made in relation to the terminal size (E_8) as (Krstić et al., 2019b): "small" with an annual capacity of up to 100,000 TEUs (Twenty-foot Equivalent Unit), "medium" with a capacity of 100,000 to 200,000 TEUs, "large" with a capacity between 200,000 and 400,000 TEUs, "very large" with a capacity between 400,000 and 1,200,000 TEUs and "mega" with a capacity of over 1,200,000 TEUs. Subsequently, within the defined groups, a further TS classification was made in relation to other key elements. In relation to transport modes (E_{11}) terminals can be divided into uni-modal (only one transport mode is present, usually road, and the main role is usually consolidation of flows), bimodal (connecting two transport modes, most often appear in the form of road-rail, maritime-road and river-road ITs), tri-modal (connecting three transport modes, most often appear in the forms of maritime-rail-road and river-rail-road ITs) and quadri-modal (most commonly connecting road, rail, river and maritime modes of transport) (Notteboom & Rodrigue, 2009). In relation to the place and role in the network/chain (E_3) ITs can be divided into two basic groups: maritime and inland terminals. Maritime terminals appear in nine basic types (Park & Medda, 2010): terminals in dominant ports, terminals in superior ports, terminals in indirect ports, terminals in versatile ports, terminals in ordinary ports, terminals in development ports, terminals in specialized ports, terminals in industrial ports and terminals in peripheral ports. On the other hand, inland ITs can be classified into five basic tyoes (Woxenius, 1997): direct connection terminals, corridor terminals, hub & spoke terminals, fixed-line terminals and assigned route terminals. Regarding the structure of functions and services (E_5), ITs can be divided into four categories (Zečević, 2006): A, B, C and D. Terminals of category A perform the basic functions (reception, transshipment, disposal and shipping of transport means and ITUs), B perform basic and supplementary functions (e.g. ITUs charging and discharging, storing the goods, maintaining ITUs, etc.), C, in addition to the aforementioned, performs

the accompanying functions (e.g. ITUs collection and dispatching, collection and distribution work with non-containerized cargo, vehicles and handling equipment maintenance, etc.), and D, in addition to all aforementioned, perform additional functions in order to achieve the complete logistics service (e.g., services with the special ITUs, educational and advisory services, planning and organization of door-to-door transport, VAL (Value Added Logistics) services, etc.). By combining the various characteristics and modalities of the ITs with respect to the identified key elements, the 36 typical IT structures given in Table 6 are defined.

Table 6. Overview of the typical IT structures in relation to the key elements

Typical structure	Terminal size	Transport modes	Place and role in the network	Functions structure
TS_1	"small"	road	direct	A
TS_2	"small"	road-rail	line	B
TS_3	"small"	road-rail	corridor	B
TS_4	"small"	road-rail	hub	C
TS_5	"small"	road-river	line	B
TS_6	"small"	road-river	corridor	B
TS_7	"small"	road-river	hub	C
TS_8	"small"	road-rail-river	corridor	C
TS_9	"small"	road-rail-river	hub	D
TS_{10}	"medium"	road-rail	line	B
TS_{11}	"medium"	road-rail	corridor	C
TS_{12}	"medium"	road-rail	hub	C
TS_{13}	"medium"	road-river	corridor	C
TS_{14}	"medium"	road-river	hub	C
TS_{15}	"medium"	road-rail-river	corridor	C
TS_{16}	"medium"	road-rail-river	hub	D
TS_{17}	"medium"	road-rail-maritime	peripheral	D
TS_{18}	"large"	road-rail	line	C
TS_{19}	"large"	road-rail	corridor	C
TS_{20}	"large"	road-rail	hub	D
TS_{21}	"large"	road-rail-river	corridor	C
TS_{22}	"large"	road-rail-river	hub	D
TS_{23}	"large"	road-rail-maritime	ordinary	D
TS_{24}	"large"	road-rail-maritime	superior	D
TS_{25}	"very large"	road-rail-river	hub	D
TS_{26}	"very large"	road-maritime	indirect	C
TS_{27}	"very large"	road-rail-maritime	versatile	D
TS_{28}	"very large"	road-rail-maritime	superior	D
TS_{29}	"very large"	road-rail-maritime	dominant	D
TS_{30}	"very large"	road-rail-river-maritime	dominant	D
TS_{31}	"mega"	road-rail-maritime	versatile	D
TS_{32}	"mega"	road-rail-maritime	indirect	D
TS_{33}	"mega"	road-rail-maritime	superior	D
TS_{34}	"mega"	road-rail-maritime	dominant	D
TS_{35}	"mega"	road-rail-river-maritime	versatile	D
TS_{36}	"mega"	road-rail-river-maritime	dominant	D

5. CONCLUSION

The paper proposes a new methodology for defining typical IT structures that involves identifying a wide set of structural elements, the factors that influence them, as well as the strength of these influences. The methodology included the development of an MCDM model that combines the fuzzy Delphi method, by which the importance of the factors and the strength of their influence on the structural elements is determined, and the fuzzy VIKOR method, by which the ranking and selection of the key structural elements is performed. It has been found that elements that are crucial for the formation of typical IT structures are: transport modes, place and role of the terminal in the network/chain, terminal size and structure of functions and services. By combining various characteristics and modalities of the defined key elements and research of the real-life ITs in Europe, 36 typical IT structures have been defined.

By defining the typical IT structures, preconditions for their detailed analysis, comparison, performance research, efficiency, etc. have been created with the aim of finding typical structures that can serve as benchmarks for other terminals with mutually comparable characteristics. The defined methodology could be used with certain adjustments to define the structures of other types of logistics centers, which could be the subject of some future research. Besides that, significant future research direction would be more detailed research and analysis of the identified TSs and their efficiency estimation, as well as modeling the IT structures, that were not defined as the typical ones since they have not been identified in practice, but which could be competitive with the defined TSs. The proposed MCDM model could also be used for solving the problems from various fields.

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DECISION TREE AS A TOOL FOR DECISION MAKING IN RETREADING TIRE TECHNOLOGY

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Abstract: *In modern business, more and more production companies are taking responsibility for the products at the end of their exploitation. For this reason, in the realization of all logistics activities, the emphasis is placed on increasing the degree of reusing products. Among such products are tires. They belong to the category of expensive vehicle parts that are usually changed several times during the lifetime of vehicles. The most popular and increasingly implemented treatment of used tires is retreading. It is the procedure of replacing the spent tire tread with new ones. Tire retreading is an economically attractive and environmentally beneficial process for extending the lifetime of used tires. Research has shown that the efficiency of retreaded tires depends on the type of tires, type of vehicle, tire manufacturers, but also on retreading technologies implemented. The aim of this paper is to provide support in decision making when retreading tires for commercial vehicles, from the aspect of selecting the retreading technology (brand). Applied technology of retreading tires can have a significant impact on the business effects of large transport companies; thus, the paper analyzes some exploitation parameters related to the economic aspect of this process - costs of labor and energy consumed for retreading. Using tools based on the decision tree, the paper has created a basis for making the decision on selecting the retreading technology, with the respect of retreading technology capacity, as well as investment costs, which are important for a company introducing an additional activity related to the regular maintenance of its vehicles in the business. For that reason, respecting economical and ecological sustainability leads to selecting the technology that requires lower energy consumption as well as an increasing degree of humanity processes.*

Keywords*: used tires, retreading, technology, decision tree*

1. INTRODUCTION

In modern business, the imperative for the survival of every business entity is focused on respecting the ecological, economic and social sustainability in all segments of the supply chain. The main objective is that each product has a possibility of further exploitation at the end of its life cycle, with the emphasis on increasing its level of reproducibility. The result of this demand is that an increasing number of manufacturers have an additional activity related to extending the responsibility for their products. Manufacturers have an obligation to take responsibility for their products by

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implementing an appropriate treatment at the end of their service life, which is in accordance with the laws of the European Union (EU). In the Extended Producer Responsibility (ERP) program, at first, there were only the ones who manufactured multicomponent and expensive products, and then they were followed by those with the possibility of extending their exploitation period.

Among the products that are designed to be repaired, with some of their parts that can be renewed in order to prolong the life of their exploitation, are vehicles. Vehicles are complex products, made of different materials, with a large number of components and parts. Components of vehicles with a significant economical and ecological influence at the end of their working life are tires. In the past few decades, the emphasis has been on their further use. During the exploitation, a tire with a worn tread can be processed in a certain manner to allow its reuse; that process is called retreading.

When the tire for some reason has to be replaced, there are various types of treatments. The legislation prohibited the permanent disposal of tires to a landfill because the period of their decomposition is over 150 years long (Dabić-Miletić and Miljus, 2018). For this reason, it is necessary to apply one of the following types of appropriate treatment: regrooving (which deepens the tire tread, unless it is completely worn-out; this procedure is performed only once in the commercial vehicle tires, using the appropriate tools), retreading, recycling, pyrolysis, and burning (as a heat source usually found in cement kilns). Retreading represents one of tire treatments whose aim is to extend the lifetime of their exploitation (Dabić-Ostojić, 2014). This process reduces the negative influence of used tires on the environment as well as natural resources exploitation.

Tire retreading is an economically attractive and environmentally beneficial process for extending the lifetime of used tires. It reduces the negative influence of used tires on the environment as well as natural resources exploitation. The decision to retread tires is affected by a relatively large number of parameters. Although it has already been theoretically and practically proven that retrieval is justified, both from the economic and environmental point of view, there are numerous questions related to this procedure: which types of tires to protect, which technology to use, which parameters to consider, etc. When a company that has a significant number of commercial vehicles in its fleet makes a decision to protect tires, there is often a very important next decision related to selecting the appropriate retreading technology. Using the approach based on a tool called the decision tree, this paper presents the analysis for the selection of one of two retreading technologies. For decision making on retreading technology, the analysis is based on labor costs and consumed electric energy, respecting the capacities of the retreads, as well as the investment costs for the retreading plant.

The paper is divided into several parts. After the introduction, a brief overview of the literature related to research in the field of treatment of used tires is presented, with the emphasis on retreading. The literature that uses the Decision Tree (DT) as one of the methods in making business decisions is particularly analyzed. After that, the characteristics of the retreading tires process are depicted through analyzing some parameters related to the increase in the number of tires in exploitation, respecting a growing emphasis on the reproducibility of used products (here retreading commercial vehicle tires). The fourth part of the paper is the main one and consists of several sections. First, the retreading technology is briefly explained. In a special section, the

basis for the choice of the retreading technology by using the DT is established. At the end, the obtained results are discussed. In conclusion, concrete and final considerations related to the problem of elective technology are provided, with a particular emphasis on the directions for future research.

2. LITERATURE REVIEW

The literature analysis demonstrates that many authors have dealt with the problems related to the logistics activities in the field of used tires management. The treatment of used tires is becoming a higher challenge for experts in this area. A significant number of authors analyze problems in the domain of treatment of used tires, with special emphasis on retreading. This form of treatment allows for an extension of their exploitation period, which is of relatively high importance from the economic and ecological point of view.

The used literature review is generally systematized in two parts. The first part considers the problems in the field of management of used tires. The second part explains the DT approach and its use, place and role in decision making in retreading tires management.

Considering the research in the domain of the treatment of used tires, including retreading, it can be concluded that these issues have become very contemporary in recent decades. Among numerous researches, only some of the publications that have been published so far are presented here. In this context, it is necessary to point out that Ferrer (1997) assumes that the lifetime of the tire does not depend on the number of the retreading operations; the number of retreading tires for commercial vehicles is unlimited. Beukering and Janssen (2001) assume that retreaded tires travel the same distance as the new ones. The complexity of the problems in the field of used tires has led to the publication of a significant number of studies in it. Two review papers were also published (Dabić-Ostojić et al., 2017 and Simić and Dabić-Ostojić, 2017). In these studies, 72 peer-reviewed international journals published in the period between 2006 and 2017 were categorized, analyzed and interpreted. The stated number of journals clearly indicates the great relevance and importance of the explored research area.

Problems in the retreading area are numerous, so different systems, tools, and methods of Decision Support Systems (DSS) are used in all segments in this field. One of the developed models uses conditional probabilities as input parameters in order to solve the problem of decision making on the number of cost-effective retreadings. The obtained results show that the retreading is economically efficient up to the traveled distance of the retreaded tire, in which the cost per km is lower than the one when the new pneumatic is used (Dabić-Ostojić et al., 2014; Dabić-Miletić and Miljuš, 2018). Conventional approaches are based on the fact that every tire can be potentially protected. The modern approach is based on formulation models that have the ability to include a significant number of parameters characterized by uncertainty in decision making. Simić and Dabić-Ostojić (2017) developed a model that has the ability to examine different permissible levels of risks related to the capacity of the retreading plants. Continuing the previously described research, the challenge is to develop a model that has the ability to consider the effects of external influencing factors that relate to complex economic, environmental and social aspects of systems for the used tires

management (Simić et al., 2017). Many authors use a combination of different approaches for making a decision on retreading. The aim is to develop models that include greater number of parameters that are characterized by the uncertainty in the decision making related to retreading, so that the treatment could be justified from different and numerous aspects.

When a company decides to protect the tires of its vehicles, it is necessary to select a retreading technology. Assuming that every technology is certified, there are numerous influential factors that determine the company's choice of the technology: investment costs, implementation period, retreading capacity, the degree of utilization, the level of implemented technology, etc. This paper presents the initial research related to the selection of the retreading technology. For the purpose of the research in this paper, the costs of labor and the consumption of (electric) energy were analyzed when deciding between one of two analyzed retreading technologies. One of the many methods that were used for this study was based on the application of the DT approach.

DTs find use in many different disciplines, including medical diagnosis, cognitive science, artificial intelligence, game theory, engineering, and data mining. Many authors deal with its structure analyses, forming methods and techniques applied in structuring; between them are Olaru and Wehenkel (2003) who present and analyze the possibility of fuzzy DT use, as well as Olivas (2007) who deals with the methods of the tree forming in general. Cho et al. (2002) suggest the methodology that is based on a variety of data mining techniques such as web usage mining, DT induction, association rule mining, and the product taxonomy. Huercio et al. (2003) developed an algorithm based on a DT analysis for production control. In this paper, a reactive scheduling algorithm is presented, which adapts the current schedule to real-time disturbances, integrated to a supervisory system capable of handling the new schedule generated, thus filling the existing gap between high production scheduling and low sequential control levels in the Chemical Process Industries. Boustani et al. (2010) use the DT approach in order to decide whether to buy new tires or to treat the old ones. They illustrate the DT for evaluating the energy benefits of retreading. Sheu et al. (2008) use DT for online group buying consumers' behavior. Starr (2002) uses DT methodology successfully to capture elements using data from a larger study of product development in the world auto industry. Kim et al. (2011) use DT for data evaluation using the number of decisions that are different from the optimal solutions of the slower dynamic programming solution method. It can be pointed out that decision making in the area of tires retreading is poorly treated in the literature. This tool was successfully used by Dabić et al. (2012) to make a decision on selecting the tire manufacturers. The analysis is performed on the concrete sample of tires for commercial vehicles of one of the largest companies for public city passenger transportation in Serbia, “JKP GSP Beograd”.

3. CHARACTERISTICS OF THE RETREADING PROCESS

The analysis of numerous studies in the field of car industry demonstrates that vehicles have a large negative environmental impact on our everyday lives, as well as significant participation of the world's capital in the vehicle industry. The total number of vehicles at the world level has been over one billion units for a long time. The first time this number was mentioned was in 2010, which is, compared to 2009, an increase of 3.6%, or the highest annual increase in this century (Dabić-Ostojić, 2014). It can be concluded

that the increase in the number of manufactured vehicles influences the increase in the number of tires in use. At the same time, the number of tires that have to be removed from the vehicle during its exploitation has increased.

Tires have an important share in the exploitation costs of commercial vehicles, and particularly in fleets of companies transporting passengers and goods. The tire usage time is significantly shorter than the period of the vehicle's exploitation. When the tire tread is worn-out to a certain depth defined by legislation (1.6 mm), it is necessary to replace it. This procedure belongs to the category of regular vehicle maintenance (Dabić-Miletić and Miljuš, 2018). According to the latest data, the world annually generates approximately 1.8 billion used tires, indicating their growing influence on environmental sustainability as one of the key imperatives of successful business operations (Dabić-Miletić, 2018; www.maschinenmarkt.vogel.de/recycling/articles/, accessed 12/01/2018).

Management of used tires is globally a crucial environmental problem (Labaki and Jeguirim, 2017; Hashemi et al., 2014; Oikonomou and Mavridou, 2009). There is a strong motivation to successfully manage this fast-growing waste flow since used tires are not biodegradable. One of the most popular approaches for sustainable environmental stewardship of used tires is retreading.

Retreading is one of the most popular ways in ecologically sustainable management of used tires (Simić et al., 2017). Retreaded tires are used tires that have undergone a process designed to extend their service life (Boustani et al., 2010). At an acceptable processing cost, tire retreading successfully takes full advantage of the value that remains in the used tires. In this process, used tires are subjected to a sequence of value additive operations and are converted to reusable ones (Mondaln and Mukherjee, 2012).

Retreading represents a group of activities performed in order to apply a new tread in the pneumatic prepared, and to prolong its exploitation period. Two technologies of retreading – setting up a new tread on a prepared tire – are being applied, namely, cold cure and hot cure retreading. Cold cure retreading is the process used for tires of commercial vehicles. This process can be repeated several times since it does not influence the structure of a tire. It is performed by applying a new tread on a tire in the form of a ring (Figure 1a) or strip (Figure 1b), and then such a tire is placed in special chambers where the pasting procedure of a new tread is completed. In commercial vehicle tires, cold retreading involves the application of a new tread on the tire at temperatures below 100°C, which is accomplished in special chambers (autoclaves). The methods of applying the tread on the tire depend on the retreading technology and have no impact on the quality of the tire.



(a) Ring shape (b) Strip shape

Figure 1. Types of treads (Dabić-Ostojić, 2014)

In practice, it has been demonstrated that 60 to 70% of used tires with a worn tread are retreadable (Dabić-Ostojić, 2014). It is important to point out that the retreaded tires, according to their techno-exploitation characteristics, can be compared to the new ones, with special attention being paid to the safety in exploitation, which has been particularly emphasized in previous studies (Dabić-Miletić, 2018). Therefore, it is increasingly insisted on the implementation of this treatment in companies with a significant number of commercial vehicles, as well as in the increase in the number of retreaded tires in exploitation.

In a number of studies, it has been argued that after each retreading, the traveled distance is reduced. The key parameters that are usually analyzed when making a tire retreading decision are: traveled distance of a tire (the new one, after the first retreading, total traveled distance…) and retreading number. In addition to these parameters, the conditions of exploitation (driving mode, vehicle load, road type…), information on the tire manufacturer and others are very important.

It can be assumed that two key parameters are random values, since they depend on a number of factors (manufacturer, driving conditions, road quality, type/load of the vehicle, mode of driving...). In order to verify this assumption, a detailed analysis of a significant sample of written-off bus tires in one of the facilities of the company "GSP Beograd" has been performed for two manufacturers—"Sava" (506 tires) and "Kormoran" (547 tires).

Based on the values from Figure 2a, it can be noted that the number of retreadings of "Sava" tires is a random value with the mean $\mu_{Sava} = 1.59$ (retread/tire). The hypothesis on the accordance of the described empirical distribution with the Poisson probability distribution law is confirmed by the Chi-squared test ($\chi^2 = 2.227$).

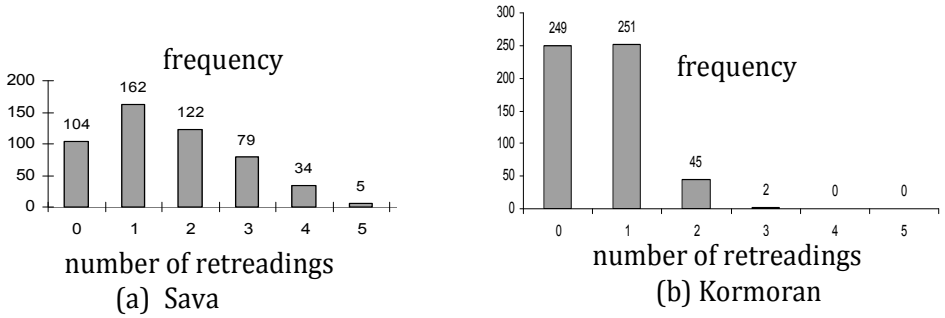


Figure 2. The empirical distribution density of a total number of retreadings (until writing-off) on an analyzed sample of tires "Sava" and "Kormoran" (Dabić and Mijuš, 2013)

For "Kormoran" tires, a significantly different distribution of retreadings per tire is noted (Figure 2b). The mean value is $\mu_{Kormoran} = 0.63$ (retread/tire), while the hypothesis on the accordance of the described empirical distribution with Poisson probability distribution law has not been confirmed. This demonstrates a significant difference between the exploitation parameters of those two manufacturers. Also, it is necessary to point that there are cases where a new tire, due to some damages, cannot be retreaded (in Figure 2 these are the frequencies for values of the random variable equal to 0). For "Sava" tires this probability is $p_{0,Sava} = 104/506 = 0.206$, and for "Kormoran" tires $p_{0,Kormoran} = 249/547 = 0.455$ (Dabić and Miljuš, 2013).

Analyzing the results obtained on a realistic sample from two manufacturers, it can be clearly seen that the number of economically justified retreading of "Sava" tires is higher than that of "Kormoran". If only the number of cost-effective retreadings were considered when selecting the type (brand) or tire manufacturer, it is clear that the company would decide to acquire "Sava" tires because they can be protected as many as 5 times, while the pneumatic producer "Kormoran" can be retreaded not more than 3 times. The analysis displays a drastic reduction in the number of tires that can be retreaded.

When the company decides to retread the tires of their vehicles in order to achieve economic savings, there are numerous questions. One of many is related to the selection of technology that will be implemented in this process. Therefore, in the following parts of the paper, the emphasis will be on the selection of an appropriate retreading technology.

4. MAKING DECISIONS ON TIRE RETREADING TECHNOLOGY

For the purposes of business decision making, a significant number of methods, techniques, and tools have been developed so far. In order to solve various and increasingly numerous problems in the domain of managing the used products and/or their parts, quantitative methods are being developed, and they are generally divided into single-criterion and multi-criteria ones. Logically, every decision is better if a multi-criteria approach is applied. One of the most commonly used approaches is based on the application of a tool called the DT (explained in Section 4.2).

This part of the paper is organized in several sections. The first of them briefly explains one of the most commonly used retreading technologies, "Bandag". For the purposes of research in the paper, every activity taken in this technology is explained. The problem solved in this paper is related to the choice of retreading technology from the aspect of some groups of costs (labor and consumed energy). In order to choose the retreading technologies, the cost of retreading plants (including equipment: machines, tools, energy consumption, etc.) and their capacity have been respected, and analyzed in detail in the second part of this paper. At the end of this part, the obtained results are discussed. These results are the basis for the main conclusions related to decision making in the tire retreading technology.

4.1 The technology of retreading tires

The tire's life is usually shorter than the vehicle's exploitation period. When the tire lifespan is over, its replacement is necessary. On a question that has been asked (for a long time) - "What to do with tires that have been removed from the vehicle?" – the answer has long been provided (see Introduction). According to the classification of used products, parts, and materials, tires belong to the category of hazardous waste, and they have a (unique) catalog number *16 01 03*, defined by the Catalog of Waste by the Ministry of Environment and Spatial Planning and the Environmental Agency (http://www.sepa.gov.rs/download/Otpad/UputstvoKatalogOtpada.pdf, accessed 11/01/2019.). Therefore, when used tires are for some reason found to be removed from the vehicle, they have to be treated (in some way). In practice, there are various kinds/forms/types of treatment: regrooving, retreading, recycling, pyrolysis, and

burning. The explanations of these treatments are not the focus of this paper, and a more detailed analysis of every treatment can be found in previous studies investigated by the authors (Dabić-Miletić and Miljus, 2018; Simić et al., 2017; Dabić-Ostojić, 2014, etc).

A retreaded tire has the same features as the new one, regarding the aspect of reliability, safety, durability, capacity, and vehicle load. The only condition that has to be respected for retreaded tires is their use and treatment, the same as for the new ones (regular maintenance, tire pressure check, load-bearing constraints, driving and road conditions). Retreading technology has improved over time, so that the retreaded tires are hardly recognizable when compared with the new ones, except for a label that is printed on the outside - the basis of the tire (stating it has been protected, the date, the country in which the retreading was carried out, the technology type, the number of previous retreadings, etc).

Tire retreading is performed by certified technology. Every technology is characterized by a significant number of control activities (after almost every operation). However, the main problem that may cause prudence in the purchase of tires is the lack of users' confidence, or insufficient information on the retreading technology and the quality of the retreaded tires, which is a consequence of the relatively poor market promotion. The motive for improving the field of market activities can be found in the fact that the guarantee for the retreaded tires is the same as for the new ones (according to all criteria).

For the purposes of this research paper, it is necessary to know the basic steps in retreading technology. One of the very famous retreading technologies is "Bandag", and it is also used for bus tires in one of the facilities of “GSP Beograd". Some of the basic activities of this technology (Figure 3, Dabić-Miletić and Miljuš, 2018) are briefly explained (https://www.bandag.com/en-ca/why-retread, accessed 12/01/2019):

1 - Initial inspection: when used tires arrive in the tire retreading plant, they are unloaded from large trailer trucks and sent for storage; every used tire planned for retreading is initially inspected to determine whether it is reusable, retreadable, as is or EoL (End of Life) (e.g. tread depth is too low, tire is significantly damaged, etc);

2 - Visual inspection: retreadable tires are visually inspected by the trained specialists using proper equipment, thus trying to identify any damage missed during the initial inspection; only tires that pass this activity are forwarded to next inspection;

3 - Shearography inspection: this is an advanced nondestructive inspection procedure based upon shearography cameras; in this way, it is possible to determine even the smallest anomalies in tire structure under forced conditions of exploitation (e.g. holes, stitches, etc.);

4 - Buffing: this procedure mechanically removes the tread and corrects deviations in the circumference of the tire;

5 - Filling repair: buffed retreadable tires are sent to the filling repair activity to clean them off, to fill their remaining minor damage, and eventually restore the original strength of their casing;

6 - Final preparation: applying the thin layer of adhesive mass around cleaned tire casing;

7 - Building: retreadable tire prepared for the building is mounted on a machine that rotates at a certain speed and applies pressured tread rubber around the circumference of its casing accurately and consistently;

8 - Enveloping: retreadable tire with new tread is firstly placed inside the outer envelope before the inner envelope is fitted into it; (clearly: to serve as a wrapping or covering for...; to surround entirely);

9 - Curing (for this type of technology, capacity is 22 tires/300min): enveloped tires are vacuumed out and sent to curing at a moderate temperature and pressure that adheres new treads to them;

10 - Marking tires: putting the mark on the retreaded tire;

11 - Final inspection: the last activity of the tire retreading process; it assures that only the labeled retreaded tires that meet rigorous industry quality standards and customer demands are allowed to leave the tire retreading plant.

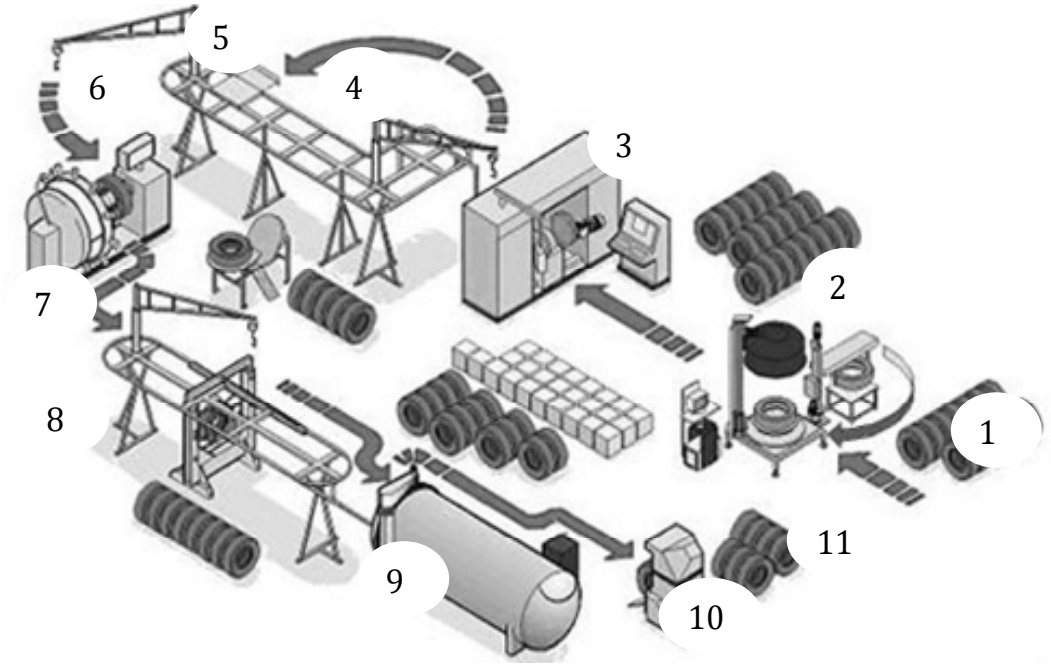


Figure 3. Basic steps in retreading tires, "Bandag" technology
(Dabić-Miletić and Miljuš, 2018)

Based on the analysis of activities in the "Bandag" retreading technology, general conclusions and assumptions that characterize every retreading technology can be made with:

- line production/processing, with the tire successively moving from one workplace to another;
- a high degree of stochasticity at all levels and in every segment of all retreading technologies;
- a significant number of control activities in order to register any deficiencies due to the retreading process as soon as possible; although it is permanently insisted

on the automation of industrial processes and the human aspect of the realization of every modern business branch (related to Industry 4.0), it is necessary to secure the presence of an operator in retreading plants, mainly for the control activities of both the machine operations and the tires in the retreading process.

When a company that has a significant number of commercial vehicles in its fleet makes a decision to retread tires, the next step is to select a tire manufacturer and the type of retreading technology. The choice of the manufacturer has already been discussed. However, the question that very often arouses is the one about the selection of a retreading technology. Based on the survey conducted among the employees in the company GSP Beograd, the choice of "Bandag" technology is randomly made. The selection criteria has been primarily related to the positive experiences in the application of this technology, but also to the number of vehicles, i.e. the number of retreaded tires. A description of the activities in the "Bandag" technology is presented in Table 1.

Table 1. Description of the "Bandag" retreading technology process

ORDINAL NUMBER OF THE PROCESSES (i)	PROCESSES (short explanation)	DESCRIPTION PROCESS (necessary elements/entities for the process)	MEAN VALUE OF THE CAPACITY PER PROCESS m_i (TONES/H)	P_i (PROCESS PROBABILITY)
0	Storages		/	/
1	Initial inspection	1 worker	1.67	0.50
2	Visual inspection	1 worker, machine, energy	2.08	0.75
3	Shearography inspection	2 workers, machine, energy (x5)	5.00	0.65
4	Buffing	1 worker, machine, energy (x2)	3.33	0.75
5	Filling repair	1 worker, machine, energy, material (old and thin rubber)	2.50	0.85
6	Final preparation	1 worker, machine, energy, material (adhesive)	1.25	1
7	Building	1 worker, machine, energy (x4), material (rubber)	2.50	1
8	Enveloping	1 worker, machine, energy	1.67	1
9	Curing (300min/22 tires)	3 workers, oven, energy (x10), 5 hrs	1.14	0.95
10	Marking tires	1 worker, tool(s)	1.14	1
11	Final inspection	1 worker	1.14	1

4.2 Selecting the retreading technology using the DT approach

Nowadays, there are numerous certified retreading technologies on the market. The differences in technologies are related to the volume of initial investments in them, following the number of activities that every machine can perform in the process (more modern machines perform more activities, though they are also more expensive).

Significant differences are also found in the capacity of the represented technologies (a number of retreaded tires per time unit).

This paper is the initial research related to the selection of the tire retreading technology. For this purpose, a model based on DT has been developed. ***A decision tree*** is a diagram used to describe decision alternatives and chance events. ***A decision strategy*** is a particular branch path in a DT and includes all the decisions and chance events along that branch path. DT generally includes two or more possible decision strategies. One decision strategy is generally found to be the "preferred decision strategy", since decision strategies can be compared by computing their respective ***E****xpected* ***V****alues* (*EV*). ***Decision tree analysis*** is the process of evaluating decision alternatives emanating from the root node. The analysis requires calculating and then comparing the expected values. The analysis can also involve making adjustments to probabilities and payoff values to determine how changes to those values may affect the expected values.

In this paper, the developed model testing was performed with respect to real conditions and parameters related to two cost groups in the retreading technology. It was necessary to calculate the EV for any chance node by summing together all the EVs for each branch connected to the node. In order to count EVs and to decide accordingly, the following input data are required:

- The weight of a single tire is 40kg; for the purposes of calculation and due to the shape of the tire, the capacities are presented in tons/hour
- The mean value of the capacity of each workplace - m_i (tons/hour) ("Bandag" retreading technology, Section 4.1, Table 1) and m_j ("Marangoni" retreading technology, Section 4.2, Table 2)
- The probability that after the i-process the tire will be retreadable (*Pi*) (the probability that after the i-process the tire can be sent to the next one (*i*+1), because there were no defects, errors, deformities, etc. identified, which would exclude the tire from the retreading process) (Section 4.1, Table 1 and Section 4.2, Table 2);
- Retreading is a complex waste management system with many of its components being uncertain. Fluctuations in time of operational capacities of all retreading entities (i.e. initial inspection, visual inspection, shearography inspection, buffing, filling repair, final preparation, building, enveloping, curing, labeling and final inspection) are caused by the variations of used tire type and shape as well as equipment and labor conditions. Actually, the operational capacities of retreading entities, observed as random uncertainties, are fixed with a level of probability that reflects the risk of violating the uncertain retreading capacity constraints (Simić at al., 2017); for these reasons, probability values were adopted based on empirical research and analysis of all activities in the retreading process.

The general formula for calculating *EV* at any chance nodes is given as:

$$EV_{chance\ node} = EV_{branch\ 1} + EV_{branch\ 2} + \ldots + EV_{branch\ N} = \quad (1)$$

There are several key facts that are respected for calculating *EV*s, and they are:

- Labor costs in the waste management sector - independent variable of retreading technology, constant (26.7 €/hour) (Eurostat, 2018a,

http://epp.eurostat.ec.europa.eu (http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=lc_lci_lev&lang=en, accessed 17/03/2019) (*A* – in formulas (2) and (3));

- Costs of consumed energy at every step of the process (0.1€/tire; they depend on the type and device capacity (the number of tires being processed in time) at a particular workplace (Table 1 and Table 2 show the level of multiplication, e.g. Table 1, Shearography inspection, energy (x5)) (Eurostat, 2018b. https://ec.europa.eu/eurostat/statistics-explained/index.php/Electricity_price_statistics, accessed 20/03/2019) (*B* - in formulas (2) and (3));
- Material costs, or costs of a new tread 14 €/tire (Bandag technology), 11 €/tire ("Marangoni" technology) *(C* - in formulas (2) and (3));
- Retreading technologies differ in the number of logistics activities, the method of the process development, the machines that are used for certain operations (e.g., at some workplaces/machines several operations can be performed);
- The basic differences in these technologies are: the number of simultaneously vulcanized tires (the autoclaves capacity), as well as the separation and/or unification of the operations carried out between two basic steps (shearography inspection and vulcanization/curing), which are usually completed by the machines that require the largest investment.

The paper analyzes the choice of one of the two proposed retreading technologies. A description of the activities in the other one is provided in Table 2. Respecting the mentioned facts, the sum of all *EV*s for each activity gives the total cost value achieved by applying the appropriate retreading technology:

- Labor costs, prices of energy and materials used for retreading (the new tread per tire, the additional material) are fixed, regardless the technology;

- According to the result (cost values), a decision is made to choose the technology with lower operating costs (labor and energy consumption).

Based on the information available and relating to the characteristics of the Bandag technology (Table 1), the formula for calculating EV is:

$$EV_{Bandag} = \sum_{i=1}^{n} P_i \cdot (A + B(material) + C) = \quad (2)$$

22.30€+42.55€+…+30.44€ = 882.52€

The same procedure for "Marangoni" retreading technology tires results with the following formula:

$$EV_{Marangoni} = \sum_{J=1}^{n} P_j \cdot (A + B(material) + C) = \quad 708.38€ \quad (3)$$

Some important assumptions for making a decision include the following:

- The result with the lower costs, i.e. the lower total value of *EV*s points to the retreading technology which should be selected for the tire supply chain management;
- The analyses include only a part of the total costs that appear in the retreading plant activities, and they are related to labor costs (in this kind/type of process) and energy spent in the retreading process.

Table 2. The description of the "Marangoni" retreading technology process[2]

ORDINAL NUMBER OF THE PROCESSES (j)	PROCESSES (short explanation)	DESCRIPTION PROCESS (necessary elements/entities for the process)	MEAN VALUE OF THE CAPACITY PER PROCESS m_j (TONES/H)	P_j (PROCESS PROBABILITY)
0	Storages		/	/
1	Initial inspection	1 worker, machine, energy	5.00	0.60
2	Shearography inspection	2 workers, machine, energy (x5)	3.13	0.50
3	Buffing	1 worker, machine, energy (x2)	2.50	0.75
4	Repairing	1 worker, machine, energy, material (old and thin rubber + adhesive)	2.08	0.90
5	Building	1 worker, machine, energy (x4), material (rubber)	2.50	1
6	Monorailing[3]	1 worker, machine, energy	1.67	1
7	Curing (300min/15 tires)	3 workers, oven, energy (x10), 5 hrs	1.67	0.95
8	Labeling/marking tires	1 worker, tool	1.67	1
9	Final inspection	1 worker	1.67	1

The results obtained by using the DT approach to select the retreading technology are presented in Figure 4. It can be concluded that the "Marangoni" retreading technology is more economically suitable in comparison to "Bandag".

[2] The casings (basic tire structure) are handled in such a way as to prevent any contact with impurities and debris, using a made-to-measure monorail that, exploiting a double envelope system, ensures maximum adhesion of new parts to the casing.

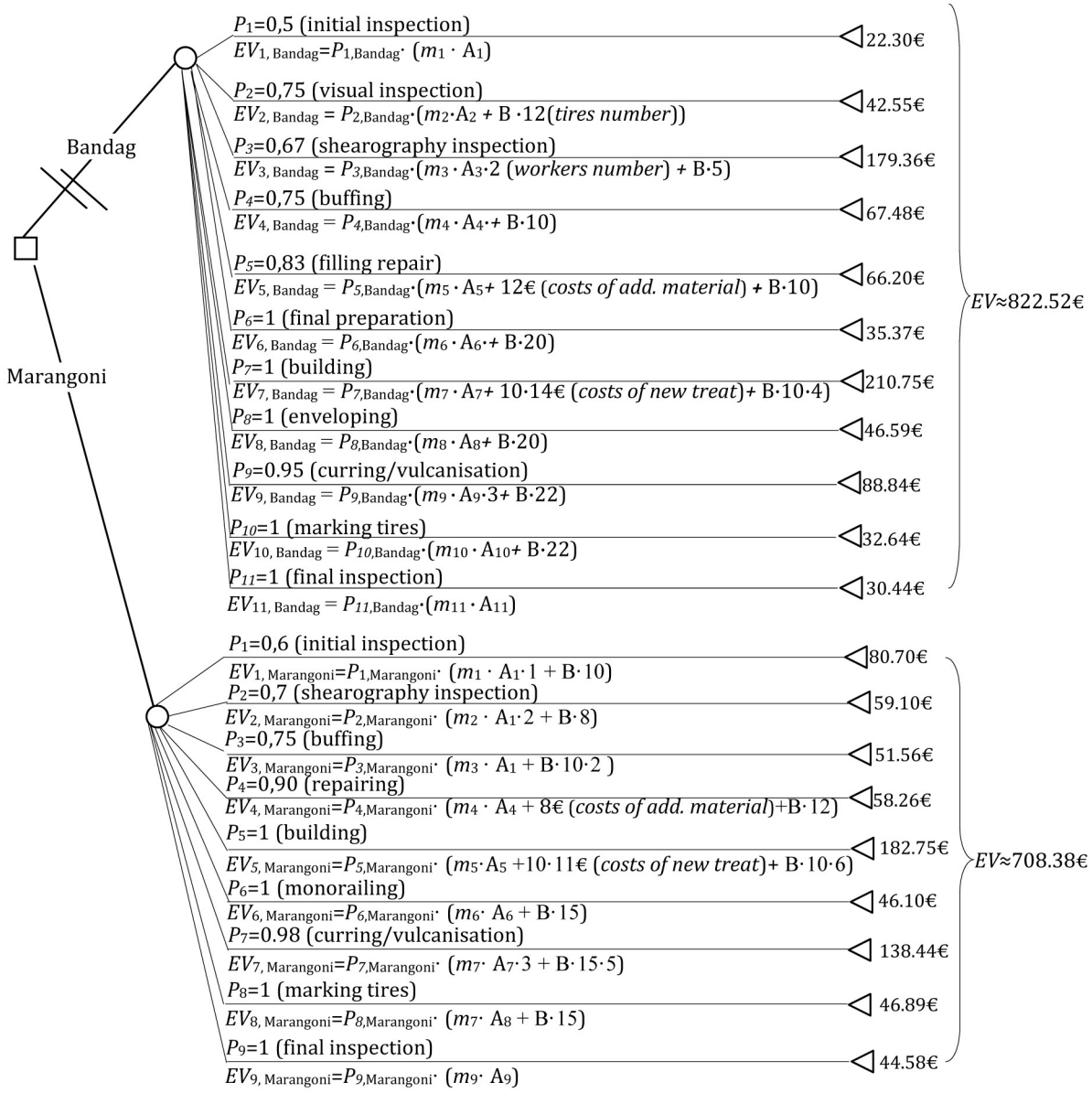


Figure 4. Decision Tree for selecting the retreading technology

4.3 The analysis and discussion of final results

In this paper, one of the ways for selecting the retreading technology has been shown (using the methods based on DT). The aim is related to selecting one of the two proposed technologies. The operating costs of the "Bandag" and "Marangoni" technologies have been analyzed in detail. Capacities, as well as the investment costs (for introducing the new technology), have been taken into consideration.

Capacities are significantly different; thus, by using the Bandag technology, 22 tires can be protected simultaneously, while by the "Marangoni" technology, the number reaches 15 tires (the duration of the new tread adhesion process on the prepared tire is the same for both technologies and lasts for 5hrs). If another technology was used, the capacity (and the time of vulcanization) would differ in comparison to the analyzed two (Simić and Dabić-Ostojić, 2017). Having in mind this fact, two technologies that require the same time of vulcanization have been analyzed in this paper. The operating costs of

each technology are expressed in accordance with the mean capacity value of every machine/process per ton of tires.

The results of the research exhibit the following: when applying the "Bandag" technology, the labor costs and the energy consumed for retreading 1 ton of tires (cca 25 tires) are estimated at € 822.52, while with the use of the "Marangoni" technology, the costs are estimated at € 708.38. The difference in costs shows that the retreading according to the "Marangoni" technology is more than 15% cheaper when compared to the one according to the "Bandag" technology. Of course, this only refers to reducing labor costs and consumed energy in the process (per ton of tires). However, from the capacity aspect, the "Marangoni" technology simultaneously vulcanized 15 tires, as opposed to the "Bandag" technology that can perform a simultaneous retreading process for up to 30% more tires (22 tires). The conclusion is that the technology with greater retreading capacity is more expensive. Considering other factors, such as the number of activities included in the retreading process ("Bandag" 11 activities, "Marangoni" 9 of them), and the cost of a new tread ("Bandag" 14€/tire, "Marangoni" 11€/tire), the preference is for the "Marangoni" technology.

In this paper, the choice of retreading technology is considered only from the aspect of two mentioned parameters. However, some of the parameters could be considered in relation to the need for retreading, as well as the size of the company that introduces the retreading process (the number of commercial vehicles), the type of the logistics activities, etc. Those parameters need to be included in future studies.

5. CONCLUSION

This paper represents the initial research in the field of selecting the optimal retreading tire technology. The problem of decision making on one of the two analyzed retreading technologies, which are most often applied in practice, was solved. As the input data, the capacities of every machine/activity were used, but also the probability that after a certain activity, the tire would be sent to the next activity if there are no damages that would exclude the tire from entering the retreading process. It is necessary to emphasize that this is a certified technology, which indicates that the retreaded tire guarantee is the same as for the new ones and that this process can generate significant savings in a transport company. The implementation of another activity (retreading: space, equipment, etc.) requires a notable investment, which is also discussed in the paper. The size/volume of the investment depends on the price of the machine (stochasticity), which means that some of the existing machines in the retreading plant can be exchanged for the new, more productive ones. Every machine requires significant energy consumption, and the presence of workers in the retreading process is inevitable, bearing in mind the fact that during and after any operation, a detailed inspection of the processed tires is performed. Therefore, the selection of the technology is based on the operating cost of the retreading plant, respecting two parameters: labor costs in the waste management sector (26.7 €/workhour) and energy price unit (0.1 €/tires). Logically, the energy consumption for every process/machine is not the same, and there is also a variation in the number of workers engaged in analyzed technologies.

Considering the obtained results, and according to the currently available data, the decision is to introduce the "Marangoni" retreading technology as the new one. Of

course, this decision may be influenced by other numerous parameters that have not been considered in this paper: the needs and capabilities of the company implementing retreading, available resources, the benefits and costs ratio, etc. Bearing in mind the rapid development of science and technology, the future studies should focus on considering some newer retreading technologies, the degree of their presence, and the possibility of extending and upgrading every operational activity in the retreading plants, etc., which involves analyzing other parameters with a significant degree of stochasticity.

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AN APPLICATION OF DEA TO MEASURE THE EFFICIENCY OF LEADING CARGO AIRLINES

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Abstract: *The air cargo industry is very important in the global economy, due to the fact that it is recognized as the main mode of transport for perishable goods, luxury goods, and other high value products. In order to survive in highly competitive market, cargo airlines must identify the needs of their customers and provide the appropriate services. The common measure that implies how much a firm can meet its predetermined goals is the efficiency. This paper provides the efficiency analysis of the 18 world leading cargo airlines in 2017. A Date Envelopment Analysis (DEA) models with three inputs and two outputs are created to assess and optimize the cargo airline productivity. In these models the efficieny indicators such as number of employee, number of aircraft and offered capacity are defined as inputs, while realized traffic and revenue are defined as outputs. The basic model was used to evaluate the efficiency of the selected cargo airlines and it provides satisfactory results. However, in order to improve these results and to evaluate the operation indicators which affect cargo airline efficiency and which are not in the same order of magnitude, the weighted DEA is proposed. The weights are derived by using Analytic Hierarchy Process (AHP). The results of the models include a benchmark and cargo airlines ranking, as well as the directions for improving the efficiency of inefficient airlines. Moreover, it is shown that the weighted DEA provides more logical results, since the relationship between the indicators is defined in accordance with their real significance. It should be noted that this is the first research where integrated AHP and DEA are used for assessing the efficiency in cargo airline industry. The high flexibility of the proposed models enables its application on different markets as well as on all types of airlines.*

Keywords*: Cargo Airline Efficiency, DEA, AHP.*

1. INTRODUCTION

World trade is increasingly more dependent on air cargo services, despite being a costlier mode of transportation. Air cargo is growing in popularity as the choice when it comes to shipping time sensitive goods, belongings, and documents from one place to another. Moreover, the demand growth of air freight is being impacted by the rise of e-commerce that put pressures on sales channels for faster delivery and optimum supply chain. The growth in the global cross-border e-commerce is expected to increase future demand for the air cargo industry. In particular, The Asia-Pacific region, which

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accounted for 37% market share is identified as a biggest emerging region for the air e-commerce market (Air Freight Industry, 2018).

The benefits of air cargo are its reliability, safety, security and speed especially over long distances. It is an important catalyst of globalization, as it supports the global trade and allows the set-up of complex just-in-time supply chains. However, to continue to compete effectively with other modes of transport, the air cargo industry must ensure that the service benefits of air transportation warrant the price premium charged.

Economic activity has the primary influence on world air cargo development. After a slow recovering from the global financial crisis in 2008, the air cargo fully recovered in 2017. Roughly 56 million tonnes of freight were carried in 2017. Growth of scheduled total freight traffic, expressed in terms of scheduled total freight tonne-kilometres performed (FTKs), was at 9.5% in 2017. This growth is significantly higher than the 3.6% recorded in 2016 (WorldACD, 2018).

However, airfreight demand slowed in 2018 but still increased by 4.5% (ICAO, 2018). Although international e-commerce continues to grow, there were signs of weakness in global economic activity (IATA, 2019). One of the reasons for the decline in cargo volumes in 2018 is partly the result of the ongoing trade war between the United States (US) and China (WorldACD, 2018). More precisely, the China-US trade route registered a decrease of 5% and in the opposite direction there was an 8% fall (WorldACD, 2018). Albeit significantly smaller, five of the six regions reported year-on-year demand growth in 2018 – Asia Pacific, Europe, North America, Middle East and Latin America (Figure 1). After a few years of positive developments in Africa, the freight traffic decrease in 2018 as demand conditions on all key markets to and from Africa "remain weak" (IATA, 2019). North American airlines recorded the fastest growth of any region with an increase in demand of 3.1% year on year. Once again the strength of the US economy and consumer spending has helped support the demand for air cargo over the past year, benefiting US carriers. Unlike their across-the-ocean neighbours, European airlines experienced a reduction in freight demand of 0.2% in comparison to the 2017 as weaker manufacturing conditions for exporters, and shorter supplier delivery times particularly in Germany, impact the demand. Middle Eastern airlines' freight traffic stayed stable and recorded the increase by 1.7% in 2018 (IATA, 2019).

2. AIR CARGO INDUSTRY – OVERVIEW

Air cargo services are provided by a several group of airlines that offer differing services based upon wide ranging customer demands. Generally, there are four basic types of airlines that provide these services:

- Integrated express operators - operate a fleet of scheduled aircraft, trucks, and couriers offering door-to-door delivery service;
- All-cargo airlines - dedicated to air cargo transport;
- Scheduled passenger airlines - transport freight as a way of filling up spare capacity on their passenger aircraft;
- Cargo charter airlines - unscheduled air charter operators who transport freight from airport-to-airport.

It is a common practice in many industries that competition is based on demand or price. However, in air cargo market, multi-dimensional competition comprising

promised delivery time (PDT) and demand/price is of great practical significance (Wang et al., 2017). Delivery logistics (i.e. PDT) is an important competitive factor (Wen et al., 2011) to evaluate service quality. By definition, PDT is the sum of loading and unloading time, inventory time, airport processing time, waiting time and flight time (Feng et al., 2015b). Many air cargo carriers, especially the express carriers, make efforts to shorten delivery time and provide delivery service with time guarantee.

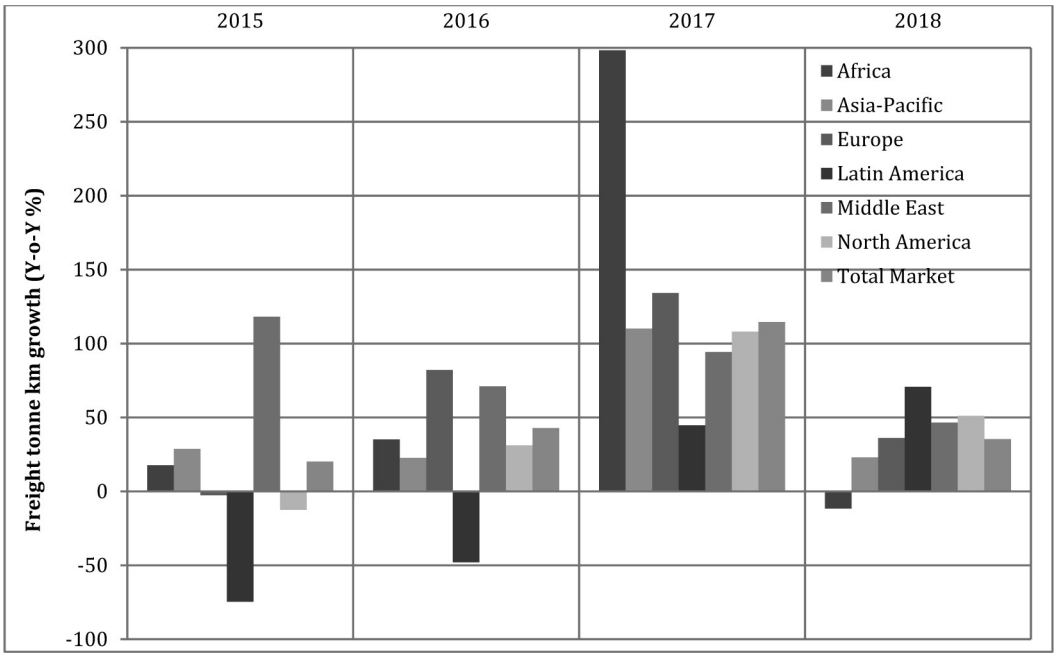


Figure 1. Scheduled international freight tonne kilometres annual growth by region (2015-2018), Source: IATA, 2019

All-cargo airlines and scheduled passenger airlines are major general cargo operators and coexist in some markets. However, together with the growth of air cargo market, integrated express operators for years expand their worldwide service network and scale and aggressively develop hub-and-spoke network for efficient delivery.

Even if the first effect of deregulation and growing demand for air cargo services was the emergence of new cargo airlines, very soon many airlines began to merge resulting in high concentration of the contemporary airline cargo industry (Pavlović and Babić, 2018). The distinction between express and general air cargo continues to blur. Traditional providers are expanding their time-definite offerings, and express carriers, cargo airlines, and postal authorities are consolidating. The acquisition of TNT by FedEx will further change the competitive environment of the express industry (FedEx, 2016).

The growing demand for air cargo transportation services has opened new challenges for the service providers. Airlines are challenged to manage their air cargo operations efficiently by developing strategic operation plans that allow these airlines to promptly adapt and respond to changes in the global competitive environment. Triggered by rising fuel cost and trade growth, they need to be focused on implementing fuel-efficient solutions and accommodate innovative technologies to provide cost-effective services.

The efficiency of the airline, as in other industries, is measured as the ratio of output produced per unit of input. The goal is to achieve the highest economic result (output)

with the lowest possible economic investment (input). In other words, efficiency could be defined as ability to fulfil determined goals with minimal utilization of available resources.

The objectives of the present paper are to explore the operational performances and efficiency of leading air cargo airlines in the world market. To carry out our research, the survey data are collected and the most relevant parameters are identified. The selected data are grouped as inputs and outputs and the comparative performance of selected cargo airlines is analysed by employing the data envelopment analysis (DEA). Furthermore, in order to improve the basic DEA model that allows us to estimate not only efficiency measures but also the preference weights, we proposed weighted DEA model. The weights for this model are determined by the Analytic Hierarchy Process (AHP). This paper, for the first time, proposes a novel AHP-DEA approach to measure efficiency of cargo airlines. By determining the performance of the cargo airlines' operations one can get further insights from the obtained results and can develop appropriate policy for further improvement of the operational performance.

After the introduction and literature review, the AHP-DEA research methodology, including both basic and weighted DEA models, is presented. The appropriate inputs and outputs are proposed and pairwise matrices are created based on authors' knowledge. Further, the data are described and comparative analysis of DEA models is provided. The results are discussed and followed by concluding remarks.

3. LITERATURE REVIEW

DEA is one of the most popular a non-parametric approach to measure efficiency of comparable organizational units with common inputs and outputs. DEA model is introduced by Charnes, Cooper, and Rhodes (1978), and built upon the efficiency frontier model of Farrell (1957). This model is commonly known as CCR model, which can be presented in two basic variants, i.e. input-oriented and output-oriented. Another also popular DEA model is introduced by Banker, Chames and Cooper (1984) and it is known as BCC model. Unlike the CCR model that measures efficiency assuming constant returns to scale (CRS), the BCC model allows for variable returns to scale (VRS).

There are many papers in the academic literature that deal with the productivity and efficiency analyses in the airline industry using DEA. One of the first works in the estimation of efficiency in the airline industry applying DEA is done by Schefczyk (1993). The author explores key strategic determinants of high profitability and performance based on the comparison of international airlines. Moreover, regression analysis is employed in order to analyze relationship between profitability and performance by considering efficiency. Good et al. (1995) employ both DEA method and Cobbe-Douglas econometric model to examine the efficiency of the largest European and American airlines in the period which coincides with the process of deregulation and liberalization of the air transport markets.

Scheraga (2004) uses the CCR DEA model for the purpose of assessing the efficiency for 38 international airlines in the time period from 1995 to 2000. He studied pre- and post-9/11 terrorist attack effects on operational and financial efficiency of international air carriers. Chiou and Chen (2006) implement both CCR and BCC basic DEA models, in order to evaluate the performance of Taiwanese domestic air routes from the

perspectives of cost efficiency, cost effectiveness and service effectiveness during the year 2001.

Assaf and Josiassen (2011) apply an output-oriented BCC DEA model with efficiency score bootstrapping, for the purpose of assessing the performance of 15 UK-based air carriers for the period 2002–2007. Merkert and Morrell (2012) implement both CCR and BCC basic DEA models with input orientation, in order to evaluate the efficiency of international and European air carriers. Jain and Natarajan (2015) and Sakthidharan and Sivaraman (2018) investigate the technical and scale efficiency of Indian airlines for different time period. They use the VRS model of DEA with two inputs and two and more outputs. Airline efficiency performance in the turbulent period before and after economic crisis is presented by Kuljanin et al. (2017). Hong et al. (2018) use a three-stage model, applying DEA in the first stage to calculate airline efficiency in the period 2008-2015. The authors take four different methods such as CRS and VRS with input and output orientation to give different DEA airline efficiency measures for each year.

It should be noted (from the abovementioned literature review) that basic DEA has been applied as standalone technique in many studies that evaluate efficiency of different airlines in different time period. Moreover, there have been a vast number of studies that used some modification of the standard DEA approach combined with different techniques. Barbot et al. (2008) apply DEA approach combined with the Total Factor Productivity index. The Malmquist index is combined with modified DEA by Chow (2010). He employs the CCR input-oriented DEA model attempting to evaluate the efficiency of Chinese airlines. The author investigates the association of airline ownership status with efficiency, comparing the productive efficiency of state-owned and privately-owned Chinese airlines for different time periods. The study shows that privately-owned airlines have exceeded state-owned airlines in terms of productive efficiency. Further, some modification of the standard DEA approach are combined with regression models (Greer, 2009; Barros and Peypoch, 2009), Tobit model (Fethi et al., 2000; Bhadra, 2009), the two-stage DEA approach, with partially bootstrapped random effects Tobit regressions in the second stage (Merkert and Hensher, 2011), the B convex DEA model (Barros et al., 2013), and fuzzy logic in a fuzzy-based DEA approach (Kuljanin et al., 2019). Kottas and Madas (2018) provide the comparative efficiency analysis of major international airlines using an integrated methodological framework employing DEA with super-efficiency and intertemporal approach. Considering above-mentioned literature, it can be seen that efficiency of cargo airlines are not represented in the literature to the appropriate extent.

The noticeable issue is that DEA approach is combined with the AHP in different ways and in different fields (Sinuany-Stern et al., 2000, Yang and Kuo, 2003; Lozano and Villa, 2009, Lai et al., 2015; Dožić and Babić, 2015, etc.). More precisely, two main ways could be distinguished: DEA could be applied firstly in order to determine efficient units, and AHP to rank them, or AHP could be employ firstly to determine weights which will be incorporated in DEA model. Besides the fact that DEA and DEA in combination with AHP have successful application in different fields, it can be seen, in view of the cited literature, that DEA-AHP has not been used for evaluating cargo airlines efficiency yet. Bearing in mind that efficiency is crucial issue for the airlines operating in the changeable market, and the fact that DEA is very effective method for evaluating efficiency, the authors decided to employ it with the AHP in this paper.

4. RESEARCH METHODOLOGY

Our approach to the problem of measuring the efficiency of leading cargo airlines can be illustrated by Figure 2. At the beginning, appropriate inputs and outputs should be defined to reach the final goal, i.e. to determine and analyze the efficiency of leading cargo airlines. Once inputs/outputs have been selected the DEA should be applied in the basic model, or weights for inputs/outputs should be determined in the weighted DEA model. The basic model would enable to distinguish efficient and inefficient cargo airlines, while weighted DEA model would pointed out the efficient airlines based on the significance of each input and output which is determined by their weights. Moreover, both models would enable a benchmark and cargo airlines ranking and further enable offering the directions for improving the efficiency of inefficient airlines.

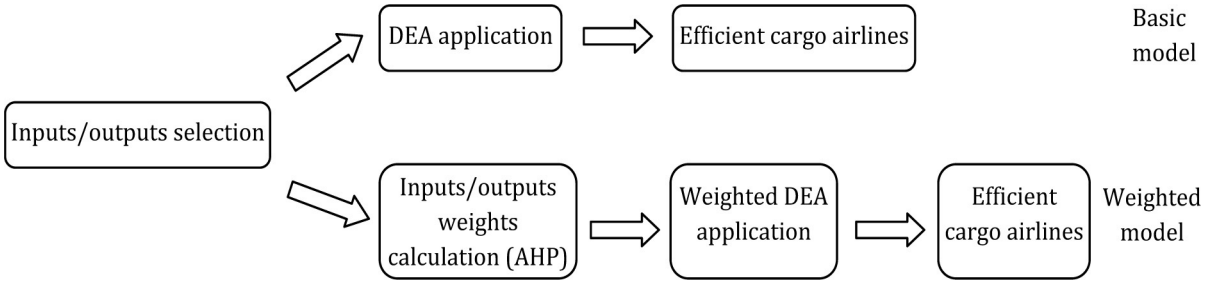


Figure 2. Process of measuring the cargo airline efficiency

The following sub-sections explain the inputs and outputs selection, application of AHP to derive inputs and outputs weights and DEA models. In Section 5 the proposed models for measuring leading cargo airlines efficiency are applied to the leading world cargo airlines.

4.1. Selection of inputs and outputs

In order to assess and optimize the airline productivity in air cargo transport, we should identify the most relevant parameters which should be taken as inputs and outputs. Depending on airline business model (full service or low-cost, scheduled or charter, passengers or cargo) and its mission on the market, different parameters are considered. In line with previous researches, it is noted that the major trade-off in airline management is between capital and labour. Finally, we selected the number of employee, number of aircraft in the fleet and available freight tonne-kilometres (AFTK) as three inputs, while the freight tonne-kilometres (FTK) and revenue are selected as two outputs to reflect the cargo airlines efficiency. In both DEA models the same three input factors and two output factors are used.

The input parameters: Number of employee (I_1) is considered as input parameter and it is used by many authors (Chow, 2010; Merkert and Hensher, 2011; Barros et al., 2013, etc.). Number of aircraft in the fleet (I_2) represents the size of the airline's fleet. It should be noted that this parameter does not indicate the size of the aircraft, but only the size of the fleet. However, it is still used in DEA studies (Barbot et al., 2008; Barros and Peypoch, 2009). Available freight tonne-kilometres (I_3) represent the available capacity of an airline in tonnage and it is commonly used in similar researches (Schefczyk, 1993;

Scheraga, 2004; Jain and Natarajan, 2015; Sakthidharan and Sivaraman, 2018; Kuljanin et al. 2019). It is measured as the sum of the product of weight capacity (in tonnes) multiplied by distance covered (in kilometres) for each flight.

The output parameters: Freight tonne-kilometres (O_1) represent the realized traffic and it is calculated as the sum of the product of freight carried (in tonnes) multiplied by distance covered (in kilometres) for each flight. Actually, one FTK is one metric tonne of revenue load, carried one kilometre. This measure represents non-passenger traffic related output for the industry (used by Scheraga, 2004; Barbot et al., 2008; Merkert and Hensher, 2011, etc.). Revenue (O_2) is measured in monetary units, more precisely in millions of United States Dollars (USD), and it is calculated for one year. This measure is in line with several studies e.g. Merkert and Morrell (2012), Barros et al. (2013).

Once we defined inputs and outputs, we can proceed with the DEA models and AHP weights calculation.

4.2. Proposed DEA models

The efficiency in DEA model is measured based on two components: the technical efficiency which estimates how best the inputs are converted to outputs, and the scale efficiency which describes the deviation from the most efficient scale size for a unit under consideration. The unit under the consideration in DEA terminology is defined as Decision Making Unit (DMU). The main assumption in CCR model is that the unit operates at constant returns to scale (CRS). DEA model calculates the weights that can be assigned to the input and output for the DMU to achieve the best efficiency within the specified constraints. It should be noted that a DMU found to be efficient by DEA is only efficient relative to the other DMUs in the study and does not imply that an efficient DMU is efficient in all respects in its individual capacity. The efficiency determined by DEA depends on the number of DMUs included in analysis, as well as on the number and the structure of inputs and outputs. The desired number of DMUs should be three times the sum of the number of inputs and outputs for better discrimination in a standard DEA formulation (Cooper et al., 2007).

In DEA model with multiple inputs and multiple outputs, efficiency is the ratio of the weighted sum of outputs to the weighted sum of inputs. The weights for the inputs and outputs for each DMU are calculated in order to maximize the efficiency of the considered DMU while restricting the efficiencies of the other DMUs within 0 and 1. The basic DEA model with *n* DMUs in which each has *i* inputs and *r* outputs for assessing the relative efficiency of *k*-th DMU is presented by (1).

$$\begin{aligned} \max \quad & h_k(u,v) = \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \\ s.t. \quad & \frac{\sum_{r=1}^{s} u_r y_{rk}}{\sum_{i=1}^{m} v_i x_{ik}} \le 1, j = 1,2,...,n \\ & u_r \ge 0, r = 1,2,...,s \\ & v_i \ge 0, i = 1,2,...,m \end{aligned} \tag{1}$$

where h_k denotes relative efficiency of k-th DMU, n is the number of considered DMUs, s is number of outputs, m the number of inputs, u_r is weight for the output r, v_i is weight for the input i.

As abovementioned, DEA is usually implemented in two forms, i.e. input-oriented and output-oriented. Input-oriented CCR model (input minimization model) determines the relative efficiency of a DMU by analyzing how efficiently the inputs are utilized to produce the given output. On the other hand, the output-oriented CCR model (output maximization model) estimates the relative efficiency of a DMU in order to determine the optimal amount of output to be produced for the considered input combination. Chosen cargo airline outputs explained in terms of FTK and revenue are not factors that can be influenced by the airline management. However, selected input factors (number of employee, number of aircraft and AFTK) can be controlled by the airline. Thus, the input minimization model of DEA (CCR) is used for this study.

A general input-oriented CCR model expressed in the following linear programming form (2):

$$\begin{aligned} \min \quad & \sum_{i=1}^{m} v_i x_{ik} \\ s.t. \quad & \sum_{r=1}^{s} u_r y_{rk} = 1 \\ & \sum_{r=1}^{s} u_r y_{rk} - \sum_{i=1}^{m} v_i x_{ik} \le 0, \qquad k = 1,\ldots,n \\ & u_r, v_i \ge \varepsilon; \qquad r = 1,\ldots,s; \qquad i = 1,\ldots,m \end{aligned} \tag{2}$$

where ε is a non Archimedean infinitesimal introduced to insure that all the factor weights will have positive values in the solution. A DMU is considered to be efficient if it has an efficiency score of 1 and inefficient if it has efficiency score less than 1.

In order to improve results gained by basic DEA model, we proposed weighted DEA model where the weights were obtained through AHP approach. Integration of DEA and AHP is not novel (Sinuany-Stern et al., 2000; Yang and Kuo, 2003; Wang et al., 2008; Lai et al., 2015), but, to the best of our knowledge, it has not been applied to the cargo airlines efficiency evaluation. The first step is to apply the AHP method to determine input/output weights, and then to use these results in weighted DEA model. Having explained the conceptual definition of DEA we proceed next to the explanation of inputs/outputs weights calculation by AHP.

4.3. Inputs/outputs weights calculation by AHP

AHP is a multi-criteria decision-making approach which decomposes the problem into a hierarchy of issues which should be considered (Saaty, 1980). It presents a theory of measurement through pairwise comparisons made using a scale of absolute judgments. The absolute judgements represent the domination measure of one element over another with respect to a given attribute. In order to enable comparison of alternatives and criteria Saaty (1980) introduced a fundamental scale which indicates the intensity of importance on an absolute scale. Pairwise comparison matrices for criteria and alternatives enable computing of local and global priorities as well as ranking of alternatives.

In this research AHP is used to determine the significance of the inputs and outputs parameters for weighted DEA model. In order to achieve the goal and find the efficient cargo airlines, the problem is structured as four-level problem (Figure 3). After the overall goal which is set in the first level, inputs and outputs are set in the second level of hierarchy. The third level includes input parameters (number of employee, number of aircraft and offered capacity) considered as sub-criteria of input, as well as output parameters (realized traffic and total revenue) considered as sub-criteria of output. The fourth level could include different cargo airlines selected to be candidates in the set of alternatives, but it is not considered in this research. Moreover, instead to finish the AHP procedure and determine the global priorities (which determine rank of airlines), the local priorities (relative importance of inputs and outputs over each other) are calculated. Furthermore, using the local priorities it is possible to compute the ratio of different inputs, as well as ratios of selected outputs, which are needed in defining significance of the inputs and outputs parameters for weighted DEA model.

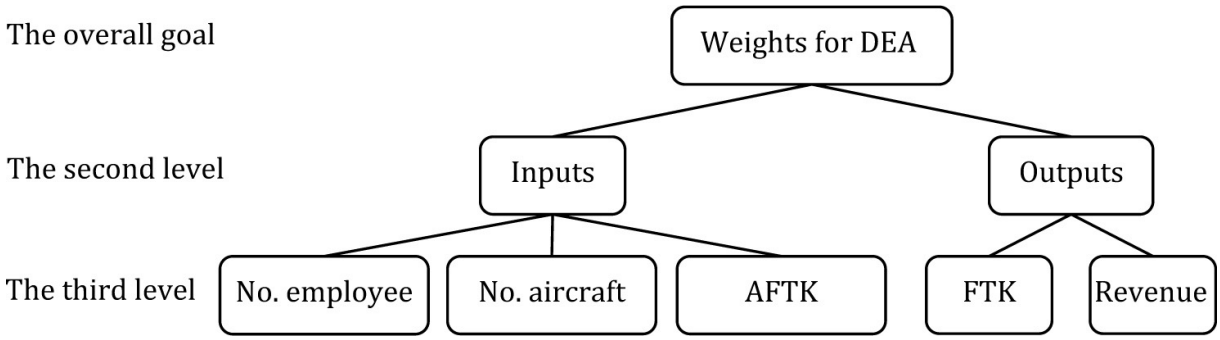


Figure 3. Hierarchical structure of the AHP

Priorities from pairwise comparison matrices can be derived in different ways using: eigenvector method, geometric mean method or arithmetic average method. In this research, the eigenvector method is used to determine weights of the input and output parameters for DEA models. The priorities of the elements can be estimated by finding the principal eigenvector w of matrix A, $AW=\lambda_{max}W$, where λ_{max} is maximum eigenvalue of the matrix A (Saaty, 1980). Since the pairwise comparisons are not perfectly consistent, consistency should be checked by calculating consistency ratio (CR) as ratio of Consistency Index (CI) and Random Index (RI). Inconsistencies are acceptable and a reliable result may be expected if $CR<0.1$. Random Inconsistency Index (RI) for small problems is adopted in accordance with Saaty (1980) and Saaty (1990), while consistency index is calculated as $(\lambda_{max} - n)/(n - 1)$.

To derive the weights, sometimes it is possible to use the other techniques (fuzzy AHP, or other multi-criteria decision making techniqes), but sometimes the technique is determined on the basis of the data availability (Dožić and Kalić, 2018; Dožić et al., 2018). AHP befits better in the case when pairwise comparison of the data are available, while fuzzy AHP can use imprecise pairwise comparison, which is suitable for cases when decision makers do not . comparisons.

5. DATA AND MODELS APPLICATION

5.1. Data

In this research we use the data of 18 largest cargo airlines (DMUs) in the world for the year 2017 (Table 1). Having in mind that our DEA models use three inputs and two outputs, the number of cargo airlines is in accordance with the DEA rule related to desired number of DMUs.

The research draws data from various sources (sample airline annual reports, IATA (2018), web sites of cargo airlines, etc.). We focused on the cargo airlines that are ranked as leaders in the world based on total freight tonne-kilometres, which allows a robust sample for analysis. This sample encompasses three North American airlines, five airlines from Europe (including Turkish Airlines), three airlines from Middle East and seven from Asia Pacific region.

Table 1. Cargo airlines input-output data for 2017 and descriptive statistics

	I_1	I_2	I_3 (mil)	O_1 (mil)	O_2($ mil)
FedEx Express	208046	657	33702	16851	5037
Emirates SkyCargo	48807	112	24570	12715	27879
UPS Airlines	21312	581	23880	11940	65872
Cathay Pacific Cargo	22706	63	17163	10772	12399
Qatar Airways Cargo	31889	86	21998	10999	11597
Korean Air Cargo	20363	72	10031	8015	711
Lufthansa Cargo	4500	239	12867	7317	2882
Cargolux	3463	27	12102	7322	2264
Singapore Airlines Cargo	841	40	11127	6592	2220
Air China Cargo	5200	226	13319	6701	1522
China Southern Airlines	6791	261	13074	6174	18910
China Airlines	12645	40	7961	5741	42970
Air Bridge Cargo Airlines	1300	18	7919	5543	846
All Nippon Airways	13986	86	6800	4810	312
Turkish Airlines	24075	120	5910	4728	1317
British Airways	40680	98	8899	4364	900
Etihad Airways	24558	42	9562	4303	900
United Airlines	88531	248	13929	4249	1035
Max	208046	657	33702	16851	65872
Min	841	18	5910	4249	312
Average	32205	167	14156	7729	14158
SD	47455	177	7217	3434	21232

The sample consists of two integrated express operators, 14 schedule passenger and two all-cargo airlines. Three of 14 schedule passenger airlines transport the freight exclusively using belly hold of the passenger aircraft (All Nippon Airways, British

Airways and United Airlines). The rest of the scheduled passenger airlines are using both cargo and passenger aircraft for freight transportation. In order to make different fleets comparable, we weighted the passenger fleet of schedule passenger airlines. Namely, based on relevant data related to carried freight and available capacity of the passenger aircraft and assumption that the belly holds of passenger aircraft are always full, we estimated the share of belly hold capacity in total available capacity. Therefore, we assume that this ratio is approximately ⅓. Thus, the real number of aircraft in the fleet used in models represents the sum of number of cargo aircraft and ⅓ of the number of passenger aircraft.

Table 2. Data correlation matrix

	I_1	I_2	I_3	O_1	O_2
I_1	1				
I_2	0.651	1			
I_3	0.690	0.716	1		
O_1	0.586	0.604	0.938	1	
O_2	0.491	0.736	0.710	0.709	1

A correlation matrix for input/output data is presented in Table 2. The medium level of correlation can be observed for selected inputs and outputs.

5.2. AHP application

Pairwise comparison matrices for the AHP are designed based on the authors' knowledge and experience, and they are presented in Tables 3-5, as well as appropriate local priorities. It should be noticed that the consistency is on the required level.

Table 3. Pairwise comparison matrix for the first level

	Input	Output	Local priorities
Input	1	½	0.3333
Output	2	1	0.6667
$\lambda_{max}=2$			$CI=0$

Table 5. Pairwise comparison matrix for the outputs

Outputs	O_1	O_2	Local priorities
O_1	1	1/2	0.3333
O_2	2	1	0.6667
$\lambda_{max}=2$			$CI=0$

Table 4. Pairwise comparison matrix for the inputs

Inputs	I_1	I_2	I_3	Local priorities
I_1	1	2	1/3	0.2297
I_2	1/2	1	1/5	0.1220
I_3	3	5	1	0.6483
λ_{max}=3.00369			CI= 0.0018473	

In order to calculate importance of inputs and outputs we multiply local priorities of the inputs by local priority of input from the first level, and local priorities of the outputs by local priority of output determined from the first level. Finally, the importance of inputs and outputs are derived and their values are shown in Table 6.

Table 6. Importance of inputs and outputs

Inputs/outputs	I_1	I_2	I_3	O_1	O_2
Importance	0.0766	0.0407	0.2161	0.2222	0.4444

The values from the Tables 4-5 are further used to calculate ratios I_1/I_2, I_3/I_1 and I_3/I_2, as well as O_2/O_1, which are 1.88, 2.82, 5.31 and 2, respectively. These ratios are used for weighted DEA model in order to improve the results obtained by basic DEA model. Although it would be interesting to see how the pairwise comparison changes influence the weights and the final results, the sensitivity analysis is not carried out due to the space limitation of this paper.

6. RESULTS AND DISCUSSION

6.1. Basic DEA model

The results for basic DEA model with input-oriented CCR specification are obtained by using DEA-Solver software (learning version 8.0) and are presented in Table 7. The efficiency scores with CCR model assuming CRS shows that there are five efficient cargo airlines (Korean Air Cargo, Singapore Airlines Cargo, China Airlines, Air Bridge Cargo Airlines and Turkish Airlines) and they are thus potential reference units. These five cargo airlines shape the empirical frontier and this is the maximum possible efficiency that any of the inefficient cargo airlines can achieve in any level of inputs (for the observed population). In comparison with these airlines, all other airlines are found inefficient. According to the results, cargo airlines from Asia are more efficient than the cargo airlines from other regions. The minimum efficiency is 38.14% for DMU number 18. This means that United Airlines would have to decrease its inputs by 61.86% in order to become efficient. The mean efficiency score is 80.9%, i.e. 19.1% inefficiency, and the standard deviation is 17.72%.

In Table 7 (fifth column) the presented values are only determined for inefficient cargo airlines. These results represent references that can be used to provide the inefficient cargo airline information on which efficient airline it is compared to. In other words, to provide the information for inefficient airline which example of best cargo airlines they should follow. For example, the inefficient airline FedEx Express is compared to efficient airlines numbered 12 and 15. According to the numbers in brackets that represent intensity variable, the airline 15 (Turkish Airlines) is the most relevant DMU for the FedEx Express, since it has the highest value. For efficient cargo airlines the value in fifth column represents the number of the airlines for which this airline is benchmark. China Airlines is a benchmark for the largest number of cargo airlines (11 airlines).

A first observation in Table 7 is low efficiency for FedEx Express, which is the largest cargo airline in terms of FTK (Table 1). It is an integrated airline and this result is in contrast with the fact that this type of operators is currently considered among the best operators in air cargo industry with major market share. UPS Airlines performs better than FedEx Express in terms of estimated efficiency; however, it was not found the place among efficient airlines. Their low efficiency score in this study can be explained by the fact that the nature of their business and specific door-to-door service, usually within a stated time limit, demands the use of relatively more inputs to produce certain output.

In this way they can guarantee sufficient spare capacity. Thus, this type of efficiency measures, when only the resource utilization and cargo operations are considered, do not fits their service operation and do not give a true picture of their business success.

Table 7. Results for basic DEA model

No.	DMU	Score (%)	Rank	Benchmarks	Improvements (%)			Slack		
					I_1	I_2	I_3	I_1	I_2	I_3
1.	FedEx Express	62.53	15	12 (1.344); 15 (1.932)	-69	-57	-34	73030	146	0
2.	Emirates SkyCargo	70.29	13	6 (0.525) 12 (0.623); 13 (0.89)	-60	-30	-30	14585	0	0
3.	UPS Airlines	91.39	6	9 (0.499); 12 (1.507)	-9	-86	-27	0	451	4278
4.	Cathay Pacific Cargo	86.76	9	6 (0.308); 12 (0.259); 13 (1.23)	-51	-13	-13	8559	0	0
5.	Qatar Airways Cargo	68.62	14	6 (0.395);12 (0.24); 13 (1.164)	-60	-31	-31	9285	0	0
6.	**Korean Air Cargo**	**100**	**1**	**9**				0	0	0
7.	Lufthansa Cargo	80.31	11	6 (0.076); 12 (0.043); 13 (1.165)	-20	-88	-20	0	164	0
8.	Cargolux	90.22	7	12 (0.027); 13 (1.293)	-42	-10	-14	1099	0	465
9.	**Singapore Air. Cargo**	**100**	**1**	**2**				0	0	0
10.	Air China Cargo	70.72	12	6 (0.106); 12 (0.013); 13 (1.042)	-29	-88	-29	0	133	0
11.	China Southern Airlines	83.54	10	9 (0.579); 12 (0.41)	-16	-85	-26	0	178	1211
12.	**China Airlines**	**100**	**1**	**11**				0	0	0
13.	**Air Bridge Cargo Air.**	**100**	**1**	**7**				0	0	0
14.	All Nippon Airways	88.53	8	6 (0.592); 15 (0.013)	-11	-49	-11	0	32	0
15.	**Turkish Airlines**	**100**	**1**	**4**				0	0	0
16.	British Airways	61.41	16	6 (0.38); 12 (0.006); 15 (0.272)	-65	-39	-39	10631	0	0
17.	Etihad Airways	60.62	17	6 (0.246); 12 (0.009); 13 (0.412)	-77	-39	-39	9236	0	0
18.	United Airlines	38.14	18	6 (0.101) ; 15 (0.728)	-78	-62	-62	14193	0	0

In contrast to integrated cargo airlines, schedule passenger airlines show better results in this study. Namely, four out of five airlines identified as an efficient by the DEA model are schedule passenger airlines. These two types of airlines differ a lot in size, type of operations and the service offered. In terms of operation efficiency, it can be concluded that combining the passenger and cargo transportation on the same or dedicated fleet, airlines can perform better efficiency scores. Among the schedule passenger airlines, there are few of them (e.g. Emirates SkyCargo and Qatar Airways Cargo) which are also leading cargo airlines in terms of FTK, but show low efficiency results. This can be explained by the fact the Gulf airlines are generally enjoy the substantial supportive policies of their governments, which are reflected in the form of lower operation costs and lower labour cost in comparison to the market conditions in other regions.

All-cargo airlines show high efficiency scores. Namely, Air Bridge Cargo Airlines is recognized as an efficient airline and represent the benchmark for even seven airlines. Cargolux, one of the leading cargo airlines in Europe showed the efficiency score of more than 90%. Obviously, the decision to perform only the flying operation for cargo transportation (unlike integrated cargo operators) brings some benefits on the operational side of the cargo business for these airlines.

Finally, in the columns six, seven and eight of the Table 7 we provide the relevant calculations for inefficient DMUs. Those values are determined based on the intensity variables. The data show the size of inefficiency of the examined DMUs in relation to the reference cargo airlines. Furthermore, these values are determined in accordance with the DEA orientation, i.e. they indicate the direction that an inefficient cargo airline approaches to the efficient frontier. In particular, how much is needed to reduce the input levels while maintaining the same level of outputs. For example, in order to become efficient FedEx Express should reduce the number of employees for 69%, fleet size for 57% and offered capacity for 34%. The results also show that this correction in not enough for inefficient airlines to reach the efficient frontier, so further improvement can be made by using the slack variables. The values of slack variables are showed in the last three columns of Table 7.

6.2. Weighted DEA model

Basic DEA model determine the efficient DMUs based on the output/input ratios. If a DMU has at least one of these ratios ranked as the best one, then that DMU will be identified as efficient. This will happen even if all other ratios for that DMU are not good or are recognized as very inefficient. For example, according to basic DEA, Korean Air Cargo is efficient based on O_1/I_3 ratio, but its other ratios are very low. In order to improve the results obtained by basic DEA model, we introduced the weights derived from AHP in weighted DEA model. New results are shown in Table 8.

Table 8. The results of weighted DEA model

No.	DMU	Score (%)	Rank	Benchmarks	Improvement (%)			Slacks	
					I_1	I_2	I_3	I_1	I_2
1.	FedEx Express	40.78	15	12 (1.73)	-89	-89	-59	61962	755
2.	Emirates SkyCargo	31.72	10	12 (0.98)	-86	-84	-44	2682	220
3.	UPS Airlines	85.61	3	12 (1.65)	-57	-41	-47	0	431
4.	Cathay Pacific Cargo	33.51	9	12 (0.62)	-81	-75	-45	0	0
5.	Qatar Airways Cargo	24.06	13	12 (0.62)	-75	-71	-78	0	0
6.	Korean Air Cargo	24.40	12	12 (0.31)	-84	-70	-74	956	71
7.	Lufthansa Cargo	54.90	7	12 (0.32)	-83	-89	-57	0	118
8.	Cargolux	61.94	6	12 (0.31)	-83	-80	-86	0	4
9.	Singapore Airlines Cargo	91.42	2	12 (0.28)	-83	-98	-91	0	25
10.	Air China Cargo	42.72	8	12 (0.27)	-83	-85	-79	0	86
11.	China Southern Airlines	77.70	5	12 (0.57)	-48	-73	-33	0	180
12.	**China Airlines**	**100.00**	**1**	**17**					
13.	Air Bridge Cargo Airlines	82.51	4	12 (0.22)	-59	-97	-87	0	6
14.	All Nippon Airways	21.35	14	12 (0.18)	-56	-97	-89	619	43
15.	Turkish Airlines	26.65	11	12 (0.20)	-44	-97	-88	3764	104
16.	British Airways	15.82	16	12 (0.18)	-34	-73	-88	4051	87
17.	Etihad Airways	14.53	17	12 (0.17)	65	-62	-83	1270	48
18.	United Airlines	10.01	18	12 (0.18)	171%	-82	-87	6444	125

It can be seen that the number of efficient airlines is reduced from five to only one airline – China Airlines. This is in line with the results obtained in basic DEA model

where this airline is the benchmark for the largest number of airlines. In this model, China Airlines determines the efficient frontier. The efficiency of the sample is in wider range from 10.01% (United Airlines) to 100% (China Airlines) comparing with basic DEA. The mean value is equal to 45.31%, which is lower than in basic model, while the standard deviation is increased to 30.25.

It is also interesting to note that previously efficient airlines have changed their rank. Namely, Singapore Airlines Cargo is ranked as second with the score of 91.42%, while Air Bridge Cargo Airlines is ranked as fourth, with 82.51% of efficiency. The other two airlines that were fully efficient according to basic DEA model have very low scores according to weighted DEA. Specifically, Turkish Airlines and Korean Air Cargo are at the positions 11 and 12 having 26.65% and 24.4% efficiency, respectively. Further, it means that they need to improve their efficiency by 73.35% and 75.6%, respectively in order to become efficient. This can be explain by the fact that these two airlines have the best load factor (O_1/I_3) which qualified them for efficient airlines according to basic DEA. Assigning the weights to inputs/outputs, load factor becomes less important in comparison with the other parameters and pushes these airlines from efficient to the inefficient ones with the very low scores.

From Table 8 can be observed that potential inputs improvements of inefficient airlines are in the wide ranges. For example, potential improvements of I_1 vary from shortage of 171% to surplus of 96%, while I_2 and I_3 have only surplus which is in range 41-98% and 33-91%, respectively. Different efficiency pattern could not be observed based on the type of airlines. In the category of passengers airlines fully efficient as well as airline with the lowest DEA efficiency score can be found. For some cargo airlines (e.g. Cathay Pacific Cargo and Qatar Airways Cargo) the applied improvements are sufficient for achieving the efficient frontier. For the rest of inefficient cargo airlines, additional slacks improvements need to be applied in order to reach the efficient frontier.

7. CONCLUSION

The problem considered in this paper combines two well-known techniques DEA and AHP which have proved to be very useful in solving a variety of problems. Whereas these methods have not been employed to the cargo airline efficiency evaluation yet, we have shown their applicability in this field.

We analysed relevant, available literature and identified the appropriate inputs and outputs. Thus, it is noted that the major trade-off in airline management is between capital and labour and we followed the same concept. The main results from both models imply that the cargo airlines from Asia are more efficient than the cargo airlines from other regions. Moreover, the schedule passenger airlines show better results in efficiency scores in comparison to the integrated operators and all-cargo airlines. Also, the results specify that the most inefficiency of the cargo airlines is due to overstaffing and insufficient fleet utilization.

The results from weighted DEA model, allowed us to reduce the number of efficient cargo airlines from five to one. In this way we avoid a large number of efficient airlines which are actually efficient only due to one parameter performance, while the rest of performances show very poor results.

The key contributions of this research are twofold. The study shows for the first time the individual efficiency score of a large number of cargo airlines. In the existing literature there are some studies about general efficiency estimation in the airline industry, but none of them consider cargo airlines. The second contribution is that we propose the weighted DEA model, where the weights were obtained through AHP approach. Allowing decision maker to design AHP pairwise comparison matrices according to his knowledge and awareness of current and potential future changes on the cargo market, the proposed approach could suggest suitable weights for weighted DEA approach for different "if-then" scenarios based on different assumptions. Since the DEA and AHP usage has an important role in multi-criteria decision making and their application is extensive in a wide variety of areas, this paper shows that the DEA combined with the AHP can be successfully used as a support tool in efficiency evaluation, providing future directions for corresponding improvements.

Future research in this field should include a wider range of inputs and outputs, which will extend the research encompassing both quantitative and qualitative parameters. Moreover, in order to express the criteria importance over each other one can deal with uncertain judgements, which indicates the possibility to use fuzzy sets or fuzzy numbers, and incorporates the vagueness of human thinking.

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QUANTITATIVE METHODS FOR DETERMINING PREMIUM RATES IN TRANSPORTATION INSURANCE UNDER UNCERTAINTY

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Abstract: *In decision-making processes, including insurance decision-making processes, decisions are usually made in the circumstances of uncertainty or absence of information or knowledge of a particular problem, so it is necessary to conduct different assessments and find different solutions for the problem. Actuaries and underwriters are faced with many problems in the process of quantifying risk in conditions of uncertainty, where classical techniques are difficult to apply because of a large number of unknown parameters. Given the specificity of transportation insurance, the technique of fuzzy mathematics and the possibility theory can be used to a great extent in various transportation insurance lines, including the segment of determining the premium rates.*

Keywords*: uncertainty, fuzzy measures, c-credibility, transportation insurance, premium rates.*

1. INTRODUCTION

There is a large number of transportation insurance lines, and the most prevailing is marine cargo insurance. This insurance means insurance of the various tangible interests of many participants involved in the processes of the physical distribution of goods. This implies providing security to the insured who is exposed to various risks that can occur during the process of transportation, warehousing and manipulation of the goods, by providing financial compensation for any damage that the insured would sustain if the insured transport perils occur. The subject matter of insurance is the goods as well as the financial interests of the policyholders who are exposed to the transportation risks (Tomašić, 1987, Seltmann, 2004, Dunt, 2009, Thomas, 2009, Pavić, 2012).

Actuarial science is multidisciplinary, a combination of science and practical applications, so the subjectivity of an actuary in the parameters evaluation is significant, but also the uncertainty of occurrences in certain tasks, for example in the quantification

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of the risk parameters needed to determine the premium rates. The practice has shown that the difficulties exist in the correct setting of the problem, as well as in the subjective interpretation of the results of the experiment.

Also, in insurance practice there is often high level of complexity of the observed problems, when the experience based on human expertise is taken into account, instead of precise calculation (Gajović and Paunović, 2018). In addition to actuarial science, a very important segment in the insurance business is underwriting, especially in transportation insurance. Underwriting involves the process of analysis, selection and classification of insurance applications, assessment of the potential clients' exposure to certain risks, as well as determination of the conditions and rates of insurance cover (DeWit, 1982; 2009). Kunreuther et al. (1995) state that actuaries usually calculate the level of insurance risk and the value of insurance coverage on the basis of available statistical data, while underwriters and insurance managers usually make final decisions on accepting risks, the elements in the insurance offer and final insurance premium.

In order that the underwriters decisions should be as correct and reliable as possible, underwriters must also have, in addition to their knowledge of the insurance lines they are specialized in, a broad knowledge of actuarial theory and practice. A managerial decision of the underwriters in non-life and transportation insurance is usually made on the basis of information obtained from the client, policy holder (eg business entities, brokers, freight forwarders, carriers, agents, ports, etc.), a competent person from insurance company, outsourced personnel responsible for inspecting the subject of the insurance, institutions competent for assessing the creditworthiness of the client, etc.

In many cases, transportation insurance is contracted on the basis of the underwriter decisions. There are many reasons for this (Gajović, 2015):

- a large number of homogeneous groups of insured subject matter,
- numerous elements and sub-elements of risks,
- different modalities of insurance contracts that cover different risks or groups of risks,
- changes in transportation risks in space and time,
- limitations of coverage by insured or insurance company, etc.

In decision-making processes, including insurance decision-making processes, decisions are usually made in *the circumstances* of uncertainty or absence of information or knowledge of a particular problem, so it is necessary to make different assessments and to find different solutions to the problem. Uncertainty implies phenomena whose outcome cannot be correctly predicted in advance. The uncertainty theory is a part of mathematics which, among other things, deals with modeling the belief degree. The possibility theory is a part of the theory of uncertainty for the processing of incomplete information and it is based on a pair of dual measures, the possibility measure and the necessity measure. Taking into account the specificity of transport insurance, the techniques of mathematics and the possibility theory can find significant application in various transport insurance lines, including the segment of determining premium rates. Fuzzy mathematics and fuzzy system has proved to be applicable in the risk assessment (Paunović et al., 2018; Gajović et al., 2018) and other segments of theory and practice of insurance such as classification, risk underwriting (Kerkez and Gajović, 2016), liabilities projections, future and present values (Cummins, 1987), calculating of insurance

premiums (Young, 1996, 2004 Hosler, 1992), asset allocation, cash flows, investments (Lemaire, 1992, Ostaszewski, 1993) etc.

The classical methods of determining insurance premiums in transport insurance and the problems faced by actuaries and underwriters when determining premium rates will be set out in the following parts. Then the fuzzy measures are defined, as well as two measures of credibility in the fuzzy environment. The c-credibility measure is a new measure that represents the aggregate value of the necessity and possibility measures. Particularly discussed are the fuzzy logic and the fuzzy relations as well as the method of assigning value to relations. The above-mentioned quantification methods of transport rates are presented through the relevant examples.

2. CLASSICAL METHODS OF DETERMINING TRANSPORT INSURANCE PREMIUM

The processes of inflow and outflow of financial assets in insurance are stochastic and can be very complex. The basic approach to the insurance risk calculation is the assumption that total loss costs from all insured risks over a given period of time arises due to a stochastic process to which the insurer does not have any influence or its impact is limited. Since frequency and amount of claims represent a stochastic category, it is necessary to determine their individual distributions of probability and distribution parameters. They are most often performed on the basis of historical data used to determine the theoretical distribution characteristics, or certain approximations and assumptions are used, in the absence of a representative statistical sample. The insurance premium is a parameter that is directly related to the risk of insurance coverage.

Risk premium formula is

$$E(LC) = f_k \cdot s, \tag{1}$$

where

f_k the number of claims per exposure unit, and

s is severity (average loss per claim).

The risk premium is further adjusted by the influencing factors related to the usual actuarial techniques, limits of insurance, deducible, as well as the available data on the claims and incidents in the previous period. The further premium risk correction relates to the specificity of the insured, such as industry classification of the insured, the characteristics of the goods in the transport, the specificity of the transportation, the transport destination, etc.

There are many specific features of transport insurance, which differentiate it from other non-life insurance lines. Transport insurance lines are often complex and require a multi-disciplinary knowledge, coverage is often adapted to the specific needs of the clients etc. Unlike most other non-life insurance lines, transport insurance is often based on international law, international conventions (CMR, CMNI, CMR, TIR, ATA, FIATA, ADR, RID and others) and business ethics (INCOTERMS, for ports, shipping, packaging, security, etc.), international terms and conditions and insurance clauses, etc. Numerous authors point to the specificity of transport insurance and the complexity of the process of determining premium rates, especially in the insurance of goods in transport. Given

the fact that insurance coverage conditions are most often tailored to the special needs and requirements of the insurance policyholder, contracts in cargo insurance often coverindividual, specific risks not covered by the standard conditions or insurance clauses (Gajović, 2015).

The distribution of total claims is determined on the basis of the premium adequacy in relation to the projected expectation on losses with risk loading coefficient for the purpose of calculating the required actuarial premium (Biener, 2011). Given that the goal of any insurer is to provide the required insurance coverage with the necessary actuarial premium, the basic problem is how to ensure assessment of sufficient actuarial premium, to cover losses incurred in the future period, and to provide financial resources to settle all future obligations of insurers and actual profit from business. In addition to the total costs of the future claims, the insurer has significant additional costs incurred by the insurer organization (eg employee compensation costs, management costs, external costs, reinsurance costs, etc.). The most common indicators for determinig accuracy of actuarial and underwiters methods and assumptions are as follows: loss ratio, loss adjustment expense ratio - LAE ratio, UW expense ratio, operating expense ratio -OER, combined ratio and others. The most common methods for calculating the premium of various nonlife insurance lines based on statistics are pure premium method and loss ratio method. In the world practice, there are different modalities of those methods, such as experience rate, exposure rating, manual rating, schedule rating, retrospective rating (Neuhaus, 2004, Werner and Modlin, 2010). In case of transportation insurance lines, the judgment rate making methods are used in practice as a result of the lack of a representative statistical sample that causes low credibility. The premium is usually estimated on the basis of intuition, experience or on the basis of available, non-representative data, and it depends on the characteristics of the insurance coverage, different specificities and limitations. In practice, expert assessment of risk insurance coverage is carried out by the underwriters, who are most often specialized for certain types of insurance and have extensive knowledge and experience of risk management in relation to the subject of insurance and insurance coverage. The established premium or premium rate determined by the statistical or expert-based underwriters methods can be adjusted, depending on the number of influences on the level of risk of insurance coverage, various costs, modalities and specificities of the various insurance contracts, etc.

There are many corrective factors that often need to be considered and included in the various nonlife and transportation insurance policies when deciding on the final premium rate for specific insurance coverage, such as (Gajović, 2015):

- ***Reinsurance*.** Reinsurance is the most common instrument for transfer of a part of risk over the own insurer capacity. The risks that the insurer keeps for himself is called retention. Determining the reinsurance premium depends on the type of reinsurance contract and the specificity of the insurance coverage and implies the application of complex mathematical and actuarial methods and models (Daykin et al., 1995; Schmitter, 2004). Reinsurance premium has direct influence on the gross premium.
- ***Deductible*.** Deductible is the amount that is deducted, in case of occurrence, as a certain percentage or amount, depending on the contract. By contracting a deductible, the insurer transfers a part of the risk on the insured resulting in reduced

risk coverage of the insurer and in the same time stimulating insured to carry out activities in the function of minimizing damage. The type and amount of the dudectible in contract significantly affect the amount of the insurance premium (Buchanan i Priest, 2004).

- ***Type of insurance contract.*** According to their duration, transportation insurance contracts may be voyage or time contracts, and that has direct influence on the insurance premium amount. Insurance of goods in transport can be contracted through individual or general contracts (Dunt, 2009; Pavić 2012, Tomašić, 1987). The most common types of general cargo insurance contracts are the Open cover policy, Floating policy, Fronting insurance contracts, etc.
- ***Utility theory.*** Utility theory is widely used in the field of risk management and insurance due to the fact that the behavior of decision-makers on the amount of risk and its acceptability is described in accordance with the individual character of money. From the point of view of the insurance institution, the insured person often decides to pay a premium that is higher than the expected level of loss due to the utility theory and the principle of decreasing marginal utility of money (Brown and Gottilieb, 2001, Daykin et al., 1995) .
- ***Market factor***. The competition is very heavyon the international and domestic insurance market affecting the reduction of insurance premiums, flexibility of the insurer related to the insurance contracting, expanding the range of insurance products, flexibility regarding modalities of payment of insurance premiums and others. A number of authors deal with the influence of the market on the price of insurance and market process modeling in insurance.
- ***Corporate objectives***. The goal of each insurance company is to make the greatest possible profit from the insurance business. Insurance companies may have different poicies for risk acceptance or strategies that imply readiness, appetite, or tolerance regarding risk acceptance.
- ***Characteristics of insured****.* Insurer monitors the available information about the policy holder and the insured, their creditworthiness, reputation, business reputation, basic activities, possession of appropriate business standards, examines their own and experience of the other insurers, and on that basis makes decision on the modality and the price of insurance coverage, possible limitations and, in certain cases, rejecting to provide insurance.

In some cases, these factors may be of key importance in risk assessment and may, in some situations, affect the decision of the insurer on not accepting insurance risk.

In practice, different principles of calculaing premium are applied, including the area of transport insurance. The principles are actuarial rules on the basis of which insurance companies determine the premium or premium rates for the assumed risks. In the literature, there are several methods that actuaries use in defining premium principles such as Ad Hoc Method, Characterization Method, Economical Method, etc. The most common principles for determining the premium are Net Premium Principle, Expected Value Premium Principle, Variance Premium Principle, Standard Deviation Premium Principle, Equivalent Utility Principle, Exponential Premium Principle, Esscher Premium Principle (Young, 2004, 1999, Kaas and et al., 2009) and others.

Credibility can be used to calculate the price and premium rates, to determine the future premium rates based on the experience, claims provision etc. In the classical credibility theory there are two basic methods, Limited Fluctuation methods, and the Method of the greatest accuracy. When applying credibility, it is necessary to consider the characteristics of both the experience of the company and the relevant experience (experience similar to the company experience).

The basic credibility formula is

$$\text{Estimation} = Z\cdot [\text{Observation}] + (1 - Z)\cdot [\text{Other information}], \qquad (2)$$

where $0 < Z < 1$, Z credibility assigned to observation, and $1–Z$ is referred to as the complement of credibility.

Credibility implies a linear assessment of the real expectations made as a result of a compromise between observation and the previous hypothesis. Because of the uncertainty of phenomena certain difficulties exist in the real application.

Example 1. In a large population of truck drivers, the average driver makes a claim every four years, i.e. the annual claim frequency is 0,25 per year. The result of a performed random selection is a driver who had three claims over the last five years with a claim frequency of 0,55 per year. An estimate of the expected future frequency for this driver is needed. If there is no additional information about the driver, except that he belongs to the observed population, the frequency would have been 0,25. However, we know that the claim frequency for the observed driver was 0,55. There is a correlation between the previous claim frequency and the future claim frequency, but it is not perfect correlation. Due to the randomness of accidents, even the good drivers with low expected claim frequencies can be involved in some accident. On the other hand, drivers with poor driving skills can file no claims for acouple of years. According to the general formula of credibility (2), the expected value of future drivers incident frequency is

$Z \cdot 0{,}55 + (1 - Z) \cdot 0{,}25.$

The necessary number of data for credibility is called the standard for full credibility. Thus some regulators prescribe the required sample size necessary for full credibility for certain lines of insurance. For example, in Canada for liability insurance, it is 3.246, while for collision insurance that number is 1.082.

There are two methods for determining the weight in the above formula.

According to the limited fluctuation method, Z is determined as follows:

$$Z = \min\left(\sqrt{\frac{N_{comp}}{N_{fcr}}}, 1\right) \qquad (3)$$

N_{comp} - the number of insureds in the most recent historical period of the company

$N_{forecast}$ - the size of the sample needed for full credibility

According to the second method, models of a greatest accuracy credibility, formula for Z is:

$$Z = \frac{N_{comp}}{N_{comp} + K},\ K = \frac{\tau}{a} \qquad (4)$$

where *K* is the ration of the expected value of process variance and variance of hypothetical meanings.

By definition, each individual can choose any value for these parameters. The fact is that in practice the most commonly used 95% level of reliability and 5% for marginal error, does not provide scientific foundation. The actuary might want to use the other values for these parameters. As a result, for the same insurance, an actuary may consider, for example, 400 for the sample size that produces complete credibility for the experiential data. The other actuary may take into account any number of samples less than 1100 that is not sufficient the complete credibility (Klugman and Rhodes, 2009; Kerkez and Ralević, 2018).

3. THE POSSIBILITY THEORY

In the 1980s, many authors pointed to the strong link between Dempster Shafer's theory, the theory of probability and the possibility theory based on the fuzzy measures. The fuzzy measure theory is the generalization of the classical theory of the measure. This generalization is obtained by replacing the additive axiom of classical measure with the weaker axioms of monotonicity and continuity. The development of the fuzzy measure theory is motivated by the fact that the property of additive in some applications is too restrictive and, consequently, unrealistic. Some authors use the term monotone measures instead fuzzy measures. Thus, the fuzzy measure according to Sugeno is obtained by replaced additive properties with the conditions of monotonicity (in relation with inclusion) and continuity, but it was subsequently determined that the continuity is also restrictive, and it is replaced by the condition of semi continuity.

The name of possibility theory was introduced in Zadeh (1978), inspired by Gaines and Kohouta (1975). To a large extent, it can be compared with the probability theory, as it is based on a set function. Possibility and necessity measures, as monotone and semi continuous measures, are increasingly applied in real problems.

Definition 1. Let *X* be nonempty set and Σ *σ*−algebra on *X*. Fuzzy measure (*fuzzy measure in the narrow sense*) *m* on *σ*− algebra Σ is map $m:\Sigma\to[0,\infty]$ with properties

$$\text{i)}\ m(\varnothing)=0, \tag{5}$$

$$(ii)\ (\forall R,S\in\Sigma)R\subset S\Rightarrow m(R)\le m(S). \tag{6}$$

The belief measure *Bel* and plausibility measure *Pl* are special forms of monotonous measures. The measure connection with preconceived impression is called the belief measure. Measure related to information that is possible or acceptable (plausible) is called a measure of plausibility (Dubois and Prade, 1980).

Definition 2. Necessity function is a fuzzy measure on (X,Σ) if

$$nec\left(\bigcap_{i\in I}R_i\right)=\inf_{i\in I}nec(R_i), \tag{7}$$

for any family of subsets $\{R_i\mid i\in I\}$ in Σ such that $\bigcap_{i\in I}R_i\in\Sigma,$ where *I* is an arbitrary index set.

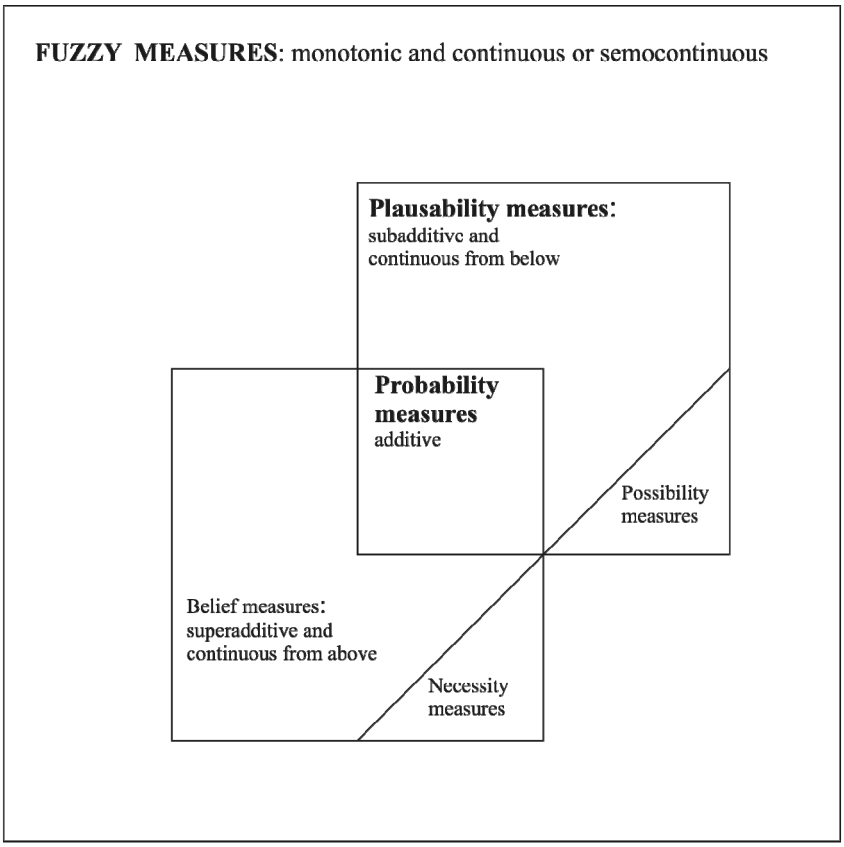


Figure 1. Relationship between the fuzzy measure classes

Definition 3. Possibility measure is a function

$$pos\left(\bigcup_{i\in I} R_i\right) = \sup_{i\in I} pos\left(R_i\right), \tag{8}$$

for any family of subsets $\left\{R_i \mid i \in I\right\}$ in Σ such that $\bigcup_{i\in I} R_i \in \Sigma,$ where I is an arbitrary index set.

Relationship between the fuzzy measure classes is shown in Figure 1.

An alternative version of the credibility theory in the fuzzy environment, as a branch of mathematics for studying behavior of fuzzy phenomena, was formulated by Liu (2007). The credibility measure (Liu and Liu, 2002) is presented as a no additive measure with self-duality property, as an average of possibility and necessity measures:

$$Cr\left(R\right) = \frac{1}{2}\left(pos\left(R\right) + nec\left(R\right)\right), \tag{9}$$

where R is the set in possibility space $\left(X, P\left(X\right), pos\right).$

In the classical theory of credibility, the main task is to find weight of measures. However, the weight here is predetermined and it is 0,5. For this very reason it is necessary to generalize the credibility measure, and that is achieved with c-credibility measure given by Ralević and Paunović (2018).

The generalization of this measure in fuzzy environment is achieved through the aggregation function. Aggregation of information takes a significant place in many knowledge-based systems, where aggregation of data or values is needed. In general, it can be said that by aggregation simultaneously, different parts of information from different sources are used, in order to make a conclusion or a decision.

Aggregation operation (Klir and Yuan, 1995) on *n* fuzzy sets (n > 2) is defined by a function $h:[0,1]^n \to [0,1]$.

When applied to fuzzy sets $A_1, A_2, \ldots, A_n$ defined on *X*, function *h* produces an aggregate fuzzy set A by operating on the membership grades of these sets for each $x \in X$.
Thus,

$$A(x) = h\left(A_1(x), A_2(x), \ldots, A_n(x)\right) \text{ for each } x \in X. \quad (10)$$

The *c*-credibility in the fuzzy environment in relation to the aggregation function *h* is defined in the following way

$$cr_h(R) = h\left(pos(R), nec(R)\right) \quad (11)$$

If aggregation function is a weighted arithmetic mean

$$h(x,y) = \lambda \cdot x + (1-\lambda) \cdot y, \ \lambda \in [0,1] \quad (12)$$

(which is not symmetrical in the general case), then c-credibility in the fuzzy environment is

$$cr_\lambda(R) = \lambda \cdot pos(R) + (1-\lambda) \cdot nec(R), \quad (13)$$

In insurance, it is often necessary to determine the appropriate premium rates for the future, i.e. to adjust the past premium to the expected value in the future period. Thus, an actuary must also take in the calculation changes in future costs due to inflation impacts, regulatory changes, technology advances, etc. Normally, the premium also includes profit and contingencies. In addition, the premium must be adjusted to reflect all premium trends, which is achieved through the so-called trend factors. In the following example, the method of determining future premium rates based on lost cost method (Brown and Gottlieb, 2001) is presented, and calculations are performed using classical actuarial technique and c-credibility.

Data on premium rates and claims by regions are given in Table 1. We need to calculate indicated rate change.

Table 1. Insurance company data by regions.

Region	Current Base rates	Earned premium at current rates	Incurred losses	Claim Count	Units of exposures
A	153	830000	330000	866	5424,8366
B	63	965000	525000	1100	15317,4603
C	102	550000	290000	320	5392,15686

For the lost cost method, we need to calculate the Units of exposures using the formula (1), ie. as ratio of earned premium rate at current rates and current base rates. Current

differential is the ratio of current base rates to the base rate of the region with highest incurred losses. Indicated differential is calculated by the same process by comparing the data for the loss cost.

Adopted differential (table 2) is then aggregation function $\left(Z \cdot d_I^n + \left(1-Z\right) \cdot d_C^n\right)^{\frac{1}{n}}$ for the different values of the parameter *k*.

Table 2. Result for loss cost model

Region	Current diff.	Loss Cost	Indicated diff.	Z	Adopted			
					k=1	k=2	k=3	k=4
A	2,428571	60,83	1,775	0,895	1,844	1,855	1,867	1,882
B	1,000000	34,27	1,000	1,000	1,000	1,000	1,000	1,000
C	1,619048	53,78	1,569	0,544	1,592	1,592	1,592	1,592

4. FUZZY RELATIONS AND FUZZY LOGIC

The concept of the relation can be generalized to provide a different degree or strength of link between the elements. The fuzzy relationship is a fuzzy set defined on the space $X = X_1 \times X_2 \times \cdots \times X_n$, where $\left(x_1, \mathrm{x}_2, \ldots, \mathrm{x}_n\right) \in X$ can have different degrees of membership in the relation.

Definition 4. Let $X_1, X_2, \ldots, X_n$ are arbitrary sets and $X_1 \times X_2 \times \cdots \times X_n$ is Cartesian product. Fuzzy set *F* defined on $X^n (n > 1)$ is the *n*−ary fuzzy relation on *X*.

For fuzzy relation *F* on $X_1 \times X_2 \times \cdots \times X_n$, value $F\left(x_1, \mathrm{x}_2, \ldots, \mathrm{x}_n\right)$ is the degree, ie. the level of connectivity of elements $x_1, \mathrm{x}_2, \ldots, \mathrm{x}_n$, in sequence, by criteria *F*. The fuzzy relationship is identify with its membership function, so it is indicated in the literature by $\mu_F\left(x_1, \mathrm{x}_2, \ldots, x_n\right)$ or $F\left(x_1, \mathrm{x}_2, \ldots, x_n\right)$.

For fuzzy relation F, the conditions of reflexivity, symmetry, antisymmetry and transitivity are fulfilled. It is simply checked that for the reflexive and transitive fuzzy relation F is $F \circ F = F$. If the fuzzy relation on the set X is reflexive, symmetric, and transitive, then it is fuzzy equivalence on X.

Phase equivalence *F* on a set is called a fuzzy equality if for all $x, y \in X$, holds $F\left(x, y\right) = 1$ then $x = y$.

For binary fuzzy relation *F* on $X \times Y$ we have:

The first projection of a fuzzy relation *F* is a fuzzy set on *X* is defined by

$$\left(\mathrm{dom}\, F\right)\left(x\right) = \sup_{y \in Y} F\left(x, y\right) \tag{14}$$

The second projection of a fuzzy relation *F* is a fuzzy set on *Y* is defined by

$$\left(\mathrm{rang}\, F\right)\left(y\right) = \sup_{x \in X} F\left(x, y\right) \tag{15}$$

$(\mathrm{dom}\,F)(x)$ is the strongest relation of $x \in X$ with any member of set *Y*, and $(\mathrm{rang}\,F)(y)$ is the strongest relation of $y \in Y$ with any member of set *X*.

Let $X = \{x_1, x_2, ..., x_n\}$ and $Y = \{y_1, y_2, \ldots, y_n\}$ are finite sets. Membership matrix of fuzzy relation is a matrix $A_F = \left[a_{ij}\right]_{n\times m}$ with elements $a_{ij} = F(x_i, y_j) \in [0,1]$.

Let *F* is binary fuzzy relation represented with membership matrix $A_F = \left[a_{ij}\right]_{n\times m}$, then for any $x_i \in X, y_i \in Y$ $(\mathrm{dom}\,F)(x) = \max\limits_{j\in\{1,\ldots,m\}} a_{ij}$ is the maximal element in the *i*-th row, and $(\mathrm{rang}\,F)(y) = \max\limits_{i\in\{1,\ldots,n\}} a_{ij}$ is the maximal element in the *j*-th column.

Composition of fuzzy relations can be defined in several ways. The following is the definition of the standard composition resulting from the operation min and max .

Let F_1 and F_2 are fuzzy relations respectively on $X \times Y$ and $Y \times Z$.

Definition 5. Standard composition of relation F_1 and relation F_2 is relation ρ on *X* × *Z*, defined by

$$\rho(x,z) = (F_1 \circ F_2)(x,z) = \sup_{y\in Y} \min\left\{F_1(x,y), F_2(y,z)\right\}. \qquad (16)$$

Fuzzy relation ρ can be represented by its membership matrix.

Let $A_{F1} = \left[a_{ij}\right]_{n\times k}$ and $A_{F2} = \left[b_{ij}\right]_{k\times m}$ membership matrices of fuzzy relations F_1 and F_2. Membership matrix of the fuzzy relation $\rho = F_1 \circ F_2$ is $A_\rho = \left[c_{ij}\right]_{n\times m}$, where $c_{ij} = \max\limits_{s\in\{1,..,k\}} \min\left\{a_{is}, b_{sj}\right\}$ for all $i \in \{1,2,...,n\}$ and $j \in \{1,2,...,m\}$.

Composition of fuzzy relation can also be defined through other operations. There are several ways of assigning values to relations. Methods that attempt to determine a kind of similar form or structure of data through different metrics are called similarity methods (see Zadeh, 1973 or Dubois and Prade, 1980). There are dozens of these methods (see Ross, 1995), and through the example we will introduce the max-min method.

Example 2. An insurance company has formed a team of experts to determine certain classes of damage on goods in road transport, for a particular type of goods, in the observed geographical area. The following table shows the results of the expert analysis by the levels of damage: without damage, moderate damage and major damage.

Table 3. Results of the expert analysis

Region	x_1	x_2	x_3	x_4	x_5
without damage	0,4	0,2	0,6	0,1	0,2
moderate damage	0,7	0,4	0,6	0,2	0,4
major damage	0,2	0,5	0,2	0,2	0

For max-min method formula for elements of fuzzy relation is

$$a_{ij} = \frac{\sum_{k=1}^{m} \min\left(x_{ik}, x_{jk}\right)}{\sum_{k=1}^{m} \max\left(x_{ik}, x_{jk}\right)}, \; i, j = 1, 2, \ldots, n. \tag{17}$$

Using the previous formula, we obtain a symmetric matrix that shows the similarity of damage by areas.

$$A_{\rho} = \begin{bmatrix} 1 & & & & \\ 0,500 & 1 & & & \\ 0,800 & 0,471 & 1 & & \\ 0,385 & 0,455 & 0,357 & 1 & \\ 0,462 & 0,545 & 0,429 & 0,375 & 1 \end{bmatrix}$$

Further, through the equivalence relation, the areas can be classified into certain categories of similar properties, as an indicator of damages (claims), as well as a correction factor for future premium rates.

Introducing labels that indicate more precise descriptions and gradual transitions is the method of quantification of the uncertainty by fuzzy logic (Dubois and Prade, 1987). Fuzzy logic implies the membership degree of an element to a particular set. It can belong to different sets, but with a certain degree. There is a gradual transition between the sets, and they can overlap in a certain degree. Fuzzy logic is the generalization of classical logic in the way in which the fuzzy sets are generalization of classical sets.

Truth value *T*(*P*) assigned to some proposition *P* in fuzzy logic can take some arbitrary value from interval [0,1], ie. $T : P \rightarrow (0,1)$. This actually means that in fuzzy logic exist a degree of truth (truthfulness) of some statement. This degree of truth is derived from the membership functions of fuzzy set on which the statement defined.

Suppose that proposition P is assigned to fuzzy set A, then the truth value of the proposition is $T(P)$, $T(P) = \mu_A(x)$, where $0 \le \mu_A(x) \le 1$, i.e. the degree of truth for $P : x \in A$ is equal to the membership degree of *x* to the fuzzy set A.

Let proposition *P* is defined on the fuzzy set *A* and proposition *Q* defined on set *B*, then we have:

i) $T(\overline{P}) = 1 - T(P)$ negation

ii) $P \vee Q : x$ is A *or* B,

$T(P \vee Q) = max(T(P), T(Q))$ disjunction

iii) $P \wedge Q : x$ *is* A *and* B,

$T(P \wedge Q) = min(T(P), T(Q))$ conjunction

iv) $P \rightarrow Q : x$ *is* A, then x *is* B,

$T(P \rightarrow Q) = T(\overline{P} \vee Q) = \max(T(\overline{P}), T(Q))$ Zadeh's implication.

The often used implications is Lukasiewicz's implication

$$T(P \to Q) = min(1 - T(P) + T(Q), 1) \tag{18}$$

Implication can be presented in the form of rules

$P \to Q$: if *x* is equal to *A*, then *y* is equal to *B*, and that equivalent with fuzzy relation

$\rho = (A \times B) \cup (\overline{A} \times Y)$ same as in classical logic.

Then membership function of ρ is represented by the formula

$$\mu_\rho(x, y) = max\left[(\mu_A(x) \wedge \mu_B(y)), (1 - \mu_A(x))\right]. \tag{19}$$

Example 3. Suppose we evaluate the possibility of changing a certain transport insurance product in order to estimate the expected effects of its placement on the market. We use two metrics to make a decision about validity for product change. The units of measurement are the "uniqueness of the adjusted product", marked on the scale of uniqueness, $X = \{1, 2, 3, 4\}$ and "market size" for the product, denoted on the scaled market size, $Y = \{1, 2, 3, 4, 5, 6\}$. On the both scales, the smallest numbers are assigned to "the greatest uniqueness" and "the largest market". Let's say that the product is rated "middle uniqueness", marked by the set E and the mean market size, the set F. We want to determine the implications of such a result, ie. IF *E* THEN F.

Let:

$E = 0,5/2 + 0,2/3 + 0,3/4,$

$F = 1/1 + 0,5/2 + 1/3 + 0,7/4 + 0,3/5.$

and row vector $Y = 1/1 + 1/2 + 1/3 + 1/4 + 1/5 + 1/6,$

Using the formula (6) and formula for Cartesian product

$\mu_\rho(x, y) = \mu_{E \times F}(x, y) = \min(\mu_E(x, y), \mu_F(x, y))$

we have

$$E \times F = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0,5 & 0,4 & 0,1 & 0,5 & 0,1 & 0 \\ 1 & 0,4 & 0,1 & 0,6 & 0,1 & 0 \\ 0,2 & 0,2 & 0,1 & 0,2 & 0,1 & 0 \end{bmatrix}, \quad \overline{E} \times Y = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0,5 & 0,5 & 0,5 & 0,5 & 0,5 & 0,5 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0,8 & 0,8 & 0,8 & 0,8 & 0,8 & 0,8 \end{bmatrix}$$

and further $\rho = \max(E \times F, \overline{E} \times Y)$, i.e.

$$\rho = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 0,5 & 0,5 & 0,5 & 0,5 & 0,5 & 0,5 \\ 1 & 0,4 & 0,1 & 0,6 & 0,1 & 0 \\ 0,8 & 0,8 & 0,8 & 0,8 & 0,8 & 0,8 \end{bmatrix}$$

5. CONCLUSION

Availability of information of numerous risk parameters in transportation insurance, collected from the often limited past period, affects the reliability of risk estimates and accuracy of determining premium rates. In certain cases, in this line of insurance, it is possible to access statistical data on realized risks, but the data are most often not representative. For this reason, in order to analyze, evaluate, and control insurance risk, the economic, legal, engineering and technological knowledge, intuition and experience of various experts are often used in practice. Managerial decisions in practice imply subjectivity, uncertainty and the possibility of errors. The main causes of uncertainty and errors are the complexity and ambiguity of the problem, often the lack of accurate information, inaccurate records or data analyses and the subjective perception of the problem.

Classical actuarial methods can hardly be applied in terms of uncertainty, ambiguity, low credibility of data, and other limitations. However, combination of the various quantitative methods that are regularly applied in finance and insurance and techniques and principles based on fuzzy mathematics, can be significant support for actuaries and underwriters in decision-making. C-credibility measure in the fuzzy environment was introduced as a regular measure in relation to the aggregate value of possibility and necessity measures. Premium rates in nonlife or transportation insurance are often only calculated at the average level with the approximate values so application of the c-credibility measure can give a more accurate premium rates closer to the characteristics of each insured. Also, the concept of relations with generalization is presented for a different degree or strength of connection between the observed elements.

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OPTIMIZATION METHODS AND HEURISTICS AND THEIR ROLE IN SUPPLY CHAINS AND LOGISTICS

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Abstract: *In the past decades, our capability to solve hard and large optimization problems has improved intensely. The paper addresses a review of optimization methods, heuristics, and metaheuristics. Their role in supply chain management, logistics, and transportation is also discussed. The main goal is to update interested readers about an enormous class of prevailing optimization methods and heuristics that have been designed for solving of numerous types of optimization problems. It is assumed that comprehensiveness of the overview of these methods is one of the main contributions of this paper. In the perspective of actual practice, it is also briefly stressed how and where optimization methods can be effectively applied in the field of supply chains and logistics.*

Keywords*: Optimization Methods, Heuristics, Metaheuristics, Supply Chain Management, Transportation, Logistics.*

1. INTRODUCTION

Nowadays, optimization is present practically everywhere, from industrial manufacturing to engineering design, from important decisions of any kind to just routine business transactions, from planning our holidays to choosing our career path, and so on (Yang, 2008). In all these actions or activities, we always have some issues (objectives) that we are trying to optimize, whether they are the optimization of costs, performance, profit, enjoyment, quality, customer-rating, or optimization of something else.

By other words, we make decisions all the time that we believe can minimize or maximize our objectives. Some other typical examples of such decisions are finding a shortcut to minimize the time necessary to reach a specific destination, disclosing the best possible house that can fulfil maximal conditions within certain cost constraints, or finding a lowest-priced item in the store.

Although optimization has been experienced in some form from the early ancient era, this area has significantly erupted during the last five decades. Modern civilization lives not only in an atmosphere of strong competition but is also constrained to plan its

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progress in a sustainable fashion with due apprehension for the preservation of resources. Accordingly, it has become authoritative to design, plan, manage, and operate assets and resources in an optimal manner (Chinchuluun et al., 2009).

The formal approach to optimization problems represents the main part of the mathematical optimization, also called **mathematical programming** (Yang, 2008). The themes of mathematical optimization are extensive, and the optimization literature is enormous. It is often a frightening job for beginners to find an appropriate book and to study the right algorithms. Even for lecturers and researchers, it is not trivial to decide what algorithms to teach or apply in a practice since there are so many algorithms we can choose. There are many books about optimization, attributable to some motives. Firstly, the topic itself is mathematically quite rigorous, and there are many solution methods that we need to understand and examine. Namely, no single solution method can be conducted to all types of optimization problems (Arora, 2015). Therefore, a strong understanding of the problem, as well as solution procedures is essential to achieve an appropriate and adequate solution to the optimization problem.

Secondly, with the progression of time, optimization problems have also become more and more complex. It is often necessary not only to find the global optimal solution but also to find local optimum as well (Arora, 2015). Moreover, modern problems are frequently of the multiobjective type, where contradictory objective functions have to be handled. Generally, optimization represents finding the most suitable solution among many feasible solutions available, where all constraints should be fulfilled. The most suitable solution could be the one that minimizes the cost of a certain process or maximizes the efficiency of the certain system (Arora, 2015). The function that is being optimized is usually referred to as the target or objective function, sometimes also called the performance index. The function is some quantity such as profit, cost, size, shape, efficiency, weight, and so on (Arora, 2015). Regarding the companies and other organizations, the profit maximization or cost minimization are usually major considerations.

Optimization is usually described as a **three-step decision-making process**, which includes the following steps (Arora, 2015; Appa et al., 2006): 1. the knowledge of the system, mathematically considered as **modeling the process**; 2. finding a measure of system efficiency (**the objective function**) and setup of all **constraints**; 3. finding a best solution with respect to applied optimization model and appropriately chosen optimization method. By using modeling, we can create the objective function as well as the constraint functions for the given optimization problem. Afterward, we can use various optimization methods for solving such problems.

The modeling of many real systems is ruled by continuous mathematics. Such models are frequently a satisfactory simplification of reality, but the discrete nature of many real processes is often observed at a microscopic level, where continuous modeling might not provide an appropriate simplification. On one side it is true that continuous mathematics is more established and cohesive than discrete mathematics, and the calculus is a quite dominant tool for the optimization of numerous continuous problems. However, on the other side, many systems have a discrete nature (e.g. construction problems, finite element analysis, etc.) and are much more common in decision-making processes (operations research) or information systems (computer science) (Arora, 2015; Appa et al., 2006).

The variables that arise in the objective function are usually symbolized as the **decision (design) variables**. They can belong to a group of real or discrete numbers, often they are binary or integer values. Although a majority of the decision variables are typically real, some of them can also be discrete. In a strict mathematical sense, modeling represents expressing and linking problem's measurement variables into mathematical form by the means of basic mathematics' building blocks such as subtraction, addition, division, multiplication, functions, and certain numbers with proper units (Arora, 2015; Appa et al., 2006). If the applied model does not produce expected results, it has to be polished by accompanying further experiments. Further, many problems do not have closed-form solutions and have to be numerically simulated to reach the proper solutions.

Optimization theory had progressed originally to offer generic solutions to optimization problems regarding the linear, nonlinear, unconstrained, and constrained domains treated within the framework of mathematical programming. At the beginning, the optimization problems were classified into two distinctive categories, linear and nonlinear programming problems. Here, the continuous variables played the main role. However, during the more recent history, various classes of assignment and other discrete-based problems, which required treatment of both continuous and integer variables, have appeared. This fact was leading us to mixed integer linear programming problems (**MILP**) and nonlinear mixed integer programming problems (**MINLP**). Due to their complex nature, these problems were very hard to be efficiently solved in a reasonable time.

Nevertheless, with the arrival of computers in the 1980s, which progressed into a very powerful form in the last two decades, the efficient solutions of many large-scale hard optimization problems could be found. Present-day optimization problems are not only multiobjective but also of the multidisciplinary type. Moreover, the solution methods that are conducted today to solve hard optimization problems are not just classical such as the gradient-based and other similar algorithms within the scope of exact mathematical programming methods. Conversely, these methods can also include modern non-traditional methods, **heuristics,** and **metaheuristics** such as ant colony optimization, genetic algorithms, particle swarm optimization, or simulated annealing algorithms, which mimic natural processes (Arora, 2015).

Contrary to the exact methods, the heuristics are techniques consisting of a set of certain rules which seek (and hopefully find) satisfactory solutions at a reasonable computational cost (Maniezzo et al., 2009). They are approximate in the sense that they usually provide good solutions for relatively little-invested efforts, but they do not guarantee optimality. Heuristics just offer a simple mechanism of indicating which among several possible alternatives seems to be the best one (Maniezzo et al., 2009).

These modern methods are particularly useful when we are seeking for global optimums of objective functions since they prevent to stay captured at a local optimum. Namely, this deficiency is typical for many classical mathematical programming methods. On the other hand, for instance, the genetic algorithms that were derived from biology, or simulated annealing that was inspired by optimality of the annealing process, are examples of two quite potent methods, which can effectively seek for global optima without being locally stucked. Moreover, during the last decade, a class of completely new optimization methods called **matheuristics** has appeared. These methods are some

sort of **hybrids** since they combine certain good properties of exact mathematical programming methods on one side, and simplicity of approximate heuristics on the other side. As it turns out, these methods represent another significant milestone in the optimization field, since they provide quite promising results when compared to the other optimization methods.

In the modern era, optimization methods are needed to solve problems from all disciplines, whether being the economic and social sciences, natural sciences, or engineering sciences. Optimization methods are also crucial in the field of logistics, transportation, supply chain management (SCM) and operations research (OR). A whole plethora of difficult problems can be found in these areas, such as different kinds of transportation problems, scheduling and planning problems, vehicle routing problems (VRP), traveling salesperson problems (TSP), location-routing problems, school bus routing problems, and many other combinatorial or discrete optimization problems (Rardin, 1998; Voss and Woodruff, 2006; Parker and Rardin, 1988; Geunes and Pardalos, 2005; Minis, 2011).

The main purpose of this paper is a short review of optimization methods that have been developed for solving of various types of optimization problems. It is believed that an extensiveness of the overview in this paper might serve as one of the major contributions of this paper. In the context of real practice, it is also shortly stressed where and how optimization methods can be efficiently used in the field of logistics, supply chain management, and transportation. We believe that our contribution might not be useful only for the beginners in the field, but also for the optimization experts and researchers.

2. THE LITERATURE REVIEW

2.1 General literature and surveys about optimization

In the last decades, there was an almost uncountable number of different optimization based books published. Some of them are quite general, explaining the basic mathematical principles of optimization methods and algorithms. The other are more oriented to the use of specific program package or language, for instance, statistical program language R, or the language of technical computing Matlab. Some of these books are mainly dedicated to the practical examples and applications, while the others are more focused on certain specific optimization area, for instance on global optimization or discrete optimization. Table 1 shows some of the important books covering the optimization from the general point of view (Arora, 2015; Antoniou and Lu, 2007; Cortez, 2014; Floudas, 2000; Diwekar, 2008; Parker and Rardin, 1988; Sarker and Newton, 2008; Appa et al., 2006; Chinchuluun et al., 2009; Forst and Hoffman, 2010; Grossmann, 1996; Hendrix and G.-Tóth, 2010; Levy, 2001; Nocedal and Wright, 1999; Rao, 2009; Marecek, 2010; Talbi, 2009; Rothlauf, 2011; Maniezzo et al., 2009; Yang, 2008; Venkataraman, 2009; Messac, 2015; Onn, 2010; Kouvelis and Yu, 1997; Wolsey, 1998; Weise, 2009; Williams, 2013; Dréo, 2006). These books are mostly written in engineering style, which means that they are also understandable for the non-mathematicians from any engineering faculty, who have a decent mathematical background. Moreover, these books are written in easy to follow style, but still rigorous enough. Our opinion is that even the beginner can obtain quite good knowledge about the topic after the focused studying of books in Table 1.

Table 1. Some of the typical generally oriented optimization books

Author	Title
Arora	**Optimization - Algorithms and Applications**
Antoniou and Lu	**Practical Optimization: Algorithms and Engineering Applications**
Cortez	**Modern Optimization with R**
Floudas	**Deterministic Global Optimization: Theory, Methods and Applications**
Diwekar	**Discrete Optimization**
Parker and Rardin	**Discrete Optimization**
Sarker and Newton	**Optimization Modelling: A Practical Approach**
Appa et all.	**Handbook on modelling for discrete optimization**
Chinchuluun et al.	**Optimization and Its Applications**
Forst and Hofmann	**Optimization -Theory and practice**
Grossmann	**Global Optimization in Engineering Design**
Hendrix and Toth	**Introduction to Nonlinear and Global Optimization**
Levy	**Basics of Practical Optimization**
Nocedal and Wright	**Numerical Optimization**
Rao	**Engineering Optimization**
Marecek	**Handbook of Approximation Algorithms and Metaheuristics**
Talbi	**Metaheuristics: From Design to Implementation**
Rothlauf	**Design of Modern Heuristics: Principles and Application**
Maniezzo et al.	**Matheuristics: Hybridizing Metaheuristics and Mathematical Programming**
Yang	**Introduction to Mathematical Optimization**
Venkataraman	**Applied Optimization with MATLAB Programming**
Messac	**Optimization in Practice with MATLAB for Engineering Students and Professionals**
Onn	**Nonlinear Discrete Optimization: An Algorithmic Theory**
Kouvelis and Yu	**Robust Discrete Optimization and Its Applications**
Wolsey	**Integer Programming**
Weise	**Global Optimization Algorithms – Theory and Application**
Dreo et al.	**Metaheuristics for Hard Optimization: Methods and Case Studies**
Williams	**Model Building in Mathematical Programming**

Besides the investigation of optimization books available, we have also examined contributions focusing on general surveys or reviews about extensive generally oriented optimization literature. Surprisingly, the number of these contributions was quite low since we managed to identify only 24 such works (see Table 2 (Addis, 2004; Awad and Chiban, 2015; Beheshti, 2013; Bertacco, 2005; Bianchi et al., 2009; Bixby, 2012; Blum and Roli, 2003; Fernandes and Lourenço, 2007; Floudas et al., 2005; Fu et al., 2006; Genova and Guliashki, 2011; Hoffman, 2000; Hu et al., 2012; Jones, 2001; Kallrath, 2000; Koch, 2004; Laguna, 2002; Newman and Weiss, 2013; Osman and Laporte, 1996; Quttineh, 2012; Raidl, 2006; Schichl, 2003; Sergienko et al., 2009; Urli, 2015)). As can be seen from Table 2, the majority of these contributions are papers, while some of them are also doctoral or master theses or chapters in books. From Table 2 can be noticed that the majority of these surveys were focused on global and/or combinatorial

optimization, where the heuristics and metaheuristics have taken a special dedication. Since the majority of works presented in Table 2 penetrate into addressed topics more deeply, it is supposed that the interested reader has a good mathematical understanding of the basic optimization theoretical principles. Furthermore, some of the contributions, for instance, those discussing metaheuristics for stochastic combinatorial optimization, or about model-based randomized methods for global optimization, demand quite advanced understanding about the topic.

Table 2. Surveys or reviews about generally oriented optimization literature

Author	Title
Sergienko et al.	**Classification of Applied Methods of Combinatorial Optimization**
Awad and Chiban	**Recent Advances in Global Optimization for Combinatorial Discrete Problems**
Hu et al.	**A Survey of Some Model-Based Methods for Global Optimization**
Jones	**A Taxonomy of Global Optimization Methods Based on Response Surfaces**
Fernandes and Lourenço	**Hybrids Combining Local Search Heuristics with Exact Algorithm**
Raidl	**A Unified View on Hybrid Metaheuristics**
Bianchi et al.	**A survey on metaheuristics for stochastic combinatorial optimization**
Beheshti et all.	**A Review of Population-based Meta-HeuristicAlgorithm**
Osman and Laporte	**Metaheuristics: A bibliography**
Genova and Guliashki	**Linear Integer Programming Methods and Approaches – A Survey**
Bixby	**A Brief History of Linear and Mixed-Integer Programming Computation**
Laguna	**Global Optimization and Meta-Heuristics (chapter)**
Urli	**Hybrid Meta-Heuristics for Combinatorial Optimization (thesis)**
Blum and Roli	**Metaheuristics in Combinatorial Optimization: Overview and Conceptual Comparison**
Kallrath	**Mixed Integer Optimization in the Chemical Process Industry - Experience, Potential and Future Perspectives**
Bertacco	**Exact and Heuristic Methods for Mixed Integer Linear Programs (thesis)**
Newman and Weiss	**A Survey of Linear and Mixed-Integer Optimization Tutorials**
Koch	**Rapid Mathematical Programming (thesis)**
Addis	**Global optimization using local searches (thesis)**
Schichel	**Mathematical Modeling and Global Optimization (habilitation thesis)**
Floudas	**Global optimization in the 21st Century: Advances and challenges**
Fu et al.	**Model-Based Randomized Methods for Global Optimization**
Quttineh	**Models and Methods for Costly Global Optimization and Military Decision Support Systems (thesis)**
Hoffman	**Combinatorial Optimization: Current successes and directions for the future**

2.2 Specific literature and surveys about optimization in logistics and SCM

In the next step of our literature review investigation, we had examined how many books were published about the optimization exclusively focused on logistics, supply chain management, or operational research. Surprisingly, we have managed to identify only seven such works, which are given in Table 3 (Voss and Woodruff, 2006; Geunes and Pardalos, 2005; Geunes et al., 2002; Minis, 2011; Puranen, 2011; Rardin, 1998;

ManMohan S. Sodhi, 2010). These works are more or less dedicated to the majority of typical optimization problems, which can arise in afore-mentioned research fields. Here, the design of various optimization models, as well as the working principles of optimization techniques is also discussed. Besides these six books, the optimization in logistics and SCM is also partially covered in some of the general optimization books from Table 1. Moreover, an interested reader can also find some issues about this topic in several operations research books (Hillier and Lieberman, 1974; Winston and Goldberg, 2004; Taha, 2011), or specialized books about the logistics and SCM (Ghiani and Laporte, 2004).

Table 3. Identified books about optimization in logistics, supply chain management, or operational research

Author	Title
Voß and Woodruff	**Introduction to Computational Optimization Models for Production Planning in a Supply Chain**
Geunes and Pardalos	**Supply Chain Optimization**
Minis et al.	**Supply Chain Optimization, Design, and Management: Advances and Intelligent Methods**
Geunes et al.	**Supply Chain Management: Models, Applications, and Research Directions**
Puranen	**Metaheuristics meet metamodels: a modeling language and a product line architecture for route optimization systems**
Rardin	**Optimization in operations research**
MacMohan and Sodhi	**Long View of Research and Practice in Operations Research and Management Science: The Past and the Future**

Besides the investigation of optimization books within the scope of logistics, supply chain management, or operational research, we have afterward also reviewed contributions focusing on surveys or reviews about optimization in the context of logistics and SCM. We were surprised again since the number of such kind of contributions was also quite low (only 23 identified works – see Table 4 (Abo-Hamad and Arisha, 2011; Aravendan and Panneerselvam, 2014; Archetti and Speranza, 2014; Bertacco, 2005; De Jaegere N and Kb, 2015; Díaz-Parra et al., 2014; Drexl and Schneider, 2014; Eksioglu, 2002; El-Sherbeny, 2010; Eskandarpour, 2014; Gaze, 2013; Grossmann et al., 2001; Kumar, 2012; Laporte et al., 2015; Ławrynowicz, 2011; Lourenço, 2001; Pino et al., 2011; Respen, 2015; Romero Morales, 2000; Ropke, 2005; Sadrnia et al., 2014; Soysal et al., 2012; Subramanian, 2012)). From Table 4 can be noticed that the majority of these contributions are papers, similarly as in the case of table 2, while we have detected five doctoral or master theses here. From Table 4 can also be seen that seven works are dedicated to the optimization in supply chains from a general point of view. Conversely, the majority of other contributions (even nine of them) are devoted to the routing problems of some kind. The remaining seven contributions cover other optimization problems that can typically arise in logistics and SCM. Regarding the optimization methods (heuristics, exact methods, hybrids), it can be seen from Table 4 that they are on average equally involved in research, perhaps slightly bigger attention is devoted to the modern methods and metaheuristics.

Table 4. Surveys or reviews about optimization in logistics, supply chain management, or operational research

Author	Title
Drexl and Schneider	**A Survey of the Standard Location-Routing Problem**
Grossmann et al.	**Discrete Optimization Methods and their Role in the Integration of Planning and Scheduling**
Ławrynowicz	**A Survey of Evolutionary Algorithms for Production and Logistics Optimization**
Morales	**Optimization Problems in Supply Chain Management (thesis)**
Archetti and Speranza	**A survey on matheuristics for routing problems**
Lourenço	**Supply Chain Management: An opportunity for Metaheuristics**
Sadrnia et al.	**A Review of Nature-Based Algorithms Applications in Green Supply Chain Problems**
Eksioglu	**Network Algorithms for Supply Chain Optimization Problems (thesis)**
Aravendan and Panneerselvam	**Literature Review on Network Design Problems in Closed Loop and Reverse Supply Chains**
Soysal et al.	**A Review on Quantitative Models for Sustainable Food Logistics Management**
Eskandarpour	**Generic models and optimization algorithms for sustainable supply chain network design (thesis)**
Respen	**From packing to dispatching: supply chain optimization techniques (thesis)**
Arisha	**Optimisation Methods in Supply Chain Applications: a Review**
Díaz-Parra et al.	**A Survey of Transportation Problems**
Laporte et al.	**Road-Based Goods Transportation : A Survey of Real-World Applications from 2000 to 2015**
Bertacco	**Two-Echelon Freight Transport Optimisation: Unifying Concepts via a Systematic Review**
Gaze	**Exact Optimization Methods for the Mixed Capacitated General Routing Problem**
Jaegere et al.	**The vehicle routing problem: state of the art, classification and review**
Subramanian	**Heuristic, Exact and Hybrid Approaches for Vehicle Routing Problems (thesis)**
Kumar and Panneerselvam	**A Survey on the Vehicle Routing Problem and Its Variants**
Ropke	**Heuristic and exact algorithms for vehicle routing problems**
Villanueva et al.	**Heuristic Solutions to the Vehicle Routing Problem with Capacity Constraints**
El-Sherbeny	**Vehicle routing with time windows: An overview of exact, heuristic and metaheuristic methods**

3. OPTIMIZATION METHODS

In this section, we will briefly describe some of the important classes of optimization methods related to combinatorial optimization and global optimization. Depending on the complexity of the optimization problem, it may be solved by the means of an exact method or an approximate method (Talbi, 2009). Figure 1 shows the widely accepted classification of combinatorial optimization methods. Exact methods find optimal

solutions and guarantee their optimality. For NP-complete optimization problems, exact algorithms belong to the class of non-polynomial time algorithms. On the other side, approximate (or heuristic) methods provide high-quality solutions in a reasonable time, but there is no guarantee of obtaining the global optimal solution (Talbi, 2009).

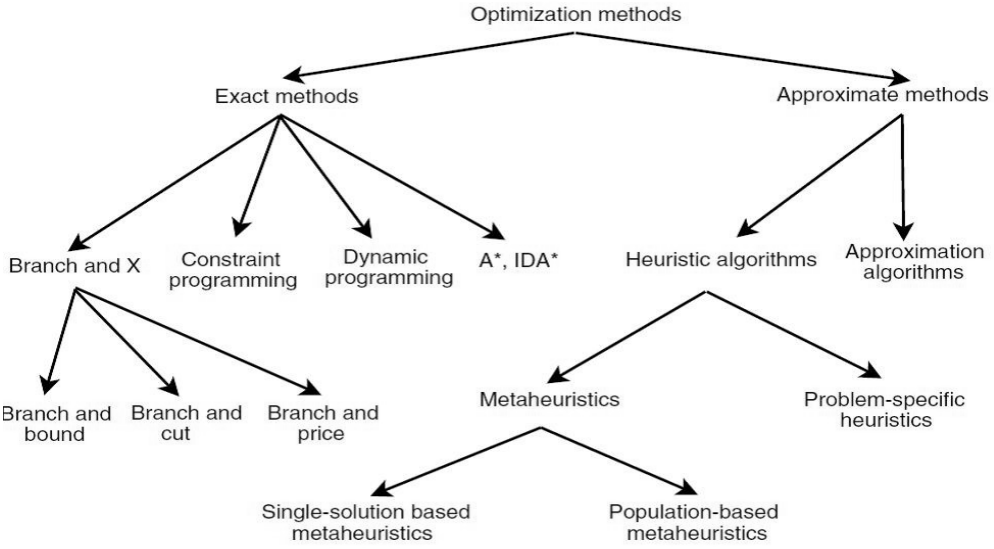


Fig. 1: Classification of combinatorial optimization methods adopted from (Talbi, 2009)

3.1 Classification of Applied Methods for Combinatorial Optimization

The subjects considered in combinatorial optimization (CO) are usually (Sergienko et al., 2009): subsets, graphs, integers, arrangements, permutations, and other structures that can be generalized under the concepts of the combinatorial object. In general, CO covers tree types of methods (see Fig. 1): **the exact algorithms, the approximate (approximation) algorithms, and the heuristics or metaheuristics**. As afore-mentioned, the exact algorithms guarantee a computation of optimal solution in a finite time. They can also conclude that the optimal solution does not exist in the case of an unsolvable problem. According to (Sergienko et al., 2009), exact algorithms can be divided into two categories: general and special methods. Most popular general methods are: the branch-and-bound algorithm, exhaustive search, branch-and-cut method, dynamic programming, sequential analysis, and elimination of alternatives (Sergienko et al., 2009). A typical example of special methods is the Balazs Hungarian method applied to solve a linear assignment problem.

On the other hand, the approximate algorithms return an alternative solution in a finite time, while their accuracy can be estimated via a priori or posteriori estimates. The a priori estimate is a guaranteed estimate that should be specified before the solving of the optimization problem, while a posteriori estimate is computed during or after the problem-solving process.

Conversely, when the heuristic algorithms are taken into consideration, their accuracy estimate is absent or not known. The latter means that for a specific problem, the heuristics may return a “bad” solution (considering the objective function) or even no solution. However, on the other side, the heuristics are correct in the sense that they do not provide alternative solutions when these are not feasible (Sergienko et al., 2009).

Approximate and heuristic algorithms belong to the group of approximate ("inexact") methods. Such algorithms have shown to be effective for many real-world problems. On the other side, in many cases, the exact methods are not always applicable. Namely, they can usually be conducted only for small-dimensional optimization problems, while they cannot be applied for more complex problems such as dynamic or uncertainty-based problems (Sergienko et al., 2009).

As claimed by (Sergienko et al., 2009), all the approaches for solving complex combinatorial optimization problems can be defined as search procedures, which iteratively generate and estimate the alternative solutions. He adopted seven approximate CO algorithms. The first three classes (Sequential algorithms, Deterministic local search, Stochastic local search) have been used for a long time and are in detail explained in the literature. On the other hand, the **evolutionary methods** represent a wide class of algorithms that engage the basic principles of biological evolution for solving of optimization problems (Sergienko et al., 2009). Conversely to the other algorithms, **swarm intelligence** algorithms represent a class of decentralized algorithms. Here we are dealing with decentralized systems of simple agents that locally cooperate with certain medium and with each other (Sergienko et al., 2009). Despite the lack of a centralized control structure, local interactions between the agents result in a global behavior of the entire system.

The approximate CO methods can also be classified concerning the following characteristics (Sergienko et al., 2009): 1. The decision-making principles; 2. The complexity of the structure; 3. The type of used spaces; 4. The type of formed trajectory; 5. The influence on the search landscape; 6. The use of memory; 7. The presence of adaptation or training; and finally: 8. The presence of the special model.

3.2 Heuristics and Metaheuristics

The main characteristic of heuristic algorithms is that they can find a "good" solution to large-size problem instances (Talbi, 2009). These algorithms provide acceptable performance at acceptable costs for a wide range of different optimization problems. Generally, the heuristics can be classified into two major classes: **specific heuristics** and **metaheuristics**. The methods of the first class are specially tailored and designed to solve a specific problem. Conversely, the metaheuristics are general-purpose methods that can be conducted to solve almost any optimization problem (Talbi, 2009).

Polya firstly introduced the heuristic concept for solving the optimization problems in the year 1945. The simplex algorithm, designed by Dantzig in the year 1947, can be treated as a local search algorithm for linear programming optimization problems. Edmonds was the first who applied the greedy heuristic for combinatorial optimization in the year 1971 (Talbi, 2009). Further development of different heuristics can be seen in (Talbi, 2009), where the years of introducing of the individual algorithms are also represented. Moreover, Talbi (2009) precisely illustrates the genealogy of the various metaheuristic algorithms in his work.

Perhaps even more accurate, updated and in some details slightly different chronology of major metaheuristic algorithms is given by Beheshti and his colleagues (Beheshti, 2013). They indicated the list of 35 most important metaheuristic algorithms during the last four decades, their creators, and the dates of their appearance.

Metaheuristics can be classified in many ways. Talbi (2009) classified metaheuristics according to some of the typical criteria for the classification of metaheuristic algorithms: Nature inspired versus nonnature inspired, Memory usage versus memoryless methods, Deterministic versus stochastic, Population-based search versus single-solution based search, Iterative versus greedy.

An excellent representation of the classification of metaheuristic algorithms is also given by (Beheshti, 2013). The main criterion borders to divide algorithms are settled in the following directions: nature-inspired versus non-nature inspired, population-based versus single point search, single neighborhood versus various neighborhood structures, dynamic versus static objective function, and memory usage versus memory-less algorithms.

When constructing a metaheuristic, two conflicting criteria must be taken into consideration (Talbi, 2009):

- exploration of the search space (**diversification**),
- exploitation of the best solutions found (**intensification**).

Promising regions of the search space are those regions that are determined by the revealed "good" solutions. In the intensification process, the promising regions are discovered more exhaustively by using local search methods in the hope to find even better solutions. Conversely, in the diversification process, non-explored regions should be visited to be certain that all regions are equally explored and that the search is not limited to only an incomplete number of regions. While doing the diversification, the random search algorithms are applied in the sense of the exploration. As it turns out, in general, the single-solution metaheuristics (**S-metaheuristics**) are more exploitation oriented, while the population metaheuristics (**P-metaheuristics**) are more exploration oriented (Talbi, 2009).

It is presumed that the metaheuristic algorithms will become more and more popular in the future since the optimization problems will remain to increase in size and complexity. Talbi, (2009)summarizes the main characteristics of optimization problems that justify the use of metaheuristics. Naturally, it is clear that the metaheuristics should be used only in the cases when other methods or even powerful optimization solvers (e.g. Lindo, CPLEX, XPRESS-MP) fail to complete their tasks efficiently. Sometimes it is even impossible to unambiguously define an appropriate analytical mathematical formulation of the objective function. This happens in simulation-based optimization problems, when the objective function may be a completely black-box based function without any mathematical formulation. Namely, many engineering problems in logistics, production, finance, computational biology, telecommunications, etc., are based on simulation to assess the quality of solutions. Here, metaheuristics can be of great use since they have, unlike mathematical programming, a restrictive assumption in formulating the model (Talbi, 2009).

As it turns out, the evaluation of the objective function is the most time-intensive part in metaheuristics for many optimization problems. To avoid this, we can often approximate the objective function, which means that we can replace it with its approximation function. Such an approach is known as **meta-modeling approach** (Talbi, 2009). There are several meta-modeling techniques available to employ for expensive objective functions. Typical examples of such approximate models are the

neural network models and response surface models. Sometimes we can also apply the Gaussian processes, support vector machines, or Kriging models. Once the meta-model is designed, it can be used in combination with the original objective function. This way, we can switch between the original model and the approximated one with respect to different management strategies of meta-models.

3.3 Global optimization

In many nonlinear optimization problems, the objective function contains a big number of local minimums and maximums. Finding the global optimum (minimum or maximum) of a function is far more difficult that finding its local optimum. A classification of GO methods in deterministic and stochastic methods is the most common in the existing literature (see (Weise, 2009, Addis, 2004; Awad and Chiban, 2015; Floudas, 2000; Floudas et al., 2005; Fu et al., 2006; Grossmann, 1996; Hendrix and G.-Tóth, 2010; Hu et al., 2012; Jones, 2001; Laguna, 2002; Neumaier et al., 2005; Pinter, 2009; Quttineh, 2012; Schichl, 2003; Weise, 2009)). In these works, an interested reader can find more details about GO methods and their working mechanisms..

If we are using local search techniques, we can easily get stuck in the local minimum. To avoid this and to escape from the local minimum, many alternative methods have been developed. In general, if we restrict ourselves to S-metaheuristic family of algorithms for GO, we have four different approaches that can be adopted to avoid the local optimum (Talbi, 2009):

- Iterating from different initial solutions;
- Accepting non-improving neighbors;
- Changing the neighborhood; and
- Changing the objective function and/or the input data of the optimization problem.

"Accepting non-improving neighbor" methods also enable moves that are allowed to worsen the current solution temporarily. In "Changing the neighborhood" methods, the neighborhood structure can be changed, which also changes the landscape of the problem. The latter can also be changed by using the "Changing the objective function and/or the input data of the optimization problem" methods. Here, the problem can be converted by applying perturbations of the objective function, input data of the problem, or the constraints. By doing such perturbing, we hope that we can solve the original problem more efficiently (Talbi, 2009).

4. OPTIMIZATION IN LOGISTICS AND SUPPLY CHAIN MANAGEMENT

Optimization also plays an essential role in practically all fields of logistics, SCM, and transportation. Here, the reduction of all kinds of unnecessary costs and maximization of a profit of all the major SCM players are of particular importance. Moreover, the performance of SCM members should be synchronized in the largest possible manner to make information flows and material flows maximally fluent.

There exist many books and almost a countless number of papers that are addressing optimization problems in logistics, SCM, and transportation. However, regarding the books, there are only several of them containing a really good representation and consistent explanation of the mentioned problems (e.g. (Ghiani and Laporte, 2004; Wolsey, 1998; Sarker and Newton, 2008; Williams, 2013)). Moreover, authors define a

classification of optimization problems in logistics in several different ways, which can perhaps cause even some confusion, particularly for the beginners from the field. By our opinion, a far best classification is given by Ghiani and his colleagues in (Ghiani and Laporte, 2004). According to (Ghiani and Laporte, 2004), we can classify typical problems that arise in logistics and SCM as it is shown in Fig. 2 (Ghiani and Laporte, 2004).

If the **problems in designing the logistics network** are considered, *facility location and allocation problems* are here particularly important. Regarding **inventory management problems**, we could classify them into two major categories: deterministic problems and stochastic problems. Here, the optimal inventory policies must be built on the basis of deterministic or stochastic inventory models used to minimize the inventory cost function. As shown in Fig. 2, **problems in designing and operating warehouses** primary consist of the following problems: the *warehouse design problems*, *order picker routing problems*, and *packing problems*. Freight transportation is another essential category within the field of logistics planning and control. According to (Ghiani and Laporte, 2004), freight transportation can be divided into two major categories: **long-haul freight transportation** and **short-haul freight transportation**. In the case of long-haul freight transportation, goods are relocated over relatively long distances, for example between terminals or other important facilities (warehouses, plants, etc.). Moreover, commodities can be transported by rail, trucks, ships, or by any combination of different modes. Conversely, in the case of short-haul freight transportation, goods are usually moved by trucks on the routes between pick-up and delivery points located in the same area (e.g. between a terminal, or a warehouse, and a set of customers). Such jobs are usually executed during a shorter duration, while vehicle tours are carried out via a sequence of tasks (Ghiani and Laporte, 2004).

Careful investigation of the relevant literature shows that different kinds of transportation problems have received particularly big attention in studying and solving various problems in the logistics. Moreover, probably the far most research has been dedicated to the different types of the ***Vehicle routing problems (VRP)***, the ***Traveling salesperson problems (TSP), Arc routing problems (i.e. Chinese postman),*** and the ***School bus routing problems (SBRP)*** (see Fig. 2) (Dragan et al., 2016; Hertz, 2005; Kramberger et al., 2013; Kramberger and Žerovnik, 2008; Kramberger et al., 2012). Within the scope of the SBRP problems, some works were also dedicated to a research of how the reduced driving kilometers (i.e. the reduced total vehicles' distance travelled) influence on the decrease of emission gasses (Dragan et al., 2016; Kramberger et al., 2013).

We have a whole plethora of approaches to solve problems introduced in Fig. 2. We can solve them by adopting a certain optimization method from the set of methods shown in Fig. 1 to 5. For instance, if we are taking into consideration the VRP problems, the historic-based evolution of methods for their solving can be represented as given in Fig. 3.

While introducing Table 4, we have already briefly discussed about the contributions focusing on the surveys or reviews about the optimization in the context of logistics and SCM. As we have had seen, seven works in Table 4 are dedicated to the optimization in the supply chains from a general point of view; nine are devoted to the routing problems

of some kind, while the remaining seven cover other optimization problems that can typically arise in logistics and SCM. An interested reader can get a more in-depth insight into these works in the corresponding references. At this place, we will only take a brief overview of the papers detected in an interesting study (Laporte et al., 2015). Here, a survey of real-world applications from 2000 to 2015 is conducted for road-based goods transportation. Table 5 shows the collected papers, their authors, journals in which these papers were published, and applied optimization algorithms (Laporte et al., 2015) (see also references therein). The estimated improvements after applied optimization (see a far-most right column of Table 5) are typical evidence how the optimization can play an essential role in logistics and transport.

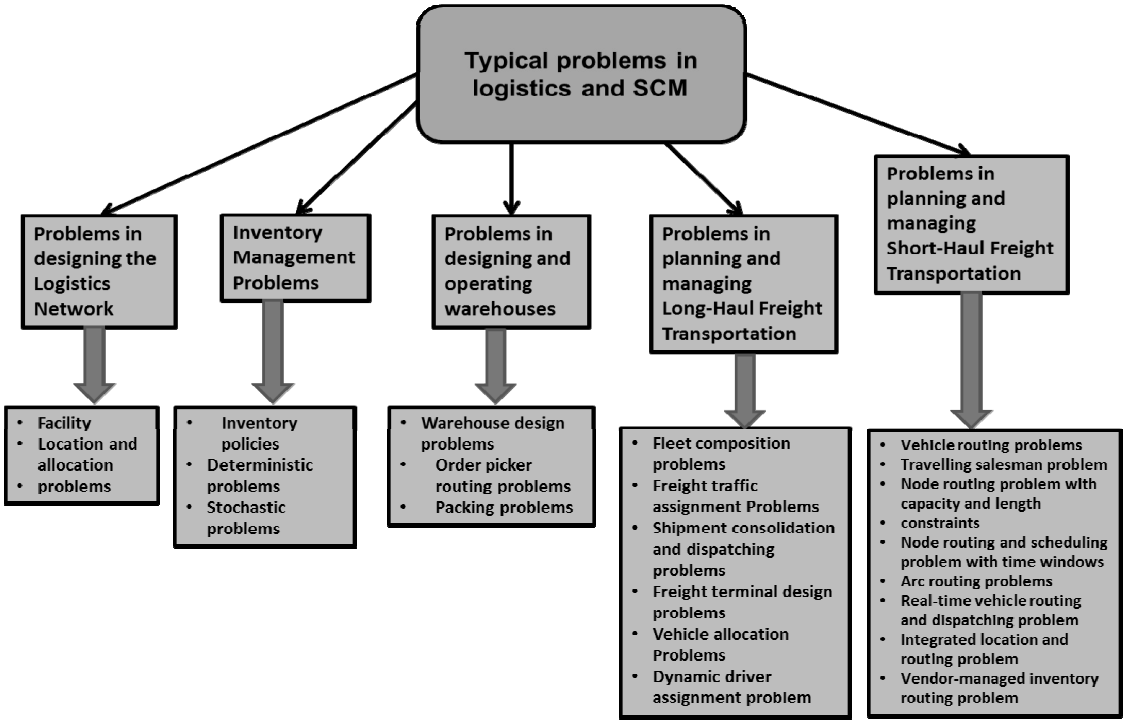


Fig. 2: Classification of typical problems that can arise in logistics and SCM (adopted from (Ghiani and Laporte, 2004))

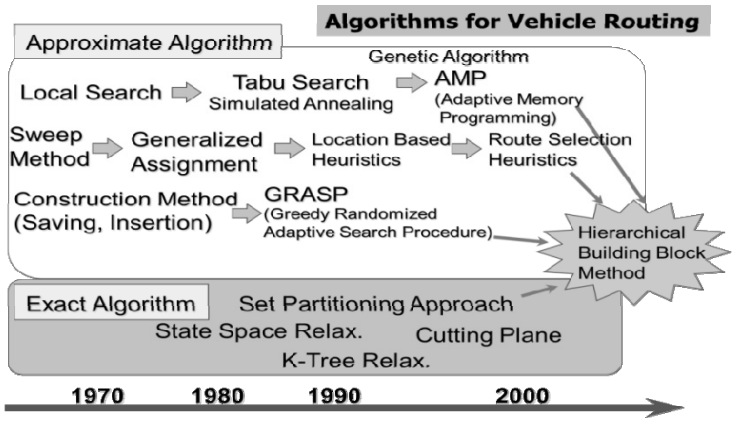


Fig. 3: Historic-based evolution of algorithms for Vehicle routing problem (adopted from Mikio, 1994)

Table 5: Collected papers in the survey of real-world applications from 2000 to 2015 conducted for road-based goods transportation (adopted from (Laporte et al., 2015) – see also the references therein)

Author	Year	Journal	Algorithm	Product/Company/Location	Estimated improvement
Avella et al.	2004	EJOR	Set partitioning and branch-and-price	Fuel	**22-25% reduction in total costs.**
Belenguer et al.	2005	JFE	Constructive heuristic with tabu search improvement	Meat/Valencia, Spain	**8.96% distance deduction**
Belfiore and Yoshizaki	2009	EJOR	Scatter search	Supermarkets/Brazil	**7.5% cost reduction**
Caramia and Guerriero	2010	INTER	Mathematical programming and local search multi-start	Milk/ASSO. La. C./Italy	**14.4% distance reduction**
Cheong et al.	2002	APJ	Tree search, column generation over a set covering formulation	Soft drink/Singapore	**Consistent reduction in the maximum number of vehicles required**
Chiang and Russell	2004	EJOR	Set partitioning and tabu search	Propane/One of the largest USA distributor/Illinois and Michigan	**9.4% reduction in total cost and 21.5% in number of vehicles.**
Cohn et al.	2007	TS	Column generation and enumeration based heuristics	Courier/UPS/USA	**Cost reduction of about 5%**
Cornillier et al.	2009	COR	Heuristic based on arc and route preselection	Fuel/Easters Quebec, Canada	**22% reduction in distance.**
Cornilliet et al.	2008	JORS	Matching and column generation	Fuel/Easters Quebec, Canada	**17.2% reduction in distance and 1.16% increase in quantitie delivered.**
Day et al.	2009	OME	Three-phase heuristic	Carmon dioxide/Indiana	**30% reduction in driver labor cost**
Faulín	2003	IJL	Heuristics and linear programming	Canning/Alimentos Congelados S.A./Navarra, Spain	**Average of 4.6% distance reduction**
Faulín	2003	OME	Heuristics and linear programming	Canning/Alimentos Congelados S.A./Navarra, Spain	**Average of 4.6% distance reduction**
Faulín et al.	2005	INTER	DSS based on savings and sweep algorithm	Frozen goods/Frilac/ Pamplona, Spain	**13.5% distance and 10.8% in cost reduction**
Gaur and Fisher	2004	OR	Mathematical programming and matching	Supermarket/Albert Heijn/ The Netherlands	**4% cost reduction**
Hollis et al.	2006	EJOR	Set covering with column generation	Mail/Australia Post/ Australia	**Potential cost savings of 10%**
Ioannou	2005	JFE	DSS with GIS, look ahead heuristic	Sugar/Greece	**About 25% in total transportation cost**
Ioannou et al.	2002	JORS	DSS with GIS, look ahead heuristic	Packaged goods and beverages/Athens	**Lower number of routes and vehicles**
Kant et al.	2008	INTER	ORTEC software based on and local search	Soft drinks/Coca-Cola/ USA	**Annual cost saving of $45 million**
Lahyani et al.	2015	OME	Branch-and-cut	Olive oil/Tunisia	**11.7% distance reduction**
Martínez and Amaya	2012	JORS	Insertion, tabu search and bin packing heuristics	Spanish paella	**25.5% in total trip time over a set of 19 instances**

Table 5: Collected papers in the survey of real-world applications from 2000 to 2015 conducted for road-based goods transportation (adopted from (Laporte et al., 2015) – see also the references therein) (continued)

Author	Year	Journal	Algorithm	Product/Company/Location	Estimated improvement
Ng et al.	2008	JORS	Heuristic and programming with multiple objectives integer	Information is not given	**Better route design and increased volume delivered.**
Nuortio et al.	2006	ESA	Guided variable neighborhoo thresholding metaheuristic	Municipal waste/Jätekukko Ltd/Finland	**12% distance reduction on average**
Prins	2002	JMMA	Construction, improvement and tabu search algorithm	Furniture/Nantes, France	**Reduction in distribution times of 11.7%**
Privé et al.	2006	JORS	Constructive and improvement	Soft drink/Distribution J. Dubois/Quebec, Canada	**23% in distance reduction**
Repoussis et al.	2009	EJOR	DSS with haybrid metaheuristics	Lube oil/Greece	**25% to 30% reduction in per unit cost**
Ruiz et al.	2004	EJOR	B&B with Lingo	Animal food/Nanta S.A./ Spain	**Reduction of up to 11% in cost and 12% in distance**
Sahoo et al.	2005	INTER	Iterative two-phase algorithm	Waste/Waste Management Inc./USA	**984 fewer routes, saving $18 million**
Sungur et al.	2010	TS	Insertion based and tabu search	Courier/UPS/USA	**Up to 20% over a weighted objective function**
Tarantilis and Kiranoudis	2001	JFE	Backtracking adaptive threshold accepting	Milk/Athens	**28% distance reduction**
Tarantilis and Kiranoudis	2002	JFE	List-based threshold accepting	Meat/Athens	**17% distance reduction**
Teixeira et al.	2004	EJOR	Three-phase heuristic	Glass, paper, plastic, metal/Portugal	**29% reduction in distance**
Tung and Pinnoi	2000	EJOR	Heuristic route construction and improvement	Household and street solid waste/Urenco/Hanoi, Vietnam	**4.6% operating cost reduction**

5. CONCLUSIONS

The paper addressed a comprehensive and systematic review of optimization methods with a particular focus on applications in logistics, supply chain management, and transportation. Nowadays, optimization plays an essential role in all areas of natural sciences, social sciences, and engineering. Moreover, optimization software has become much more accessible and reliable, while the hardware has essentially improved in the sense of a larger speed and lower prices. The high-level optimization languages have been considerably improved, which has significantly facilitated all efforts invested in modeling of the complex optimization problems.

The main purpose of this work was to provide an interested reader with the key information about a quite huge class of existing optimization methods that have been designed for solving of various types of optimization problems. When optimization methods are taken into consideration, they can generally be classified into exact and

approximate methods. Among the latter, various heuristic and metaheuristic methods are particularly gaining in popularity in the last two decades. Metaheuristics like genetic algorithms, ant colony, simulated annealing, iterative local search or tabu search are just some of the methods, which became essentially important in many research fields, particularly for the case of solving the combinatorial or global optimization problems.

While analyzing real-world applications from the field of logistics, SCM, and transportation, we can see that advanced and sophisticated optimization methods should be used practically in all serious applications. The main reason is a high complexity of the optimization problems, which usually contain a massive number of decision variables and/or constraints, while the objective functions are often quite complicated.

To the best of our knowledge, there have not been published a lot of scientific papers, which would include such a comprehensive review of optimization methods as it was done in our paper. So we hope that this work will contribute to the fastest possible absorption of this exciting topic, particularly for those who are beginners or less experienced researchers.

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AN APPROACHES TO LOCATING DISTANCE DEPENDENT COLLECTION POINTS IN RECYCLING LOGISTICS NETWORKS

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Abstract: *The recycling logistics network must be designed in such way that supports the need for efficient collection of the recyclable products from the end user, in terms of adequate quantities since they are input into the recycling process. On the other hand, those products have a low market value and costs related to recycling activities are relatively high. In order to make returned products available for the recycling process, the first step is their efficient collection. So, it is necessary to determine the locations of facilities for the collection of returned products on the first level of the recycling logistics network. This paper describes the problem of designing one part of recycling logistics network, particularly concentrating on review of mathematical modeling approaches used for selecting distance dependent locations of collection points for recyclables in recycling logistics networks.*

Keywords*: recycling, logistics networks, distance dependent collection points.*

1. INTRODUCTION

Municipal solid waste (MSW) is usually defined as "waste from households (household waste), as well as other waste which is similar to waste from households, due to its nature or composition" (Law on Waste Management, 2009). According to the World Bank (2018), an estimated 2.01 billion tonnes of MSW were generated in 2016, and this number is expected to grow to 3.40 billion tonnes by 2050, on a global level. About 37 % of these waste quantities are disposed of in some type of landfill, 33 % is openly dumped, 19 % undergoes materials are recovered through recycling and composting, and 11 % is treated through modern incineration (World Bank, 2018). On the other hand, MSW represents a valuable resource of secondary materials which can be used again, that is unused waste represents an economic loss. It is estimated that the materials sent to landfills could have an annual commercial value of around € 5.25 billion (EEA, 2010). So, a number of countries introduced strict environmental regulation, in order to deal with MSW problem.

For example, the European Union (EU) Waste Framework Directive sets a target of 50 % of MSW to be prepared for reuse and recycled by 2020 in the EU Member States for at least four categories (i.e. paper, glass, metals, plastics) of waste (EEA, 2018). In the EU during 2018, The Waste Framework Directive, Landfill Directive and Packaging Waste

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Directive, were amended to include a number of new targets and measures beyond 2020, such as (EEA, 2018):

- targets to increase preparing for reuse and recycling of MSW to at least 55% of MSW by 2025, 60 % by 2030 and 65 % by 2035;
- targets to increase recycling of packaging waste to at least 65 % by 31 December 2025 and 70 % by 31 December 2030;
- a target to reduce landfill to a maximum of 10 % of generated MSW by 2035;
- a ban on landfilling of waste suitable for recycling effective from 2030;
- etc.

Therefore, one solution to the MSW management problem represents recycling by obtaining revenues through the sales of collected materials, ensuring thus an adequate supply of raw materials for manufacturing recycled products and producing important environmental benefits (Vidović et al., 2016).

Recycling, as one of the treatment option for MSW, has been steadily increasing in Europe from 31% in 2004 to 45% in 2016 (EEA, 2018) and as the demand for raw materials is expected to dramatically increase in the upcoming years, the worldwide market for recycling and re-use technologies will offer increasing opportunities (EC, 2013). For example, prices of virgin and recycled materials for different types of packaging materials are presented in Table 1.

Table 1. Comparison of market prices of virgin and recycled material (European Commission, 2014)

Material	Virgin material (€/t)	Recycled material (€/t)	Price of Recycled material/ Virgin material (%)
Glass	52-59	12.5-34	24-58
Paper-cardboard	717-776	115-136	16-18
Aluminium	1719-1774	650-1080	38-61
Steel	394-630	160-180	41-29
HDPE Plastics	990-1200	245-280	25-23
PET Plastic	1550-1700	390-475	25-28

Recycling is defined as any recovery operation by which waste materials are reprocessed into products, materials or substances, whether for the original or other purposes (EEA, 2018). Hence, recycling creates reverse flows of products, materials, parts, etc. comparing to traditional (forward) logistics flows (Figure 1). Reverse logistics system involves the following activities:

- acquisition of returned products, materials, parts, etc.
- collection
- inspection/sorting/testing operations
- choice of disposition, followed by recovery options
- and final disposal if returned products, materials, part, etc., cannot be recovered through any available recovery options.

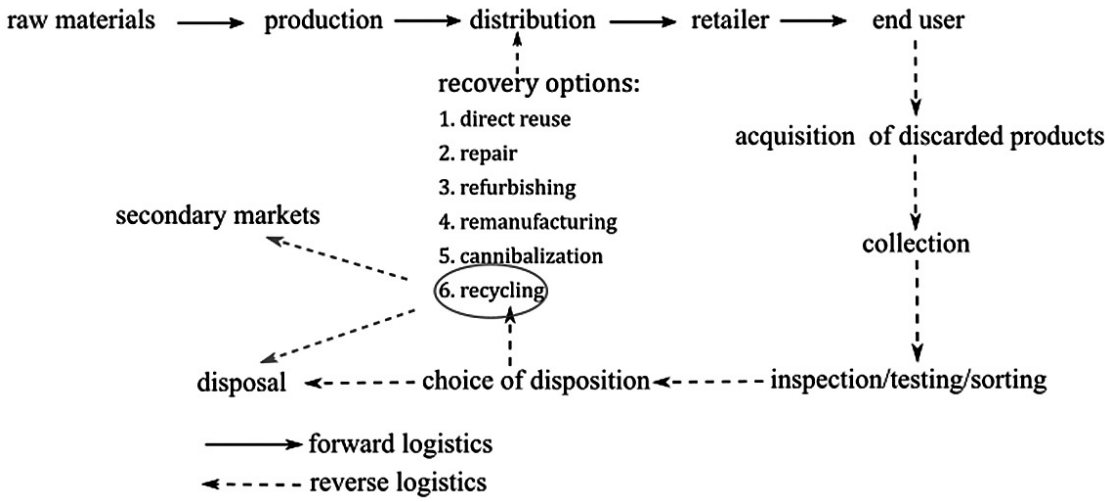


Figure 1. Reverse logistics flows (adapted from Rachih et al., 2019)

On the other hand, recycling logistics network (RLN) may include for example secondary markets for recycled products, so the process of redistribution is added to these networks. Hence, reverse logistics networks have different network structure compared to traditional or forward logistics networks due to new activities/processes (i.e. recovery options), facilities (i.e. recycling factories), as well actors in the system. Additionally, when talking about recycling, the value of products, intended for recycling is usually really low and costs related to recycling activities, especially collection can account up to 70% of the entire cost of MSW management (Vidović et al., 2016). Therefore, appropriate RLN must be designed to encompass all recycling activities in order to manage reverse logistics flows in a profitable way. The profitability of RLN is influenced by the efficiency achieved through coordination and integration of all involved participants (Helms and Hervani, 2006).

One of the activities in the recycling process, as can be seen from Figure 1, is collection recyclables from end users, which can been done in different ways. One of the most efficient ways of collecting recyclables is through the separation of MSW into fractions like plastics materials, glass, metal cans, paper, etc. So, an adequate system of collection points (CPs) must be established (set) to encompass all specificities of RLNs. Having in mind that the success of recycling systems lies mostly in end users' participation, which determines the type and amount of materials to be collected (Gallardo et al., 2010), acceptable walking distance for end users, can be used as a criterion to locating CPs in RLNs. Hence, the emphasis in this paper is on modeling approaches used for selecting distance dependent locations for CPs, as facilities on the first level of the RLNs.

In the last two decades, a number of researchers investigated the problem of designing RLNs. It should be mentioned that there are a number of review papers on reverse logistics systems and design such as Engeland et al. (2018), Rachih et al. (2019), Prajapati et al. (2019), Thierry et al. (1995), Fleischmann et al. (1997), Srivastava (2007), Sasikumar and Kannan (2008a, 2008b, 2009), Rubio et al. (2008), Akçali et al. (2009), Chanintrakul et al. (2009), Melo et al. (2009), Pokharel and Mutha (2009), Agrawal et al. (2015), Govindan et al. (2015), Govindan and Soleimani (2017). A review paper by Purkayastha et al. (2015) is, to the authors' best knowledge, the only one of that kind which offers comprehensive insight in location-allocation approaches used for

locating CPs in waste management systems. Authors stated that only a few studies have been addressing the problem of recycle bin location-allocation problem.

From here, the paper is structured as follows: Recycling processes and designing inputs for a recycling network as well as the relevant literature are addressed in Section 2. Detailed examples of locating distance dependent CPs in RLNs for different types of products are presented in section 3. Finally, concluding remarks are given in section 4.

2. CHARACTERISTICS ON RECYCLING LOGISTICS NETWORKS DESIGN

Generally, to handle returned products in logistics system, a completely new reverse logistics network need to be designed or an existing logistics network must be redesigned (Figure 2). Two main characteristics of reverse logistics flow must be considered when designing reverse logistics networks: convergent structure, where products flow from many sources to few destinations, and uncertainty in quantities of returned products (Melo et al., 2009).

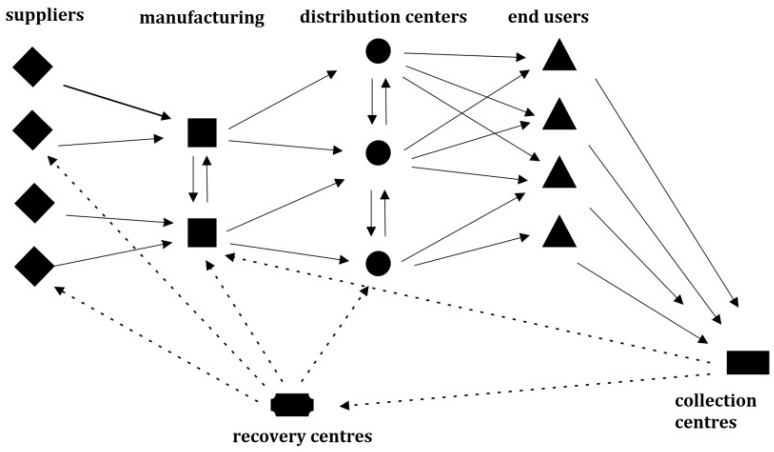


Figure 2. Forward and reverse logistics flows (Melo et al. 2009)

Designing of RLN falls in the category of strategic network design problems. When designing RLN, two additional distinctive characteristics of RLN must be considered. As mentioned, the economics of the RLN is characterized by low value per volume collected, and high investment costs for specialized equipment and deployed technologies (Bloemhof-Ruwaard et al., 1999). Due to the limited number of recovery options and the fact that material recycling is fairly robust with respect to input quality, a centralized network structure concentrating processing capacities at few locations is a characteristic of RLN (Bloemhof-Ruwaard et al., 1999).

Particularly, strategic design of RLN may include: the selection of locations for collection, inspection, testing or sorting of recyclables as well treatment facilities; the selection of technologies to be deployed in those facilities; determination of capacities of those facilities; allocation of the physical flows between located facilities on the network, etc. Decisions regarding the allocation of the physical flows between located facilities on the network, that is determining transport connections between objects in the RLN, can be made in two ways. Selecting the locations of facilities in the RNL and then defining the vehicles' routes, when problems of locating facilities and finding vehicle routes are

solved independently, or solving these two problems simultaneously. The second approach is referred to in literature as the location-routing problem (LRP).

The design of RNL depends on a number of economic, environmental and social factors such as quantities of generated waste, transport infrastructure, the composition of generated waste, public attitudes towards facilities such as transfer stations, collection points, etc. The general structure of the RLNs can be presented through a number of layers or echelons on the network, or the RLN can be consisted of different levels and facilities (Figure 3). From Figure 3, it can be seen that regardless of the system's complexity, RNL begin with the end user and finish with the end market (Jahre, 1995b).

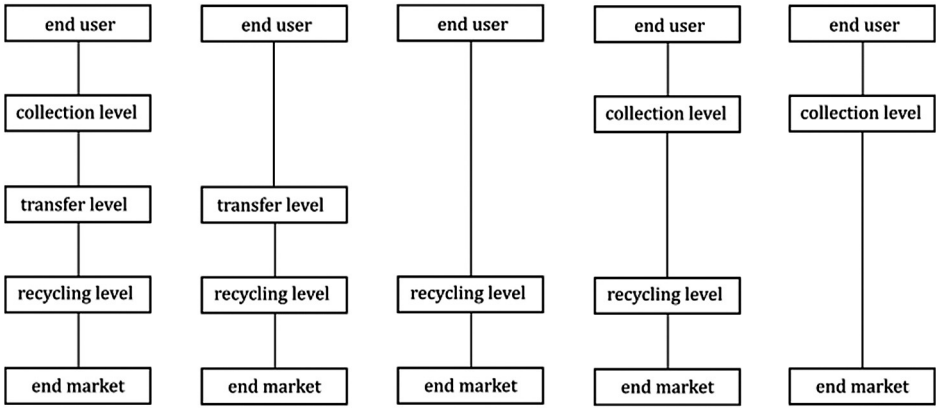


Figure 3. Possible layers in RNL (adapted from Jahre, 1995a)

Of course, the question who is end user in RLNs plays a vital role when deciding on collection strategies as well as the structure of the network. Generally, all end users as generators of recyclables can be divided into two groups: households and industry and commercial sector. This distinguishing factor is made primarily on the generated quantities of recyclables. Households generate recyclables materials such as packaging materials, household appliances, textiles, furniture, etc., but in much smaller quantities than the industrial and commercial sector. These quantities, with other factors, determine a way of organizing the RLNs. Namely, since the industry and the commercial sector generates larger quantities of recyclable products and materials, the collection is usually organized in a defined time interval when vehicle or vehicles comes to the generator's location and the recyclables that are generated for a given time period is then transported to the next location in the RLNs. When it comes to the household or individual generators of recyclables, there are several strategies for collecting recyclables, which are encountered in practice and in the literature. These strategies are:

- curbside collection (also referred to as "door-to-door" collection service) - each household has its own container or in case of apartment buildings containers are located in interior courtyards of the building. In both cases, containers are placed outside the household/building on collection days.
- drop-off locations (or bring collection system) - end users are required to bring their recyclables to allocated drop-off points.
- buy-back centers - end users may deliver recyclables to allocated locations as well in drop-off strategy, but in this case, receiving a certain monetary compensation. Also, the number of sites for buy-back centers is significantly lower than the number of locations for drop-off strategy.

- Refill/deposit system - primarily intended for beverage products, nowadays is applied to batteries, tires, etc.

Each of these strategies has its advantages and disadvantages. For example in the case of curbside collection strategy recyclables are collected on a fixed schedule and associated cost are high, but end users have minimal effort in disposing of their recyclables. In the case of drop-off collection strategy, compared to curbside collection strategy costs are lower, due to the smaller number of CPs, but in this case end users have a greater effort compared to curbside collection strategy. Depending on the type of recyclables and available sites for discarding recyclables, end users can decide on what location for generated recyclables is more suitable for them.

In order to make returned products available for the recycling process, the first step is their efficient collection. So, it is necessary to determine the locations of facilities for the collection of returned products on the first level of the network, regardless of the strategy in place. Biehl et al. (2007) point out that CPs are essential elements of any reverse logistics system in order to increase the collection of returned products and reduce transportation costs. Kao and Lin (2002) stated that selecting too many CPs increases the collection cost, while selecting too few may reduce customer satisfaction and probably cause less efficient recyclables process. So, the participation of end users is crucial for a successful recycling program, where the level of participation depends on the convenience associated with accessing recycling CPs (Lin et al., 2011). End users are responsible for sorting products in their homes and delivering recyclables to selected CPs locations. The most common way to encourage the participation of end users in the recycling process in order to collect as large quantities of recyclables is by stimulating them with some incentive (monetary compensation). But when voluntary action is required, personal costs related to the time required for sorting and delivering recyclables to defined CPs locations must be minimized to ensure the greatest possible participation of end users. In many studies (Perrin and Barton 2001, Domina and Koch, 2002; Gonzalez-Torre and Adens-Díaz 2005; Valle et al. 2009) has been shown that proximity and accessibility of CPs location plays a key role for the active participation of end users. One way to reduce the end user's inconvenience is to minimize the distance from the end user to the CP's location. Gonzalez-Torre and Adens-Diaz (2005) confirmed previous researches conducted in Scotland (Speirs and Tucker 2001) and Spain (Domina and Koch 2002), in which authors found that if end users have a greater number of containers for disposal of recyclables which are located closer to their homes, they are more willing to sort and bring recyclables to CP's locations. That is, the amount of collected and sorted recyclables is significantly higher compared to the case when the number of CPs is smaller and farther away from the end user's homes. Those studies also found that the majority of end users who are sorting three or four kinds of products for recycling walk less than five minutes from their homes to the CP's location. Perin and Barton (2001) found that distance to CPs is the main obstacle to effective recycling. Also, González-Torre and Adenso-Díaz (2005) found that the distance to the selective recycling bins affects the number of fractions that end users separate at home.

It should be mentioned that, in the case of some recyclables, allowable distance of end users from CPs can also be specified by legislative measures. For example, this is the case for end-of-life vehicles in Germany and the United Kingdom.

The following section describes mathematical modeling approaches used for selecting distance dependent locations of CPs for recyclables.

3. MODELING APPROACHES FOR LOCATING DISTANCE DEPENDENT COLLECTION POINTS

When talking on recycling, the first association is usually packaging materials such as paper, glass, wood, metal or plastics materials, but vast number of materials and products can be recycled nowadays: electronic and electrical equipment, end-of-life vehicles, furniture, carpets, batteries, medical waste, construction and demolition waste, etc. Hence, researches addressed different types of products when solving the problem of locating CPs in RLNs.

In order to model the influence of the distance between users and CPs on the optimal locations of facilities to be found, Ratkovic et al. (2012), introduced the CP's catchment area (Figure 4).

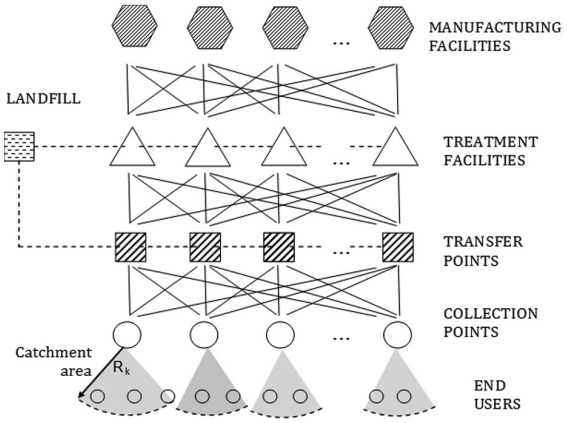


Figure 4. Modeled reverse logistics network (Ratkovic et al., 2012)

Authors presented a multi-level, multi-product facility location model for reverse logistics network design. The proposed model finds effective strategies for the return of discarded products from end users to recycling factories, via CPS, transfer facilities and treatment facilities, with minimal costs. Special emphasis was in analyzing the impact of collection point's catchments area. The catchment area (Figure 5) models the influence of the distance between end users and CPs in a way that collection service may exist only when end users are within the certain (reasonable) distance from a collection point *k*. That is, any arbitrary end user *i* can be allocated to the CP only if it is located within the CP's catchment area.

R_k radius of the CP's *k* catchment area
$d_{ki''}$ distance betwen CP *k* and end user *i"*
$d_{ki'}$ distance betwen CP *k* and end user *i'*

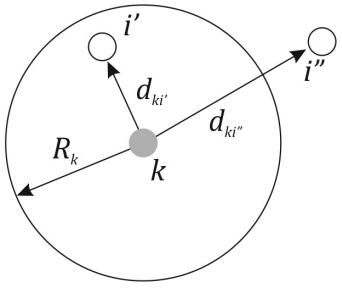


Figure 5. Collection point's catchment area (Ratkovic et al., 2012)

For end user *i*, CP *k* and product *p*, catchment area is formulated as:

$$(d_{ik} - R)X_{pik} \leq 0, \forall i, p, k \qquad (1)$$

where variable X_{pik} represents a fraction of product p transported from end user i to CP k, d_{ik} distance between CP k and end user i, and R radius of the catchment area. Authors tested the behavior of the system with different values of R, in order to examine the impact of R on the collected quantity of recyclables from the one side, and on the logistics network configuration from the other.

Lin et al. (2011) proposed Integer Programming (IP) model to determine convenient CPs in two-shift collection plan on the basis of proximity and then applied Ant Colony Optimization algorithm to determine the most effective routing plan of each shift. Firstly, the authors defined the regions eligible for a two-shift collection schedule and the coverage radius of each recycling CPs. These recycling CPs in the one-shift collection plan are conveniently located for the end users. But, in the two-shift collection plan, end user unable to access their closest CP at the scheduled collection time can dispose of their recyclables at one of the alternative accessible CPs (AACPs) in the second shift. Authors defined the term "coverage radius" representing the maximum distance that end users have to walk from the nearest CP to an AACP. The relationship between a CP (point 1), coverage radius (R), and the AACPs of the observed CP (i.e., points 3 and 4) is presented in Figure 6.

Then, the IP model is formulated to determine the minimal number of CPs required within a predefined coverage radius and to classify the CPs into day and night shifts. Authors used four coverage radii in this study: 50, 75, 100, and 500 m.

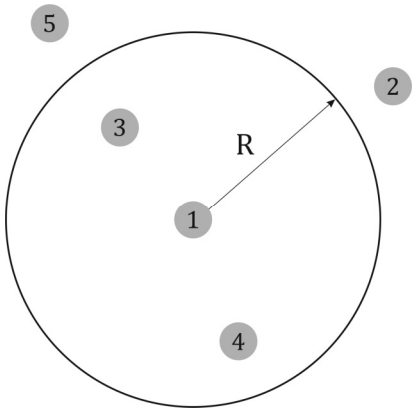


Figure 6. Coverage radius for CPs and AACPs (Lin et al. 2011)

Kim and Lee (2018) proposed two collection network design models: a single-period static model for time-invariant demands and a multi-period restricted-dynamic model for time-variant demands over a planning horizon. Proposed models determine the locations and capacities of CPs as well as the allocations of returned products to the opened CPs. Authors incorporated the maximum allowable distance between CPs and demand points as well as the minimum recovery rates of CPs in the model. Authors incorporated the maximum allowable distance between CPs as well as the minimum recovery rates of CPs in the model. Maximum allowable distance between CPs and demand ponts is formulated as:

$$d_{ij}x_{ij} \leq S_j y_j^k \tag{2}$$

where dij represents the distance between nodes i and j (demand points and potential locations for CPs $i \neq j$), S_j represents the maximum allowable collection distance at the CPs

opened at node *j*, y_j^k and x_{ij} are binary variables. Maximum allowable distances were generated from a discrete uniform distribution with value range (140, 200).

$$x_{ij} = \begin{cases} 1, \text{if the products at node } i \text{ are allocated to CP located at node } j \\ 0, \text{otherwise} \end{cases} \quad (3)$$

$$y_j^k = \begin{cases} 1, \textit{if CP with capacity k is opened at node j}, \\ 0, \textit{otherwise} \end{cases} \quad (4)$$

Coverage radii, used in these papers, are basically lean on the idea which stands behind formulations of covering location problems introduced by Toregas et al. (1971) and Church and ReVelle (1974). In the context of locating CPs in RLNs, as stated collection service exists only when end users are within the certain (reasonable) distance from a specific CPs. It is clear that defining value of coverage radius strongly influences the design of RLN. Recyclables beyond defined distance are not covered at all, that is not collected. This seems to be an unrealistic modeling assumption in many potential applications (Berman et al., (2003), Eislet and Marianov, (2009)). Hence, Berman et al., (2003), Eislet and Marianov, (2009), Church and Roberts, (1983), Berman and Krass, (2002), suggested that the coverage provided by the facility is assumed to fall off gradually according to some decay function (Figure 7).

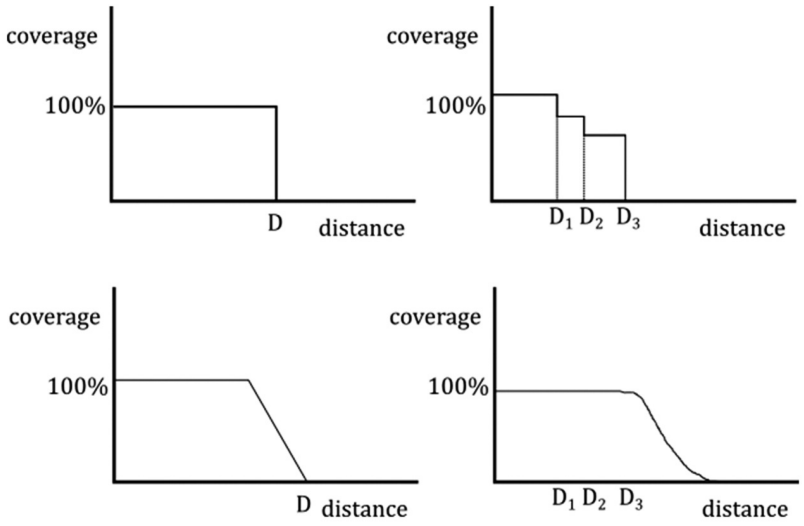


Figure 7. Coverage decay functions (Eislet and Marianov, 2009).

This decay function for selecting optimal locations of CPs was used in Vidovic et al. (2016). Authors presented a mathematical model of a two-echelon LRP in case of recyclables collection with a profit and distance dependent collection rate in the urban environment. Authors modeled the influence of distance between end users and CPs by assuming that the recyclables collection rate, $f(d) \in [0, 1]$, is a known function of distance. This function models the influence of the distance between end users and CPs, in a way that the collection rate is inversely proportional to the distance (Figure 8). Authors defined two characteristic distances, l and u ($l < u$), as in Berman et al. (2003), between an end user and CP, where l represents the lower and u upper bound of walking distance to a CP for each end user. When the distance from the end user to the closest CP

is 0≤ $d \le l$, then $f(d) = 1$, while in case when $d \ge u$, $f(d) = 0$. If the distance between the end user and CP is $l \le d \le u$, it is assumed that the collection rate corresponds to $f(d) = \frac{u-d}{u-l}$ (Figure 8).

So, the collection rate Z_{ikb} for end user i and CP k, in city block b, for the distance d_{ikb} is calculated as:

$$Z_{ikb} = \begin{cases} 1, when\ 0 \le d_{ikb} \le l \\ f(d_{ikb}), when\ l \le d_{ikb} \le u \\ 0, when\ d_{ikb} > u \end{cases} \quad (5)$$

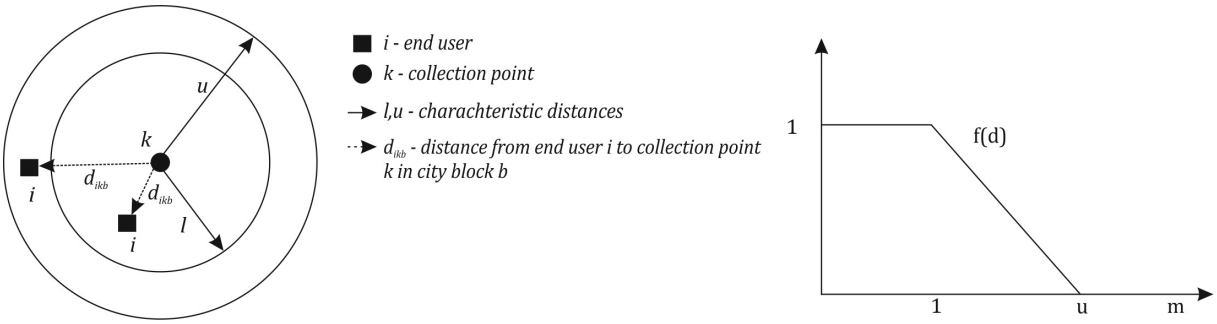


Figure 8. Characteristic distances and shape of function *f(d)* (Vidovic et al., 2016)

Similar idea was used in the paper by Rahim and Sepil (2014), where authors addressed an LRP in glass recycling. Authors combined maximal covering location problem in the presence of partial coverage and selective traveling salesman problem to determine the location of CPs for glass and the routes of collecting vehicles. They assumed that the rate of recycling of a resident in zone i to a CP located at site j, along with the distance between zone i and site j denoted as d_{ij} can be expressed as $q \times k_{ij}$ where:

q is the daily expected amount of recyclable bottles produced per end user, and

$$k_{ij} = \begin{cases} 1, \text{if } d_{ij} \le S, \\ 1 - \frac{d_{ij} - S}{T - S}, if\ S < d_{ij} \le T \\ 0, \text{otherwise} \end{cases} \quad (6)$$

S and T are parameters representing the linear partial coverage function. Authors stated that the values of S and T parameters, that define the critical distances for full and partial coverage, affect the solutions considerably. After preliminary testing, they set the ratio of S to T as 0.75.

Explained approaches used for selecting locations of CPs, refers to typical recyclables generated by end users like paper, metal cans, plastic bottles, etc., where CP is usually container for collecting returned products. Distance between end users and CP's location is the distance between the end user's residency and actual potential location of the container. But in case of, for example, end-of-life vehicles (ELVs) or waste on electric

and electronic equipment (WEEE), CP is a different type of facility (usually buy-back centers), so slightly different approaches for selecting CP's location can be used.

In case of end-of-life vehicles (ELVs) as recyclables, classical covering location models used for selecting locations of CPs would aggregate end users in a zip code area by the zip code's centroid, which allows the problem to be manageable regarding the problem's size and available data. This kind of approach, although reasonable, introduces errors in solution's accuracy such as (Vidovic et al., 2011):

- the district that is considered to be covered is actually not. This is the case when the service zone area is only partially covered by the CP, while the service zone's centroid is covered (the centroid is on the distance smaller than the service radius)
- the service zone that is considered to be uncovered is actually partially covered. This happens when the service zone area is partially covered by the CP, while the service zone's centroid is not covered (the centroid is on the distance greater than the service radius);
- overlapping of the service zone circles affects the predicted number of ELVs collected. This is the case when the service zone area is partially covered by two or more CPs, while the service zone's centroid is covered by one or more facilities;

Vidovic et al. (2011) proposed a novel covering approach for locating CPs for ELVs which decreases aggregation error by introducing the concept of multiple service zones.

For allowable distance from end users to CP's locations, authors used two concepts, found in the UK and Germany ELV legislation. Firstly, the authors proposed a mathematical model for designing RLN based on only one allowable service distance, R_{fix}, between the end users and the CPs. This kind of service radius was found in German legislation in which the maximum distance from the end user and a CP should not exceed 50 km. Secondly, the authors proposed a mathematical model for designing RLN based on two allowable service distances, $R_{\min}$ and $R_{\max}$, between the end users and the CPs. This kind of service radii was found in the UK legislation, which stated that 75% of end users should be within 10 miles on average of the nearest collection facility and no one should be more than 30 miles, in which case free take back is applied.

The proposed approach to decrease of aggregation error was based on an innovative concept aggregation of the service zones centroids. Authors introduced the idea of service zone partitioning to define subzones (subsets of demand locations), which are covered by one or more CPs. Then, the subzones are aggregated into subzone centroids which demand is then calculated as a fraction of the total service zone's demand (proportional to the covered zone area). In Figure 10 proposed service area partitioning concept for the case of two allowable service distances is illustrated.

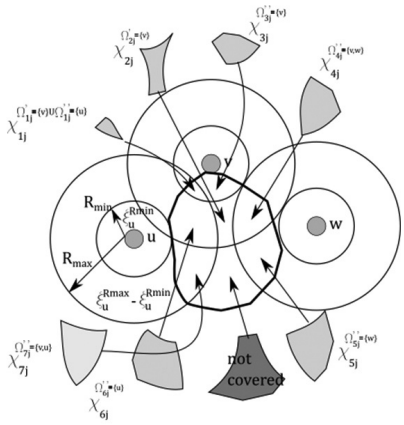


Figure 10. Service area partitioning concept (Vidovic et al., 2011)

As UK legislation stated, the radii of the circles whose centers are located at the same potential location for the CP are denoted as $R_{\min}$ and $R_{\max.}$ The smaller and the greater areas of the circles are denoted as $\xi_i^{R\max}$ and $\xi_i^{R\min}$, while the difference between these two values $\xi_i^{R\max} - \xi_i^{R\min}$ represents the ring area. Then, any subzone *k* of district *j*, with an area $\chi_{kj}^{\Omega_{kj}}$ is expressed as an intersection of district *j*, and an arbitrary number of circles $\xi_i^{R\min}$ and ring areas $\xi_i^{R\max} - \xi_i^{R\min}$. Set Ω_{kj}, representing potential locations of the CPs whose circle or ring areas fully cover the *k*th subzone of district *j*, is divided into two subsets: $\Omega_{kj}^{'}$ and $\Omega_{kj}^{''}$. Set $\Omega_{kj}^{'}$ contains the potential locations that cover the subzone with the circle areas $\xi_i^{R\min}$, while set $\Omega_{kj}^{''}$ contains the potential locations that cover the subzone by the ring areas $\xi_i^{R\max} - \xi_i^{R\min}$. Then, zone partitioning concept for the case of two allowable distances, is expressed as follows:

$$\sum_{i\in\Omega_{kj}^{'}} x_i \geq y_{kj}^{'}, \forall j,k \tag{7}$$

$$\sum_{i\in\Omega_{kj}^{''}} x_i \geq y_{kj}^{''}, \forall j,k \tag{8}$$

$$y_{kj}^{'} + y_{kj}^{''} \leq 1, \forall j,k \tag{9}$$

where

$$x_i = \begin{Bmatrix} 1, \text{if location } i \text{ is selected} \\ 0, \text{otherwise} \end{Bmatrix}, \forall i \tag{10}$$

$$y_{kj}^{'} = \begin{Bmatrix} 1, \text{if the } k\text{th subzone of the district } j \text{ is served from the distance } R_{\min} \\ 0, \text{otherwise} \end{Bmatrix}, \forall j,k \tag{11}$$

$$y_{kj}^{''} = \begin{Bmatrix} 1, \text{if the } k\text{th subzone of the district } j \text{ is served from the distance } R_{\max} \\ 0, \text{otherwise} \end{Bmatrix}, \forall j,k \tag{12}$$

Constraints (6) and (7) allow a subzone *k* of district *j* to be served from the distances R_{min} or R_{max}, respectively, only if one or more CPs that cover it within those distances are

opened. The constraints (8) provide that subzone *k* of district *j* is not counted twice in the objective function when coverage is provided from both distances.

On the other hand, some of the authors studied the problem of locating CPs in RLNs in the case when end users receive an incentive for returned products. Some of the authors argue that the financial incentive offered to the end users must be involved in designing the collection network (Hosseini et al. (2019); Aras and Aksen (2008); Boyacı et al. (2006); Aksen et al. (2009)). Of course, this statement depends on the type of returned products. In the case of recycling process, this fact is valid for the case of ELVs, WEEE, etc. Aras and Aksen (2008) assumed that each end user decides whether or not to return the product, based on both the financial incentive and the proximity to the nearest CP. They formulated a mixed-integer nonlinear facility location-allocation model to determine the optimal locations of the CPs and the optimal incentive values for each return type so as to maximize the profit from the returns. Authors expressed the proportion P_{jq} (Figure 11) of product holders of type q located in zone j who will return a used product, when the company offers incentive R_q for type q returns and the distance to the nearest collection center is d_j as:

$$P_{jq} = \Pr(R_q - kd_j - R_{0q} > 0) = \min\left\{1, \frac{\max\left\{0, R_q - kd_j - a_q\right\}}{b_q - a_q}\right\} \tag{13}$$

where kd_j represents the cost of carrying the used product to the collection center with the coefficient k (the cost per distance traveled), a_q and b_q represent the minimum and maximum incentive levels of product holder of type q. Authors assumed that each product holder has a reservation incentive for returning his/her used product denoted as R_{0q}.

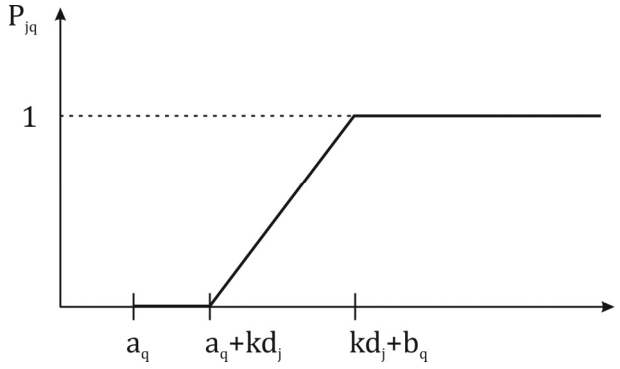


Figure 11. Return proportion P_{jq} as a function of incentive $R_{q.}$ (Aras and Aksen, 2008)

Geographic Information Systems (GIS) was used as a tool for selecting CPs in RLNs for modeling distance between end users and CPs locations, in some papers. Gautam and Kumar (2005) proposed a model to analyze the trade-off between the number and capacity of CPs, average walking distance to drop-off CPs, the population covered (recyclables quantities), and the distance traveled by collection vehicles, in a GIS environment. Authors defined two goals: the first was to provide as many CPs as possible within the collection network, and the second to distribute CPs as evenly as possible on the network. In order to achieve these goals, authors formulated the GIS-based programming model with two objectives: maximization of the population served by the recycling CPs, and minimization of total walking distance from household to recycling CPs. Minimal and maximal acceptable walking distance, as input parameters in

the model, were 250 and 500 m, respectively. Gallardo et al. (2015) used GIS for determining number, capacity, and location of CPs for different types of MSW as well as collection strategies. Although, authors didn't specifically observed RLNs, they proposed a comprehensive methodology to locate the minimum number of MSW CPs in a certain geographic area. Some of located CPs, were intended for collecting recyclables and authors took into account input parameters like the capacity of CPs, the frequency of collection, walking distance for end users in different types of collection strategies, etc. Tralhão et. al (2010) incorporated a multi-objective optimization model in a GIS-based interactive decision support system to determine the number of CPs to be opened, CPs capacities, locations, and the dwellings assigned to each CP. Proposed multi-objective optimization model consists of four objectives. The first objective minimizes the total investment costs; the second one minimizes the average distance from dwellings to CPs; the third objective minimizes the number of individuals too close to any CP, and final objective minimizes the number of dwellings too far from the CP. Authors considered four types of MSW for recycling: glass, plastic, paper and other (mainly organic waste). As an input parameter in the model authors used the assumption that no dwelling may be more than 200 m from an open CP and formulated it as:

$$d_{ij}x_{ij} \le D, i \in S, j \in C \tag{14}$$

where d_{ij} represents the distance between the sector $i \in S$ and the candidate site $j \in C$; x_{ij} is a binary variable which takes 1 if the sector $i \in S$ is assigned to the candidate site $j \in C$ for recyclables deposition, 0 otherwise; and as mentioned D=200m. The second objective function that minimizes the average distance from dwellings to CPs is formulated:

$$\min \frac{1}{F} \sum_{i \in S} \sum_{j \in C} f_i d_{ij} x_{ij} \tag{15}$$

where F is the total number of dwellings, f_i number of dwellings of sector $i \in S$, while x_{ij} and d_{ij} are previously explained. Due to a large number of dwellings in the observed numerical example, authors aggregated dwellings into linear sectors along the streets.

4. CONCLUSION

In this paper, we presented approaches used for designing one part of RLNs, particularly concentrating on mathematical modeling approaches used for selecting locations of CPs for recyclables collection. Selecting locations for CPs, some authors claim, is a key element of RLNs, since those locations directly influence on the success of recycling process through collected recyclables quantities and associated transportation costs, among others. Namely, since transportation cost associated with the collection of recyclables can be up to 70% of total system costs, location-allocation decisions regarding CPs define the effectiveness of establishing a recycling network as a whole.

A number of factors must be considered when locating CPs conveniently for end users (economic, social and environmental). For end users, distance to CPs is found to be one of the factors that influence on delivering generated recyclables to designated CPs' locations. An appropriate or optimal, when possible, locations of CPs in RLNs can improve the existing system, through easier accessibility of CPs for every end user in the

observed geographical region, thus influencing on collected recyclables quantities and transportation costs, which is the overall aim of every recycling system. Acceptable walking distance for end users to CPs differs, not only from country to country, region to region, but from city to city, due to different cultural, economic and demographic characteristics. So, research on recycling motives of end users need to include those characteristics and to be input parameters when designing RLNs. Defining functions that model the dependency of distance between end users and CPs on collected recyclables' quantities, based on aforementioned characteristics of particular cities/regions, could be one of the future researches in this filed. On the other hand, when solving the problems of real size dimensions, it is common practice to aggregate end users in centroids, sectors, etc. which introduces errors in solution's accuracy. Hence, in this case, future research should be concentrating on approaches which decrease an aggregation error.

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A VARIABLE NEIGHBORHOOD SEARCH METAHEURISTIC IN SOLVING THE VEHICLE ROUTING PROBLEMS: LOGISTICS CASE EXAMPLES

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Abstract: *Despite the unquestionable significance of the vehicle routing problem for stakeholders in logistics processes, and numerous research conducted with the goal of improving solution procedures of the problem, its complexity caused that there is no universally applicable procedure for solving different variants of the problem. In this research we present the implementation of the variable neighborhood search algorithm in solving inventory routing, container drayage and travelling repairmen problems, with the goal to introduce an interested reader to the practical implementation of the VNS in solving vehicle routing based logistics problems.*

Keywords*: variable neighborhood search, vehicle routing problem, inventory routing, container drayage, travelling repairmen.*

1. INTRODUCTION

Operation of logistics systems are an area in which efficient solving of the vehicle routing problem (VRP) play very important role in the realization of everyday tasks. Despite the unquestionable significance of the VRP for numerous stakeholders in logistics processes, and hundreds of researches conducted with the goal of improving solution procedures of the VRP, its complexity caused that so far there is no universally applicable procedure for solving different variants of the VRP. As a consequence, accommodation of specially designed procedures is the most efficient way of solving the VRP. Accordingly, implementation of heuristics and metaheuristics algorithms in solving real-life problems has attracted the vast majority of scientific researches, and proved to be very efficient. Usually, some new algorithm, or solving concept, is accepted as a procedure for solving a problem if it improves solution either in terms of solution quality, or computational time, or both.

In this research we focus on the implementation of one metaheuristic concept that proved to be very efficient in solving large number of combinatorial optimization problems. More precisely, we give short overview of the variable neighborhood search (VNS) algorithm's development and implementation in three research studies conducted at the Logistics department of the Faculty of Transport and Traffic Engineering in the

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previous seven years: inventory routing, container drayage and travelling repairmen problems. The goal of this paper is to bring to an interested reader closer look to the implementation of the VNS in solving VRP based logistics problems.

Accordingly, this paper is organized in such a way that in Section 2 we give a short overview of the VRP's main features. In Section 3 we present main concepts that drive the VNS. Afterwards, in Section 4 we give overview of the implementation of the VNS in solving three before mentioned VRP bases logistics studies. Eventually we give a brief conclusion regarding the experience in using the VNS.

2. THE VEHICLE ROUTING PROBLEM

The VRP is one of the most discussed optimization problems for which a large number of exact and heuristic approaches have been developed. The application areas of the VRP are practically unlimited and refer to any system in which there is a need for transportation on a network of nodes (source locations, user locations, pick up locations, delivery locations etc.). Dantzig and Ramser (1959) presented the original work in which the VRP was first formulated as "The Truck Dispatching Problem". The authors observed the problem of fuel distribution from a depot (bulk terminal) to a large number of service stations, where solving the problem involves the assignment of stations to capacitated vehicles with routes construction in order to minimize the total distance travelled while meeting the demand of all stations. Since 1959, a large number of papers have been published for the VRP, which discussed various variants of the classical VRP problem. The classical capacitated VRP consists of one depot and a set of users that need to be serviced by a capacitated set of vehicles. Toth and Vigo (2002) define the following basic variants of the VRP (Figure 1):

- Capacitated VRP (CVRP)
- Distance-Constrained CVRP (DCVRP) – vehicles have a maximum allowed route length (time or distance related);
- VRP with Time Windows (VRPTW) – with a service time window in each node;
- VRP with Backhauls (VRPB) – service nodes (or customers) are divided into two sets. One set is for linehaul deliveries, and the other is for backhaul pickups. All linehaul customers must be served before any backhauling in each route;
- VRP with Pickup and Delivery (VRPPD) – each customer can have mixed delivery and pick-up quantities, where both can be serviced simultaneously in one node.

Many extensions of the VRP can be found in the literature that tries to solve problems which came from real-life situations with a different set of specific constraints and/or additional interdependent objectives. One of those approaches is the Inventory Routing Problem (IRP) that extends the classical VRP with simultaneous optimization of routing and inventory related decisions (stock level, time and quantity of delivery, etc.). The Location Routing Problem includes location aspect, while Production Routing Problem includes production aspect. In the case of real-time optimization where important information becomes available during the realization of a solution, we have Dynamic VRP. Also, the Stochastic VRP is a variant where some conditions are uncertain and can be described by a probability distribution. The VRP with synchronization tries to solve routing problems where different vehicles need to be synchronized (e.g. routes of trucks with cargo and mobile cranes should be synchronized for those nodes that do not have

material handling equipment). Travelling Repairman Problem (TRP) is a variant of the VRP in which routing is defined with a simultaneously interest of all customers as a focus, resulting in the increased complexity of the problem. In the case of route consistency requirements (e.g. customers must be visited by certain drivers) we have the Consistent VRP. The split delivery VRP observes the possibility of satisfying a customer's demand by more than one vehicle (a quantity for a customer can be delivered by multiple vehicle routes). If special vehicles with compartments are used, we have the case of the VRP with compartments (transportation of milk, fuel etc.). When vehicles can be used for multiple routes, we have the case of the Multi trip VRP, while in the case of multiple depots with vehicles we have the Multi depot VRP. In the Clustered VRP customers are partitioned into zones (clusters) that are served by its vehicle. The Arc Routing Problem is a special case of vehicle routing where network links (arcs) between nodes should be visited (instead of the nodes).

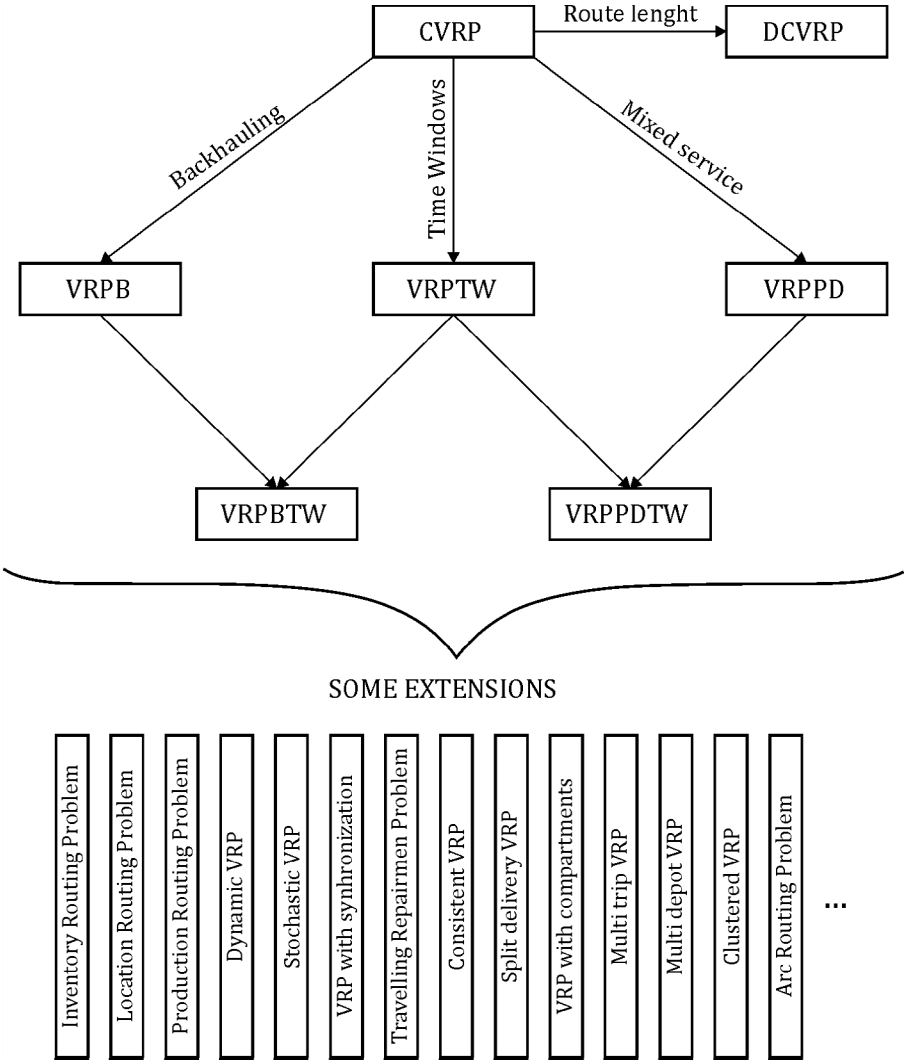


Figure 1. The basic variants of the VRP and extensions (adapted from Toth and Vigo, 2002 & 2014)

As for the objectives of the VRP models, Toth and Vigo (2002) and Toth and Vigo (2014) define the following typical objectives (standalone or that can be combined in weighted objective function):

- minimization of the global transportation costs, based on the travel distance or time and fixed cost per vehicle used;
- minimization of the number of vehicles used;
- balancing of the routes, regarding total time or vehicle load;
- minimization of the penalties regarding the service of the customers;
- can be in the scheduling and time-windows context (waiting time, time of finishing the route, etc.);
- energy consumption and pollutant emission control in the routing context;
- infeasibility penalties as a mean of guiding metaheuristics towards feasible solutions in a hybrid models.

Laporte (2009) published a review paper on the major developments in the field of exact algorithms and heuristics that were developed during the 50 years of research since the publication of the first paper. The author states that the problems with around 100 nodes can be solved by exact models (based on linear and dynamic programming), while for the real-scale problems of larger dimensions various heuristic models are a necessity (due to the NP-hard nature of the VRP). The classical heuristics for solving the VRP can be classified as (Laporte, 2009):

- The Savings Algorithm;
- Set Partitioning Heuristics;
- Cluster-First, Route-Second Heuristics;
- Improvement Heuristics.

Braekers et al. (2015) in their survey paper regarding the VRP literature published between 2009 and June 2015, state that heuristics and metaheuristics are often more suitable for practical applications. The main difference between heuristics and metaheuristics is that the latter includes mechanisms for avoiding the local optima trap. For the observed period in the survey, authors found 233 models of metaheuristics to solving the VRP, while other methods (exact, heuristic, real-time and simulation) had a total of 106 models. Laporte (2009) classified metaheuristics for solving the VRP in three general groups:

- Local Search – with Tabu Search, Simulated Annealing, Deterministic Annealing, VNS, Very Large Neighborhood Search and Adaptive Large Neighbourhood Search;
- Population Search – with Genetic algorithms as best representative;
- Learning Mechanisms – with Neural Networks, Ant colony optimization, Bee Colony Optimization.

The VNS metaheuristics with its variants are one of the most used to solving the VRP and its variants and extensions, as it is shown in Table 1.

Table 1. The analysis of the research related to the VRP and VNS (for the three relevant publishers, until January 2019 using publishers' search engines)

	NUMBER OF RESEARCH PAPERS	
PUBLISHER	With the term "vehicle routing" in the paper title, abstract or keywords	Papers from the previous column with the term "variable neighborhood search" in the paper
Elsevier	1957	388
Springer	432	231
Taylor & Francis	219	112

3. THE VARIABLE NEIGHBORHOOD SEARCH

The VNS belongs to the class of heuristic algorithms known as metaheuristic algorithms. Prefix meta refers to the basic characteristic of that class of heuristic algorithms that their strict implementation is not providing a solution to the problem, but it rather gives a framework in which good solution can be obtained by including all specificities of the problem. Metaheuristic algorithms are widely used in solving logistics related combinatorial optimization problems (such as VRP) of real-world scale sizes, mainly because they provide good quality solutions in a relatively reasonable computation time, as well as they are not too hard to comprehend and implement.

The VNS is presented to the research community in 1997 (Mladenović and Hansen, 1997), although Hansen et al. (2019) stated that previous work that initiated VNS formulation had been reported several years earlier. Its practical applicability and permanent researchers' interest in VNS has resulted that today there are almost no referent literature regarding metaheuristics without a chapter dedicated to the VNS (Glover and Kochenberger, 2003; Labadie et al., 2016, Siarry, 2016). VNS's principles are used not only for solving combinatorial and general discrete optimization problems but also for continuous global optimization, for automatic programming etc. For more details in versatile use of VNS we refer an interesting reader to the Hansen et al. (2019).

The VNS belongs to the class of metaheuristic algorithms that search for the best solution by perturbing the best known solution (also known as the incumbent solution, or just the incumbent). Perturbation implies that one sort of solution change (referred from now on as a move) is performed in every possible way on the incumbent. For example if the incumbent solution of a route is a sequence of eight nodes then change that implies selection of successive four nodes and change of their position in the solution results in twenty new solutions. Similarly, if a move implies selection of six successive nodes from the incumbent it will result in six new solutions. These two moves are known as Or-opt 4, and Or-opt 6 moves, respectively. All solutions generated by implementation of some move are known as incumbent's neighbourhood for that move. Figure 2. shows complete neighbourhoods of Or-opt 4 and Or-opt 6 moves for the incumbent solution 1-2-3-4-5-6-7-8.

In the case when all solutions from a neighbourhood are compared to the incumbent it is said that the best improvement search strategy is implemented in the neighbourhood exploration. However, since that strategy may be time consuming due to a very large number of solutions in a neighbourhood, alternative strategy is to stop neighborhood exploration as soon as the first improved solution is obtained. That strategy is known as the first improvement strategy.

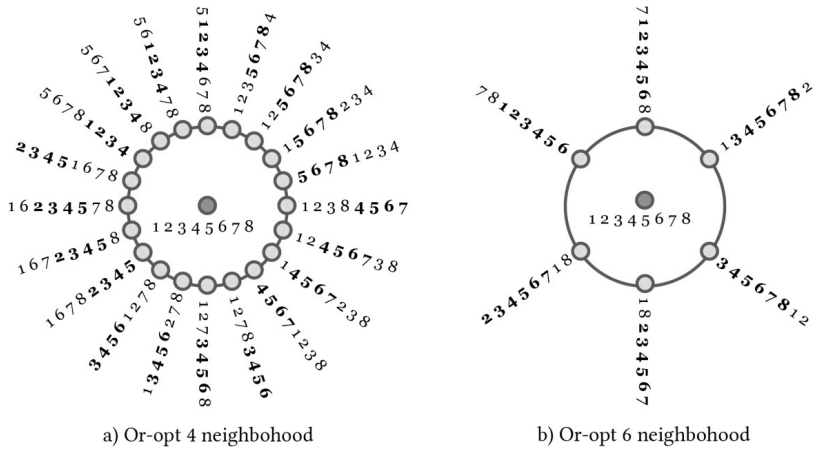


Figure 2. An example of Or-opt 4 and Or-opt 6 neighborhoods (Bjelić, 2014)

Regarding the changes on the incumbent, moves can induce change on only one route of the incumbent (intra-route moves), or on multiple routes (inter-route moves). Theoretically there is unlimited number of moves both for intra- and iter-route moves. However, typical moves that proved efficient in solving VRP related problems are Or-opt k (k=1,2,…), 2-opt, 3-opt for the intra-route moves, and 2-opt*, swap, move, cyclic for the inter-route moves.

The VNS procedure implies exploration of more than one neighborhood with systematic selection of neighborhoods to be checked. According to Hansen et al. (2010) "VNS systematically exploits the idea of neighborhood change, both in descent to local minima and in escape from the valleys which contain them". In that sense, VNS is based the following three observations: (1) a local minimum with respect to one neighborhood most probably is not a local minimum for another neighborhood; (2) a global minimum is a local minimum with respect to all possible neighborhoods; (3) for many problems local minima with respect to one or several neighborhoods are relatively close to each other. Accordingly, the VNS implies implementation of several neighborhoods, which have to be defined prior to the beginning of the procedure, as well as the rules for change of neighborhood to be explored. Therefore, if time limit for algorithm run time is not required the VNS does not require any other parameter except for defined neighborhood structures and rules for their changes. Hansen and Mladenović (2003) present the general VNS (GVNS) which is in a pseudo code form given as Algorithm 1.

Shaking is a procedure whose role in the VNS is escaping the trap of a local optimum. Therefore in the shaking phase a random solution from a neighborhood is selected. That solution is taken as a center of the local search phase in which detailed search of solution space around the center is conducted.

As it can be seen from Algorithm 1, the GVNS implies implementation of the Variable Neighborhood descent (VND) as a local search phase. However, in the basic case of the VNS (BVNS) any other local search algorithm can be applied. The VND is a deterministic local search algorithm which also explores three aforementioned observations upon which the VNS is based. Accordingly it is also based on systematic changes of the neighborhoods according to best or first improvement strategies. Nevertheless, neighborhoods explored in the VND (N_l) do not have to be the same as neighborhoods used in the shaking phase (N_k). Sequence in which neighborhoods are explored is a subject of the algorithm settings. However, because neighborhoods with lower values of

indices k and l will be explored more frequently they are usually related with the neighborhoods of smaller cardinality.

Algorithm 1. General VNS algorithm.

Initialization. Select the set of neighborhood structures $\mathcal{N}_k$, for k =1, …, k_{max} that will be used in the shaking phase, and the set of neighborhood structures $\mathcal{N}_l$, for l =1, …, l_{max} that will be used in the local search; find an initial solution x; choose a stopping condition;
Repeat the following sequence until the stopping condition is met:
(1) Set k=1:
(2) *Repeat* the following until $k= k_{max}$
(a)*Shaking*. Generate a point x' at random from the k^{th} neighborhood $\mathcal{N}_k(x)$ of x;
(b)*Local search* by VND
(b1) Set l=1;
(b2) *Repeat* the following until $l= l_{max}$;
(b2.1) *Exploration of neighborhood*. Find the best neighbor x'' of x' in $\mathcal{N}_l(x)$;
(b2.2) *Neighborhood change*. If $f(x'')<f(x')$ set $x'=x''$ and l=1; otherwise set $l=l+1$;
(c) *Neighborhood change*. If obtained local optimum (x'') is better than the incumbent then x=x'' and k=1, otherwise k=k+1;

It should be emphasized that although only two variants of the VNS (GVNS and BVNS) have been mentioned in the previous text, VNS has much more application variants (e.g. reduced VNS, skewed VNS, Variable Neighborhood Decomposition Search, etc.). However, since their detailed description is not in the scope of this research, we advise interesting reader to check some of the following papers Hansen and Mladenovic (2003), Hansen et al. (2010), Hansen et al. (2019) for further details regarding the VNS metaheuristic and its variants.

4. LOGISTICS CASE STUDIES

Since the VNS is a metaheuristic algorithm it requires that all specificities of considered problems must be respected in its implementation in order to obtain quality solutions for acceptable solution time. Bearing in mind that logistic problems are fruitful ground for implementation of the VNS algorithms in this section we give a deeper insight into the implementation of the VNS in solving three vehicle routing based problems with significant practical importance in realization of logistics process. The considered problems are inventory routing problem, container drayage problem and travelling repairmen problem.

4.1 Inventory routing problem

The inventory routing problem (IRP) is an extension to the vehicle routing problem where inventory management segment must also be taken into consideration, usually in the planning horizon of several days. In the IRP, the vehicle routing and the inventory management are simultaneously optimized: for each day of planning horizon delivery quantities incurs decision variable regarding the inventories segment, while vehicle movement for delivering goods incurs decision variables regarding routing segment. The IRP can be applied in systems where the Vendor Managed Inventory (VMI) concept exists which allows a supplier to make decisions regarding day, structure and quantity of deliveries (opposite to traditional distribution systems where customers make

orders). The VMI concept enables the supplier to better utilize the vehicles, while customers have the benefit of shifting the responsibility of inventory management to the supplier. The seminal research paper which observed the IRP was Bell et al. (1983), where authors considered a distribution of liquefied industrial gases and used the linear programming model to obtain the delivery plan for short-term planning horizon. Since then, numerous papers were published on the topic of the IRP in the replenishment of stores and supermarkets, maritime transportation, textile, automotive and petrochemical industries etc. (see Popović, 2015). In general, the IRP for real-life problems cannot be solved to optimality in reasonable computational time due to the problem complexity (routing problem with allocation of deliveries over an observed planning horizon) and therefore a heuristic approach is required. Popović et al. (2012) observed the IRP in fuel delivery using multicompartment vehicles for petrol stations replenishment. Authors presented the MILP and VNS models to solving the observed problem. In the rest of this section, we describe the fuel delivery problem and the VNS approach from Popović et al. (2012).

The authors observed the secondary distribution of different fuel types from one depot location to a set of petrol stations by a designated fleet of multi-compartment vehicles, and for which a single oil company has control over all of the managerial decisions over all of the resources. The problem has the following key assumptions:

- the delivery quantities for several fuel types and set of petrol stations must be determined for each day within the planning horizon;
- fuel is transported by a fleet of homogeneous multi-compartment vehicles of unlimited size (only full compartments are delivered to petrol stations);
- every petrol station has a daily fuel consumption per type;
- petrol stations are equipped with underground tanks of known capacity;
- stations can be served only once a day;
- it is not allowed that inventory levels in petrol stations for any fuel type fall below their defined daily fuel consumption;
- the total inventory costs are assumed to be dependent on the sum of the average stock levels in each day of the planning horizon, whereas transport costs depend on a vehicle's travel distance;
- one vehicle can visit up to three stations per route (real-life constraint due to the number of compartments in vehicle and fuel types).

The VNS model developed to solve the IRP in fuel delivery is based on three neighborhoods (changes of the delivery plan): relocation of individual compartments; relocation of all compartments for the observed station's fuel type; and relocation of all compartments for the observed station.

The construction of the initial solution is based on compartment transfer (CT) heuristic approach. The CT heuristic used the idea of solving the inventory model (the MILP used to solve the IRP but without routing decision variables) and iterative change of the delivery plan by transferring the delivery quantities (represented as full compartments) to be realized one or a few days earlier (compartment transfers to days ahead would incur violation of minimal inventory levels). The Sweep method was used for route construction (starting from the station that has the biggest "polar gap" to its nearest preceding station) which showed good results for vehicles with compartments.

The Randomized Variable Neighborhood Descent (RVND) guided search with the first improvement approach was used for the local search procedure. The first occurrence of improvement in neighborhood search is accepted, and the search is repeated until no more improvements can be found. Instead of using the same order of neighborhoods, randomization of the neighborhoods order after each shaking move was applied (for increased diversification of local search). The RVND local search has two levels: the micro level (intra-period search) where routes improvement is carried out in each day of planning horizon; and the macro level (inter-period search) with aim of minimizing the total inventory and routing costs by the reallocation of deliveries over the planning horizon. For the local intra-period search, three neighborhood structures were used: (1) the interchange of a single station between two routes for the same day; (2) the removal of a single station from one route and its insertion into another route for the same day; and (3) 2-opt*, the removal of two arcs (one from each route) and finding the best possible routes reconnections. For the inter-period search, three neighborhoods were used: (1) the transfer of individual compartments; (2) the transfer of all compartments from a fuel type; (3) the transfer of all compartments from a station.

The shaking procedure is based on the deliveries transfer between days of the planning horizon. Shaking procedure has the task of changing only the time instants of each delivery in the current best solution. Four types of shaking were used: (1) shaking of individual compartments; (2) shaking of all compartments of the same fuel type in the observed station and day; (3) shaking of all compartments in the same station in the observed day; (4) combined shaking of all previous three types.

The feasibility of the solution was respected in all search procedures with regards to: minimum and maximum inventory level, vehicle capacity, single route per vehicle, single delivery in each day for a single station, and maximum three stops per route. The algorithm of the VNS heuristic from Popović et al. (2012) is presented in Figure 3. The stopping criterion becomes active in the case when the last neighborhood in the last shaking procedure does not incur an improvement of the current best solution.

To test the proposed models, three set of instances were developed:

- P1 - small scale instances with 10 petrol stations and planning horizon of 3 days;
- P2 - medium scale instances with 15 petrol stations and planning horizon of 4 days;
- P3 - large scale instances with 20 petrol stations and planning horizon of 5 days.

Additionally, three cases of different vehicle types were observed per each instance: vehicles with 3 compartments of 6t; vehicles with 4 compartments of 6t; and vehicles with 5 compartments of 6t. The MILP model was implemented through the CPLEX 12 on a desktop PC with a 2.0 GHz Dual Core processor with 2 GB of RAM memory. All of the input data needed for the model implementation as well as for the heuristics were implemented in Python 2.6.

The MILP model was able to solve only P1 set of instances, while the VNS heuristics obtained good quality solution for P1 compared to optimal solutions (incurs in average 0.271% higher total costs than MILP model, with the lowest error in the case with the 3x6t vehicle type). As for the P2 and P3 instances, the VNS model was able to solve these instances in acceptable computational time with good convergence of the objective function.

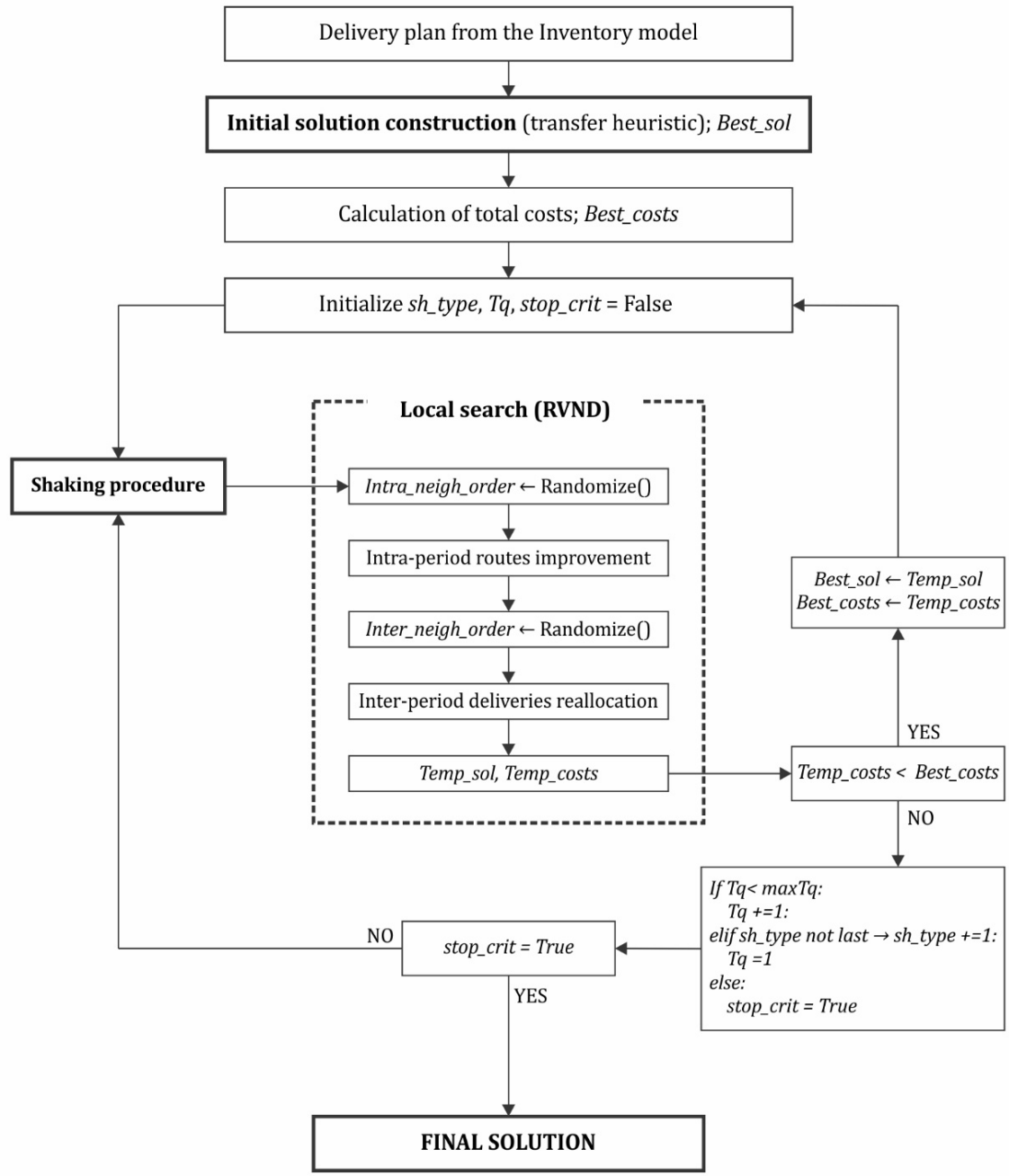


Figure 3. The algorithm of the VNS heuristic to solving the IRP presented in Popović et al. (2012)

4.2 Container drayage problem

The container drayage problem (CDP) involves pickup and delivery operations of full and empty containers usually between an intermodal terminal and set of locations (e.g. shippers) which are generators of transportation requests. The CDP can be classified as the VRPPDTW, which is the case for the majority of research papers in the available literature on container drayage (see Vidović et al. 2016). The main characteristic of the CDP that distinguishes it from most other VRP problems is the size and structure of the cargo. Mainly, transportation requests can be 20ft and 40ft containers (few countries allow 45ft and larger container sizes).

In Vidović et al. (2016) authors developed a generalized multiple matching model formulated as a mixed integer linear program (MILP) and VNS approach to solving homogeneous simultaneous drayage of multi-size containers. The cases with different container vehicle types were observed: standard vehicles (due to the weight limitation vehicle can carry only one 20ft or 40ft container); modular concept vehicles (with capacity of two 20ft or single 40ft container); longer combination vehicles (with capacity of up to four 20ft or two 40ft container on vehicle with attached trailer). Imai et al. (2007) have shown that the container drayage problem is NP-hard and therefore authors developed the VNS model to solve large-scale instances. In the rest of this section, we describe the problem formulation and the VNS approach used in Vidović et al. (2016).

A network of a single terminal and a set of nodes was observed. Nodes can simultaneously have both container demand (-) and supply (+) requests. Each request can be for 20ft or 40 ft container, therefore 4 different types of requests exist in the system: 20+, 20-, 40+, 40-. A task node represents one request from a node (each node can have multiple requests and therefore multiple task nodes). A vehicle route can be defined as multiple matching of task nodes to a vehicle, where a solution represents the order of requests to be served by a vehicle. An example of a feasible sequence of task node types for a longer combination vehicle can be (20-,20+,20-,20+,40-,40+). In any arbitrary sequence of task nodes types, these must be ordered in such a way to enable the realization of pickup tasks (free space on the vehicle to accommodate container pickup). The objective function of observed problem tries to minimize total transportation costs of all vehicle routes, where each node has time windows constraints.

The first application of VNS heuristic to solve the CDP was presented by Popović et al. (2014). Vidović et al. (2016) made an extension by introducing additional local search and shaking procedures, as well as new vehicle type. The initial solution procedure is obtained by the sweep method with “polar gap”. The construction of routes starts from the task that has the biggest "polar gap" to its nearest preceding task. The "polar gap" between two nodes refers to the angle formed by two nodes viewed from a depot.

For the local search procedure, the Variable Neighborhood Descend (VND) with four neighborhoods was used: (1) reallocating and (2) interchange of tasks between routes, (3) reallocating of nodes that have two tasks in a single route to another route, and (4) interchange of nodes that have up to two tasks between two routes. The two latter neighborhoods make larger changes (increases the diversification of search) in search procedure that cannot be explored by the first two neighborhoods (they are based on single task changes). The local search procedure examines all possible changes in a neighborhood of a current solution for improvement of its objective function. If a change in observed neighborhood incurs improvement, the local search is restarted within the observed neighborhood.

For the shaking procedure, four different methods (*Sh_type*) were used in the following order: (1) random reallocation of tasks between some pairs of routes, (2) random interchange of tasks between some pairs of routes, (3) "destruction" of randomly chosen route/routes with multiple stops and construction of single stop (direct) routes to each of those stops, and (4) method that combines all previous three methods. During the shaking procedure, each method starts from a small intensity of random change (the number of changes is limited by parameter *Sh_size_max*) which is and gradually

increased. Also, multiple repetitions of one shaking intensity are made because of the stochastic nature of shaking (to intensify the search, each shaking size is repeated for *Sh_pass_max*). The total number of shaking neighborhoods is defined by the *Sh_type*, *Sh_size_max*, and *Sh_pass_max* parameters. The stopping criterion of the VNS heuristic becomes active when the shaking and local search procedures for the last neighborhood do not incur improvement in current best solution value. The algorithm od the VNS heuristic is presented in Figure 4.

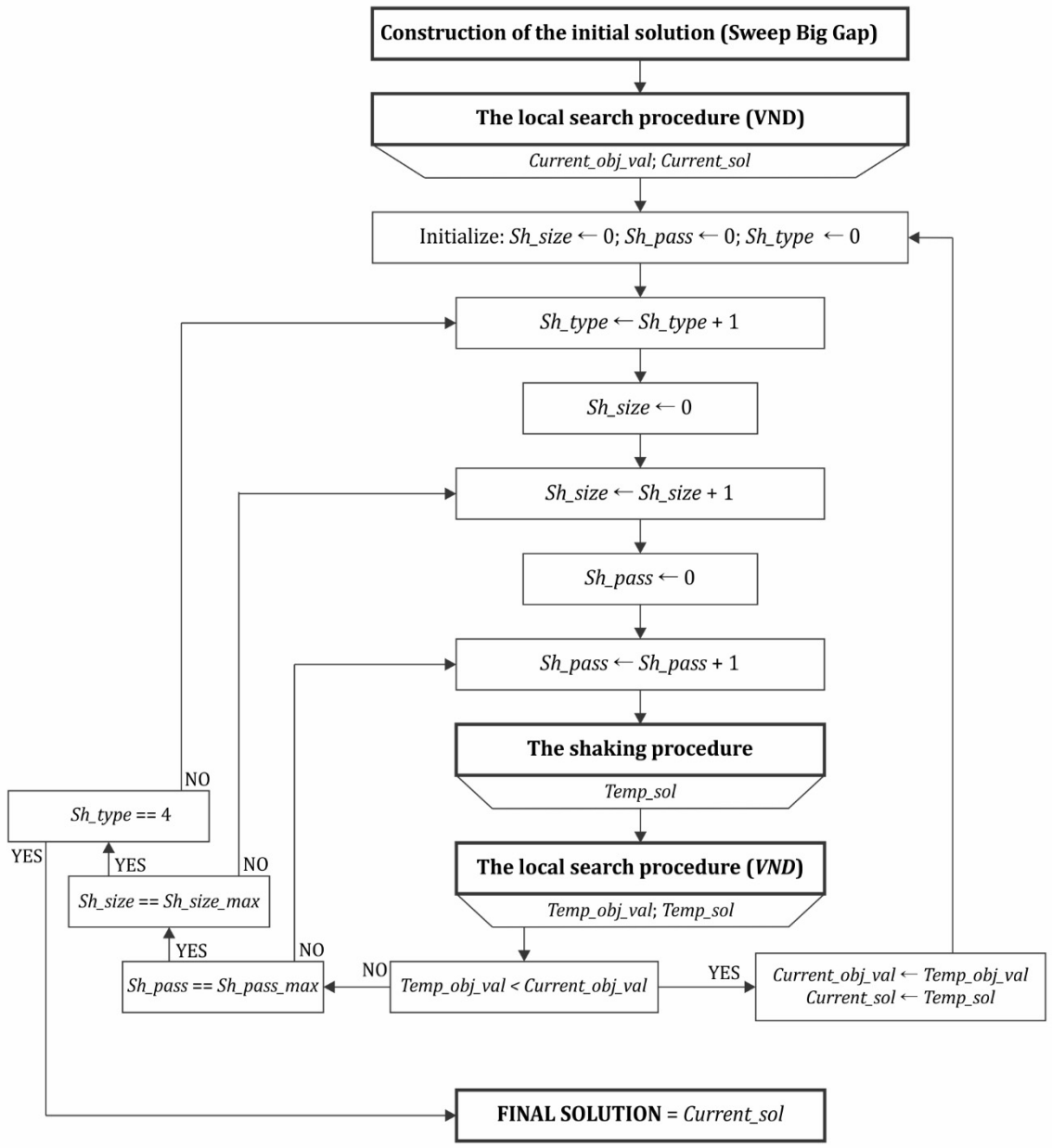


Figure 4. The algorithm of the VNS heuristic to solving CDP presented in Vidović et al. (2016)

The multiple matching MILP formulation and VNS heuristic were tested on the set of instances generated according to the Solomon VRPTW benchmark problems (http://web.cba.neu.edu/~msolomon/problems.htm). Test instances used to evaluate proposed models can be divided in the following way:

- small scale instances that include two groups: first 10 and first 15 nodes from Solomon instances;
- medium scale instances that include two groups of first 50 nodes from Solomon instances where the first group has fewer tasks than the second;
- large scale instances that include all 100 nodes from Solomon instances.

Mathematical models were implemented by the CPLEX 12.4. on the Intel(R) Core(TM) i3 CPU M380 2.53 GHz with 6 GB RAM, while the VNS model was implemented in C++ and Microsoft Visual Studio 2012.

The research has shown that the proposed MILP model can optimally solve small problem instances and medium scale instances with fewer tasks and only in the case when modular concept vehicles are used. However, the medium scale problem instances with a small number of tasks and longer combination vehicles, as well as the medium scale problem instances with a large number of tasks and large-scale instances, could not be solved to optimality in reasonable computational time.

The VNS heuristic model was able to obtain very accurate results since it solves almost all small-scale problem instances and a certain number of medium scale problems to optimality. In the cases where the MILP model could not find optimal solutions, VNS heuristics obtained results in reasonable computation time. This research has verified that VNS heuristics performances are very good and give an opportunity for solving CDP of realistic size.

The proposed approach is tested in cases when standard, modular concept and longer combination vehicles are used. One important result from the practical point of view is that modular concept vehicles and longer combination vehicles outperform standard vehicles in its drayage characteristics. Of course, modular concept vehicles and longer combination vehicles are more expensive and are not able to reach every network node because they require wider roads with a larger radius, but results show their huge potential for application.

4.3 Heterogeneous travelling repairmen problem with time windows

Travelling repairmen problem (TRP) is a special case of the Traveling Salesman Problem (TSP). Salesman in the TSP visits all customers in a planning horizon with the goal to minimize traveled distance. Repairman is less selfish because he does not put his own interest as the focus of the work but but rather focuses on better customer satisfaction. Therefore, objective in the TRP is minimization of the sum of times all clients wait until the end of a service. TRP's objective function has numerous possibilities of application, especially in client oriented processes. Some examples of such processes are: regular and emergency equipment repairs, deliveries and pick-ups of shipments to and from clients, scheduling of special material handling equipment (heavy load hoists, specialized pumps etc.).

A great majority of researches that considered the TRP are based on an assumption that all tasks are already available for a service at the beginning of the planning horizon, meaning the service begins as soon as the repairman reaches task location. However, real situations imply that this does not have to be the case, and if the repairman reaches task's location before the task is available for a service he will have to wait for the beginning of the service. In Bjelić et al. (2013) and Bjelić (2014) authors considered a

variant of the TRP which respects the possibility that not all tasks are present in the system at the beginning of a planning horizon. Moreover the TRP they considered is further generalized by assuming that service is realized by a fleet of heterogeneous repairmen whose characteristics differ in terms of moving speed between locations and times needed for service realization. Therefore, the analyzed problem is classified as the heterogeneous traveling repairmen problem with time windows (hetTRPTW). Note that the tasks' time windows in the hetTRPTW are opened on the right hand side. Because of the space limitation, for deeper literature review of the hetTRPTW we refer an interested reader to Bjelić et al. (2013).

As a special case of the TSP, the TRP belongs to the class of NP-hard problems. The cumulative nature of the TRP's objective function makes this problem harder to solve than its TSP counterpart. Therefore for solving problem instances of practical sizes in Bjelić et al. (2013) authors present a GVNS algorithm presented on Figure 5.

Initial solution for the VNS algorithm is a solution from the widely used insertion algorithm. Precisely authors used the insertion algorithm given in van der Meer (2000) for generation of the initial solution.

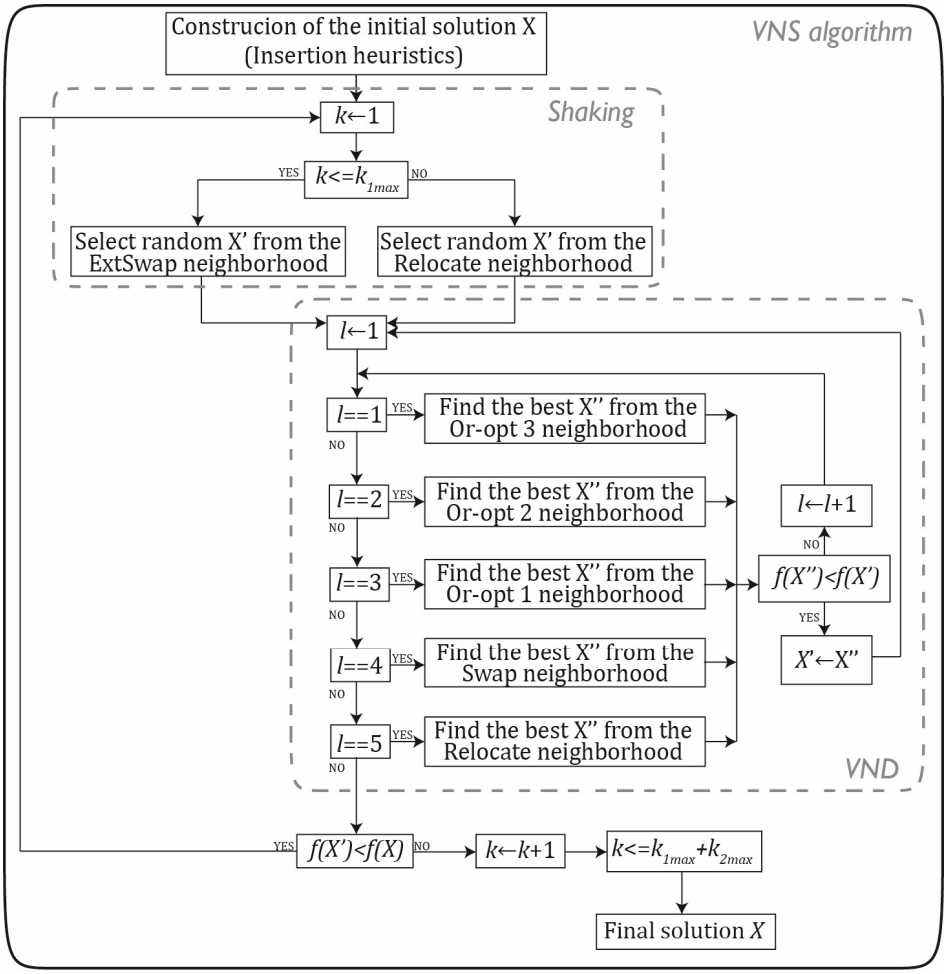


Figure 5. The algorithm of the VNS heuristic to solving hetTRPTW presented in Bjelić et al. (2013)

As the local search algorithms authors propose the VND. Three moves are used for generating neighborhoods. The first neighborhood structure $\mathcal{N}'_1$ is generated by

execution of Or-opt moves on each repairman's sequence of tasks with the aim of improving the solution by reordering the current service sequence. Reordering implies the removal of 1, 2 and 3 adjacent tasks from the existing sequence of a repairman, and their insertion into all of the possible positions in the remainder of the sequence, excluding their original position. The second neighborhood structure $\mathcal{N}'_2$ is generated by execution of swap move with one task. Similar to the case of the Or-opt move, swap move keeps the same structure of the solution, regarding a number of tasks allocated to devices. However, the swap move attempts to find an improved solution by exchanging a task served by different repairmen. Relocation move forms the third neighborhood structure $\mathcal{N}'_3$ by changing the existing structure of the incumbent. Namely, a relocation move attempts to improve a solution by removing one task from a repairman, and inserting it at all possible locations on other repairmen. Order of implemented neighborhoods exploration is selected according to the cardinalities of neighborhoods, meaning that firstly is checked neighborhood generated by the Or-opt 3 move, afterwards Or-opt 2 neighborhood, followed by Or-opt 1, swap and relocate neighborhoods.

For the shaking procedure, two sets of nested neighborhoods are used. ExtSwap move chooses the next region for exploration by a random selection of two tasks for swapping. This procedure is an extension of the swap move because selected tasks can be of the same repairman meaning that it covers domain of the Or-opt move. Nested neighborhood structures $\mathcal{N}_k$ ($k = 1,2,\ldots,k^1_{\max}$) are formed by successive implementations of the ExtSwap moves on the incumbent. The second set of nested neighborhood structures, $\mathcal{N}_k$ ($k = k^1_{\max}+1,\ k^1_{\max}+2,\ \ldots,k^1_{\max}+k^2_{\max}$), is formed by the successive execution of the Relocation moves used for the generation of $\mathcal{N}'_3$.

Because of the rapid growth of the solution space, running time of the VNS algorithm prolongs significantly with the increase of a number of tasks, or a number of repairmen in the problem. Therefore, authors tried to reduce neighborhood cardinalities by implementing a reduction strategy which considers only solutions that fulfill predefined conditions. These conditions are defined for each neighborhood structure in the VND and the VNS algorithm. Exploration of reduced neighborhoods in the local search resulted in new version of the VNS algorithm, referred as the RdVNS.

$\mathcal{N}'_1$ structure is reduced by shortening sequence of tasks on which Or-opt move is performed. Starting from the leftmost task in a task sequence, for each pair of adjacent tasks it is checked if the reverse order of their service provides faster end of service for the firstly served task. If this is not the case it is supposed that there are no tasks in considered sequence that will provide faster end of service for the firstly realized task. Therefore that task is excluded from the sequence on which Or-opt move will be applied. The same procedure is then repeated on a shortened sequence of tasks. However, if the swap of adjacent tasks results in faster realization of the firstly realized tasks, we implement Or-opt move on the whole sequence in order to find a more appropriate position for the leftmost task of the original sequence.

Reduction of the $\mathcal{N}'_2$ structure is realized by limiting the set of tasks that can be included in the swap procedure of a considered task. Namely, because of the problem's nature there is a low chance that an improved solution will to be found if swap move is executed on the tasks from the beginning and the end of the considered planning period, i.e. on the tasks with considerable time gap between their arrival times. Therefore, a

coefficient α is introduced. α denotes the ratio of the time period between arrivals of tasks included in the swap move and the time width of the planning horizon. Swap move is allowed only if α is not greater then α_{crit}. Level of neighborhood reduction, as well as quality of obtained solutions is influenced by the value of α_{crit}. According to the small experimental study the best tradeoff between the reduction level and solution quality is achieved for α_{crit}=0.3.

In the case of the $\mathcal{N}'_3$, structure reduction implies that the inserted task can be put before a task scheduled to another repairman only if arrival of the inserted task happens sooner than the beginning of a service of the previously scheduled task. In this way consideration of solutions in which the repairman waits for the arrival of an inserted task instead of serving an already allotted task is avoided.

Efficiency of presented VNS based algorithms is tested on four benchmark test sets originally used for the TSPTW problem. All considered instances are adjusted to the hetTRPTW by removing right hand sides of the time windows, and by introducing variability of repairmen in the system. In the case of small scale instances (up to 20 tasks) optimal solutions (if possible) are obtained by implementation of branch and bound algorithm found in CPLEX 12.2 with the memory limit of 1GB for the tree structure. In the cases of B&B algorithm, instances are solved once, while in the case of the VNS and RdVNS algorithms the solution procedure is repeated five times.

From 153 instances solved by B&B algorithm, VNS was outperformed, in terms of objective value, only in six with the largest deviation of 1.16%. In all other experiments VNS gave solutions of equal or better quality. The number of solutions with lower value of VNS's objective function increases with the complexity of problem caused by growth in number of tasks and/or number of repairmen in the system.

Relative distances of all RdVNS solutions to the VNS results show that a deviation of RdVNS objective values decrease with the increase of problem complexity. The reason for this pattern is that with larger complexity of the problem the number of good solutions with a relatively small difference in objective values increases as well. This gives better chance to the RdVNS algorithm to find a solution close, in terms of a objective function, to the VNS's solution. Presented results also show that the implementation of reduction strategies resulted in the reduction of running times for more than 50% on average. The largest average time reduction is achieved for the case of two repairmen, and the lowest for the case of ten repairmen in the system.

5. CONCLUSION

VNS is one of the leading metaheuristic approaches in solving numerous combinatorial optimization problems. Probably the most important reason for its wide applicability, beside its simplicity, is its flexibility in implementing different neighborhood exploration strategies, which resulted in several variants of the algorithm. In presented researches the GVNS concept has been used, with implementation of first and best improvement concepts, nested neighborhoods, reduction of neighborhoods, numerous different moves used in local search and shaking phases etc. Quality of solutions obtained in the considered studies, as well as solution times, proved a practical implementation of given VNS algorithms in real-life systems.

Finally it should be emphasized that presented problems are just an example of numerous logistics problems in which the VNS can be successfully applied. Of course, specificity of every problem must be included in algorithms constructions.

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BIG DATA ANALYTICS IN LOGISTICS

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Abstract: *The aim of the Big Data analytics is to make data-driven decisions. In this paper will be explored how Big Data analytics could help logistics companies to become data-driven. The main goal of this research was to explore the possibility to predict volume and structure of import and export in the food industry of the Republic of Serbia using supervised machine learning methods. In the first phase, in order to better perceive characteristics of available dataset and calculate the basic quantitative indicators of foreign trade in the food industry of the Republic of Serbia, the dataset is analyzed using standard methods of descriptive statistics. In the second phase, the initial dataset is used to build machine learning models based on different machine learning algorithms. The goals of the models were to predict volume of import or export of food products for different set of independent variables, such as: month, quarter, clearance procedure, import/export country, buyer/seller country, import/export company, customs tariff, etc. Some of the developed machine learning models have shown satisfying performance; therefore, the most important goal of this research has been achieved: the prediction analysis methodology has been defined and verified. All the stages that exist in the process of machine learning: data preprocessing, model building, model evaluating, model testing, and model deployment are thoroughly described in the paper. Only few of the results obtained through descriptive and predictive analysis are presented graphically and tabularly in the paper. The research has shown that Big Data analytics based on machine learning technics can be successfully applied to predict volume and structure of the foreign trade of a country or company. Models based on the following machine learning algorithms have shown the best performance: Random Forest, k-Nearest Neighbors and Random Tree.*

Keywords*: Machine learning, Predictive analytics, Logistics, Big Data, Foreign trade*

1. INTRODUCTION

Digital business and the application of modern information and communication technologies in logistics and supply chains have enabled the collection of large amount of data from different sources. These data are crucial for analysis and prediction of logistics flows and requirements, i.e. logistics planning and decision making. However, the problem which raises the question of how to use these data effectively in logistics decision making often arises. To solve this problem successfully, it is necessary to develop and apply different large data tools and models. This paper deals with Big Data analysis and application in logistics.

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This research is conducted with the following aims: to review existing methods and solutions for Big Data analytics that can be used in logistics and supply chain management, to propose methodology of descriptive and predictive Big Data analytics that can be used in a foreign trade, and to test proposed methodology on the case study of the food foreign trade for the Republic of Serbia.

The section 2 contains a short introduction to Big Data and Big Data analytics, which follows literature review and several case studies on Big Data predictive analytics applications in the field of logistics and Supply Chain Management (SCM). The full cycle of data processing methodology including data exploration, data preprocessing, descriptive analytics and predictive analytics is described in the third section. Special attention is paid to the development and application of the machine learning models for the foreign trade volume prediction. In the fourth section the proposed methodology is applied on the foreign trade in the food industry of the Republic of Serbia and received results are discussed and analyzed. The last section covers conclusions related to the capabilities of using machine learning models for foreign trade prediction.

2. LITERATURE REVIEW

Oxford dictionary defines Big Data as "an extremely large data sets that may be analyzed computationally to reveal patterns, trends, and associations, especially relating to human behavior and interactions". Big Data can be characterized by four dimensions such as: Volume, Variety, Velocity and Veracity, where "volume" refers to the scale of the data generated, "variety" refers to heterogeneity in a dataset, "velocity" refers to the speed at which data is generated and analyzed, while "veracity" refers to the certainty of data by verifying unreliable and uncertain data. Tien (2015) highlights that Big Data allows better integration or fusion and subsequent analysis of quantitative and qualitative data, better observation of rare but great impact events, greater system and system of systems efficiency and effectiveness; decision making that can overcome the prejudices of the unconscious mind. Applications of Big Data is wide and diverse – data is collected from numerous different sources and analyzed with the aim to improve business decision-making and overall performance in different fields including medicine, retail, finance, manufacturing, logistics, and telecommunications. As these datasets are too large, they cannot be captured, stored, managed and analyzed by using typical relational database software tools. Therefore, a number of different set of tools have been developed including Hadoop, HBase, CoughDB, etc.

2.1 Big Data analytics (BDA)

Even before the emergence of Big Data, different data analytics technics were developed with the aim to analyze data and find different correlations between them. Considering the depth of analysis, data analytics techniques can be classified into descriptive, predictive and prescriptive analytics. Descriptive analytics is performed at standardized periods or on demand and uses techniques such as online analytical processing or drill down with the aim to identify problems and opportunities within existing processes and functions. Predictive analytics is based on machine learning techniques and other computational algorithms of data mining in order to discover explanatory and predictive patterns within data. The aim of predictive analytics is to predict what will happen in the future and provide reasons. Rozados and Tjahjono (2014) used predictive analytics to

analyse real time and historical data to make predictions in the form of probabilities about future events. Prescriptive analytics uses multicriteria decision-making, optimization and simulation tools with the aim to investigate alternative decisions that involve objectives with the aim to improve business performance. White et al. (2017) observe that prescriptive analytics is "mainly associated with optimization and simulation, and have special relevance in contexts of uncertainty relying on stochastic computational programming of random variables".

In 1959, Arthur Samuel defined machine learning as a "Field of study that gives computers the ability to learn without being explicitly programmed". We can say that machine learning is generalization of a knowledge based on the previous experience (data related to phenomena that are our subject of learning). Today, in the Big Data era, machine learning is used as one of the leading techniques in predictive analytics.

Two main forms of machine learning are supervised and unsupervised learning. Soni (2018) highlights that "the goal of supervised learning is to learn a function that, given a sample of data and desired outputs, best approximates the relationship between input and output observable in the data". Unsupervised learning, on the other hand, does not have labeled outputs, so its goal is to infer the natural structure present within a set of data points. Supervised machine learning algorithms can be further divided into the following three classes: Linear Machine Learning Algorithms, Nonlinear Machine Learning Algorithms and Ensemble Machine Learning Algorithms. Linear algorithms assume that the value of an attribute that is going to be predicted represents a linear combination of independent attributes. Nonlinear algorithms do not make solid assumptions about relationships between independent and dependent attributes whose value will be predicted. Ensemble methods combine predictions received by applying different models with the aim to make more robust prediction.

Brynjolfsson et al. (2011) state that there is a strong evidence that business performance can be improved using data-driven decision making. Janković et al. (2018) wrote that "Big Data analysis is the process that can help organizations to make data-driven business decisions". Sanders (2016) induced that the advancements in machine intelligence have created significant new opportunities for both the data and the development of algorithms. The amount of data is huge disabling manual analysis and tools such as traditional (relational) databases. Rozados and Tjahjono (2014) defined Big Data analytics (BDA) as "the union of two disciplines intrinsically linked: Big Data and advanced analytics". BDA is technologically enabled ability which can help process huge amount of data to extract meaningful and useful insights to gain competitive advantage. Tien (2015) explained that "in contrast to the traditional, mostly statistical, approach, Big Data seeks to unleash information in a manner that can support informed decisions – by somewhat overcoming data quality issues with data quantity, data access restrictions with on-demand cloud computing, causative analysis with correlative data analytics, and model-driven with evidence-driven applications".

2.2 BDA in logistics management and SCM

As previously said, applications of BDA are wide and diverse, it can be used in many fields including supply chain management and logistics. Council of Supply Chain Management Professional describes that SCM "encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all

logistics management activities", while logistics management represent a small part of SCM that deals with the management of goods in an efficient way.

The Economist in 2010 estimated that a firm that manages supply chain deals with more than 100 gigabytes of data on a daily basis. Tien (2015) projected that the amount of digital data created and replicated each year would reach 35 Zeta bytes by 2020. Therefore, there is a growing need to analyze huge amounts of data using Big Data analytics techniques within SCM. Rozados and Tjahjono (2014) consider that SCM Big Data Analytics is the natural evolution of data analysis in SCM. They defined SCM BDA as "the process of applying advanced analytics techniques in combination with SCM theory to datasets whose volume, velocity or variety require information technology tools from the Big Data technology stack; leveraging supply chain professionals with the ability to continually sense and respond to SCM relevant problems by providing accurate and timely business insights". Additionally, they defined the meaning of the BDA in the context of SCM and its evolution from the previous analytics technologies and explored its potential to solve some complex SCM challenges.

Although the term "Big Data" is not new, the applications of big data in supporting supply chain operations is relatively new area. Sanders in 2014 published a book that combines both SCM theory and Big Data and Big Data driven SCM. The book provides great insight in the managerial implications of implementing BDA. Studies that followed conducted by Sanders (2016) or by Hopkins and Hawking (2018) have focused mainly on definitions from different perspectives and proposed various frameworks for implementing BDA to SCM, while Tan et al. (2015) provided BDA infrastructure. Mishra et al. (2018) presented an extensive review of literature on Big Data and SCM over the period of 10 years with top contributing authors, countries and key research topic related to this field. Arunachalam et al. (2017) presented the bibliometric and thematic analysis of research papers related to BDA from 2008 to 2016. Wang et al. (2016) have reviewed and classified the literature that deals with the application of big data business analytics in logistics and SCM and provided classification based on the nature of the analytics: descriptive, predictive and prescriptive.

Hofmann (2015) agree that BDA has the potential to transform the entire business process by improving the various supply chain processes and logistics management. Sanders (2016) states that BDA can be used in SCM and logistics to optimize inventory, identify optimal distribution center locations and supply routes, and minimize transportation costs. In the context of SCM, Cecere (2013) sees Big Data as an enabler for decision-making and a tool for improving business processes. Zhong et al. (2015) stated that Big Data information could be used in effective logistics planning, production planning, and scheduling. Waller and Fawcett (2013) argue that data science, predictive analytics, and big data could help in adjusting to changes in the supply chain environment. Additionally, they noted that the juncture of logistics, SCM and predictive analytics can provide numerous opportunities for further research.

Studies that focus on practical applications of BDA in SCM are still scarce. Rozados and Tjahjono (2014) offered some examples of practical applications of BDA in SCM together with four levers (marketing, procurement, warehouse management, and transportation analysis) in the Big Data driven supply chain.

2.3 Big Data predictive analytics in logistics and SCM

Sanders (2016) states that supply chains generate huge amounts of data that companies can turn into intelligence through analytics, from POS, GPS, and RFID to social media feeds. Nikoličić et al. (2015) discussed the impact of data collected by RFID technology on increasing the efficiency of logistics processes in retail supply chains. Although Big Data analytics has a transformative potential for SCM, studies exploring Big Data Predictive Analytics (BDPA) in SCM are rare. Gunasekaran et al. (2017) have thoroughly investigated the BDPA assimilation on supply chain and organizational performance. Schoenherr and Speier-Pero (2015) explored the current use of predictive analytics in SCM and identified several benefits of Big Data and predictive analytics on supply chain performance, such as better informed decision making, increased visibility, better management of supply chain risk, improvement in supply chain costs, enhanced bargaining position in negotiations with suppliers, improvement in supply chain efficiencies, enhanced demand planning capabilities, enhanced sales and operations planning capabilities, enhanced bargaining position in negotiations with customers, ability to respond faster to changing environments, and real-time decision-making capability. Sanders (2016) proposed a framework for implementation based on lesson learned based on leading companies experience. Schoenherr and Speier-Pero (2015) identified current assessment of the extent to which SCM predictive analytics are used in industry and primary benefits and major obstacles to SCM predictive analytics, while Hazen et al. (2014) highlighted the importance of data quality in SCM.

Hazen et al. (2016) stressed the need for research examining relationship between BDPA and sustainable SCM. Authors established theoretical perspectives that BDPA can affect financial, social, and environmental performance measures. The article reviews eight theories that can be used by researchers to examine and clarify the nature of BDPA's impact on supply chain sustainability. The theories that were reviewed include: actor-network theory, institutional theory, social capital theory, resource dependence theory, agency theory, transaction cost economics, resource-based view, ecological modernization theory. This theories' reviews can be used as the basis for future research activity, and this article can be used as means to understand how company-wide BDPA initiatives might impact measures of supply chain sustainability.

2.4 Big Data case studies in logistics and SCM

Although firms are aware that BDA can give firm a competitive advantage, only few of them have successfully integrated BDA into their operations across their supply chains. Walmart is a great example how BDA should be used in SCM. Dezyre, an Online Academy, published in 2015 an article where highlighted that Walmart started to use BDA much before the term Big Data became popular in the industry. Their Big Data solution is based on technologies such as Hadoop and NoSQL. The system provides internal customers the access to real-time data that have been collected from different sources and centralized. The solution deals with multiple Terabytes of new data and petabytes of historical data every day. It uses data mining technics to discover patterns in the sales data. The system is able to provide product recommendations to the users based on which products were bought together or which products were bought before the purchase of a particular item. Walmart gathers information on what customer's buy, where they live and what are the items they like. Every clickable action on Walmart.com

is analyzed in the context of local events, local weather deviations, etc. All the events are captured and analyzed intelligently by big data algorithms to discern meaningful big data insights for the millions of customers to enjoy a personalized shopping experience.

Another company that uses BDA is UPS - the world's largest package delivery company and a leading global provider of specialized transportation and logistics services. They have implemented ORION (On-Road Integrated Optimization and Navigation) which enables drivers to find the most efficient route in their delivery areas. It is based on RFID technology which is used to track inventory in motion, capture both location and quantity, as well as monitor security. They acquire data that come from telematics sensors in over 46,000 vehicles. The collected data include the speed, direction, braking, etc. The data is used to monitor daily performance and to drive a major redesign of UPS drivers' route structures.

These two companies recognized the potential that lies behind Big Data and analytics techniques and use them in their every day business with the aim to gain competitive advantage over competitors.

3. METHODOLOGY

The research was conducted through four phases in the following order: Data exploration, Data preprocessing, Descriptive analytics, and Predictive analytics. The results of each phase are used in the succeeding research phase as represented on Figure 1.

3.1 Data exploration

In the era of Big Data, data-driven approach is ubiquitous; it is used in information systems engineering, decision support systems, system monitoring, etc. As each Big Data set has specific characteristics in terms of 4Vs (Volume, Variety, Velocity, Veracity, Value, etc.) even the developed methodology used for processing Big Data must be data-driven. Therefore, the first data processing phase in this research is data exploration. This phase implies getting acquainted with the characteristics of the initial data set (raw data) such as: data volume, completeness of data, validity of data, potential relations between individual data elements, different ways raw data is organized and stored.

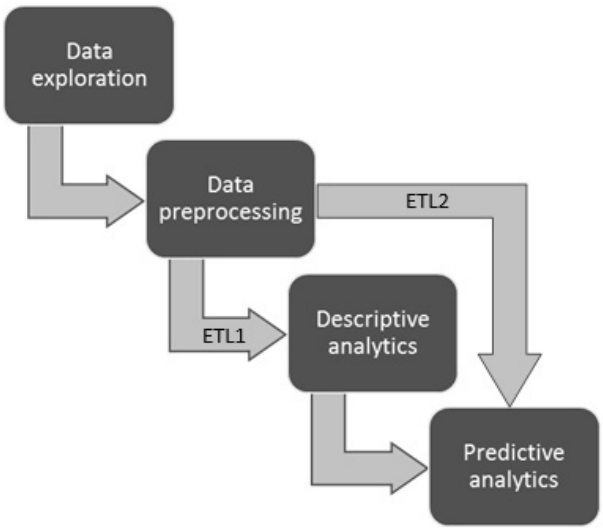


Figure 1. Phases of the research

3.2 Data preprocessing

Data preprocessing includes standard ETL (Extract, Transform and Load) operations. Janković et al. (2014) state that ETL operations often represent the first stage in integrating data from different sources. ETL1 operations are performed on the initial dataset with the aim to retrieve new dataset that can be analyzed by using descriptive analytics methods. As a result of ETL2 operations a new dataset suitable for applying machine learning technics is generated. ETL operations include: data import, data querying, data cleaning, data formatting and data export. ETL2 also includes division of the entire available dataset obtained from the previous transformations into training and test dataset as well as an application of appropriate filters over attributes and/or records of dataset with the aim to adjust data to the selected machine learning algorithm.

3.3 Descriptive analytics

To answer the question "What happened?" we calculated different descriptive statistics using traditional relational databases, business intelligence (BI) tools, and visualizations. In order to calculate descriptive statistics, the following data processing methods are used: selecting records that satisfy various complex criteria, selecting attributes, records grouping, applying aggregative functions on the records groups such as: SUM, COUNT, AVERAGE, etc. and records sorting. Calculated descriptive statistics are visualized in a standard way, using column and bar charts, pie charts, line graphs, tables, and so on.

3.4 Predictive analytics

The aim of predictive analytics in this research is to predict the volume and structure of import and export of food products in the Republic of Serbia. To answer the question "What will happen?" we used machine learning techniques. Machine learning process consists of the following phases: data preprocessing, model building, model evaluation, model testing and model deployment. Data preprocessing phase includes ETL operations described in the section 3.2. The remaining phases of predictive analytics conducted in this research will be explained later in the paper.

Machine learning is an iterative process in which above mentioned phases are repeated as many times as necessary. The repeating of these phases finishes when all available algorithms, all attribute combinations, available data preprocessing mechanisms and hyperparameters of algorithms are exhausted, or when a model with satisfying performances is achieved. The visualization of the relationship (dependences) between label and the observed attribute can help choose relevant attributes. Once, when model testing shows that the model has satisfying performance, the model can be used to predict selected label.

3.4.1 Model building

As we were equipped with the labeled dataset, we have developed models based on supervised machine learning algorithm. Building each of the supervised machine learning model consisted of the following phases:

1. Defining the goal of the model,

2. Choosing dependent variables (label, class), i.e. the dataset attribute which value we want to predict using the machine learning model,
3. Selecting relevant attributes (features) of a dataset,
4. Selecting supervised machine learning algorithm, according to the nature of labels and attributes,
5. Datasets (training and test) preprocessing that fulfills requirements of the selected algorithm,
6. Model tuning – setting hyperparameters that are specific for each type of the machine learning algorithm. Hyperparameters control how model will learn its parameters. They are fixed before the model training starts.
7. Model training – application of the selected machine learning algorithm on the training dataset in order to obtain model parameters.

Selecting relevant attributes has the aim to find those attributes that affect the value of the dependent variable (label), and to reduce the number of necessary attributes in order to make the model as simple as possible. Reducing the number of attributes is done by identifying mutual dependent attributes and eliminating those that are uniquely dependent on some other attribute. Selecting relevant attributes is not a one-time task but rather a repeated job, sometimes it is necessary to repeat it many times in order to build a model. Only when the model training and model evaluation is done, it can be concluded if the selected attributes have significant influence on the label value.

Machine learning model results from learning algorithm applied on a training dataset. Parameters of a model establish the rules of how X will translate into Y. They are learnt during the model training (minimizing loss function). In regression, coefficients of features are the parameters.

3.4.2 Model evaluating

Cross-validation is a method for getting a reliable estimate of model performance using only training data. There are several ways to cross-validate. The most common one is 10-fold cross-validation. These are the steps for 10-fold cross-validation:

1. Split training data into 10 equal parts, or “folds”,
2. Train model on 9 folds (e.g. the first 9 folds),
3. Evaluate model on the 1 remaining “hold-out” fold,
4. Perform steps (2) and (3) 10 times, each time holding out a different fold,
5. Average the performance across all 10 hold-out folds.

The average performance across the 10 hold-out folds is a final performance estimate, also called cross-validated score. Basically, all we need to do is perform the entire cross-validation loop explained before on each set of hyperparameter values we want to examine.

Witten et al. (2017) proposed several alternative measures that can be used to evaluate the success of numeric prediction. The predicted values on the test instances are p1, p2, …, pn; the actual values are a1, a2, …, an.

Mean-squared error (1) is the principal and most commonly used measure.

$$Mean-squared\ error = \frac{(p_1 - a_1)^2 + \ldots + (p_n - a_n)^2}{n} \quad (1)$$

Mean-absolute error (2) is an alternative: just average the magnitude of the individual errors without taking account of their sign. Mean-squared error tends to exaggerate the effect of outliers—instances when the prediction error is larger than the others—but absolute error does not have this effect: all sizes of error are treated equally according to their magnitude.

$$Mean-absolute\ error = \frac{|p_1 - a_1| + \ldots + |p_n - a_n|}{n} \tag{2}$$

Root mean-squared error (3) is obtained in the obvious way.

$$Root\ mean-squared\ error = \sqrt{\frac{(p_1 - a_1)^2 + \ldots + (p_n - a_n)^2}{n}} \tag{3}$$

Relative-squared error (4) refers to something quite different. The error is made relative to what it would have been if a simple predictor had been used. The simple predictor in question is just the average of the actual values from the training data. Thus, relative squared error takes the total squared error and normalizes it by dividing the total squared error of the default predictor.

$$Relative-squared\ error = \frac{(p_1 - a_1)^2 + \ldots + (p_n - a_n)^2}{(a_1 - \bar{a})^2 + \ldots + (a_n - \bar{a})^2} \tag{4}$$

The root relative-squared error (5) is obtained in the obvious way.

$$Root\ relative-squared\ error = \sqrt{\frac{(p_1 - a_1)^2 + \ldots + (p_n - a_n)^2}{(a_1 - \bar{a})^2 + \ldots + (a_n - \bar{a})^2}} \tag{5}$$

Relative-absolute error (6) is just the total absolute error, with the same kind of normalization.

$$Relative-absolute\ error = \frac{|p_1 - a_1| + \ldots + |p_n - a_n|}{|a_1 - \bar{a}| + \ldots + |a_n - \bar{a}|} \tag{6}$$

The final measure is the correlation coefficient (7), which measures the statistical correlation between the a's and the p's. The correlation coefficient ranges from 1 for perfectly correlated results, through 0 when there is no correlation, to –1 when the results are perfectly correlated negatively.

$$Correlation\ coefficient = \frac{S_{PA}}{\sqrt{S_P S_A}} \tag{7}$$

Where,

$$S_{PA} = \frac{\sum_{i=1}^{n} (p_i - \bar{p})(a_i - \bar{a})}{n-1} \tag{8}$$

$$S_p = \frac{\sum_{i=1}^{n} (p_i - \bar{p})^2}{n-1} \tag{9}$$

$$S_A = \frac{\sum_{i=1}^{n} (a_i - \overline{a})^2}{n-1} \tag{10}$$

But, which of these measures is appropriate for a particular situation? Fortunately, it turns out that in most practical situations the best numerical prediction method is still the best no matter which error measure is used.

At the end of this process, we will have a cross-validated score for each set of hyperparameter values for each algorithm. Then, we pick the best set of hyperparameters within each algorithm.

3.4.3 Model testing

By now, we have one "best" model for each algorithm that has been tuned through cross-validation. Most importantly, we have only used the training data so far. To predict the performance of a model on a new dataset, we need to assess its performance measures on a dataset that played no part in the formation of the model. This independent dataset is called the test dataset. We assume that both the training data and the test dataset are representative samples of the underlying problem. The process is very straightforward:

1. For each of our models, make predictions on our test dataset,
2. Calculate performance metrics using those predictions and the "ground truth" target variable from the test dataset.

Comparing test vs. training performance allows us to avoid overfitting. If the model performs very well on the training data but poorly on the test data, then it is overfit.

3.4.4 Selecting a winning model

Finally, we use these questions to pick the winning model:

- Which model had the best performance on the test dataset? (performance)
- Does it perform well across various performance metrics? (robustness)
- Did it also have (one of) the best cross-validated scores from the training set? (consistency)
- Does it solve the original business problem? (win condition)

3.4.5 Labels prediction

In order to predict values of the selected labels in the future, it is necessary to prepare the appropriate dataset and apply the machine learning model that has shown the best results. Dataset that is used for prediction must have the exactly same structure and data format as the training dataset.

4. RESULTS

According to the methodology described in the Section 3, a descriptive analysis of Serbian Food Foreign Trade dataset is performed and different machine learning models for prediction of import/export volume are developed and applied.

4.1 Serbian Food Foreign Trade dataset exploration

Serbian Food Foreign Trade dataset that is used in this research contains data on the foreign trade of the Republic of Serbia in the food industry, for the period from January 2015 to May 2018. Initial dataset consisted of 8 smaller datasets: 2015 NetWeightKG, 2015 AmountEUR, 2016 NetWeightKG, 2016 AmountEUR, 2017 NetWeightKG, 2017 AmountEUR, 2018 NetWeightKG, 2018 AmountEUR. Each record in these 8 datasets contains data on one task of importing/exporting food products in the Republic of Serbia. All datasets have the following attributes: IE (Import/Export), ClearanceProcedure, RegistrationNumber, VATIN, CompanyName, CountryOfBuyer/Seller, CountryOfImport, CountryOfExport, CustomsTariff, CustomsTariffName, Year, Month, Quarter and TradeName. Except previously mentioned attributes, 4 datasets had the following attributes: UnitOfMeasure, Quantity and NetWeightKG, while the remaining 4 datasets also had the AmountEUR attribute. The most important disadvantage of the initial dataset was the lack of data for some months in the year of 2018, so the whole year was excluded from further analysis. Additionally, a large number of attributes were redundant in two datasets. In terms of data formats not significant deviations were noticed.

4.2 Dataset preprocessing

The first preprocessing of the initial dataset consisted of integrating 8 smaller datasets into one large dataset. The new dataset consisted of 772517 records, and each record contained data related to one import or export task. The new dataset contained the following attributes: IE (Import/Export), ClearanceProcedure, RegistrationNumber, VATIN, CompanyName, CountryOfBuyer/Seller, CountryOfImport, CountryOfExport, CustomsTariff, CustomsTariffName, Year, Month, Quarter, TradeName, UnitOfMeasure, Quantity, NetWeightKG, and AmountEUR. The preprocessing eliminated the unnecessary repetition of the same attributes in different datasets and enabled later examination if individual attributes are dependent on other attributes. Dataset is cleared from incomplete records while attributes NetWeightKG i AmountEUR are formatted as numerical enabling future statistical calculations on them. Some of the dataset attributes were excluded because they were uniquely dependent on some other attributes. For example, for company identification we kept attributes such as RegistrationNumber and CompanyName while we excluded attribute VATIN from the dataset as unnecessary. An attribute CompanyName was kept as it was used in formatting descriptive analytics reports, while RegistrationNumber was more applicable for machine learning techniques. Although CustomsTariffName attribute is completely dependent on CustomsTariff attribute, both of them remained in the dataset as the first one is used in descriptive analytics, while the second one is more appropriate for predictive analytics. As the initial dataset was in XLSX format, the first dataset preprocessing was done in BI tool: Microsoft Excel. As a result of this first manual preprocessing, a CSV file with dataset ready for descriptive and predictive analytics was obtained.

After that, transformation of dataset from CSV file to Microsoft Access Database named Serbian Food Foreign Trade was done automatically. Microsoft Access enables simple import/export of data into different formats and supports applications of standard techniques in descriptive analytics such as grouping, filtering, records sorting and calculating basic statistics. Because of this, Access has been selected as an environment

in which descriptive analytics and dataset preprocessing would be performed according to the requirements of the predictive analytics.

4.3 Descriptive analytics

Descriptive analytics was performed by creating and executing more than 180 different queries on Serbian Food Foreign Trade database. Some of the query results were presented graphically using different types of diagrams.

The first groups of queries represents selection of records and/or attributes according to various criteria, such as: Import (with all attributes), Export (with all attributes), Import/Export for selected ClearanceProcedure, Import/Export for selected CompanyName, Import for selected CountryOfImport, Export for selected CountryOfExport, Import/Export for selected CustomsTariff, Import/Export for selected TradeName, Import/Export for selected CompanyName and CountryOfImport/Export, Import/Export for selected CompanyName and CustomsTariff, Import/Export for selected CountryOfImport/Export and CustomsTariff, and so on.

The second group of queries represents grouping of records that satisfy different criteria and calculating the sum on one of the attributes: NetWeightKG or AmountEUR for the selected records. Some of the queries from this group are: Import/Export by Year-NetWeightKG, Import/Export by Year-AmountEUR, Import/Export by Year and Month-NetWeightKG (Figure 2 and Figure 3), Import/Export by Year and Month-AmountEUR, Import/Export by Year and Quarter-NetWeightT (Table 1), Import/Export by Year and Quarter-AmountEUR (Table 1), Import/Export by Year and ClearanceProcedure-NetWeightT, Import/Export by Year and ClearanceProcedure- AmountEUR, Import/Export by Year and CountryOfImport/Export–NetWeightT (Figure 4), Import/Export by Year and Customs Tariff–Net WeightT, Import/Export by Year, Month and CountryOfImport/Export-NetWeightKG, Import/Export by Year, Month and CountryOfImport/Export-AmountEUR, Import/Export by Year, Month, RegistrationNumber and CountryOfImport/Export-NetWeightKG, Import/Export by Year, Month, RegistrationNumber and CountryOfImport/Export-AmountEUR, Import/Export by Year, Month, RegistrationNumber, CountryOfImport/Export and CustomsTariff-NetWeightKG, Import/Export by Year, Month, RegistrationNumber, etc.

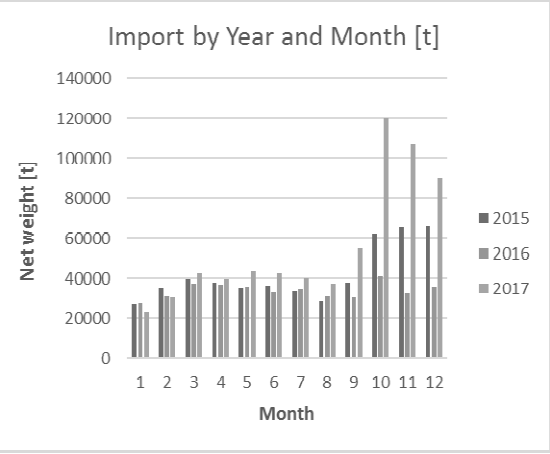


Figure 2. Import by Year and Month-NetWeigh

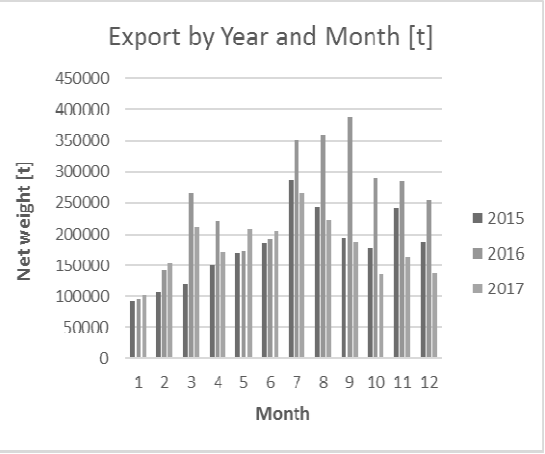


Figure 3. Export by Year and Month-NetWeight

Table 1. Import/Export by Year and Quarter - Amount [EUR]/Net Weight [t]

Year	Quarter	Import		Export	
		Amount [EUR]	Net Weight [t]	Amount [EUR]	Net Weight [t]
2015	Q1	147387697	101858.0539	199228764	321095.6302
	Q2	161651487	109682.5859	264307255	505283.3228
	Q3	148230619	100722.6865	301663954	723586.9371
	Q4	198293828	194738.9037	247381106.2	605656.7998
2016	Q1	157374153	96834.48268	247521583	502375.9095
	Q2	159504404	105557.8246	304689452	585155.5197
	Q3	147362513	96301.30058	387181504	1098752.743
	Q4	183334959	109949.5562	329266411	830845.8023
2017	Q1	187320557.1	96798.6449	258036363.2	465091.6423
	Q2	218913350.2	126033.9844	302096850.7	583948.0215
	Q3	202936950.2	132815.3515	330111516.4	674343.6248
	Q4	298875769.2	317312.1103	230284752.3	436649.1199

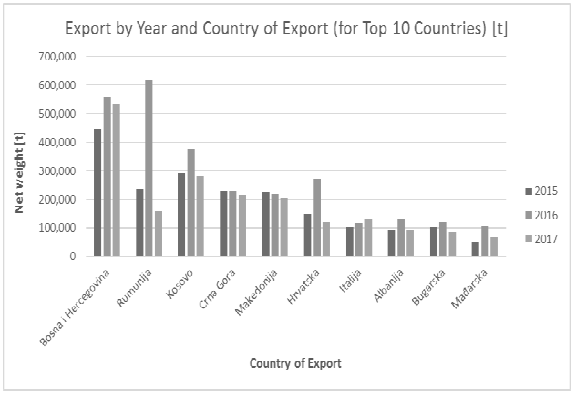


Figure 4. Export by Year and Country of Export (for Top 10 Countries) [t]

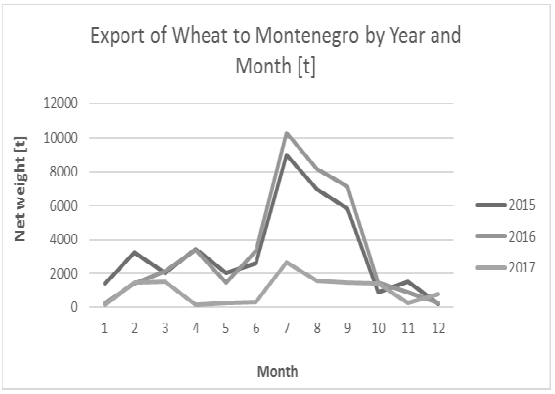


Figure 5. Export of Wheat to Montenegro by Year and Month [t]

The third group of queries was created by combining grouping and selecting records that satisfy different criteria and calculating sum on one of the attributes NetWeightKG or AmountEUR for the selected group of records. Some of the queries from this group are: Export of Wheat to Montenegro by Year and Month-NetWeightT (Figure 5), Export of Water to Montenegro by Year and Quarter-NetWeightT, "Apatinska pivara" Export to Montenegro, Bosnia and Herzegovina and Croatia by Year and Month-NetWeightKG, Month and RegistrationNumber-NetWeightKG, "Imlek" Export to Montenegro, Bosnia and Herzegovina and Croatia by Year and Month-NetWeightT, etc.

4.4 Predictive analytics

For predictive analytics we used an open source data mining software called Weka 3.8.3. Weka is a collection of machine learning algorithms used in data mining. It contains tools for data preparation, classification, regression, clustering, association rules mining, and visualization.

Considering the structure of the available dataset, the following goals for the future models are defined: Prediction of import volume - Net weight [kg], Prediction of import volume - Amount [EUR], Prediction of export volume - Net weight [kg] and Prediction of export volume - Amount [EUR].

The following attributes of the dataset are selected: Net weight [kg] and Amount [EUR] for labels.

Since four different goals for future models were identified, our task was to build four groups of machine learning models. Data mining is an experimental science. At the beginning of the research it is not known in advance which machine learning algorithm will be the most appropriate for the defined goal of the model. In addition, not each machine learning algorithm can be applied on every dataset. The set of available algorithms that can be applied is determined, first and foremost, by the nature of the dependent variable. If dependent variable has nominal value, we use Machine Learning Algorithms for Classification, otherwise if dependent variable is numeric, we use Machine Learning Algorithms for Regression. Since our dataset labels (Net weight [kg] and Amount [EUR]) are numeric continuous, we have chosen machine learning models based on the most popular regression algorithms:

1. Linear Regression,
2. k-Nearest Neighbors,
3. Decision Tree,
4. Support Vector Machine for Regression and
5. Neural Network.

Dataset preprocessing includes transformations of attribute values and label value, such as: nominal to binary, numeric to nominal, numeric to binary, normalization, discretization, etc. Whether a transformation is necessary depends on the initial dataset and on the types of attributes and labels that are allowed for the particular sort of algorithm. Some algorithms require particular attribute types and/or label, so the transformation is done due to the requirement of the algorithm. Transformation can be done even if it is not necessary in order to examine how different attribute types affect the performance of the model.

The most important hyperparameters that are adjusted for the selected types of machine learning algorithms are:

- For Linear Regression algorithm: attribute selection method (M5 method, no attribute selection, greedy method), eliminate colinear attributes (True or False), Ridge parameter, etc.
- For k-Nearest Neighbours algorithm: the number of neighbors to use, cross validate (True or False), nearest neighbor search algorithm, etc.
- For Decision Tree algorithm: the maximum tree depth, the minimum total weight of the instances in a leaf, no pruning (True or False), etc.
- For Support Vector Regression algorithm: the complexity parameter C, filter type (normalize training data, standardize training data, no normalization/standardization), etc.
- For Neural Network algorithm: nominal to binary filter (True or False), hidden layers, normalize attributes (True or False), normalize numeric class (True or False), training time, etc.

In order to form a dataset for prediction, we used initial datasets with all 14 attributes selected in the preprocessing phase and created by selecting only those records related either to import or export. However, after performing machine learning algorithms it has been shown that none of them had satisfying results for these datasets. Later on, we tested different algorithms on datasets that were obtained by grouping or selecting records using different criteria but machine learning algorithms did not show satisfying results. In the third phase we used datasets received as a result of queries that simultaneously select and group records, and finally in this case some of the machine learning algorithms yield to good results. Two examples are described below. In both cases, part of the dataset that contain data for years 2015 and 2016 was used as a training dataset while the part of the dataset that relates to the 2017 year was used as a test dataset.

Example 1. Training dataset: "Apatinska pivara" Export to Montenegro, Bosnia and Herzegovina and Croatia by Year and Month-NetWeightT 2015-2016, number of instances: 72, attributes: Month, CountryOfExport, SumOfNetWeightKG, Test mode: 10-fold cross-validation.

The performance of eight different machine learning models created by using eight different algorithms on this training dataset are shown in Table 2.

Table 2. Performance measures for eight prediction models in Example 1

Algorithm	Linear Regression	Multilayer Perceptron	SMOreg	IBk	M5P	Random Forest	Random Tree	REPTree
Correlation coefficient	0.9393	0.9619	0.9366	0.9806	0.9582	0.9835	0.9806	0.9727
Mean absolute error	407711.37	391087.55	392452.58	208927.70	326183.58	189980.92	208003.04	237471.15
Root mean squared error	673829.28	548225.78	692218.80	402656.92	561686.26	358611.63	402191.23	461461.42
Relative absolute error	23.04 %	22.10 %	22.18 %	11.81 %	18.43 %	10.74 %	11.76 %	13.42 %
Root relative squared error	33.98 %	27.65 %	34.91 %	20.31 %	28.32 %	18.09 %	20.29 %	23.27 %

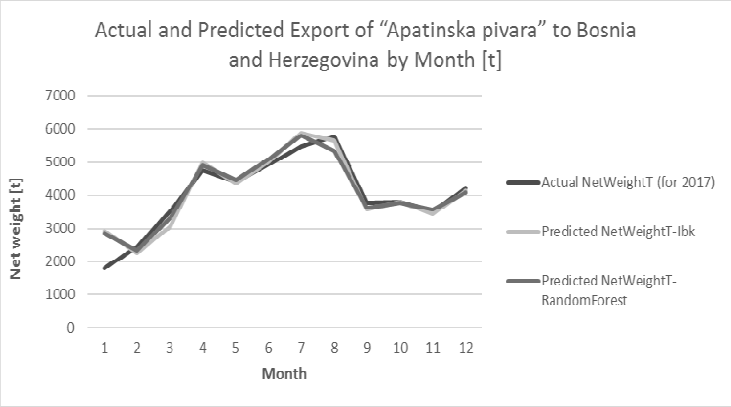


Figure 6. Actual and Predicted Export of "Apatinska pivara" to Bosnia and Herzegovina by Month – Net Weight [t]

According to the results of the models shown in Table 2, the model that has the best performance was based on Random Forest algorithm. Considering all performance

measures this model shows the best performance. The second-place share two models with very similar performances: the first is based on Ibk (k-Nearest Neighbors) and the second one on Random Tree algorithm. The Figure 6 shows relationships between actual values from test dataset and values predicted using the machine learning models that are selected as the best ones (Random Forest and IBk).

Example 2. Training dataset: Import of Coffe from Italia by Year and Month-NetWeightKG 2015-2016, number of instances: 75, attributes: Month, CustomsTariff, SumOfNetWeightKG, Test mode: 10-fold cross-validation.

Table 3 shows the performance of eight machine learning models. The results in Table 3 show that the best performance has models based on Random Forest, Ibk (k-Nearest Neighbors) and Random Tree algorithms, as in Example 1.

Table 3. Performance measures for eight prediction models in Example 2

Algorithm	Linear Regression	Multilayer Perceptron	SMOreg	IBk	M5P	Random Forest	Random Tree	REPTree
Correlation coefficient	0.9762	0.9697	0.9757	0.9798	0.9492	0.9815	0.98	0.9751
Mean absolute error	5117.82	6492.80	4432.62	4519.26	11281.23	4190.3952	4432.57	4662.38
Root mean squared error	7957.96	8980.41	8067.29	7397.58	13820.69	7027.27	7376.91	8137.51
Relative absolute error	15.23 %	19.32 %	13.19 %	13.45 %	33.57 %	12.47 %	13.19 %	13.87 %
Root relative squared error	21.54 %	24.31 %	21.83 %	20.02 %	37.41 %	19.02 %	19.97 %	22.02 %

5. CONCLUSION

In this paper we have used supervised machine learning technics for predicting volume and structure of import and export in the food industry of the Republic of Serbia. We have proposed and thoroughly described methodology for predicting import and export volume in all its phases: data exploration, data preprocessing, model building, model evaluating, model testing and model deployment. A great number of machine learning models based on the application of the most popular regression algorithms were built, verified and tested: Linear Regression, k-Nearest Neighbors, Decision Tree, Support Vector Machine for Regression and Neural Network. Some of built machine learning models have shown satisfying performance, thus verifying the proposed prediction methodology. The best results were received by models based on Random Forest, k-Nearest Neighbors and Random Tree algorithms. This means that the independence of the attributes of the observed dataset is better described by nonlinear machine learning algorithms and ensemble machine learning algorithms than by linear machine learning algorithms.

One of the conclusions of this research is that performing standard descriptive analytics and visualization of relationships dependent on independent variables on the initial dataset in the earlier phase yields the process of predictive analytics more efficient.

Since dependent variables (labels) in this research were numerical continuous and that developed models were based on regression algorithms, the future research could be based on label discretization and applying of classification algorithms.

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