Assessment of the Logistics Solutions in the Automotive Using Operational Research

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Abstract. The different aspects of logistics solutions affect the choice of transport mode during exporting cars. The aim of the paper is, based on an analysis of different aspects as a determinant of the choice of means of transport in the transfer of cars, to compare the individual modes of transport involved in the provision of logistic processes in automotive industry in the Slovak Republic. The main objective is to create a mathematical-statistical model. Model enables to simulate the required output effect (transport mode) on the basis of the change in the significance of the decision criteria, as well as to point out important factors and determinants influencing/selecting the means of transport and the mode of transport in this process with respect to the social-economic and environmental requirements in the context of sustainable development. The simulation consists of a sequence of steps that follow each other and depend on the decision method used. Application of the Multi-Criteria Decision Analysis (MCDA) in determining the significance of selected options – the most suitable transport mode create the basis for simulating the required conditions.

Keywords: Efficiency · Transport mode · Simulation · Logistics · MCDA

1 Introduction

Vehicle production is a sector in the Slovak economy with an extremely strong expansion in the last two decades. Car manufacturing has been a driver of growth - not least because it has strong links to a number of other sectors due to the complexity of the product [1, 2]. Therefore, the expansion of car production indirectly generates growth in other industries [3].

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I. Kabashkin et al. (Eds.): RelStat 2020, LNNS 195, pp. 367–376, 2021.
https://doi.org/10.1007/978-3-030-68476-1_34
The driving force behind the growth of the industry was the gradual arrival of four large multinational companies, which ensure the finalization of the production chain (completion of cars). In addition, the segment of companies producing components (but also more complex units such as gearboxes and motors) has developed. Foreign companies used the existing industrial base in the Slovak Republic, which, however, lacked a promising production program during the economic transformation and restructuring. And they used the support tools offered by the government (investment incentives, etc.). They gradually strengthened cooperation ties with domestic entities until a significant domestic supply network was established [4].

The dynamics of this sector in the Slovak Republic is unique in the Central European region (see Fig. 1). The 1995 baseline has more than increased 40 times. At the same time, the growth of the sector for the EU was not significant (for the period 1995–2017, the sector’s outputs increased to 2.2 times the initial level). The weaker performance of the EU can be seen in modest or no growth in traditional car manufacturers in advanced European economies (Italy, France, Germany).

![Fig. 1. Performance index in car production. (1995 level = 1) [own calculations according to Eurostat].](image)

*Notes: Indices are calculated from value added data at constant prices. These are therefore changing in real volumes without being affected by price movements.*

In the entire V4 group, the dynamics of car production was significantly higher than that of traditional car manufacturers in more advanced economies. This is clearly the result of the relocation of such production activities to countries with the competitive advantage of low costs. However, the expansion of this sector in the Slovak Republic is significantly more apparent in comparison with other V4 countries.
The above-mentioned dynamics of the industry led to the fact that the Slovak Republic achieved world leadership in car production in terms of population (198 - according to the Association of the Automotive Industry). Of passenger cars produced per 1,000 inhabitants in 2018), the total number of cars produced is skies 1.1 million per year (2018, 2019). In addition to the long-term growth trend, annual volumes have their significant fluctuations (Fig. 1 shows a significant fluctuation in the economic depression in 2009, preliminary results show an extreme downward fluctuation even in the current economic depression). The current economic depression (“coronavirus crisis”) fully poses a problem of fragmented global chains: the automotive industry is limited by the reliability and timeliness of deliveries from the global environment between follow-up activities - and it is these flows that are stuck in a pandemic. However, we assume that the strong position of car production in the Slovak Republic will not be disturbed in the long run [5, 6].

![Fig. 2. Shares of the car industry in the Slovak economy (%) [own calculations according to Eurostat data].](image)

**Notes:** The share of gross output and the share of value added is calculated from data at current prices. The share of industrial production is calculated as the share of value added of the car industry in the value added of the entire industrial sector. The share of employment is calculated from data on the number of employees according to the methodology of national accounts (domestic concept). The share of investments is calculated from data on gross fixed capital formation at current prices.

In less than two decades, the share of the car production industry in the parameters of the Slovak economy has multiplied. Figure 2 shows a comparison of the weight of this sector in the Slovak economy in 2000 and 2019. From the point of view of thinking about the transport of products, the shares in the volumes of the economy’s outputs are important:
– Car production accounts for 14% of the economy’s gross output;
– It accounts for about a fifth of industrial production;
– Cars make up about 30% of exports from the Slovak Republic (outside Fig. 2, according to Eurostat).

It is noteworthy that the share of gross output is significantly higher than the share of value added. This is due to the relatively low share of value added in sales (gross production) of the industry.

In terms of importance for transport performance, it is necessary to consider not only the long-term increase in the physical volume of the sector’s outputs, but also its transport intensity. It is a sector that is transport-intensive at the entrance (the need for a large number of diverse supplies, a very high share of intermediate consumption, it is a strongly “globalized” product) and also at the output (almost all production in the Slovak Republic is exported) [7, 8]. It is precisely the issues of transport of finished products (car) that are the subject of our analysis.

2 Methods

The evaluation of the usability of transport modes in the transport of cars is realized using Multi-Criteria Decision Analysis. This method provides a framework for preparing effective decisions in complex decision-making situations, helping to simplify and speed up the natural decision-making process [9].

2.1 Multi-Criteria Decision Analysis

Analytic Hierarchy Process (AHP) is a method of decomposing a complex unstructured situation into simpler components and thus creates a hierarchical system of the problem.

At each level of the hierarchical structure, the Saaty method of quantitative pairwise comparison is used. Using subjective evaluations of pairwise comparisons, this method assigns to the individual components quantitative characteristics expressing their importance. The synthesis of these evaluations then identifies the highest priority component that the decision maker will focus on in order to obtain a solution to the decision problem.

The method can be used for any type of information about preferential relationships between model components. The only condition is that the user can determine from this information the direction and intensity of the preference between all pairs of components being compared.

A hierarchical structure is a linear structure comprising several levels, each of which contains several elements. The arrangement of the individual levels of the hierarchical structure corresponds to the arrangement from the general to the specific. The more general the elements are in relation to a given decision-making problem, the higher they occupy them in the respective hierarchy and vice versa.

The intensities of the interaction of the individual elements in the hierarchy can be quantified in some way. The top level of the hierarchy always contains only one
element that defines the goal of the decision or analysis. This element is assigned a value of one, which is then divided among the elements at the second level. Similarly, the value of each element is divided into other lower levels of the hierarchy until we get the lowest grade rating.

The basic levels of multi-criteria analysis are the goal of decision-making, decision criteria (C) and solution variants (Table 1).

The basic steps of multi-criteria analysis are:

1. Form a panel of experts and participate in the weights determination for each criterion category. The panel of experts consists of appropriate members nominated by authors.
2. The final weights for the criteria categories are created as an average of percentages assigned by individual experts. The weights are determined by experts’ panel with each expert creating a preferential matrix.
3. Each criterion is pairwise compared on a scale of 1 to 5. The score is noted on both sides of the matrix and in an inverse manner:
   - Preference of value 1 represents equal importance between Criterion A compared to Criterion B.
   - Preference of value 5 represents an extremely higher preference for Criterion A over Criterion B. It is also noted in an inverse manner, so Criterion B is 0.2 times important over Criterion A.
   - If Criterion A is less important than Criterion B (e.g. by half), the preferential value of Criterion A over Criterion B is 0.5. Inversely, the preferential value of Criterion B over Criterion A is 2 [10].

|            | C - A | C - B | C - C | C - D | C - E |
|------------|-------|-------|-------|-------|-------|
| Criterion A| 1.00  | a     | b     | c     | d     |
| Criterion B| 1/a   | 1.00  | e     | f     | g     |
| Criterion C| 1/b   | 1/e   | 1.00  | h     | i     |
| Criterion D| 1/c   | 1/f   | 1/h   | 1.00  | j     |
| Criterion E| 1/d   | 1/g   | 1/i   | 1/j   | 1.00  |

Weights: % % % % %
Determination of the values of the eigenvector of the matrix for the individual rows of the decision matrix based on the relation to the calculation of the geometric mean:

$$w_i = \sqrt[\sum_{j=1}^{n} s_{ij}} = \sqrt[N]{s_{i1} \times s_{i2} \times \ldots \times s_{in}}.$$  \hspace{1cm} (1)

Determination of the normalized eigenvector of the matrix:

$$v_i = \frac{w_i}{w_1 + w_2 + \ldots + w_n}.$$  \hspace{1cm} (2)

Determining the eigenvalue of the matrix based on the relation:

$$S_i \times v = \lambda_i \times v \text{ toho vyplýva } \lambda_i = \frac{S_i \times v}{v_i}.$$  \hspace{1cm} (3)

The formula will be in form:

$$S_{i1} \times v_1 + S_{i2} \times v_2 + \ldots + S_{in} \times v_n = \lambda_i \times v_i,$$  \hspace{1cm} (4)

where

$$\lambda_i = \frac{S_{i1} \times v_1 + S_{i2} \times v_2 + \ldots + S_{in} \times v_n}{v_i}.$$  \hspace{1cm} (5)

From the values obtained, the mean value is calculated, which represents the largest eigenvalue of the matrix:

$$\frac{1}{n}(\lambda_1 + \lambda_2 + \lambda_3 + \ldots + \lambda_n)_{\text{max}}.$$  \hspace{1cm} (6)

The calculation procedure must be applied for the first time at the level of comparison of criteria and for the second time at the level of comparison of individual solution variants.

### 2.2 Application of MCDA and Simulation of Significance of Criteria

MCDA determines the most suitable variant of transport on the basis of the determined weights of individual criteria.

The goal of decision process consists of determining the transport mode, that is the most suitable for car transport depending on the selected criteria.

For the application of the decision-making process, we propose 5 decision criteria, among which are the price of transport, delivery time, degree of infrastructure construction, transport safety and environmental aspects.

Road, rail and water transport, which are currently involved in the car transport process, were chosen as the options being compared. Air transport can be excluded from the analysis process as it is not used in connection with the transport of cars or is
used only in specific cases (e.g. in the transport of military equipment, which is not the subject of research) [11, 12].

The simulation consists of a sequence of steps that follow each other and depend on the decision method used (Fig. 3). Application of the AHP method in determining the significance of selected variants - the most suitable transport mode forms the basis for simulating the required conditions. The starting point for the simulation process is the determination of the matrix that compares the individual criteria and the subsequent calculation of the normalized vector “$v_i$”, which represents the weight of significance of the criterion. To calculate the weighted sum - order of significance of individual variants, it is necessary to apply the decision analysis for each criterion separately in relation to the compared variants - transport mode. By calculating the weighted sum, we get the preference of transport modes based on the weights of the criteria. The result of the decision analysis is “baseline model”, which forms the basis for the simulation of the required conditions – required model.

The simulation process consists in increasing or reducing the weight of the selected criteria in relation to the transport mode. The rate of change is defined as a percentage. The rate of change of the weight of the criterion in relation to one transport mode influences the change of the value of the normalized vector “$v_i$”, that is the basis for the calculation of the weighted sum. The result is preference of each transport mode.

![Fig. 3. Steps of Simulation [authors.]](image)

### 3 Results and Discussion

The results of the MCDA point to the current preferences of individual transport solutions for the transport of cars. By determining the weights of individual criteria and subsequent comparison of the examined variant solutions using the MCDA, it is possible to compile an evaluation of the compared transport modes in relation to the choice of a suitable transport mode in the transport of cars in the Slovak Republic. They represent the initial state of the investigation (Table 2).

The model situation assumes of transport over medium and long distances (1,000 km and more). The analysis for water transport does not include transport from the production plant to the place of loading and from the place of unloading to the place of destination. The highest weight was assigned to the criterion “price”.
From the results of the MCDA, it can be concluded that rail transport appears to be the most suitable mode of transport for car transport. Road transport in medium and long-distance transport is the third preference. Results show that rail transport currently does not have direct competition in medium and long-distance transport. Inland waterway transport, as a direct competitor of rail transport in public transport, is in this case disadvantaged on the one hand by the state of the existing fleet and on the other hand by its relatively long distance to a suitable transport infrastructure.

### 3.1 Assessing the Feasibility of Transport Modes

The process of simulating the required conditions is based on the percentage increase or reducing the weight of criteria in relation to the transport mode. This is the basis for simulating a change in the results of a decision analysis. Changes in the state of significance of individual criteria in comparison with other transport modes can result in significant changes in the final evaluation.

The result of the decision-making analysis that assessing the 5 selected criteria resulted in the compilation of a preference of individual transport modes in relation to car transport in Slovakia. Water transport ended up in second place after rail transport. Changing the selected criterion may result in a change in transport mode preference.

Multi-Criteria Decision Analysis brings real results based on the analysis of selected criteria and solution variants. The weighted sum as an output of the decision analysis determines the order of significance of the compared variants. It represents the so-called “The baseline model” for the simulation. Sensitive changes in the input data for the decision-making process can result in a change of order or output of the MCDA. The simulation model enables simple simulation of the required conditions by increasing or reducing the significance of individual criteria in relation to the solution variants by a percentage change in their dependencies (Table 3).

**Table 2. MCDA Results in Current Conditions (year 2020) [authors].**

| Criterion          | Weight | Road transport | Rail transport | Water transport |
|--------------------|--------|----------------|----------------|-----------------|
| Price              | 0.375  | 0.1220         | 0.3196         | 0.5584          |
| Time               | 0.218  | 0.3586         | 0.5171         | 0.1243          |
| Infrastructure     | 0.055  | 0.5695         | 0.3331         | 0.0974          |
| Safety             | 0.115  | 0.0974         | 0.5695         | 0.3331          |
| Environmental aspects | 0.237 | 0.1365         | 0.6250         | 0.2385          |
| Weighted Sum       |        | 0.1989         | 0.4645         | 0.3367          |

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On the example of the price change of the selected transport mode - water transport, it is possible to see the effect of the price change on the overall MCDA result. Even with a 5% change in the selected criterion, there are significant changes in the MCDA results (see Fig. 4 below).

### Table 3. Example of changing the price of transport of the selected transport mode (Water transport) [authors].

| Variant | Road  | Rail | Water | $II S_{(i,j)}$ | $w(i)$ | $v(i)$ | Increase | Reduction |
|---------|-------|------|-------|----------------|--------|--------|----------|-----------|
| Road    | 1     | 0.33 | 0.75  | 0.25           | 0.62996| 0.19855| 0.00%    | 0.00%     |
| Rail    | 3     | 1    | 1.00  | 3              | 1.44225| 0.45456| 0.00%    | 0.00%     |
| Water   | 1.333 | 1    | 1     | 1.333333       | 1.10064| 0.34689| 5.00%    | 0.00%     |

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**Fig. 4.** Simulation of a change in the significance of criteria in relation to transport mode [authors].

## 4 Conclusion

Based on the results of MCDA analysis, a simulation model was created, that by increasing or reducing the percentage of significance of the selected criteria allows easily simulate the desired results of the decision analysis. The model provides a simple insight into the impact of changing the selected criteria on the final evaluation.

Export of cars from Slovak cars is currently focused only on road and rail transport. The share of road and rail transport in Slovakia is 67% to 33%. Water transport in Slovakia is not used at all for the transport of cars. In the case of the PSA Peugeot - Citroën, the use of water transport is conditioned by the modification and completion of the Vah waterway. This will create navigation conditions suitable for class Va navigation. The condition for the use of the Vah waterway is also the construction of a port in its vicinity equipped with a car terminal.
Acknowledgements. This work is the result of the Project VEGA No. 1/0128/20: Research on the Economic Efficiency of Variant Transport Modes in the Car Transport in the Slovak Republic with Emphasis on Sustainability and Environmental Impact, Faculty of Operation and Economics of Transport and Communications: University of Zilina, 2020-2022.

References

1. Kalina, T., Jurkovic, M., Vyzinkar, P., Vaclavinek, P.: Comparison of economic efficiency of LNG with traditional fuels in freight transport. In: Transport means 2017: Proceedings of the 21st International Scientific Conference. September 20 – 22, 2017. Kaunas University of Technology, Lithuania, pp. 213–219 (2017)

2. Nadanyiova, M.: Implementation of the green marketing principles in the Slovak automotive industry. In: Transport means 2016: Proceedings of the 20th International Scientific Conference: October 5–7, 2016 Juodkrante, Lithuania. Kaunas University of Technology, Kaunas (2016)

3. Luptacik, M., Habrman M., Labaj, M., Rehak, S.: National economic importance of the automotive industry in Slovakia Empirical results. Department of Economic Policy, University of Economics in Bratislava (2013). https://doi.org/10.13140/2.1.2476.4167

4. Gorzelanczyk, P., Krawiec, M., Kalina, T., Jurkovic, M.: Risk assessment in the transport of hazardous materials on the example of the greater voivodeship. In: LOGI 2019 - Horizons of Autonomous Mobility in Europe. 1st edn., Vol 44: pp. 283–289. Elsevier, Amsterdam (2020). https://doi.org/10.1016/j.trpro.2020.02.041

5. AUTOVINY Homepage, https://www.autoviny.sk/reportaze/119380/ako-je-na-tom-slovensky-automobilovy-priemysel-v-skutocnosti-pozrite-si-dolezite-statistiky. Accessed 17 Jul 2020

6. Galierikova, A., Sosedova, J.: Environmental aspects of transport in the context of development of inland navigation. Ekologia Bratislava 35(3), 279–288 (2016)

7. Minken, H., Johansen, B.-G.: A logistics cost function with explicit transport costs. Economics of Transportation, 19 (2019). https://doi.org/10.1016/j.ecotra.2019.04.001

8. Garceau, T., Atkinson-Palombo, C., Garrick, N., Outlaw, J., McCahill, Ch., Ahangari, H.: Evaluating selected costs of automobile-oriented transportation systems from a sustainability perspective. Res. Transp. Bus. Manage. 7, 43–53 (2013). https://doi.org/10.1016/j.rtbm.2013.02.002

9. Stoilova, S., Munier, N., Kendra, M., Skrúcaný, T.: Multi-criteria evaluation of railway network performance in countries of the TEN-T orient-east med corridor. Sustainability 12, 1482 (2020). https://doi.org/10.3390/su12041482

10. SCRIPT. http://etext.czu.cz/php/skripta/kapitola.php?titul_key=79&idkapitola=16. Accessed 11 May 2019

11. Madudova, E., David, A.: Identifying the derived utility function of transport services: Case study of rail and sea container transport. In: 13th International Scientific Conference on Sustainable, Modern and Safe Transport, TRANSCOM 2019, vol. 40, pp. 1096–1102 (2019)

12. Gorzelanczyk, P., Pyszewska, D., Kalina, T., Jurkovic, M.: Analysis of road traffic safety in the Pila poviat. Scientific Journal of Silesian University of Technology. Series Transp. 107, 33–52 (2020). https://doi.org/10.20858/sjsutst.2020.107.3