*Advances in Reliability, Safety and Security, Part 8 – Kołowrocki, Magryta-Mut (eds.)*


**Advances in Reliability, Safety and Security**

ESREL 2024
Monograph Book Series

# Optimisation Of Road Transport Performed By Empty Vehicles, Theoretical Basis - Part 1

Jarosław Ziółkowski, Aleksandra Lęgas, Mateusz Oszczypała, Jakub Konwerski, Jerzy Małachowski

*Military University of Technology, Warsaw, Poland*

**Abstract**

Road transport performed by empty runs both in the EU and in Poland constitute a significant percentage of unprofitable transport, and they arise as a result of the lack of balance between demand and supply observed on the market of transport services. This publication consists of two parts, in the first one the phenomenon of road transport performed by empty runs has been outlined, the assumptions and methodology of the procedure are defined, while in the second practical part the mentioned methodology has been illustrated with a numerical example. Empty runs are not only a financial loss for the company, but also have ecological significance. In practice, this problem cannot be eliminated, it is and will always be a problem for people involved in planning transport routes. In this work, the authors took up a single-criteria optimization problem, for which a commonly available MS Excel spreadsheet with the Solver was used.

*Keywords*: road transport, empty runs, optimization, transportation network

## 1. Introduction

The issues concerning road transport modelling is discussed in a large number of publications. The task, in its conventional form, is often presented as linear programming (An et al., 2021; Angelelli et al., 2021; Ghayour-Baghbani et al., 2021; Park and Lim, 2021) where both the objective function and the limiting conditions are described as linear equations or inequalities. In the area of road transport, authors of publications often present modern methods (Karagul and Sahin, 2020; N. Wang et al., 2023), algorithms (Mnif and Bouamama, 2020), tools (Al Theeb et al., 2020; Szkutnik-Rogoż and Małachowski, 2023) or optimisation techniques (Borucka and Kozłowski, 2023; Theeraviriya et al., 2020), affecting the key transport performance indicators (X. Wang et al., 2021; Wróblewski and Lewicki, 2021). The set of decision-making problems to be solved in the area of transport is diverse and often highly individualised. Examples of work in this area include:

1) optimising the installation of truck ramps along motorways (Chen et al., 2023);
2) mathematical modelling of road transport (Aydoğdu and Özyörük, 2020; Ziółkowski and Lęgas, 2019);
3) reducing the likelihood of a road accident (Izdebski et al., 2022);
4) empty runs reduction (Ziółkowski and Lęgas, 2018);
5) minimising the costs of transport (Andrzejczak and Selech, 2017; Zieja et al., 2019);
6) a flow-based formulation of the travelling salesman problem (Kowalik et al., 2023).

There are several transport classification criteria in the literature on the subject. In this study, we refer to the basic division by the environment in which the transport operations are executed (Fig. 1).

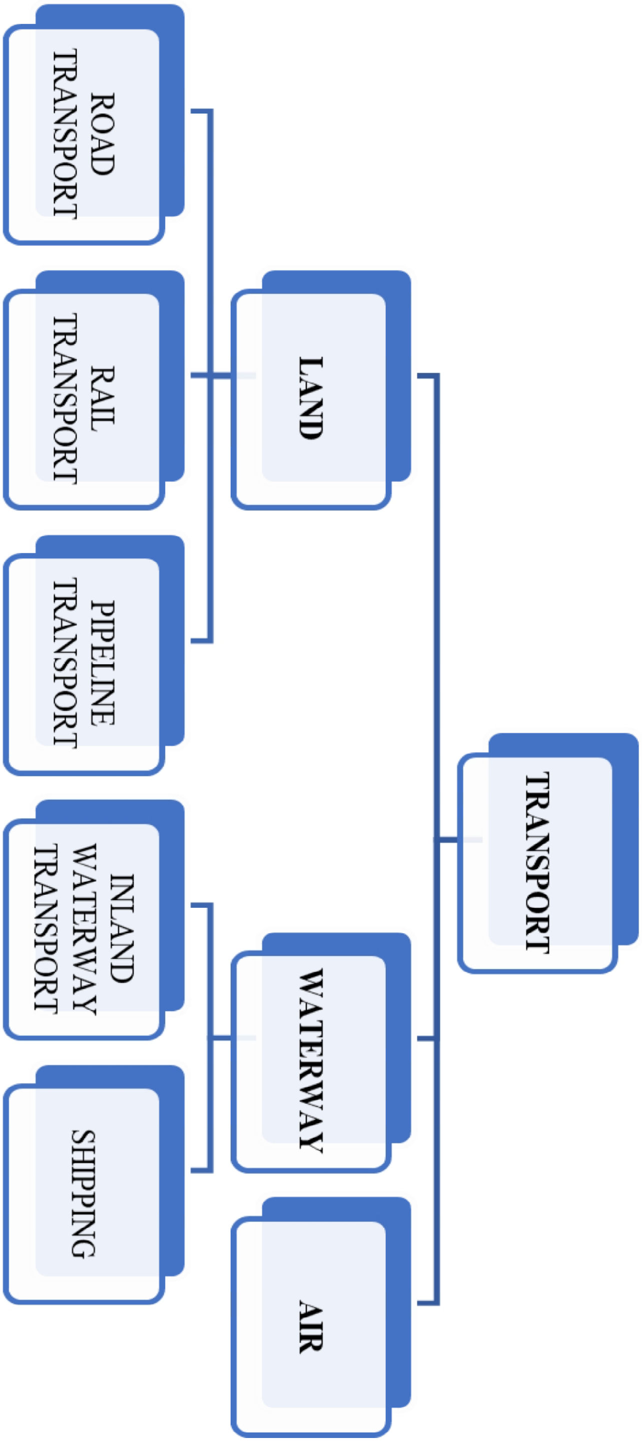


Fig. 1. Basic modes of transport.

When analysing individual modes of transport in terms of transport performance, sea transport invariably dominates globally. Sea transport is predestined for transporting bulk loads. However, in Poland, as in the entire European Union, road transport plays the most important role. There are two main arguments in favour of road transport, i.e. the small area of the Old Continent and therefore relatively short distances and a well-developed road network. The dominant role of road transport when it comes to cargo transport is shown in Fig. 2.

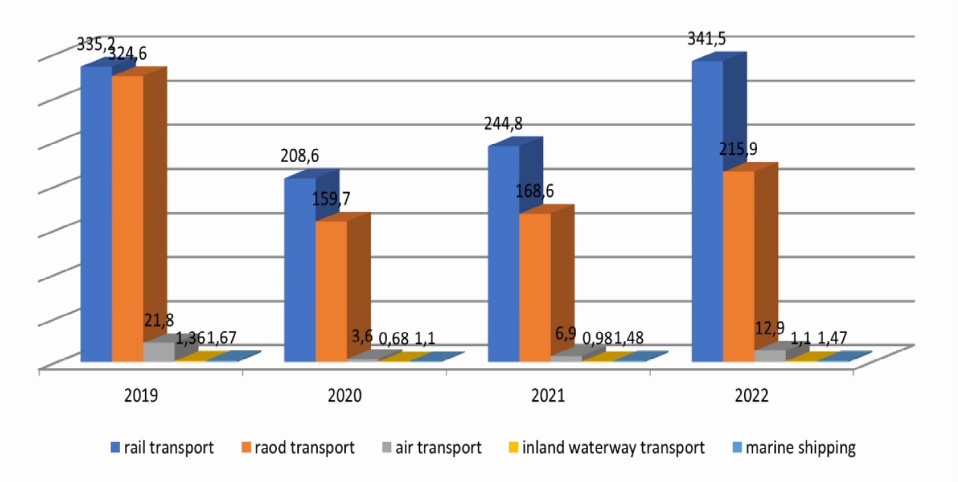


Fig. 2. Share of individual modes of transport in cargo transport in Poland in 2022 [million tonnes].

The statistical data on passenger transport in Poland are slightly different. As presented in Fig. 3, since 2019, the dominant role has been assigned to rail transport. It is consistent with the sustainable development strategy, which assumes increasing importance of rail transport, indicating railways as environmentally friendly transport.

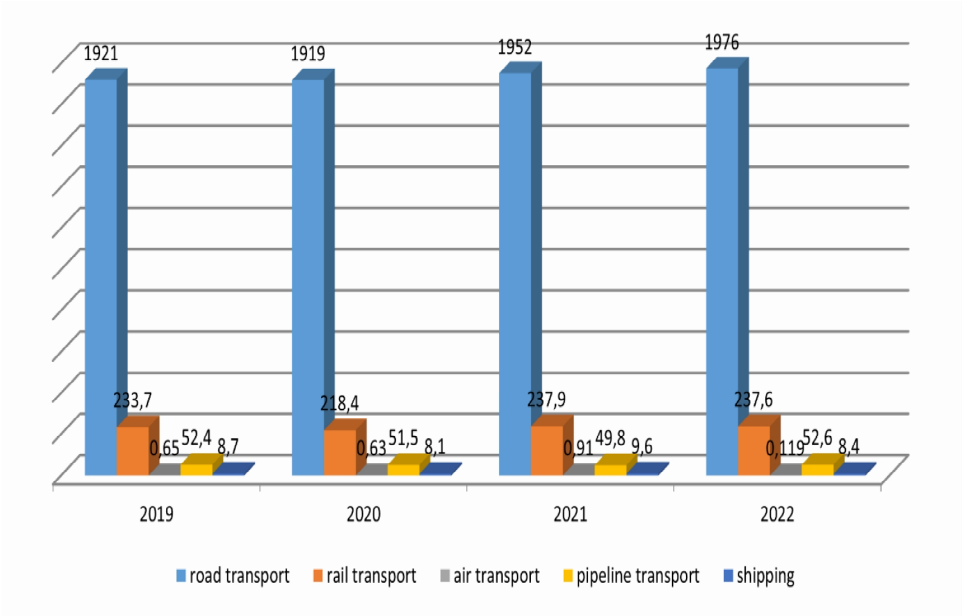


Fig. 3. Share of individual modes of transport in passenger transport in Poland in 2022 [million passengers].

A characteristic feature of the modern environment in which the transport industry operates is macroeconomic shocks. Market analysis shows that the main challenges companies face are high salaries, inflation and energy price fluctuations. The activities executed by transport companies must adapt to the above conditions. It should be borne in mind that the transport industry is one of the pillars of the Polish economy and it regularly contributes to the creation of added value and jobs. In terms of GDP generated in 2022, the sector generated a 7% share with a value of PLN 375 billion, becoming one of the most important employers (in terms of employment its share was 6.5%) on the Polish market (Report "Road transport in Poland 2023"). Polish carriers also play a dominant role in the EU (Key figures on European transport – 2022 edition), especially in international road transport (Fig. 4).

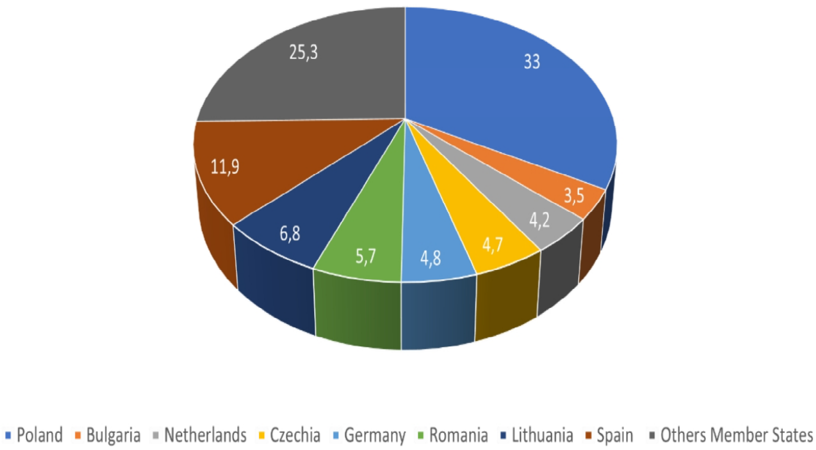


Fig. 4. Share of Member States in total EU international road freight transport, 2022 [%]

Transport is often interpreted as a production process, the effect of which is a change in the spatial sales of the transported item (cargo or people) fulfilling specific needs. An inherent phenomenon in road transport is empty runs. Empty runs are not beneficial because they increase pollution and operating costs of transport companies.

The issue of empty runs applies especially to enterprises providing transport for their own needs and on their own (inter-company transport), as well as to smaller transport companies providing such services on commission (transport on commission). In the latter case, the possibilities of minimising empty runs are much more limited than in the case of companies that have their own transport fleet or cooperate with other carriers. The problem of empty runs may concern any branch of transport except fixed transport installations, but road transport is most affected by this problem. Currently, thanks to widespread monitoring of transport using the GPS system and virtual vehicle and freight exchanges, unprofitable transport can be reduced, but unfortunately cannot be completely eliminated. The basic action aimed at reducing empty runs is based on the appropriate organisation of transport.

However, modern technologies offer more possibilities. In road transport, empty runs are unavoidable and there are at least several pieces of evidence supporting this thesis. The empty runs are a result of an imbalance between the demand and supply of transport services. The requirements of the market, which is focused on short delivery times and quick arrangement of transport for new orders, are also of great importance. The European Union's policy (the so-called mobility package) also has an impact, as it has the potential to reduce the percentage of empty runs in the future. The number of empty runs is also affected by the industry for which the transport is performed.

In fact, it is difficult to expect that it will be possible to arrange, for example, a "return load" for oversized goods (e.g. wind turbine components). The situation is similar when transporting fuel or construction materials. It can therefore be assumed that some specialised transport is somewhat "resistant" to optimisation. Therefore, the influence of planners on reducing empty runs is limited or even non-existent. There are greater possibilities in this respect when transporting more common goods (e.g. palletised cargo) that can be transported in curtainsider semi-trailer or refrigerated trailers.

## 2. Theoretical Background For The Mathematical Model

Enterprises conducting business activities generally incur costs resulting from the consumption of resources, while their activities are focused on manufacturing products, providing services or selling goods. One of the cost components is streamlining the use of means of transport, both in terms of optimal use of cargo space, determining the shortest transport route and reducing empty runs. The following assumptions were made in this study:

- transport is carried out within one branch of road transport;
- the same means of transport are used in terms of load capacity;
- transport operations are executed between many fixed points in the transport network;
- each point can be a loading and/or unloading point;
- the number of points is known and constant, and transport operations are executed between these points only (loads of a specific size and time are transported to and from each transport point);
- the distribution of transport between transport points is known and transport volumes are expressed in the number of means of transport of a given type;
- the distances between points of the transport network are known;
- only the transport operations carried out by the total number of means of transport of a given type are allowed;
- there are suppliers of empty means of transport, i.e. nodes where inbound transport is greater than outbound transport;
- there are recipients of empty means of transport, i.e. nodes where outbound transport is greater than inbound transport.

Minimising empty runs in transport involves determining the optimal travel plan for empty means of transport (from suppliers to recipients) in the transport network. The feature of the optimal plan is the minimal village of vehicles without a load and:

- the supply of empty means of transport will be utilised;
- the demand for empty means of transport will be met.

In the considered optimisation problem $i,j$ represent the numbers of the transport point $i, j = 1, \ldots n$, while the decision variable will be an empty list of means of transport $x_{ij}$ that should be moved from the *i-th* transport point (supplier of empty means of transport) to *j-th* transport point (recipient of empty means of transport).

It is necessary to adopt specific notations, which for the analysed task are as follows:

$d_{ij}$ – the distance from the *i-th* to the *j-th* transport point;
$c_{ij}$ – the transport volume from the *i-th* to the *j-th* transport point (number of fully laden means of transport);
$e_i$ – volume of cargo exported from the *i-th* transport point (number of fully-laden means of transport), calculated as:

$$e_i = \sum_{j=1}^{n} c_{ji} \qquad (i = 1, \ldots, n). \tag{1}$$

$i_i$ – cargo transport volume from the *i-th* – this transport point (number of fully-laden means of transport), determined using the following relationship:

$$i_i = \sum_{j=1}^{n} c_{ji} \qquad (i = 1, \ldots, n). \tag{2}$$

whereas for the entire transport network (but not necessarily for individual transport points), the number of means of outbound transport must be equal to the number of means of inbound transport (closed transportation problem), so equation (3) must be met:

$$\sum_{i=1}^{m} e_i = \sum_{i=1}^{m} i_i. \tag{3}$$

the transportation points for which $e_i < i_i$ are suppliers of empty means of transport, and their supply takes the form:

$$a_i = i_i - e_i \qquad (a_i > 0). \tag{4}$$

the transportation points for which $e_i > i_i$ are recipients of empty means of transport, and the demand for them is calculated as:

$$b_j = e_i - i_i \qquad (b_j > 0). \tag{5}$$

the transportation points for which $e_i = i_i$, are omitted in further analysis because for them the balance of inbound and outbound transport is equal to zero, and therefore they do not generate the problem of empty runs.

The optimisation task is to find such shifts of empty means of transport $x_{ij}$ for which the total distance of vehicle-kilometers is minimal, according to the following objective function:

$$\sum_{n=1}^{n} \sum_{j=1}^{n} d_{ij} x_{ij} \quad \rightarrow \text{min.} \tag{6}$$

when the following conditions are met:

- the demand for empty means of transport at each transport point will be met according to the relationship (7):

$$\sum_{i=1}^{n} x_{ij} = b_j \quad (j=1,\ \dots,\ n). \tag{7}$$

- empty means of transport located in a specific and non-zero-balance transport point will be used according to equations/inequalities (8) and (9):

$$\sum_{i=1}^{n} x_{ij} = a_i \quad (i=1,\ \dots,\ n). \tag{8}$$

$$x_{ij} \geq 0 \quad (i, j = 1,\ \dots,\ n). \tag{9}$$

Using a spreadsheet, data for the problem of minimising empty runs will be entered, appropriately calculated and boiled down to a transport task. *Solver* will be used to solve the analysed problem. Its main task is to find such values of the equation variables that lead to obtaining the optimised value.

### 3. Calculation methodology

In the example, a transport network covering eight points is considered. The "data" sheet contains tables in which data should be entered:

- $d_{ij}$ represents the distances between transport points ;
- transport volumes determined by the number of fully-laden means of transport $c_{ij}$, omitting the cells located at the intersection of the row and the column marked with indexes *i* and *j* of the same value (transportation within the same transport point), which should contain the value zero.

After entering data based on transport volumes $c_{ij}$ inbound and outbound transport volumes for each transport point should be calculated as the sum of all inbound transports for a given transport point (sum of values in the *i-th* column of the transport matrix) and all outbound transport from this transport point (sum of values in the *i-th* row of the transport matrix). Then, the demand and supply of empty means of transport for each transport point will be compared. Based on the obtained results, the number of suppliers and recipients of empty means of transport will be found. In the next stage, an appropriate triangular table should be constructed (the main diagonal and all fields below or above will be marked as dead) for the transport task, in which the values of the distances between transport points should be listed. Similarly, a table with the previously calculated values of supply and demand for empty means of transport should be created. The next stage is to solve the transport task using the *Solver* add-on, which will contain the objective function, decision variables and limiting conditions. The above-described calculation methodology is presented in Fig. 5.

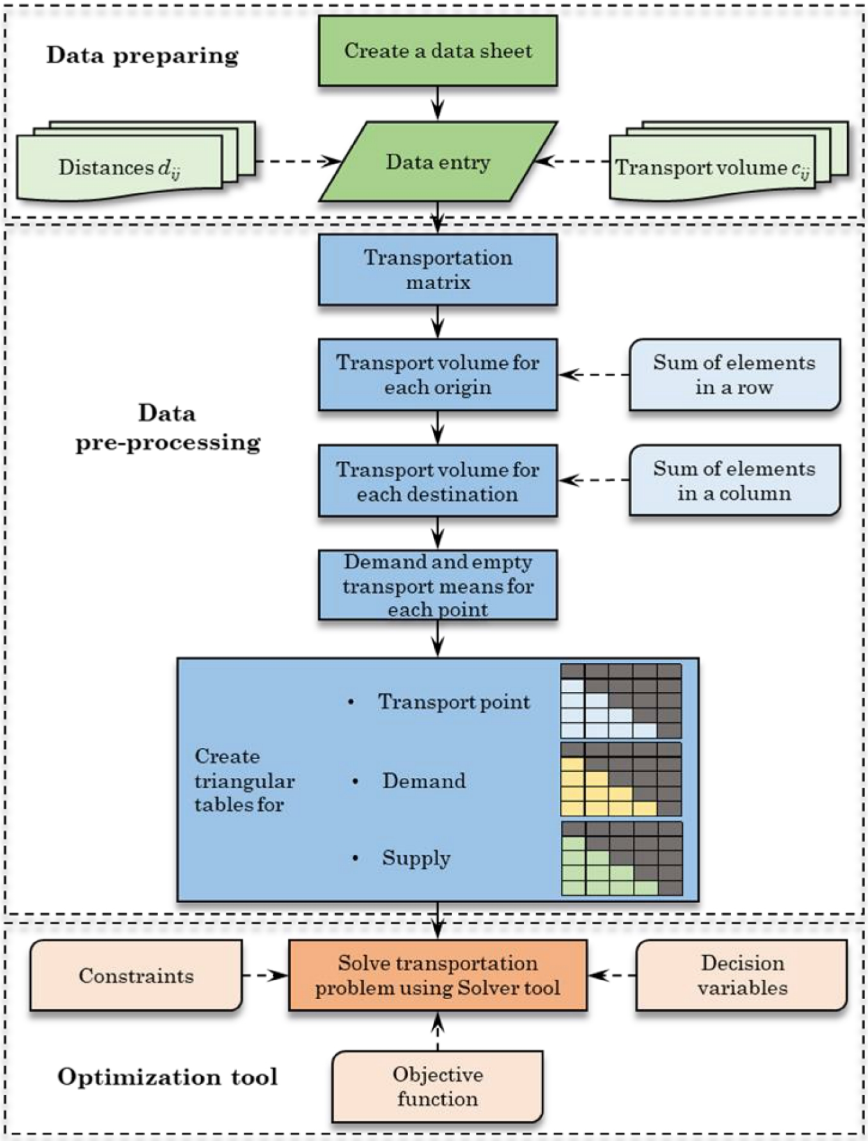


Fig. 5. Methodology algorithm.

The methodology described above will be illustrated with a numerical example in the second part of this work entitled *Optimisation of road transport performed by empty vehicles, A Case Study from Poland - Part 2.*

## Acknowledgements

The authors acknowledge the Military University of Technology for the financial support (research project UGB 22-835) in this study.


## References


Al Theeb, N., Smadi, H. J., Al-Hawari, T. H., Aljarrah, M. H. 2020. Optimization of vehicle routing with inventory allocation problems in Cold Supply Chain Logistics. *Computers and Industrial Engineering*, *142*. Scopus. https://doi.org/10.1016/j.cie.2020.106341

An, J., Mikhaylov, A., Jung, S.-U. 2021. A Linear Programming approach for robust network revenue management in the airline industry. *Journal of Air Transport Management*, *91*. Scopus. https://doi.org/10.1016/j.jairtraman.2020.101979

Andrzejczak, K., Selech, J. 2017. Quantile analysis of the operating costs of the public transport fleet. *Transport Problems*, *12*(3), 103–111. Scopus. https://doi.org/10.20858/tp.2017.12.3.10

Angelelli, E., Morandi, V., Savelsbergh, M., Speranza, M. G. 2021. System optimal routing of traffic flows with user constraints using linear programming. *European Journal of Operational Research*, *293*(3), 863–879. Scopus. https://doi.org/10.1016/j.ejor.2020.12.043

Aydoğdu, B., Özyörük, B. 2020. Mathematical model and heuristic approach for solving dynamic vehicle routing problem with simultaneous pickup and delivery: Random iterative local search variable neighborhood descent search. *Journal of the Faculty of Engineering and Architecture of Gazi University*, *35*(2), 563–580. Scopus. https://doi.org/10.17341/gazimmfd.490179

Borucka, A., Kozłowski, E. 2023. SELECTED POLYNOMIAL IDENTIFICATION TECHNIQUES TO EVALUATE MARITIME TRANSPORT TRENDS AROUND COVID-19. *Scientific Journal of Silesian University of Technology. Series Transport*, *120*, 51–68. Scopus. https://doi.org/10.20858/sjsutst.2023.120.4

Chen, D., Cheng, S., Liu, J., Zhang, J., You, X. 2023. A Simulation-Based Optimization Method for Truck-Prohibit Ramp Placement along Freeways. *Mathematical Problems in Engineering*, *2023*. Scopus. https://doi.org/10.1155/2023/4170669

Ghayour-Baghbani, F., Asadpour, M., Faili, H. 2021. MLPR: Efficient influence maximization in linear threshold propagation model using linear programming. *Social Network Analysis and Mining*, *11*(1). Scopus. https://doi.org/10.1007/s13278-020-00704-0

Izdebski, M., Jacyna-Gołda, I., Gołda, P. 2022. Minimisation of the probability of serious road accidents in the transport of dangerous goods. *Reliability Engineering and System Safety*, *217*. Scopus. https://doi.org/10.1016/j.ress.2021.108093

Karagul, K., Sahin, Y. 2020. A novel approximation method to obtain initial basic feasible solution of transportation problem. *Journal of King Saud University - Engineering Sciences*, *32*(3), 211–218. Scopus. https://doi.org/10.1016/j.jksues.2019.03.003

Kowalik, P., Sobecki, G., Bawoł, P., Muzolf, P. 2023. A Flow-Based Formulation of the Travelling Salesman Problem with Penalties on Nodes. *Sustainability (Switzerland)*, *15*(5). Scopus. https://doi.org/10.3390/su15054330

Mnif, M., Bouamama, S. 2020. A new multi-objective firework algorithm to solve the multimodal planning network problem. *International Journal of Applied Metaheuristic Computing*, *11*(4), 91–113. Scopus. https://doi.org/10.4018/IJAMC.2020100105

Park, C. H., Lim, H. 2021. A parametric approach to integer linear fractional programming: Newton's and Hybrid-Newton methods for an optimal road maintenance problem. *European Journal of Operational Research*, *289*(3), 1030–1039. Scopus. https://doi.org/10.1016/j.ejor.2019.07.010

Szkutnik-Rogoż, J., Małachowski, J. 2023. Optimization programming tools supporting supply chain management. *Bulletin of the Polish Academy of Sciences: Technical Sciences*, *71*(3). Scopus. https://doi.org/10.24425/bpasts.2023.145570

Theeraviriya, C., Pitakaso, R., Sethanan, K., Kaewman, S., Kosacka-Olejnik, M. 2020. A new optimization technique for the location and routing management in agricultural logistics. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(1). Scopus. https://doi.org/10.3390/joitmc6010011

Wang, N., Wu, M., Yuen, K. F. 2023. A novel method to assess urban multimodal transportation system resilience considering passenger demand and infrastructure supply. *Reliability Engineering System Safety*, *238*, 109478. https://doi.org/10.1016/j.ress.2023.109478

Wang, X., Kuo, Y.-H., Shen, H., Zhang, L. 2021. Target-oriented robust location–transportation problem with service-level measure. *Transportation Research Part B: Methodological*, *153*, 1–20. Scopus. https://doi.org/10.1016/j.trb.2021.08.010

Wróblewski, P., Lewicki, W. 2021. A method of analyzing the residual values of low-emission vehicles based on a selected expert method taking into account stochastic operational parameters. *Energies*, *14*(21). Scopus. https://doi.org/10.3390/en14216859

Zieja, M., Ziółkowski, J., Oszczypała, M. 2019. *Comparative analysis of available options for satisfying transport needs including costs*. *2019-October*, 1433–1438. Scopus.

Ziółkowski, J., Lęgas, A. 2018. Minimisation of empty runs in transport. *Journal of Konbin*, *48*(1), 465–491. Scopus. https://doi.org/10.2478/jok-2018-0067

Ziółkowski, J., Lęgas, A. 2019. Problem of Modelling Road Transport. *Journal of Konbin*, *49*(3), 159–193. Scopus. https://doi.org/10.2478/jok-2019-0055

https://tlp.org.pl/raport-transport-drogowy-w-polsce-2023, 2023

Key figures on European transport – 2022 edition (europa.eu), 2022