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COMPARATIVE ANALYSIS OF FREIGHT TRANSPORT SYSTEMS IN ROMANIA: INFRASTRUCTURE AND TRANSPORTED VOLUMES

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Abstract: Freight transport contributes to the development of the national economy, to regional connectivity and also to the smooth functioning of the supply chain. This research analyses the evolution of the infrastructure of road, rail, sea, and air transport systems, as well as the evolution of the volumes transported on each system analysed in Romania. The European Union Bureau of Statistics website was used for data collection. The Phyton linear programming software was also used to determine the optimal transport volumes for each transport system. In addition to the issues presented based on the processing of Eurostat data, opportunities for future research directions were also identified. The paper ends with conclusions and future research directions.

Keywords: infrastructure, transport systems, benchmarking, road transport, rail transport, maritime transport, air transport, Romania.

1 INTRODUCTION

In a global economic environment characterised by profound and rapid change, research into the evolution of freight transport systems infrastructure and analysis of freight transport trends is increasingly important for the economy (Merzlikin et al., 2022; Vázquez-Noguerol et al., 2018). This study proposes a statistical analysis of the infrastructure of freight transport systems in Romania, i.e. road, rail, sea and air transport systems, as well as a statistical analysis of freight transport trends in Romania, with the overall objective of identifying major problems and trends in transport development and future research directions.

This study is essential because of the importance of transport for the entire logistics system and for a country's economy. In the last

decade, transport has undergone many changes and modernisation, trying to achieve the shift from conventional road transport to sustainable transport. This study provides an overview of transport developments in Romania from 2013 to 2022, while identifying problems encountered in the infrastructure of transport systems and identifying opportunities for future research directions.

The paper is structured in three parts: the first part includes the specialized literature, the second presents and analyzes the obtained data and the last part presents the conclusions of the study.

2 LITERATURE REVIEW: TYPES OF TRANSPORT AND THEIR IMPORTANCE

The transport infrastructure in all countries of the European Union has undergone the fastest development in the last decades, and the impact of the transportation on sustainable development and economic growth has become a concern for policymakers as well for economists or entrepreneurs (Cigu, 2018). To identify multiple impacts of transportation infrastructure development, the studies mainly focus both on statistical results and economic fundamentals theories (Wang, 2018).

The contribution of transport infrastructure to economic growth and the causal relationship between them has received great attention from the empirical studies in the economic literature. Transport infrastructure has been always for decision-makers a political instrument reflected in government programs and subsequently implemented through public policies to reduce disparities and inequalities, as well as to promote economic growth (Brocker, 2009).

A good freight network infrastructure enables the harmonious economic development of a country. The positive effects of infrastructure allow for increased productivity, lower transport costs and increased international freight trade flows (Fu et al., 2020; Habib et al., 2021; Milewski et al., 2023). However, at the level of each country there may be negative aspects of transport network infrastructure (Cioca et al., 2017).

Transport infrastructure is intended for all transport activities, as well as transport-related activities and infrastructure management (Agache et al., 2021; Ivașcu, 2022). Infrastructures are divided into several categories: road, rail, water, air and pipeline (Draghici et al., 2021; Toto et al., 2019).

Improved infrastructure helps to reduce transport costs and delivery times (Rietveld and Nijkamp, 1992).

For freight transport, there are several types of transport systems used, namely road, rail, sea and air. These have a significant physical, social and economic impact on the environment (De Abreu et al., 2022; Kanwal et al., 2020; Toto et al., 2019).

The most widely used transport system is the road transport system, which can be used for all types of goods. The effects of pollution caused by road transport are influenced by a number of factors, such as atmospheric conditions, climate, type of fuel used, age of the vehicles and poor vehicle care (Kanwal et al., 2020).

Rail transport is usually used for transporting large quantities of goods or for constant flows. Rail freight transport contributes most to reducing environmental impacts (Habib et al., 2021; Ülker et al., 2021)

The shipping system is divided into two distinct categories: maritime transport and inland waterway transport. This type of transport system has the capacity to transport very large quantities of goods at the lowest rate, but over a longer period of time than other transport systems.

As far as air freight is concerned, one of the most important direct environmental impacts is related to the release of carbon dioxide into the atmosphere, a gas that contributes to accelerating global warming (Fu et al., 2020; Vivek et al., 2022).

3 METHODOLOGY

The data collection process was carried out with the help of Eurostat, the statistical office of the European Union. A set of road, rail, maritime and air transport data published between 2013 and 2022 was analysed. The research thus provides a detailed analysis of the four transport systems, an analysis covering infrastructure as well as volumes transported at national level for each transport system.

Thus, the present work was carried out in two steps: the collection of published data from 2012 to 2022, followed by an analysis of the identified data. This analysis includes the analysis of the infrastructure in Romania for the analysed transport systems and the analysis of the volumes transported during the reference period.

With the data collected and analysed, we aim to highlight the current trends for freight transport, but also the current infrastructure of transport circuits in Romania, by representing the data in the form of graphs, using Excel, to obtain a general perspective on the infrastructure and transport volumes. We will also explore possible issues related to freight transport infrastructure and new trends in this field.

To determine the optimal transport volumes for each system, a code was developed in Python programming language, which, to determine the simulated numerical values, was run in the Visual Studio Code application, a code editor with extensive support.

In order to write a mathematical model to determine the optimal transport volume for each transport mode, a linear programming formulation will be used. The variables are defined as follows:

x_1 - for road transport,

x_2 - for rail transport,

x_3 - for maritime transport,

x_4 - for air transport.

The objective may be to maximise or minimise a criterion, such as profit or total volume of goods transported, denoted as Z.

The mathematical model looked like this:

Min/max (Z) = $\boldsymbol{c_1x_1 + c_2x_2 + c_3x_3 + c_4x_4}$

Conditions:

$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 \leq$ b1

$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 \leq$ b2

.

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$a_{n1}x_1 + a_{n2}x_2 + a_{n3}x_3 + a_{n4}x_4 \leq b_n$

x1, x2, x3, x4 ≥ 0

c_1, c_2, c_3, c_4 are the cost or benefit coefficients for each mode of transport;

a_{ij} are the coefficients for each constraint;

b_j are the limit values for each constraint;

x_1, x_2, x_3, x_4 are the decision variables, which represent the transport volumes for each mode.

The simulation of the optimization model based on existing data for road, rail, sea, and air transport is using the Python PuLP library, which is a linear programming library. First, the PuLP library must be installed, and the appropriate variables, coefficients and constraints defined for the model. Then the model can be solved to obtain the optimal transport volumes for each mode as follows:

```
# Install the PuLP library
!pip install pulp

# Import the PuLP library
import pulp
```

```
# Define the optimization problem
prob = pulp.LpProblem("Transport_Optimization", pulp.LpMaximize)

# Define the decision variables (transport volumes for each mode)
x1= pulp.LpVariable("Road_Transport", lowBound=0) # Road transport
x2 = pulp.LpVariable("Rail_Transport", lowBound=0) # Rail transport
x3 = pulp.LpVariable("Maritime_Transport", lowBound=0) # Maritime transport
x4 = pulp.LpVariable("Air_Transport", lowBound=0) # Air transport
# Define the objective coefficients (maximizing the total transport volume)
c1 = 191.879 # Coefficient for road transport
c2 = 2.094 # Coefficient for rail transport
c3 = 43.577 # Coefficient for maritime transport
c4 = 755 # Coefficient for air transport

# Define the objective
prob += c1 * x1 + c2 * x2 + c3 * x3 + c4 * x4
# Define the constraints
# (these can also be extrapolated from existing data or defined specifically)
# In this example, let's assume we have no specific constraints
# Solve the problem
prob.solve()
# Display the results
print("Results:")
for var in prob.variables():
    print(var.name, "=", var.varValue)
print ("Optimal total transport volume:", pulp.value(prob.objective), "units")
```

4 ANALYSIS OF RESULTS

4.1 Analysis of infrastructure

4.1.1 The road transport system

The road transport system has roads as its main component. The road is a land communication route, specially designed for the movement of vehicles and pedestrians. Roads also include bridges, viaducts, tunnels and car parks. Roads are divided into several categories, such as motorways, express roads, European roads, national roads, county roads, municipal roads and local roads.

Motorways are of significant importance for freight transport in many respects, but the most important aspect is the speed at which vehicles can travel, thus reducing delivery times.

Romania currently has 1074 kilometres of motorways and expressways. Figure 1 shows a map of existing motorways and motorways under construction, reported by the National Road Infrastructure Management Company, as of 31 December 2023.

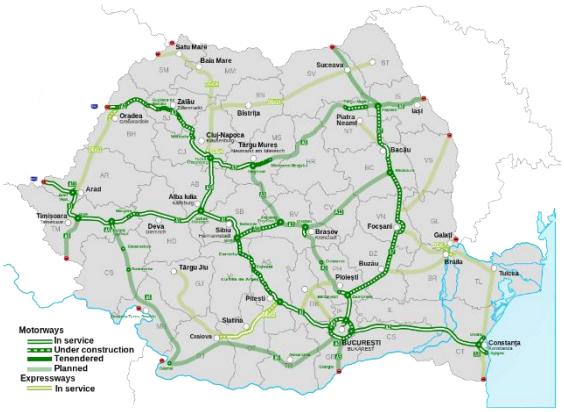

Figure 1. Map of motorways in Romania

Source: www.wikipedia.ro

In order to observe the trend of improvement of the motorway infrastructure in Romania, we carried out a statistical analysis of the number of existing kilometres over a period of 10 years. The reference period is 2014 - 2023. Figure 2 shows the evolution of road infrastructure development, specifically motorways.

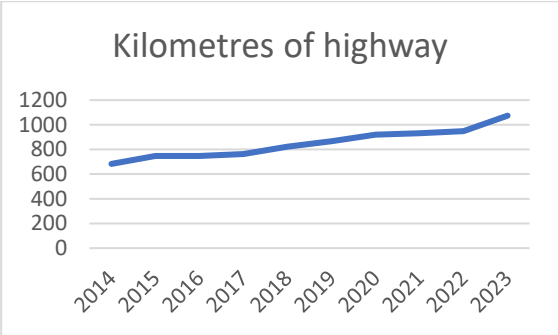

Figure 2. Evolution of number of motorway km

Source: Own processing of Eurostat data

Although a steady upward trend can be seen in the graph above, which indicates that the development of road infrastructure in Romania is growing, a slow development can be observed. In a ten-year period, 2014 - 2023, only 391 kilometres of motorway have been built and put into use. This has a negative impact on national and international freight transport for trucks transiting Romania.

4.1.2 The railway transport system

The rail transport system has as its main components railways, locomotives, wagons, yards, railway stations and traffic control facilities.

According to the National Railway Company "CFR" SA, the railway network in Romania has a total length of 19,629 kilometres; in Figure 3 you can see the map of the railway network.

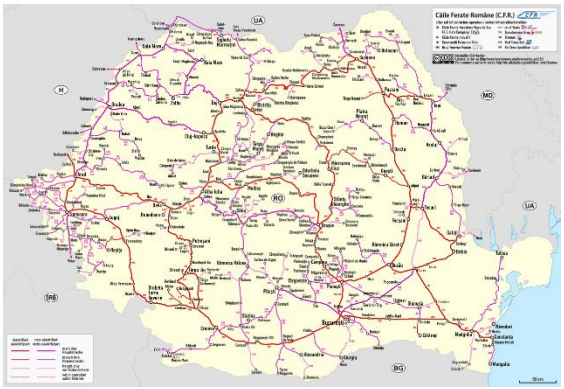

Figure 3. Map of the railway network in Romania

Source: www.wikipedia.ro

Nationally, the rail network is made up of both electrified and non-electrified railways. Over the years, rail infrastructure has developed at a slow pace, with no significant changes in the development of rail infrastructure.

According to Eurostat data, Figure 4 shows the stagnation of railway modernisation and the transition from non-electrified to electrified railways.

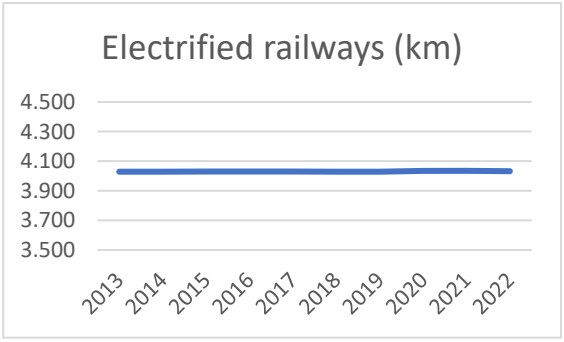

Figure 4. Evolution of the number of km of electrified railways

Source: Own processing of Eurostat data

In the graph above, over a ten-year period, 2013 - 2022, at the national level, there have been no changes to modernise the railways. At present, there are only 4,031

kilometres of electrified railways in Romania, although at European level, the development of rail infrastructure for freight transport is in full swing, trying as far as possible to replace road transport.

4.1.3 Maritime transport system

The maritime transport system has ships, ports, and the sea as its main components.

There are four seaports in Romania, namely Constanta, Mangalia and Midia.

The Port of Constanta is the largest seaport in Romania and among the 20 largest ports in the European Union. It is divided into three divisions: cargo, tourist and river ports. Figure 5 shows the geographical position of the port of Constanta.

Figure 5. Constanta port location

Source: www.wikipedia.ro

As can be seen, the port of Constanta is located on the western coast of the Black Sea.

4.1.4 Air transport system

As far as the air transport system is concerned, its main components are runway/landing, terminal, loading/unloading apron, aircraft parking apron, fast evacuation path, service apron, fuel depot and control tower. Figure 6 shows the existing international airports at national level, as well as those in the Republic of Moldova.

According to Eurostat data, there are currently 8 commercial airports operating in Romania. Table 1 shows the number of active commercial airports between 2013 and 2021.

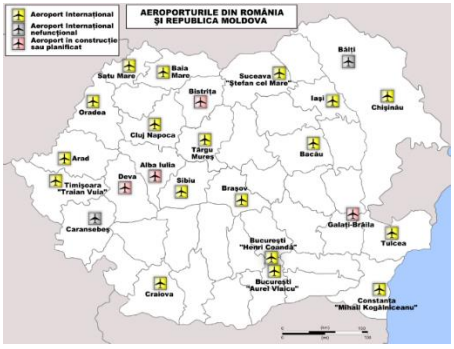

Figure 6. Airports location

Source: www.wikipedia.ro

Table 1. Number of active commercial airports (Eurostat, 2024)

	Number of commercial airports
2013	**7**
2014	**7**
2015	**7**
2016	**8**
2017	**9**
2018	**9**
2019	**9**
2020	**7**
2021	**8**
2022	**8**

According to the table above, it can be seen that in 2017 there were 9 commercial airports operating in Romania, but in 2020, two of them suspended their activity. This is due to the COVID-19 pandemic; the pandemic period negatively affecting cargo transport.

4.2 Analysis of transported volumes

Table 2. The volume of freight transport from Romania in the years 2013-2022 (thousand tonnes)

Year	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**
Road	191.879	191.308	199.220	216.621	226.796	237.496	257.004	266.976	307.357	324.895
Rail	2.094	2.324	2.053	1.856	2.617	2.601	2.114	2.164	2.154	1.735
Maritime	43.577	43.753	44.533	46.295	46.182	49.107	53.101	47.220	53.121	60.260
Aerian	755	764	768	791	802	862	922	832	778	937

Source: Authors' own processing according to the Eurostat database

4.2.1 The road transport system

A closer look at the road freight transport data for the period 2013-2022

Table 2 shows a remarkable development in the volume of goods transported by road (Fig 7). According to the Eurostat database, 191,879 thousand tonnes of goods were transported in 2013, and this figure has steadily increased over the years, reaching 324,895 thousand tonnes in 2022.

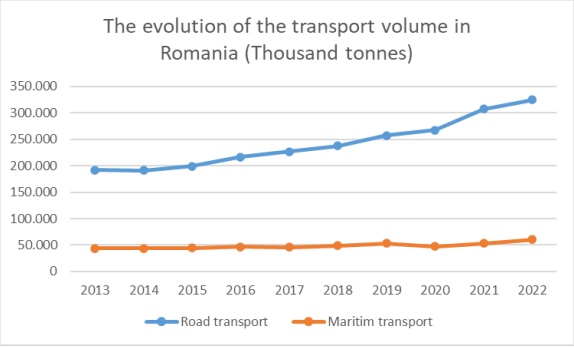

Figure 7. Evolution of the volume of goods transported by road and sea

Starting from the year 2014, road transport experienced a slight decrease of 0.571 thousand tonnes compared to 2013. However, this trend was quickly reversed in 2015, when it increased by 7.912 thousand tonnes. This growth continued in 2016 with an additional 17.401 thousand tonnes, and it was sustained in the following years, recording annual increases until 2019. In 2020, the growth slowed down with an increase of 9.972 thousand tonnes, but it surged again in 2021 with an impressive growth of 40.381 thousand tonnes. The year 2022 continued this upward trend, adding another 17.538 thousand tonnes to the total.

This significant increase indicates a growing demand for road transport services and a continued reliance on this mode of transport to ensure the mobility of goods.

This steady growth can be attributed to several factors. Firstly, Romania's steady economic expansion during this period has led to a increased demand for freight transport. Increased international trade and general economic activity have led to an increased need for transport to ensure the flow of goods to and from markets. The flexibility and accessibility offered by road transport also make it an attractive choice for many operators, which has contributed to the continuous growth in the volume of goods transported by road.

The economic implications of this growth are significant. Increased demand for road transport services means more economic activity in the transport sector, generating

opportunities for growth and job creation. In addition, an efficient and well-maintained road network is essential to sustain this growth and ensure a seamless connection between producers, distributors and consumers. Thus, the data underlines the vital importance of road transport in Romania's economy and the continued need to invest in transport infrastructure and services to meet growing market demands and sustain long-term economic development.

4.2.2 The railway transport system

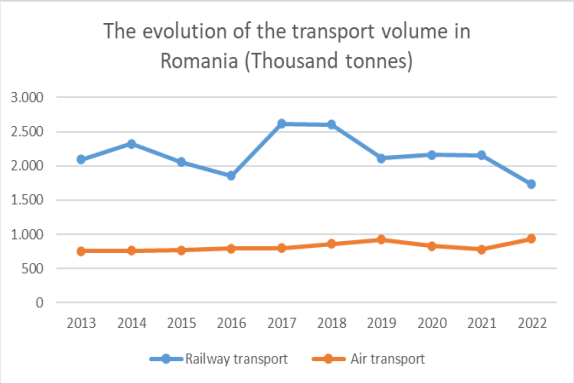

Fig. 8 - Evolution of freight volume transported by rail and air

During the period analysed, we observe a significant fluctuation in the volume of freight transported in intermodal transport units (Table 2 - rail transport). From a high of 2,617 thousand tonnes in 2017 to a low of 1,735 thousand tonnes in 2022 (Fig. 8).

The railway sector had a more fluctuating evolution. In 2014, a modest increase of 0.23 thousand tonnes compared to 2013 was recorded. However, in 2015 and 2016, the volume decreased by 0.271 and 0.197 thousand tonnes, respectively. There was a revival in 2017 with an increase of 0.761 thousand tonnes, but the volume decreased slightly in 2018. The years 2019 and 2020 brought minor fluctuations, and in 2021, a minor decrease was recorded. The year 2022 marked a significant decrease of 0.419 thousand tonnes compared to the previous year (fig. 7).

Most notable is the sharp increase in the volume of goods transported in intermodal units in 2017, when the figure reached 2,617 thousand tonnes, which is a series peak. This high level could be influenced by specific factors in that period, such as increased demand for intermodal transport or the implementation of specific transport policies or projects.

Despite yearly fluctuations, there is a general downward trend in the volume of goods transported in intermodal units over the period under review. Although there are some annual variations, overall, the volume seems to gradually decrease from the beginning of the series in 2013 until 2022.

Several factors could influence this downward trend, including changes in supply and demand for intermodal transport, changes in the structure of the economy and trade, and possible changes in transport policy or regulation.

The data series on goods transported in intermodal units reflects a significant variation over the period analysed, with an overall downward trend in the volume transported. This underlines the importance of closely monitoring the development of intermodal transport and identifying potential transport influences and trends.

4.2.3 Maritime transport system

Analysis of the data generated by Eurostat (Table 2 - maritime transport) reveals a solid upward trend (Fig. 6) in the volume of cargo handled in Romanian ports in the period 2013-2022. This steady growth is a sign of an expanding economy and increasing international trade, supported by the development of port infrastructure and favourable economic conditions.

Maritime transport experienced an upward trend, except for a minor decline in 2017. In 2014, there was an increase of 0.176 thousand tonnes compared to the previous year. The growth continued in 2015 and 2016, with 0.78 and 1.762 thousand tonnes, respectively. After a slight decrease of 0.113 thousand tonnes in 2017, the growth accelerated in 2018 and 2019, with 2.925 and 3.994 thousand tonnes. In 2020, there was a decrease of 5.881 thousand tonnes, but maritime transport rebounded in 2021 and 2022 with increases of 5.901 and 7.139 thousand tonnes, respectively.

However, it should be pointed out that some notable fluctuations have been observed in this dataset. For example, the sharp and significant increase recorded in 2022 was influenced by the military conflict in Ukraine, which generated major changes in transport routes and led to an increase in the volume of goods transited through Romanian ports.

On the other hand, the decrease in 2020 can largely be attributed to the impact of the COVID-19 pandemic on the global economy and supply chains, which caused a temporary decrease in port activity.

Overall, the data suggests that the Romanian port sector is an important driver of economic growth, benefiting from a well-developed port infrastructure and strategic positioning in the region. However, it is also important to pay attention to other factors that may influence port activity, such as changes in global cargo demand, geopolitical developments and international trade regulations.

Thus, continued investment in modernising port infrastructure, improving logistics services and diversifying trade links can help strengthen Romania's position as a vital hub in global transport and trade networks.

4.2.4 Air transport system

The analysis of the data series on air freight and mail transport over the national territory, expressed in million tonne-kilometres (MTC), provides an insight into the evolution of this sector in Romania in the period 2013-2022, as shown in Fig. 7.

Air transport recorded slight increases in 2014 and 2015, with 9 and 4 thousand tonnes, respectively. The increases became more significant in 2016 and 2017, with 23 and 11 thousand tonnes. In 2018 and 2019, the volume increased annually by 60 thousand tonnes, but decreased by 90 thousand tonnes in 2020 and by 54 thousand tonnes in 2021. A major revival occurred in 2022, with a volume increase of 159 thousand tonnes.

We observe a significant increase in air freight and mail throughout the period under review. From 755 million tonne-kilometre (TKM) in 2013, the volume has steadily increased to a peak of 937 million TKM in 2022. This upward trend indicates an increase in domestic air freight activity over this timeframe.

While we see a general increase, the data series also shows yearly fluctuations. For example, between 2013 and 2016, growth was smoother, averaging around 4-5% annually. Then, between 2016 and 2019, we see more pronounced growth, with an average annual growth rate of around 6-7%. However, in 2020 and 2021, we have a significant decrease of around 10-11%, probably influenced by various factors such as economic fluctuations or the effects of the COVID-19 pandemic on the aviation industry.

One notable aspect is the strong recovery seen in 2022, when air freight volumes peaked at 937 million TKM, surpassing previous levels and indicating a significant recovery in air transport activity.

The data suggest an overall increase in domestic air freight and mail over the period

2013-2022, with year-to-year fluctuations attributable to various factors. The strong recovery in 2022 indicates the resilience and adaptability of the air transport sector in the face of economic and pandemic challenges.

5 DISCUSSION

Following the study, it was found that the road infrastructure is in continuous development, the number of kilometers of highways and roads increasing from year to year. As a consequence of this aspect, the increase in the transport volume related to this transport system was found. It is found that the difference in the volume of goods transported by road between 2013 and 2022 is 133,016 thousand tons.

Regarding rail freight, the main problem is low investment and slow infrastructure development. This is noted by the reduced number of electrified railway kilometers in 2022, reaching only 4032 kilometers, compared to 4029 kilometers 10 years ago. The physical and moral wear and tear of the existing rolling stock, as well as the abolition of secondary routes, also having a negative impact on the evolution of rail transport in Romania.

By simulating the transport optimization model using existing data for road, rail, sea and air transport volumes over the 2013-2022 timeframe, total transport volumes were maximized with an additional 10% constraint for each transport type due to development.

The result of the simulation is as follows:

- optimal road transport volume: 357,385 thousand tonnes;
- optimal rail transport volume: 1,909 thousand tonnes;
- Optimum shipping volume: 66,286 thousand tonnes;
- optimal air transport volume: 1,031 thousand tonnes;
- total optimal transport volume: 426,609 thousand tonnes.

The most representative additional constraints that can be introduced into the model are maximum infrastructure capacity, minimum and maximum transport requirements and transport costs.

The usefulness of this program lies in its ability to simulate and optimise transport volumes for different transport modes (road, rail, sea and air) based on existing data and specified coefficients. By using a linear programming library such as PuLP in Python, the program can solve an optimization problem to determine optimal transport volumes in an efficient and accurate way.

Users can use it to make informed transport decisions such as planning transport routes, optimising resources and costs, managing supply chains and assessing the impact of different scenarios on total transport volume. It can also be useful in strategic planning and decision-making contexts in various industries involving freight transport.

6 CONCLUSION

Investment in motorway construction and expansion can make a significant contribution to improving the efficiency and speed of freight transport. Motorways allow vehicles to travel at higher speeds and avoid heavy traffic in urban or congested areas, leading to shorter transit times and optimised transport logistics.

The slow development of the motorway network in Romania, as well as the relatively low number of kilometres built in a ten-year period (2014-2023), could have a negative impact on the efficiency and competitiveness of road freight transport. The lack of extensive and well-connected motorway routes could prevent maximising the potential of road freight transport.

To support economic growth and improve the efficiency of freight transport, it is essential that the government continues to invest in the expansion and modernisation of road infrastructure, in particular the construction of motorways and expressways. The introduction and development of modern transport technologies based on the intensive use of groupage means is not an end in itself, but an effective means of increasing economic efficiency in transport. The development of an efficient and well-connected road transport network will support not only an increase in the volume of goods transported, but also long-term sustainable economic development.

The stagnation in the modernisation and expansion of Romania's railway network is evident and could negatively affect the efficiency and competitiveness of rail freight transport. Sustained investment in the modernisation of rail infrastructure is needed to support the growth of freight transport and improve domestic and international connectivity.

The development of rail infrastructure must include the extension of the electrified rail network and the modernisation of stations and equipment. This will increase the efficiency and sustainability of rail transport and reduce the associated carbon emissions.

The authorities need to develop a long-term strategic plan for the modernisation and development of rail infrastructure in cooperation with operators and other stakeholders. This plan should consider the current and future needs of the economy and prioritise investments according to their impact on freight transport and overall economic development.

The steady increase in the volume of cargo handled in Romanian ports during the period under review indicates a growing economy and increased trade activity, supported by well-developed port infrastructure.

Notable fluctuations in cargo volumes, such as the sharp increase in 2022, underline the sensitivity of the port sector to major geopolitical events and changes in global cargo demand.

Continued investment in modernising and improving port infrastructure is essential to strengthen Romania's position as a vital hub in global transport and trade networks and to adapt to changes in the economic and geopolitical environment.

The increase in the number of commercial airports between 2013 and 2017 may have facilitated better geographical coverage and accessibility, which could have contributed to the growth of air cargo activity.

The slight decrease in the number of commercial airports in 2020 could be correlated with a decrease in the volume of air cargo transported in the same year, due to travel restrictions and reduced air traffic in the wake of the COVID-19 pandemic.

The stabilisation of the number of commercial airports at 8 in 2021 and 2022 can be associated with a gradual recovery of activity in the airline industry and thus an increase in the volume of air freight transported within the national territory.

Following the mathematical calculation to determine the optimal transport volume for each transport system analysed (road, rail, sea and air) it was found that the average volumes transported, by transport system, are close to the optimal volumes determined using Phyton software.

Three promising directions for further research were identified, including: the analysis of the impact of transport infrastructure on economic competitiveness, the integration of intermodal transport and their impact on supply chains, and the correlation between transported freight volumes and economic development.

7 DIRECTIONS FOR FURTHER RESEARCH

In light of the complexity of modern transport and the need for continuous adaptation, three directions for further research have been identified to investigate more deeply the interlinked aspects of maritime, rail, road and air transport in Romania.

Investigating the impact of intermodal transport integration on the efficiency of supply chains could reveal how the coordination of sea, rail, road and air transport can improve the flow of supply chains in Romania.

Analysis of the state of transport infrastructure and its impact on economic competitiveness could highlight current and necessary infrastructure investments to increase the competitiveness and efficiency of freight transport in the country.

Research into future trends in freight transport and the impact on economic development could provide insights into how the growth of international trade and innovations in logistics will affect Romania and what opportunities and challenges they will entail.

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