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Școala Doctorală de Inginerie Industrială și Robotică

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SUMMARY THESIS

Contribuții privind eficientizarea transportului multimodal și implicații în industrie

Contributions on multimodal transport efficiency and industry implications

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Universitatea Națională de Știință și Tehnologie POLITEHNICA București
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REZUMAT
TEZĂ DE DOCTORAT

Contribuții privind eficientizarea transportului multimodal și implicații în industrie

Contributions regarding the optimization of multimodal transportation and implications in the industry

PhD student: Desdemona Isabela SCĂRIȘOREANU

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CONTENT

INTRODUCTION

Humans have always desired to travel, as evidenced by numerous journals, such as "The Diversity of the World," a work in which the Venetian Marco Polo revealed the fabulous universe of Asia to Europe. Not by chance, over 70 years ago, the United Nations General Assembly adopted and proclaimed the "Universal Declaration of Human Rights," which recognized the "right of every person to move freely." And 9 years later, through the "Treaty on the Functioning of the European Union," signed in Rome, the "right to free movement of persons across internal borders" became one of the fundamental freedoms of the European Union (EU) and its single market. Furthermore, Regulation (EU) 1315/2013 introduced the definition of multimodal transport: the carriage of passengers or goods or both by using two or more modes of transport.

However, after more than half a century since the first human set foot on the Moon, booking a journey into space, aboard a station designed for space tourism, seems simpler than booking a single travel ticket to commute from Brănești to the Dacia Mioveni plant.

The creation of an integrated reservation and ticket payment system for over 10 years has been on the European Union's transport policy agenda. However, to date, a common

platform for booking and purchasing a single travel ticket for multimodal transport in the EU has not been developed. In 2018, it was declared the "Year of Multimodal Transport," and the European Commission funded studies to identify the challenges and barriers to the development of an integrated online reservation and ticket purchase system for multimodal passenger transport at the EU level. In 2021, the European Commission presented "regulatory measures to enable the issuance of innovative and flexible tickets, combining different modes of transport," and offering passengers options for "door-to-door" travel. These measures come in the context of the EU's objective to "reduce greenhouse gas emissions by at least 55% by 2030 and achieve climate neutrality by 2050," as outlined in the "European Green Deal."

Viewed as a solution for alleviating traffic congestion and reducing pollution by encouraging the use of public transportation, multimodal transport represents the only way to connect isolated and distant localities with various cities or settlements located far apart from each other. At the same time, creating a platform to facilitate online reservation and purchase of a single travel ticket comes to the aid of those who travel or commute to and from work, as they can procure their single travel ticket using a mobile phone or computer. Last but not least, transport companies will be able to increase their sales with minimal costs (there are no costs associated with renting ticket sales spaces, utility expenses, or personnel costs for servicing these ticket sales spaces).

Furthermore, the introduction of the integrated e-ticketing system will lead to a reduction in tax evasion, better planning of the activities of transport operators, and, consequently, a more efficient utilization of the transport network's capacities. At the same time, the integrated reservation and payment system for a single travel ticket meets the current needs of society, one of which is the need for mobility.

However, the EU's concerns regarding multimodal transport are not limited to passenger travel. It must be emphasized that the transportation sector has a strong strategic component. Therefore, the cost of transporting material and human resources is reflected in the cost of goods produced in national economies, in the broader sense. In the conditions of globalization, this cost is constantly increasing. In any local market, goods produced in that area compete with those from suppliers located at great distances. Hence, analyzing the transportation sector in conjunction with industrial processes, supply chains, and distribution is absolutely necessary in terms of economic aspects and the standard of living in the current era.

Because in the European community, goods are predominantly transported by road, a mode of transport responsible for 72% of the total CO2 emissions produced by the transportation sector, efforts are being made to promote multimodal freight transport. Specifically, solutions are sought to redirect a substantial amount of goods from the road to rail, with rail transport being considered an eco-friendly mode of transportation. However, this will only be possible if the cost of rail transport becomes competitive compared to road transport, while at the same time, transportation conditions by rail are improved. Therefore, internalizing the external costs of road transport is necessary because, at present, EU member states finance different modes of transport in various ways. This creates a competitive advantage for road transport over rail transport, allowing road transport companies to offer more favorable prices to customers than rail transport operators can.

In this situation, answers have been sought to the question: What conditions must Romania meet in order to achieve the ambitious targets set by the "European Green Deal" and the "Strategy for Sustainable and Smart Mobility - Shaping the European Transport Future"? Solutions were identified through an external and internal analysis of multimodal freight transport in Romania, as well as the use of forecasting methods.

Furthermore, in the case of multimodal passenger transport, methods were found to streamline the commuting of employees to the workplace by using multiple modes of transport.

The doctoral thesis analyzes solutions for optimizing multimodal freight and passenger transport and their implications for the industry. The current state of knowledge focused on studying the current situation of freight and passenger transport, in the context of its influence on the costs of industrial processes, at the EU and Romania levels. Additionally, it analyzed the EU agenda for sustainable mobility and the national legal framework for the development of multimodal freight and passenger transport.

To identify solutions for optimizing multimodal freight transport, both external and internal analysis methods of multimodal freight transport in Romania were employed, along with strategic forecasting methods.

Additionally, a separate study focused on the cost efficiency of freight transport along the Lipova-Railport Arad Intermodal Terminal-Port Constanța-Dubai Ports World (DP World) route. This route is highly relevant concerning its significant influence on the national industry. Lipova was chosen as the starting point because several companies from various industrial sectors operate there, and the route is part of the "Freight Rail Corridor 9 Rhine-Danube," which traverses Romania. Moreover, the Railport Arad Intermodal Terminal is one of the largest inland intermodal terminals in Central and Eastern Europe, located near the Curtici station at the Romanian-Hungarian border. DP World, on the other hand, is the largest container terminal within the Port of Constanța, the primary gateway for goods entering and leaving the European Union through the Black Sea.

A separate chapter was dedicated to contributions regarding the optimization of employee transportation to the workplace. After analyzing the dysfunctions in providing transportation for employees to their workplace, a route was selected that focuses on connecting the Dacia industrial platform in Mioveni with the pool of human resources around Bucharest. This route encompasses the localities of Brănești, Pasărea, Pantelimon, Voluntari, Otopeni, Mogoșoaia, and Chitila. The Dacia industrial platform encompasses production, logistics, and export activities, with around 13,000 employees working there.

Since there are currently no public transportation means that ensure the timely transport of employees living in the outskirts of the capital, a circulation schedule for multimodal transportation between Brănești and the Dacia-Mioveni platform was designed to meet current needs.

Furthermore, simulations were conducted for the process of online reservation and purchase of a single travel ticket for the Brănești-Dacia Mioveni route and return. In this regard, to create an application for online reservation and purchase of both railway and road transportation single tickets, the process was modeled using the Unified Modeling Language (UML). Thus, an activity diagram for the application for online reservation and sale of a

single travel ticket on the Brănești-Dacia Mioveni route and return was designed. This serves as the starting point for the development of the aforementioned application.

ABREVIATION

No.	**Abreviation**	**Significance**
01	ARF	Railway Reform Authority
02	BPMN	Business Process Model and Notation
03	C_{at}	The cost of access to the DP World Constanța terminal for trucks
	C_b	Gasoline cost
04	C_d	The price of the fuel used for the movement of the train in the Port of Constanța, on non-electrified railway tracks
05	$C_{d\ 2\ vagoane}$	The price of the fuel used for towing two wagons on the non-electrified railway tracks in the Port of Constanța
06	C_{ee}	Electric energy consumption
09	CE	European Commission
07	C_F	The estimated cost of salaries for those involved in the supply of electrical energy, which includes direct material expenses, indirect costs, and general expenses for these employees. This is reported in relation to the estimated energy consumption of the railway traction network
08	C_{fp}	The cost of supplying traction electric power and the profit margin
09	C_{he}	The electric energy consumption of the Coradia Stream electric train
10	C_{ht}	The hydrogen consumption required for the train's traction
11	C_m	The cost of diesel fuel required for the road transportation of goods
12	C_{mbm}	The cost of diesel fuel for the road transportation of employees to their workplace, on the Brănești-Mioveni route
13	$C_{motorină}$	The diesel consumption for the movement of the train in the Port of Constanța, on non-electrified railway tracks
14	CNCF CFR SA	The National Railway Company „CFR” – SA
15	Container 20`	20-foot container
16	C_p	The cost of the Fetești Bridge toll (for the transportation of goods by road)
17	C_{ph}	The production cost of the hydrogen required for the train's traction
18	C_{PR}	The estimated value of the profit from the supply activity relative to the estimated consumption of electric energy of the railway traction network
19	C_r	Toll cost
20	C_{rbm}	The cost of road transportation for employees to the workplace, on the Brănești-Mioveni route, using a Master Bus minibus
21	C_{ro}	The daily toll cost for road transportation of employees to the workplace on the Brănești-Mioveni route
22	$C_{rtotalbm}$	The total cost of road transportation for the 350 employees, using

		Master Bus minibuses, on the Brănești-Mioveni route
23	C_t	The cost of road transportation for the three containers, on the Lipova-Railport Arad-DP World Constanța route
	C_{t19}	The cost of transporting goods with 19 trucks
24	$C_{totalbm}$	The multimodal transportation cost of employees to the workplace, on the Brănești-Uzina Dacia Mioveni route (transportation by railway using the hydrogen-powered Coradia Steam train)
25	C_{tf}	The cost of rail transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța route
26	$C_{tf2vagoane}$	The cost of rail transportation for the three containers, on the Lipova-Railport Arad-DP World Constanța route
27	C_{tfe}	The cost of rail transportation on the Brănești-Uzina Dacia Mioveni route, using the electric Coradia Steam train
28	C_{ti}	The multimodal transportation cost of the 56 containers on the Lipova-Railport Arad-DP World Constanța route
29	C_{tfa}	The cost of rail transportation on the Brănești-Pitești route using the hydrogen-powered Coradia Steam train
30	C_{totale}	The total multimodal transportation cost of employees, on the Brănești-Platforma Mioveni route, when rail transportation is done using the electric Coradia Steam train
31	$C_{tptotal}$	The total cost for the transportation using personal cars for the 350 employees, on the Brănești-Platforma Mioveni route
32	C_{tr}	The cost of road transportation for the 56 containers on the Lipova-DP World Constanța route
42	C_{trac}	The price of electric traction energy, on the Brănești-Pitești route, for the Coradia Steam electric train
33	C_{trm}	The total transportation cost on the road system, on the Pitești-Platforma Mioveni route
43	$C_{trmtotal}$	The cost of road transportation for employees with the 44 Renault Master minibuses
35	d	The distance in kilometers covered on the TUI section (the section corresponding to each class of track)
36	F_t	The tonnage factor symbolizing a correction coefficient applied to the gross tonnage of the train
37	INS	National Institute of Statistics
38	MTI	Ministry of Transport and Infrastructure
39	n_p	The number of passengers transported on the Brănești-Uzina Dacia Mioveni route
40	OTF	Railway undertaking
41	P_{et}	The price of traction energy on the electrified railway tracks
42	$P_{et\ 2\ vagoane}$	The price of traction energy for towing 2 wagons
43	P_{he}	The traction power of the Coradia Steam electric train
44	PIB	Gross Domestic Product
45	$P_{motorină}$	The price of diesel fuel for the movement of the train in the Port of Constanța, on non-electrified railway tracks
48	RFC	Rail Freight Corridors

49	USA	United States of America
50	SysML	Systems Modelling Language
51	t	The running time of the locomotive
52	T_c	The tariff for circulation, based on distance for each kilometer of track class
53	T_{co}	The access fee for shunting trains to/from the railway infrastructure of CNCF CFR SA
54	T_{dw}	Tariffs charged for the services provided within the DP World Constanța terminal for trains
55	TEN-T	Trans-European Transport Network
56	t_f	The time required for the rail transportation of the 56 cargo containers, on the Lipova-Railport Arad-DP World Constanța route
57	t_{fr}	The time required for the road transportation of the three containers, on the Lipova-Railport Arad-DP World Constanța route
58	t_i	The time required for multimodal transportation of the 56 containers/3 containers, on the Lipova-Railport Arad-DP World Constanța route
59	T_{medT}	Average transport tariff to the railway traction network
60	T_{min}	The gross weight of the train from which the tonnage factor is applied
61	Tonaj brut	The gross weight of the train, according to the 'Carriage Statement' form, including the locomotives in operation or the weight of locomotives or railcars in the case of circulation without towed rolling stock
62	t_r	The time required for transportation on the road network of the 56 containers, on the Lipova-DP World Constanța route
63	TTR	Timetable Redesign
64	T_{tse}	The tariff for the use of electrification elements for each kilometer of electrified track class, excluding the value of traction electric energy
65	T_{tsn}	The tariff based on tonnage for each kilometer of track class
66	TUI	Track Access Charges
67	$TUI_{circulație}$	The tariff for traffic management, based on the distance traveled
68	TUI_e	The tariff for the use of infrastructure, on the Brănești-Pitești route, in the case of using the electric train
69	$TUI_{electrificare}$	The tariff for the use of electrification equipment for each class of electrified line, only for electrically powered trains, based on the distance traveled
70	$TUI_{secție}$	The TUI value for a train traveling on a circulation route is calculated by summing the tariffs for each distance traveled on a TUI section
71	TUI_{tonaj}	The tariff for the use of railway infrastructure on a TUI section class, based on the distance traveled and the train's tonnage
72	TUI_{total}	Tariff for the use of railway infrastructure for the entire length of the train's route
73	$TUI_{total2vagoane}$	Total TUI for the transportation of two wagons on the Radna - DP World Constanța route
74	t_{ur}	The road transport time of human resources, on the Brănești-Uzina Dacia Mioveni route

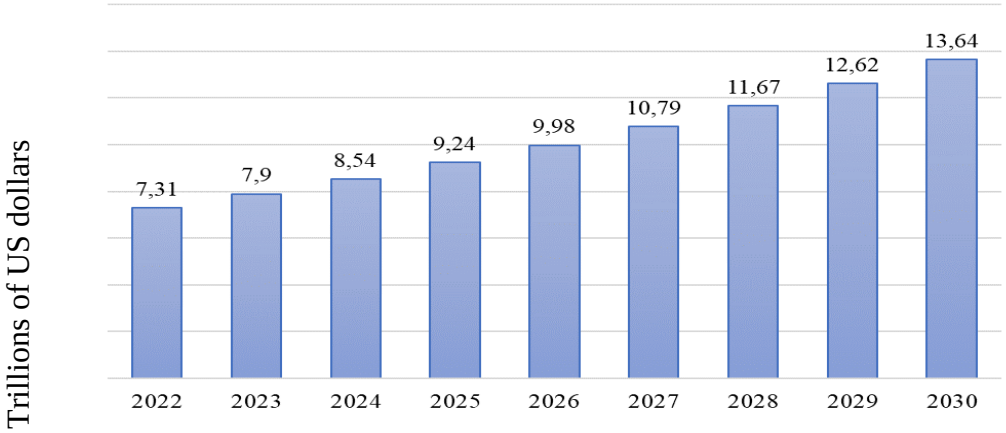
75	UML	Unified Modeling Language
76	TFUE	Treaty on the Functioning of the European Union
77	t_{um}	The multimodal transport time of human resources on the route Brănești-Uzina Dacia Mioveni, located on the Mioveni platform
78	t_{up}	The transport time of human resources by personal car, on the route Brănești-Uzina Dacia Mioveni
79	EU	European Union
80	V_{con}	The quantity of goods transported in a 20-foot container
81	V_{3con}	The quantity of goods transported in three containers
82	V_m	The quantity of goods transported in the 56 containers on the Lipova-Railport Arad-DP World Constanța route
83	η_{m3}	The efficiency of the multimodal transportation of the three containers on the Lipova-Railport Arad-DP World Constanța route
84	η_{tme}	The efficiency of multimodal employee transportation on the Brănești-Dacia Mioveni Factory route located at the Mioveni platform, when rail transport is provided by the electric train
85	η_{tf}	The efficiency of rail transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța route
86	η_{tf3}	The efficiency of rail transportation for the three containers on the Lipova-Railport Arad-DP World Constanța route
87	η_{ti}	The efficiency of multimodal transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța route
88	η_{tm}	The efficiency of the multimodal transport of employees, on the route Brănești-Uzina Dacia Mioveni, located on the Mioveni platform, in the case of transport with the Coradia Steam hydrogen train
89	η_{tp}	The efficiency of transport by employees' personal cars, on the route Brănești - Dacia Mioveni Plant, per employee
90	η_{tr}	The efficiency of the transport of employees by minibus, on the Brănești-Uzina Dacia Mioveni route
91	η_{tr3}	The efficiency of the road transport of the three containers, on the route Lipova-Railport Arad-DP World Constanța
92	η_{tr56}	The efficiency of the road transport of the 56 containers on the Lipova-Railport Arad-DP World Constanța route

Chapter 1 - Analysis of the transportation sector

1.1. Analysis of the Global Transportation Sector

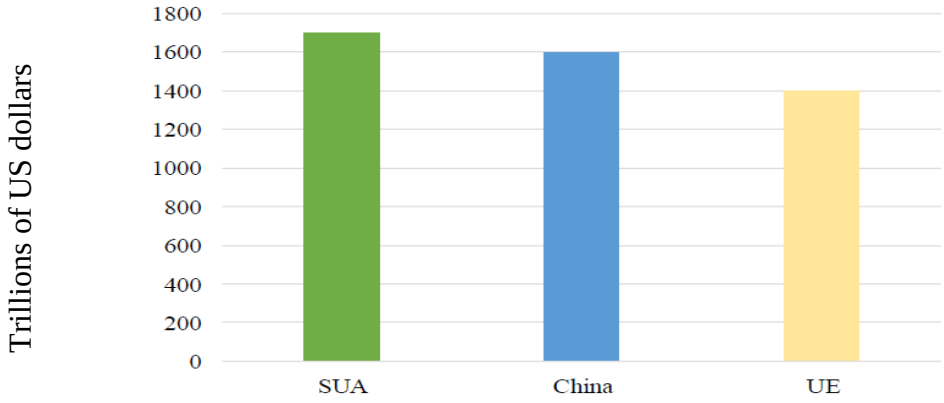
The industrial sector is closely linked to that of transportation, whether it involves transporting raw materials to production facilities, delivering finished products to customers of manufacturing companies, or transporting employees to their workplaces. Therefore, companies have sought solutions to facilitate the transportation of goods.

The size of the global market for transportation services was estimated at 7.31 trillion US dollars in 2022, and it is projected to reach approximately 13.64 trillion US dollars by 2030, with an average annual growth rate of 8.11% [1].



The estimated growth rate of the world transport market, in the period 2022-2030 [1]

In the year 2020, the transportation market in the United States was estimated to be around 1.7 trillion US dollars, while the estimated value of the transportation market in the European Union reached 1.4 trillion US dollars.

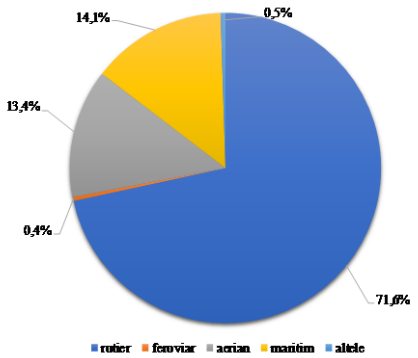


Estimated value of the US transportation market, China and the EU in 2020

1.2. Analysis of the European Union's transportation sector

Transportation is a strategic sector of the European Union's (EU) economy, essential for companies in Europe and for the global supply chains that ensure provisioning. Overall, it represents over 5% of the European Union's Gross Domestic Product (GDP), with over 10.5 million employees involved [2]. Associating the attribute of "strategic" to the transportation sector is justified by its influence on the global economy, including the EU and any national economy, in the short, medium, and especially long term, as well as in the complex issue of sustainable development. The efficiency of mobility services and global connectivity are prerequisites for almost all other economic sectors to function, enabling social exchanges, tourism, and the competitiveness of EU companies. Furthermore, according to Article 20, paragraph (2), point (a) of the "Treaty on the Functioning of the European Union" (TFUE),

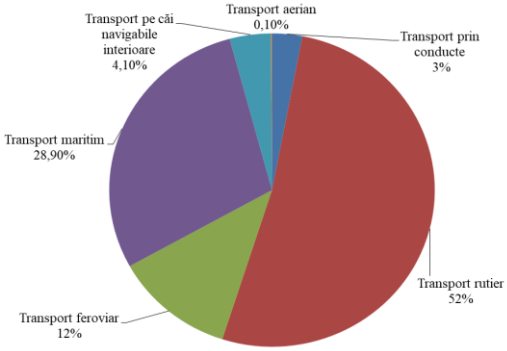
"the mobility of persons is essential for the European economy. And the right to free movement of EU citizens across internal borders is one of the fundamental freedoms of the EU and its single market" [3].
On the other hand, CO2 emissions generated by the transportation sector account for a significant share of the total greenhouse gas emissions in the EU. It is estimated that road transport is responsible for 72% of the total CO2 emissions produced by the transportation sector. Additionally, traffic congestion in road transportation results in annual costs amounting to approximately 1% of the EU's GDP [4].
Rail transport is considered the least polluting mode of transportation, accounting for only 0.4% of the total CO2 emissions resulting from transport activities.



Emisiile de CO_2 produse de sectorul transporturilor,
în UE 27, în anul 2019, pe moduri de transport [5]

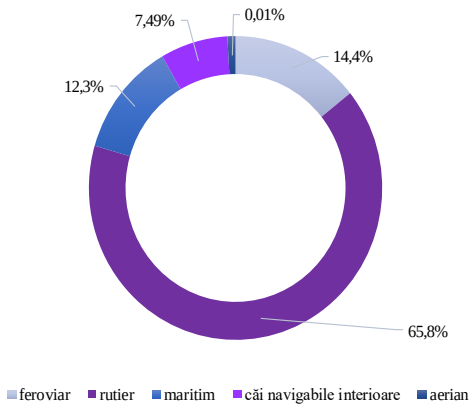
1.3. The study of the modal distribution of freight transport in the European Union

The most commonly used mode of transport in the EU is road transport, which held a share of 52% of the total freight transport in the EU-27.



Modal distribution in freight transport in the EU-27,
in 2019

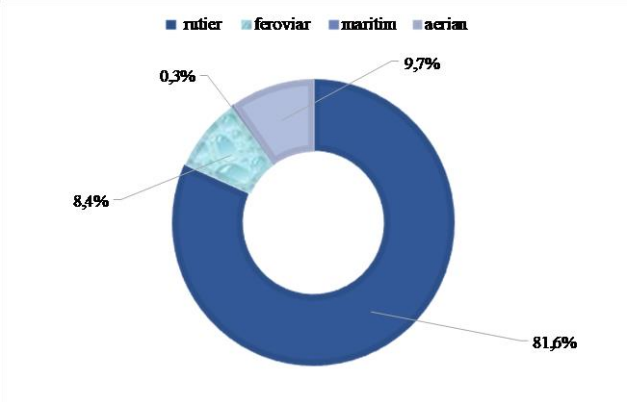
In Romania, during the period from 01.01 to 30.09.2021, road transport accounted for approximately 66% of the total modes of transport, according to statistical data from the National Institute of Statistics (INS) regarding the modal distribution of freight transport.



Modal distribution in freight transport in Romania,
01.01-30.09.2021

1.4. Study of modal distribution in passenger transport in the European Union

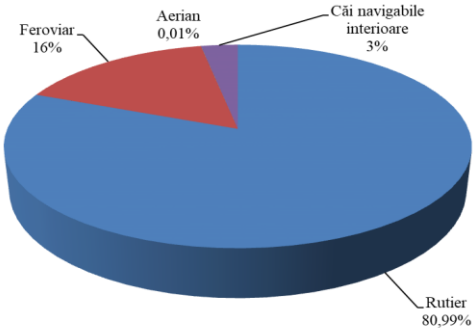
Regarding passenger transport, the total activity in the EU-27 using any motorized mode of transportation was estimated at 6.038 billion passenger-kilometers (the unit of measurement representing the transportation of one passenger through a defined mode of transport - road, rail, air, maritime, inland waterways, over one kilometer) or an average of approximately 13,498 km per person. Road transport held the largest share of total passenger transport in the EU-27, representing the preferred mode of transportation for Europeans.



Modal distribution in passenger transport in the EU-27,
in 2019

Furthermore, on average, 81.3% of Europeans chose to travel by their own cars, while in some member states, such as Lithuania and Portugal, personal car transportation accounted for nearly 90% of the total modes of transport [6]. The second most preferred mode of transport among Europeans is maritime (9.7%), followed by rail transport (8.4%).

În România, în anul 2021, transportul rutier deținea o cotă de aproximativ 81%, potrivit datelor statistice ale INS, referitoare la distribuția modală a transportului de călători.



Modal distribution of passenger transport in Romania in 2021

1.5.The influence of multimodal freight and passenger transport on industry performance

Transportation activity has been at the foundation of human civilization's development. "Transportation has managed to create a utility of time and space for products, making them available for consumption and use (leading to a reduction in production costs as transported quantities have increased), but also becoming part of the cost of products. With technological advancements, it has led to cost reduction and the production of more goods for more users," as stated in the work titled 'Freight Transportation: Concepts, Internationalization, and Management' [7]. Consequently, "transportation plays a crucial role in the economy, as without it, human activities would be impossible to organize and carry out. Transportation represents one of the significant activities in the economy across all industrial sectors, ensuring the movement of products (raw materials, materials, parts, subassemblies, finished products) from the production unit to the point of consumption. The transportation sector is a sine qua non activity within supply chains, from suppliers (upstream) to customers (downstream). Therefore, 'in most industrialized economies, the transportation sector has a significant impact on all economic activities, with transportation expenses accounting for 9-14% of the total costs of goods and services.' Thus, transportation constitutes a substantial portion of the prices of the products we purchase. Since transportation costs directly influence the cost of products, they affect pricing decisions made by companies, particularly firms whose policy is price-oriented [7] and organizations that have strategies based on cost reduction for competitive advantage [8]. Consequently, any changes in transportation costs have a direct impact on product prices, especially for products where transportation costs represent a significant proportion of the total cost of the product. The development of businesses relies on the state of transportation infrastructure. Prominent companies such as Dacia [9], Ford [10], and Daimler's subsidiary in Romania, Star Assembly [11], have urged authorities to invest in modernizing railways. Simultaneously, passenger transport facilitates access to employment, healthcare systems, culture, various events, etc. [7]. The availability of the workforce and, consequently, personnel costs are linked to ensuring connections between different areas with industrial platforms and factories. Under these conditions, an increasing number of companies are attempting to attract employees from localities near industrial platforms and provide transportation to their workplace. Thus, connections between different

modes of transportation are essential for employee transport and for addressing the human resource shortage in Romania.

Chapter 2 - Study of European Initiatives for Sustainable Transport

2.1. The European Union's agenda for sustainable freight transport

The transportation of goods is essential for supporting economic development. Therefore, over time, numerous European regulations and directives have been developed to promote sustainable freight transport. The latest steps were taken in 2019 through the 'European Green Deal for the EU' [12]. As a result, EU member states committed to 'reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels.' Subsequently, in 2020, two significant documents were published: 'Regulation (EU) 2020/1056 on electronic information for freight transport' [13] and „Strategy for Sustainable and Smart Mobility – putting European transport on track for the future" [14]. The regulation establishes a legal framework allowing economic operators to electronically share information with competent authorities concerning freight transport by road, rail, inland waterways, and air within the EU.

Regarding the EU Strategy, it emphasizes multimodality and includes provisions such as „freight rail traffic is expected to double by 2050 compared to 2015, and the majority of new vans and heavy vehicles will have zero emissions. Furthermore, the TEN-T multimodal network, designed for sustainable and smart transport with high-speed connectivity, will be operational for the core network by 2030 and for the global network by 2050"

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2.2. The European Union's agenda for sustainable passenger transport

The establishment of an integrated reservation and ticket payment system has been on the EU's transport policy agenda for over 10 years. In 2008, the 'EC Communication on the Action Plan for the Implementation of ITS in Europe' [15] was published, complementing the development program of the trans-European transport network. These applications are used for various modes of transport and to facilitate their interaction (intermodal platforms).

Among the recent initiatives is the „Directive 2016/2370/EU amending Directive 2012/34/EU concerning the opening of the market for domestic passenger rail transport services and the governance of the railway infrastructure" [16]. It includes provisions related to multimodal passenger transport: „To enable passengers to access the necessary data for trip planning and ticket booking within the Union, common systems for direct information and ticketing should be promoted, which have been developed by the market. Given the importance of promoting seamless public transport systems, railway undertakings should be encouraged to work on such systems, enabling multimodal, cross-border mobility options from origin to destination.".

So, in the near future, there is the premise that, to receive compensation for the execution of public service contracts, passenger transport operators will be required to participate in the „common system for direct information and ticketing, enabling multimodal, cross-border mobility options from origin to destination."

The next step was the „Strategy for Sustainable and Smart Mobility – putting European transport on track for the future" [13], published in 2020, which proposed ambitious targets: The strategy envisions that „by 2030, seamless multimodal passenger transport will be facilitated through integrated electronic ticketing systems, and freight transport will be digitized." These provisions complement those stipulated in the „Directive (EU) 2016/2370" [16] and emphasize the conditioning of obtaining EU funds, state aid, and compensation for the execution of public service contracts on the promotion of multimodal transport and, implicitly, the „issuance of innovative and flexible tickets, combining different modes of transport."

It should be noted that currently, Romania does not have a functional common information system that allows for online reservation and purchase of a single travel ticket for multiple modes of transport. At present, Romania is establishing a common travel ticket issuance system that connects all passenger rail transport operators (OTF), a system that has become mandatory through the transposition of „Directive (EU) 2016/2370" [16] into national legislation. Compensation for the execution of public service contracts, contracts that passenger rail transport operators conclude with the Railway Reform Authority (ARF), will only be received by railway companies in Romania based on their participation in the „common system for direct information and ticketing, enabling integrated ticketing, direct ticketing, and reservations."

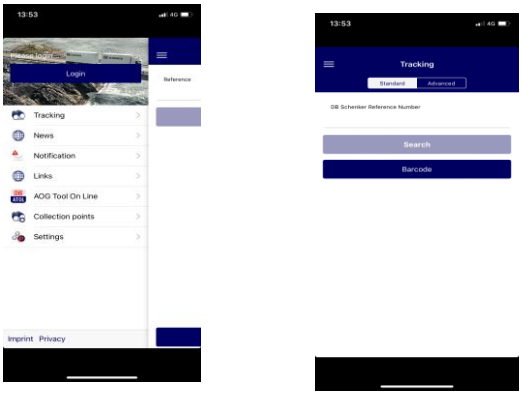
In Romania, passenger rail transport as a whole has the character of a social public service. Thus, ARF concludes public service contracts with passenger rail transport operators."

2.3. National legal framework for the development of multimodal freight and passenger transport

The national legal framework primarily consists of legislation resulting from the transposition of European legislation aimed at the development of multimodal freight and passenger transport, as well as the ratification of international conventions to which Romania is a party.

2.4. European projects for the efficiency of freight transport

Freight transport applications provide a mechanism that automatically matches the shipper's demand with the carrier's offer, using the internet. The efficient way to find, for example, the right truck and complete the delivery process helps optimize transportation by reducing empty truck trips, leading to a decrease in carbon emissions [17]. Among such projects for the efficiency of freight transport is the 'eSchenker' logistics solution, which covers all modes of transport offered by the German company. The application serves as a one-stop-shop for managing and optimizing the supply chain of DB Schenker's customers, allowing them to schedule transportation, track cargo, and more. The eSchenker tracking tool is user-friendly and provides real-time information about the location and status of the shipment, as well as the estimated delivery time, regardless of the mode of transport.

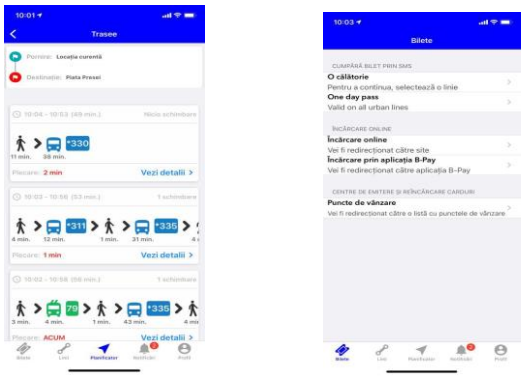


a) b)

Homepage of the eSchenker Application:a) Application Menu;
b) Shipment Tracking Function [18]

2.5. European projects for integrated passenger transport systems

In several countries within the European Union, projects have been initiated or are in the process of implementation to enhance mobility services and develop multimodal transportation. For instance, in 2011, the European Commission identified over 100 such applications, but none allowed users to find information or book a travel ticket in Europe, regardless of the number of countries or modes of transport [19]. Among the projects implemented in Europe are mobile applications for Bucharest, known as „Smart City." The Bucharest City Hall has developed five mobile applications („InfoTB," „Trafic Alert București," „Parking București," „BPay," and „Social Alert București"), collectively referred to as „Smart City." However, none of these applications currently provide users with the ability to plan their journey and simultaneously purchase a single ticket for transportation, including the metro.



a) b)

Travel options on the route from Baba Novac Street to Casa Presei Libere:
a) Travel ticket purchase options;b) [20]

For example, the "InfoTB" application, launched in 2019, helps travelers plan their journey using public transportation and choose the shortest route to their destination. Travel tickets can be purchased through the application. Tickets are available for urban travel,

regional travel, express travel, and a one-day urban pass. The "InfoTB" application can only be used by users located in Bucharest to identify the optimal travel route.

Chapter 3 - Conclusions regarding the current state of multimodal freight and passenger transport in the European Union

- *Transportation is a strategic sector of the EU economy, vital for European companies and the global supply chains, directly impacting the industrial sector. 'Sustainable transport represents an opportunity to contribute to the recovery and growth of the economy' [12].*
- *Multimodal freight transport, with a focus on rail transport, can be stimulated through the modernization of railway infrastructure and service infrastructure. Service infrastructures include intermodal terminals, and in Romania, there is a deficit of transshipment infrastructure. In this regard, it is necessary to establish state aid schemes for the modernization and construction of intermodal terminals, as well as fiscal measures to encourage infrastructure owners. Another requirement is the improvement of transshipment/transloading technologies to shorten the time required for transferring goods. This entails increasing the speed of technological transfer. Additionally, the use of new technologies that enable better traffic management for all modes of transport is necessary. Hence, applications that facilitate data exchange between transport operators for real-time tracking of the location and condition of goods shipped in multimodal traffic are needed.*
- *Concerning multimodal passenger transport, it can be encouraged, on one hand, by ensuring better connections between different modes of transport, deploying state-of-the-art rolling stock, maintaining adequate transport infrastructure quality, and implementing a system for reserving and purchasing a single travel ticket. Furthermore, for passenger transport to facilitate better connections between different modes of transport, national-level coordination is necessary to establish a general circulation schedule that ensures travel continuity (reducing waiting times) and allows sufficient passenger transfer time.*

Chapter 4 - Research and development directions, objectives, and methodology

4.1. Research and development directions

Following a critical analysis of the current state of the transportation sector at the European Union and national levels in terms of efficiency and sustainable economic development, the following research and development directions have been outlined:

D1. Characterization of multimodal transportation and assessment of its ability to meet the requirements of efficiency and sustainable economic development at the national level, in accordance with European Union regulations.

D2. Analysis of the external and internal environment of organizations operating in the multimodal freight transportation sector, identification of development trends in the field, and

the formulation of strategies to gain a competitive advantage in line with these trends. Dynamic analysis of the evolution of the external and internal environment of organizations operating in the multimodal transport sector, with a focus on rail transport, taking into account emerging trends over various time horizons.

D3. Analysis of the efficiency of multimodal freight transportation at the national level, through the evaluation of the two related components: costs and outcomes obtained, as well as their impact on the economic performance of various industrial sectors. Formulation of solutions to enhance efficiency and sustainable development.

D4. Analysis of passenger transportation as an essential means of providing human resources for the industry and the identification of solutions to streamline employee transportation to the workplace.

D5. Digitization of the ticketing service in the transportation sector to create the capability to provide a single travel ticket for multimodal transportation, round-trip, for employees commuting from populated areas to industrial zones - key strategic economic development areas in Romania.

4.2. Research and development objectives

The primary objective of the thesis (Op), derived from the Research and Development Theme of the doctoral program, is formulated as follows:

Op: To establish solutions that contribute to the efficiency of multimodal transportation and analyze its influence on economic performance in the industry. Several secondary objectives (Os) have been formulated to support the achievement of Op, as follows:

Os1: Analyze the external and internal economic environment for representative organizations in the field of multimodal transportation to gain a competitive advantage.

Os2: Determine the trends in the evolution of the transportation sector at the European Union and national levels over different time horizons.

Os3: Perform a dynamic analysis of the external and internal economic environment of organizations in the rail transportation sector in line with the evolving trends in this domain, aiming to achieve sustainable competitive advantages in the long term.

Os4: Analyze the efficiency of freight transportation on a relevant national route in the context of international transport corridors and identify solutions to improve this efficiency.

Os5: Analyze the efficiency of passenger transportation on a relevant route to ensure human resources for one of Romania's industrial development hubs and identify solutions to enhance this efficiency.

Os6: Develop the architecture of an application that provides a single multimodal transportation ticket for a relevant route connecting an industrial development hub with a significant human resource pool.

4.3. Research and development methodology

The research and development methodology required to achieve the primary objective and secondary objectives has been developed and consists of the following stages:
E1. Critical analysis of the current state of the transportation sector at the national level, within the context of its development and evolution at the European Union level. This will lead to the formulation of conclusions that serve as the basis for the primary objective and secondary objectives of the doctoral thesis.

E2. Analysis of the external and internal economic environment of relevant organizations in the transportation sector, culminating in the development of strategies that enable the attainment of a competitive advantage.

E3. Application of various strategic forecasting methods to identify trends in the evolution of the transportation sector.

E4. Dynamic analysis of the external and internal economic environment of organizations in the transportation sector based on the identified trends in the sector's evolution. This dynamic analysis aims to achieve sustainable competitive advantages.

E5. Analysis of the efficiency of freight transportation on a relevant national route with a significant impact on industrial organizations, with a focus on formulating solutions to enhance this efficiency.

E6. Analysis of passenger transportation efficiency to ensure a workforce for an industrial hub and the formulation of solutions to improve this efficiency.

E7. Development of the final conclusions of the work, allowing for the evaluation of how the primary objectives and secondary objectives of the doctoral thesis have been fulfilled.

Chapter 5 - Development of detailed research and development methodology for enhancing multimodal transportation with implications for the industry

The research and development stages aim to achieve efficiency in multimodal transportation, which offers numerous advantages over traditional transportation methods. The transportation of material and human resources (upstream) as well as finished products (downstream) represents a significant component of production costs. Therefore, the efficiency of transportation has major implications for industrial processes. The sequence of research and development stages begins with a critical analysis of the current state of the transportation sector.

5.1. Action directions resulting from the application of the research and development methodology

The development of the research methodology yields several action directions (Dact), recommendations, and guidelines aimed at achieving efficiency in multimodal transportation with effects on the industry. These actions focus on the relationship that defines efficiency, as per SR EN ISO 9000:2015, where efficiency is the relationship between the achieved result and the resources used.
The main considerations are primarily focused on:

- Reducing freight transportation costs (Ctj) and passenger transportation costs (Cuj).
- Increasing the quantity of transported goods (Vmtj).
- Reducing transportation time for both freight (ttj) and passengers (tuj).
- Increasing the number of passengers (np).

All these components, for which organizations (Oi€DT) are responsible, are involved in the processes of ensuring material resources from suppliers (Fj ind) for industrial organizations (Oind), transporting industrial products to customers (Cj ind), as well as transporting human resources participating in industrial processes within these organizations (Oind).

Chapter 6 - Analysis of the external and internal environment of multimodal freight transportation in Romania

6.1. Analysis of the external environment of multimodal freight transportation in Romania

The analysis of the external environment involves both the examination of the general external environment and the competitive external environment, as well as strategic groups [8]. The general external environment is characterized by the forces that act on multimodal freight transportation, with an exogenous nature and multiple diverse effects, such as [21]: demographic, economic, managerial and political-legal factors, socio-cultural factors, technological factors, ecological factors, and globalization.

6.1.1. Analysis of the competitive external environment of multimodal freight transportation in Romania

The competitive external environment is narrower than the general external environment. Michael Porter developed the model of the five forces that operate in the competitive external environment [8]:

F1 - Barriers to entry into the market.

F2 - Rivalry among competitors.

F3 - Bargaining power of suppliers.

F4 - Bargaining power of customers.

F5 - Threat of substitutes.

Evaluating these five forces helps determine the market's attractiveness.

6.1.2. Strategic groups

In the case of multimodal freight transportation, the strategic group includes both multinational companies such as DB Schenker Logistics Romania, Gefco Romania, Gebruder Weiss SRL, and Romanian-owned companies such as Rofersped SA or Rocombi. In this case, a cost leadership strategy is applied, which involves lower costs for research and development activities, without aiming to improve product performance but only focusing on technological solutions to cost reduction. Consequently, marketing activities are less labor-intensive because they do not promote high-performance products [8].

6.2. Analysis of the internal environment of multimodal freight transportation in Romania

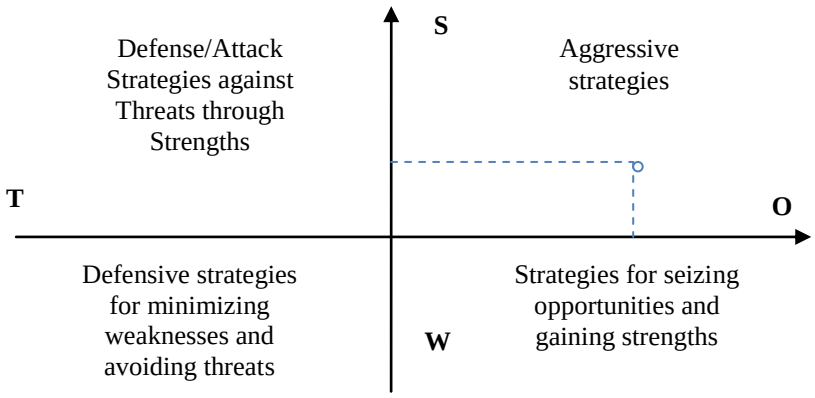
6.2.1. Elements of internal environment analysis

1. Resources: Tangible and intangible.
2. Capabilities.
3. Core competencies.

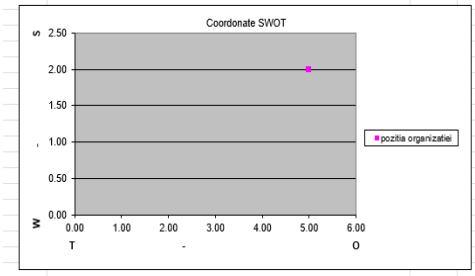
6.2.2. SWOT analysis of multimodal freight transport in Romania

To obtain results that are as close to reality as possible, it is necessary to use an analysis of the external and internal environment. Based on the SWOT analysis, the SWOT matrix was constructed, which forms the basis for the development of strategies.

From the information included in the matrix, it can be inferred that multimodal transport in Romania is in an ideal/maximum situation, which means that the strengths outweigh the weaknesses, and the external environment provides more opportunities than threats.



a)



b)

Graphic Representation of the Qualitative (a) and Quantitative (b) positioning for multimodal freight transport in Romania

Multimodal freight transport in Romania is in an ideal/maximum situation and requires an aggressive strategy to establish a clear competitive advantage. Specifically, there is a need to encourage rail freight transport to reduce carbon emissions.

6.3. Case Study - DB Schenker Logistics Romania

For the case study, the author selected DB Schenker Logistics Romania because the company provides multimodal freight transport solutions. DB Schenker Logistics Romania tailors its services to the type of goods that need to be transported, offering industrial solutions for defense, healthcare, pharmaceuticals, industrial goods, consumer goods, perishable and refrigerated products. The company also handles customs formalities. Additionally, DB Schenker Logistics Romania employs innovative IT solutions that enable real-time monitoring of freight transport globally, regardless of the mode of transportation used. Furthermore, in 2019 and 2020, DB Schenker Logistics Romania recorded the highest net turnover compared to the financial situation of companies operating in the logistics market in Romania, providing solutions for multimodal freight transport, as indicated by information posted on the Ministry of Finance's website [22]. DB Schenker Logistics Romania is a member of Deutsche Bahn (DB), a vertically integrated group owned by the German state.

In 2020, approximately 3,000 companies were active in this market. These companies generated a total turnover of €2.88 billion in that year, accounting for 0.80% of the total turnover of all companies in Romania. This was a slight decrease from €2.89 billion in 2019, which accounted for 0.77% of the national total.

6.3.1. Analysis of the external environment of DB Schenker Logistics Romania

The analysis of the external environment of DB Schenker Logistics Romania corresponds to the analysis of the external environment of multimodal freight transport in Romania, presented earlier in section 6.1. This is because the company operates within this sector, offering customers a wide range of multimodal solutions for freight transport.

6.3.2. Analysis of the internal environment of DB Schenker Logistics Romania

The following elements characterizing the internal environment of DB Schenker Logistics Romania are analyzed: resources, capabilities, and core competencies. Information posted on the Ministry of Finance's website has been taken into account.

6.3.2.1. SWOT analysis of DB Schenker Logistics Romania

Similar to the analysis of multimodal transport in Romania, in this case, the situation is ideal/maximum, with more strengths compared to weaknesses, and the external environment providing more opportunities than threats. DB Schenker Logistics Romania needs to implement an aggressive strategy to establish a clear competitive advantage. The company could potentially expand its branch network to include areas near Danube ports, with the possibility of operating intermodal terminals in the region.

6.4. Strategic Forecasting and Forecasting Methods for Rail Freight Transport in Romania

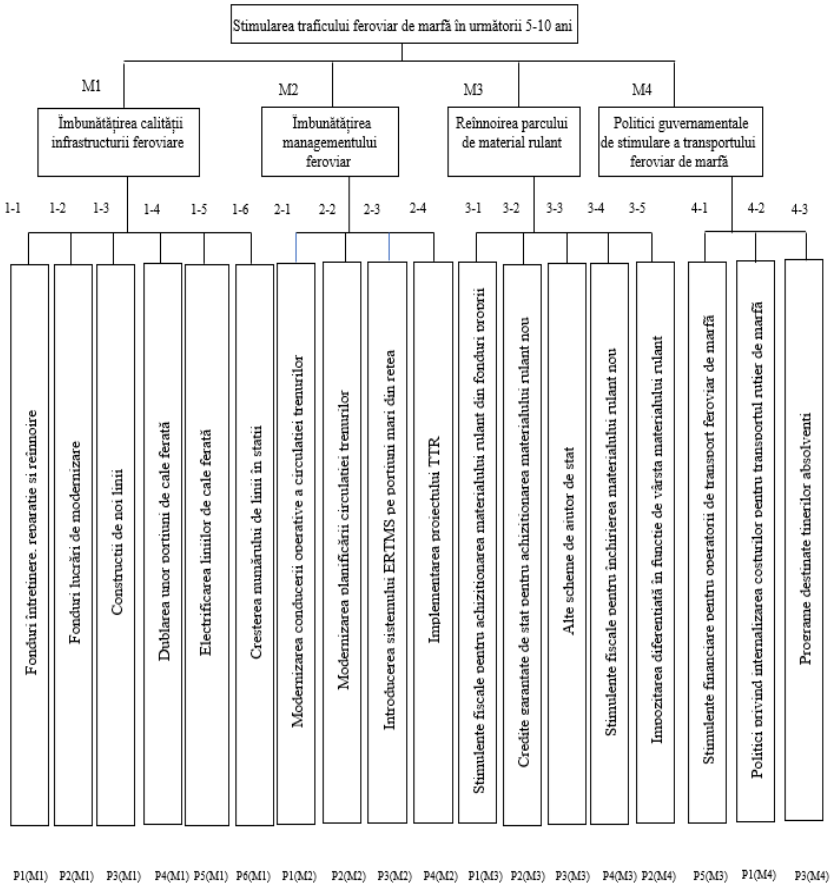
The application of forecasting methods will focus on rail freight transport because, according to the "Strategy for Sustainable and Intelligent Mobility - Shaping the Future of

European Transport," one of the important measures to make the transport system sustainable is to promote rail transport, considered an environmentally friendly mode of transportation. Four forecasting methods were used: the relevance tree method, scenario method, content analysis method, and external and internal dynamic analysis of rail freight transport in Romania over the next five years, based on identified trend developments.

6.4.1. Relevance Tree Method

The elements to be organized within the relevance tree structure are:

- Primary Objective: What is the solution to stimulate rail freight traffic in Romania?
- Methods to Achieve the Proposed Objective.
- Processes Contributing to Achieving the Objective.



Relevance Tree for Stimulating Rail Freight Traffic

From the analysis of the results, it is observed that the product corresponding to the funds for railway infrastructure modernization, in combination with measures aimed at improving rail traffic management, has the highest value. In the second position is the product corresponding to the funds needed for railway infrastructure modernization and government

policies to promote freight rail transport. In the third position is product M2×P4(M2), which is the combination of implementing the TTR project and improving rail traffic management.

6.4.2. Scenario Method

The steps for applying the qualitative scenario method are as follows:

a) Description of the existing environment through the main determinants;

b) Internal analysis;

c) Development of the three scenarios;

d) Determination of the impact factors;

e) Development of the scenario matrix;

f) Identification of the most likely scenario;

g) Preparation of contingency plans.

Three scenarios are constructed, with the first being based on current trends but adjusted to account for future disruptive events, while the other two scenarios project possible alternative futures using key determinants derived from the PEST external analysis. Impact factors, which represent the probable action of the main determinants of the predicted phenomenon (increase in freight rail traffic), are determined and positioned in the scenario matrix.

In this case, the most likely scenario can be described as follows:

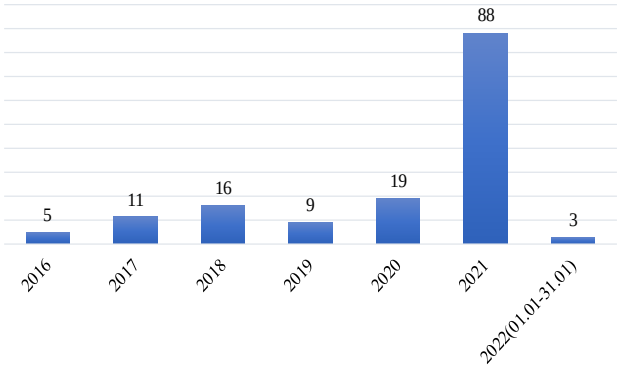
- Costs for organizations in the railway transport sector increase in line with the growth of financial resources and sources of funding.
- The increase in financial resources is closely linked to the growth of funding sources, with a focus on European funds allocated for the development of the railway transport sector.
- The bargaining power of buyers of rolling stock, facilities, and equipment will progressively increase, in parallel with the supply of rolling stock, facilities, and equipment, and funding sources. These are closely related to the progressive facilitation of access to know-how, due to the high dynamics of the technological process, leading to increased moral wear and tear of equipment and a reduced lifespan.
- A real and challenging issue remains the continuous decrease in human resources and competencies in the field. The solution lies in economic growth, where the active population would increase through the attraction of Romanian citizens who are currently working abroad, as well as immigrants.

In this case, the contingency plan is as follows: In a situation where the development conditions in the external environment of organizations in the freight railway transport sector become highly favorable, measures to attract human resources to this sector for the purpose of increasing organizational competencies must be adopted in advance. This involves, on one hand, attractive salary packages, including professional training programs, and on the other hand, a strong emphasis on access to know-how, which will be progressively facilitated through the attraction of European funds and participation in European projects involving participants from multiple countries. This will help avoid the significant moral wear and tear of rolling stock, facilities, and equipment.

6.4.3. Content Analysis Method

This method is based on a content analysis of information that has appeared in publications (printed or online newspapers and magazines) related to trends in the freight railway transport sector. In this case, the author analyzed information published from 2016 until January 31, 2022, in order to identify major evolutionary trends [23].

The theme under analysis pertains to the actions that have been, are being, or will be undertaken to increase freight rail traffic in Romania. The consolidation of the data collected, concerning the appearances in online press related to railway infrastructure, traffic management, rolling stock, and government policies in the freight railway transport sector, indicates a fluctuation in the number of appearances, with a significant spike in the year 2021.



The number of appearances in online media

Regarding the topics covered by online publications, the top theme is information related to railway infrastructure: maintenance, repair, and modernization works on the railway transport infrastructure, funds allocated for these works, tenders organized for these projects, etc. The second area of interest is related to rolling stock used by companies engaged in freight transport by rail, with an emphasis on renewing the rolling stock fleet and innovative solutions. At the bottom of the list are the details about government policies aimed at promoting freight rail transport, indicating a lack of executive concern for encouraging rail freight transport.

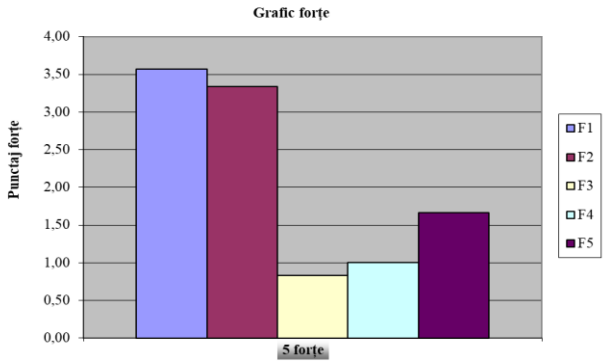
Thus, the analysis of information published in online media reveals the following trends:

- Increasing government interest in freight rail transport due to the EU's policy of promoting this sector.
- Currently, the rolling stock fleet is aging. However, maintenance and repair works on railway infrastructure, as well as modernization projects, will encourage companies involved in rail freight transport to renew their rolling stock to stay competitive.
- European funds are allocated for the modernization of railway infrastructure, especially to ensure connectivity with the Port of Constanța. European funds have also been used for the modernization of segments of the Rhine-Danube Corridor.

- Apart from providing funding for railway infrastructure development, EU policy also involves collaboration between railway infrastructure administrators and regulatory bodies in member states to implement the TTR project, aimed at increasing infrastructure capacity on European corridors dedicated to freight rail transport.

6.4.4. External and internal dynamics analysis of freight rail transport in Romania for the next five years, based on identified trends

Following the application of the forecasting methods presented earlier, several trends with a high probability of occurrence were identified. These trends were taken into account in the external and internal dynamic analysis of the railway transport sector, in the short, medium, and long term, and will be presented below. The graphical representation of the five forces is presented in the figure below.



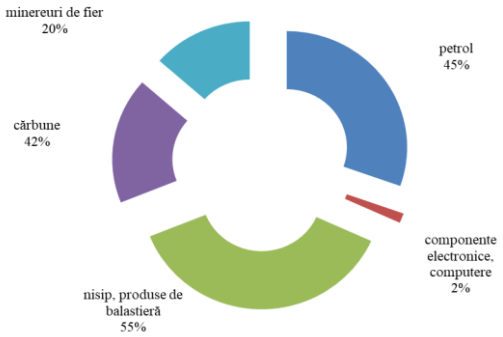
The value of the five forces, according to current trends

Conclusion: The railway transport market maintains its level of attractiveness even in light of the identified trends based on the forecasting methods presented earlier. In these conditions, the development of railway transport services is encouraged, with beneficial effects on the national economy and sustainable development. Following the internal analysis of a freight railway transport organization under the forecasted conditions, it is noted that the organization is in an ideal/maximum situation. Therefore, it is suitable to adopt an aggressive strategy to create a long-term competitive advantage, one that is also sustainable.

Chapter 7 - Contributions to the efficiency of multimodal freight transport on a relevant route

The industrial sector is closely interconnected with the transportation sector. Industrial activities cannot proceed without the supply of raw materials to production facilities. Subsequently, the transportation of finished products from production facilities to the customers of manufacturing companies is necessary. Therefore, the cost of transportation is reflected, to a certain extent, in the total cost of goods and services. For example, in the case of sand and quarry products, transportation costs can account for up to 55% of the total

production cost, 20% for iron ores, 42% for coal, 45% for petroleum, and approximately 2% for electronic components and computers.



The share of transport costs in total production costs for different types of goods

Hence, companies seek solutions to streamline the transportation costs of raw materials and finished products to increase business profitability.

This chapter of the doctoral thesis addresses the aspect of cost efficiency analysis in transport, with the proposed case study focusing on a detailed analysis of the costs of transporting containerized goods along a route that traverses Freight Railway Corridor No. 9. This corridor provides a connection to the Port of Constanța, Romania's main gateway for the import and export of goods. The author chose Lipova as the starting point, where many companies operate, and the terminal endpoint is the DP World Constanța intermodal goods terminal, the largest container terminal in the Port of Constanța. Additionally, the Railport Arad terminal is one of the largest inland intermodal terminals in Central and Eastern Europe. It is located near the Curtici station, on the Romania-Hungary border.

The transportation costs on the railway network are compared with those of the road transportation system. Finally, the costs of combined road-rail transportation of containerized goods are analyzed. Three situations are considered:

a. Transportation of goods by rail in a complete train, making rail transport cost-effective but involving high costs for road transportation.

b. Transportation of goods using a single truck with a trailer or in isolated wagons to optimize road freight transportation.

c. Multimodal transportation (road-rail) of goods in the two cases mentioned above at points a) and b).

For a complete picture of efficiency, factors such as the quantity of goods transported and the transportation time/transport speed are also taken into account to assess the results.

7.1. Improving freight rail transport through full trainload

7.1.1. Analysis of road freight transportation costs

The starting premise is that, in terms of cost-effectiveness, freight rail transport must be carried out using complete trains (any transport composed of a train with one or more

wagons transported together for one shipper, without any modification to the train's composition, from a single loading point to a single unloading point), specifically with 28 wagons carrying 56 twenty-foot containers (20′ containers). However, in this scenario, road transport requires the use of 19 MAN TGM 26 t 6x4 trucks with Kögel trailers to transport the 56 containers.

The distance between Lipova and the DP World Constanța terminal is covered in approximately 10 hours and 10 minutes, without stopping at the Railport Arad terminal.

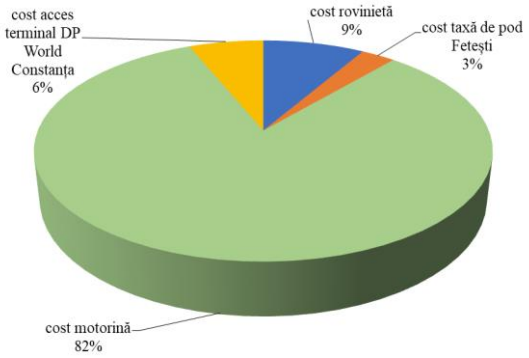
The elements included in the road transport cost of containers are as follows: road usage tax (rovinietă) Cr [lei] and the Fetești Bridge toll Cp [lei]; Cm [lei]; fees for services provided within the Railport Arad terminal (container handling); fees for services provided within the DP World Constanța terminal (truck access within the terminal – Cat [lei]). It is assumed that transport is carried out without the need for warehousing goods for more than one day, meaning storage costs are not included. Additionally, handling costs are not considered in the calculation of transport costs.

To calculate the transport cost of goods with a truck and trailer (Ct), the following formula is used:

$$C_t = C_r + C_p + C_m + C_{at}[lei]$$

The cost of transporting goods with 19 articulated lorries (Ct19) [lei] is calculated as follows:

$$C_{t19} = 19 \times C_t\ [lei]$$



The cost structure of road freight transport on the Lipova-Railport Arad-DP World Constanța route

The cost structure of road freight transport on the Lipova-Railport Arad-DP World Constanța route indicates that diesel fuel accounts for 82% of the total transport costs.

7.1.2. Analysis of freight rail transport costs for full trainload

For the transport of containers, a 2,100 HP diesel-electric locomotive and Rgs-type wagons are used. A diesel-electric locomotive was chosen because the Curtici-Constanța Ferry Boat railway line is electrified, but the rail lines within the Port of Constanța are not electrified [24]. The wagons are loaded at the Railport Arad terminal, and the train travels on

"Freight Railway Corridor No. 9 (RFC 9) – Rhine-Danube," which crosses Romania on the route: Curtici - Sighișoara - Brașov - Bucharest - Constanța.

Considering that the average commercial speed for freight trains is 19.66 km/h [25], the distance will be covered in approximately 46 hours (excluding the stop at the Railport Arad terminal for loading goods).

tf – the time required for freight rail transport on the Lipova-Railport Arad-DP World Constanța route = 46 hours.

The elements included in the costs of rail freight transport are as follows: infrastructure usage fee (TUI) [lei]; delivery price and the cost of traction electricity (Pet) [lei]; maneuvering convoy access fee to/from the CFR rail infrastructure (Tco) [lei]; fees for services provided at the Railport Arad terminal for trains (assuming that the wagons will not stay at the terminal for more than one day, these fees are not considered); fees for services provided at the DP World Constanța terminal for trains (Tdw) [lei] [26]; the price of fuel for traction on non-electrified lines within the Port of Constanța (Cd) [lei].

To calculate the infrastructure usage fee, the following formulas are used:

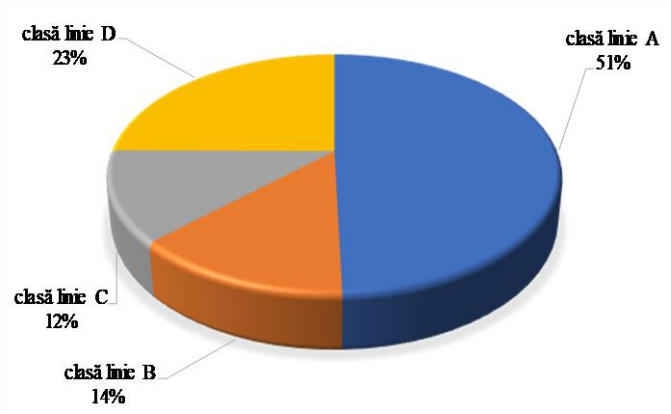
$$TUI = \sum TUI_{secție}$$

$$TUI_{secție} = TUI_{tonaj} + TUI_{circulație} + TUI_{electrificare}$$

$$TUI_{tonaj} = d \times T_{tsn}[1 + (Tonaj\ brut - T_{min}) \times F_t]$$

- d represents the number of kilometers traveled on the TUI section (the section corresponding to each line class) [km];
- Ttsn - the tariff based on tonnage for each kilometer of line class [lei];
- Gross tonnage - the gross tonnage of the train, according to the "Declaration of Wagons" form, including locomotives in action or the tonnage of locomotives or railcars in the case of travel without hauled rolling stock [t];
- Tmin - the gross tonnage of the train from which the tonnage factor applies [t];
- Ft - the tonnage factor representing a correction coefficient applied to the gross tonnage of the train for trains with a tonnage lower than Tmin.

Analyzing the length of each line class on the Corridor Freight Railway No.9, which crosses Romania on the Railport Arad-Arad-Sighișoara-Brașov-Bucharest-Constanța Ferry Boat route, it is found that only 51% of the railway lines are Class A lines, which have been modernized and allow trains to operate at a maximum permitted speed of 160 km/h.



The proportion of each rail line class in the total length of the Railport Arad-DP World Constanța route

The calculation of electric energy consumption for traction is done using the formula:

$$C_{ee} = P \times t \ [KWh]$$

- Cee represents the consumption of electric energy [KWh];
- P is the power of the diesel-electric locomotive [KW];
- t is the operating time [h].

Furthermore, the price of traction energy (Pet) is calculated using the formula:

$$P_{et} = C_{ee} \times C_{fp} \ [lei]$$

Cfp - "the cost of supplying electric traction energy and the profit share [lei/MWh]."

The price of fuel used for transportation on non-electrified railway lines in the Port of Constanța is calculated using the formula:

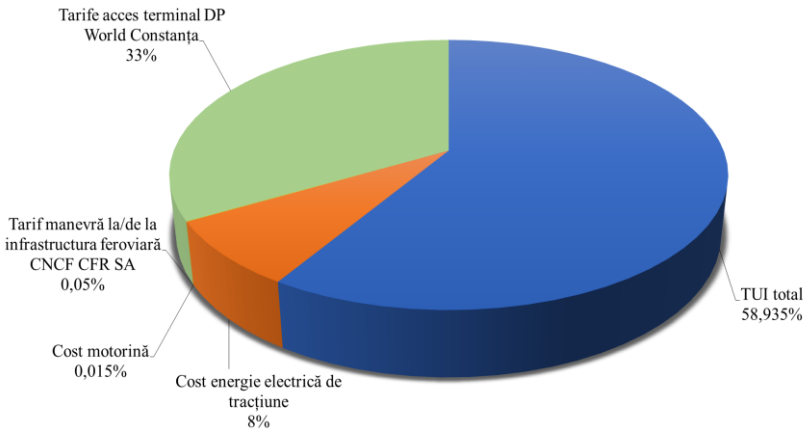
$$C_d = P_{motorină} \times C_{motorină} \ [lei]$$

- Cd represents the price of fuel used for the movement of the train in the Port of Constanța, on non-electrified railway lines [lei];
- Pmotorină is the price of diesel fuel for the movement of the train in the Port of Constanța, on non-electrified railway lines [lei];
- Cmotorină is the consumption of diesel fuel for the movement of the train in the Port of Constanța, on non-electrified railway lines [l].

The value of the railway transport cost (Ctf) is calculated using the formula:

$$C_{tf} = TUI_{total} + P_{et} + C_d + T_{co} + T_{dw} \ [lei]$$

After analyzing the cost structure of rail freight transport (56 containers), it is found that the TUI value accounts for approximately 60% of the total cost of rail freight transport, while access fees at the DP World Constanța terminal represent 33% of the total cost.



The cost structure of rail freight transport (56 containers) on the Radna-Railport Arad-DP World Constanța route

7.1.3. Cost analysis for multimodal freight transportation on the Lipova-Railport Arad-DP World Constanța route

7.1.3.1. Analysis of transportation costs on the road system within multimodal freight transport

Container transportation on the road system will occur on the Lipova – Railport Arad intermodal terminal route. Goods will be transported using the same type of semi-truck with 20-foot containers. The total distance on the road system is 49.5 km and takes approximately one hour to traverse.

The elements included in the transportation costs are as follows: toll costs (Cr) [lei], fuel price (Cm) [lei]; fees charged for services provided within the Railport Arad terminal (Cat) [lei]; (the terminal does not charge access fees for trucks).

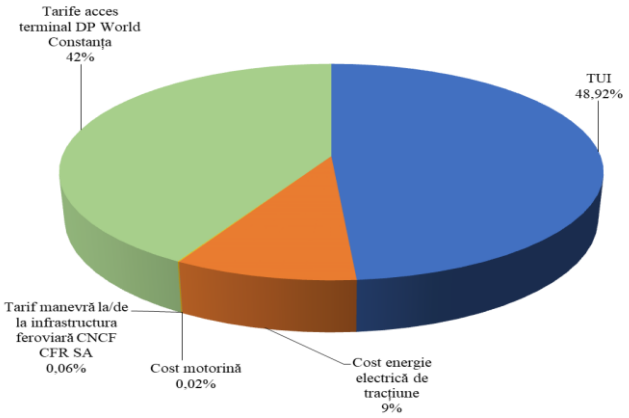
7.1.3.2. Analysis of components included in the cost of freight transportation on the railway network.

The elements included in the costs of rail freight transportation are as follows: TUI [lei]; delivery price and the cost of electrical energy required for traction (Pet) [lei]; access fees for shunting convoys to/from the CFR railway infrastructure (Tco) [lei]; fees charged for services provided within the Railport Arad terminal (since it is assumed that wagons will not stay at the terminal for more than a day, these fees will not be considered); fees charged for services provided within the DP World Constanța terminal for trains (Tdw) [lei]; the cost of fuel for train traction on non-electrified lines within the Port of Constanța (Cd) [lei].

It should be noted that, based on legislative provisions and those in the "Activity Contract" concluded with MTI, CNCF CFR SA grants a 33% reduction in TUI for complete intermodal trains when agreements have been signed between CNCF CFR SA and OTF.

From the analysis of the cost structure of rail transport for the 56 containers on the Railport Arad-DP World Constanța route (multimodal transport), it can be concluded that TUI holds the highest share, namely 49% in the structure of rail freight transport costs on the

Lipova-Railport Arad-DP World Constanța route, while fees for access to the DP World Constanța terminal account for 42%.

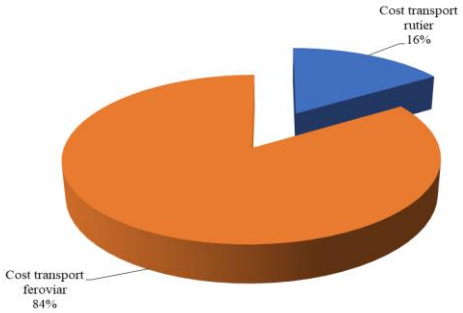


Structure of rail freight transportation costs for the 56 containers on the Railport Arad-DP World Constanța route (multimodal transport)

7.1.3.3. Calculation of costs for multimodal freight transportation

The total cost of multimodal transportation (Cti) [lei] is obtained by summing the cost of transportation on the road system (Ct) with the cost of rail transportation (Ctf) [lei].

It is observed that, out of the total cost of multimodal freight transportation on the Lipova-Railport Arad-DP World Constanța route, the rail transportation cost represents 84% because the majority of the distance is covered by rail.



Structure of Multimodal Freight Transportation Cost (56 containers) on the Lipova-Railport Arad-DP World Constanța Route

7.2. Transportation of goods with a single truck and trailer, respectively, in isolated wagons

Consideration is given to the transportation of three 20-foot containers with a single MAN TGM 26 t 6x4 truck, with a Kögel trailer. Additionally, in the context of aiming for rail transport to regain modal share in the domestic freight transport market, the solution involves including rail transport in logistics chains instead of road transport for smaller shipments. Thus, goods would be transported in two isolated wagons. In other words, rail transport could

regain its previous position if multimodal transport and transport in isolated wagons are rehabilitated [27].

7.2.1. Analysis of freight transportation costs on the road system for goods transported with a single truck and trailer

The elements included in transportation costs are as follows: toll costs (Cr) [lei]; Fetești Bridge toll (Cp) [lei]; fuel cost (Cm) [lei]; fees charged for services provided within the Railport Arad terminal (container handling; the cost of handling goods is not considered); fees charged for services provided within the DP World Constanța terminal for trucks (Cat) [lei].

The same premise is used, which is that transportation is carried out without the need for goods to be stored for more than one day, meaning storage costs are not included. Also, for the calculation of the direct transport cost, handling costs of goods are not taken into account [7].

7.2.2. Analysis of freight transportation costs on the railway network

It is assumed that the three containers are transported using two wagons, which are attached to a train consisting of a total of 28 wagons, all departing from the same station, Radna, with DP World Constanța terminal as the destination.

The calculation of the transportation cost for two wagons loaded with the three containers (Ctf2vagoane) [lei], on the Radna-Railport Arad-DP World Constanța route includes the following elements: TUI for the Radna-Arad-Curtici-Constanța Ferry Boat route (TUItotal2vagoane) [lei]; the cost of electrical energy for traction on the electrified Radna-Railport Arad-Constanța Ferry Boat line (Pet2vagoane) [lei]; the cost of diesel fuel used for traction on non-electrified lines within the Port of Constanța, namely, from Constanța Ferry Boat station to the DP World Constanța terminal (Cd2vagoane) [lei]; access fees for shunting convoys to/from the CNCF CFR SA railway infrastructure (Tco) [lei]; fees charged for services provided within the Railport Arad terminal (assuming that wagon parking is not necessary, in which case the fees for services provided within the Railport Arad terminal are not considered); fees charged for services provided within the DP World Constanța terminal for trains (Tdw) [lei].

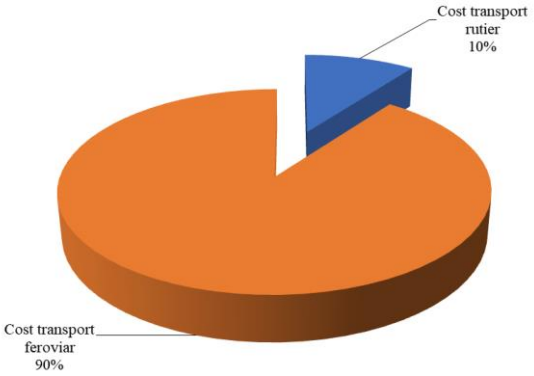
7.2.3. Analysis of costs for multimodal freight transportation with a Ssingle truck and trailer, respectively, in isolated wagons, on the Lipova-Curtici-DP World Constanța route

The transportation of the three containers on the road system will take place on the Lipova – Railport Arad intermodal terminal route. The goods are transported using the same type of semi-truck with a 20-foot container. The total distance on the road system is 68.8 km, as presented in Table 7.12. This is covered in approximately one hour.

Regarding rail transportation, the cargo is loaded at the Railport Arad terminal, and the train moves to the DP World Constanța intermodal freight terminal. Considering that freight trains have an average commercial speed of 19.66 km/h, it results in a travel time of approximately 44 hours (without considering stops at the Railport Arad terminal for cargo loading). In this case, since it does not involve complete intermodal traffic, the 33% reduction in TUI is not applied.

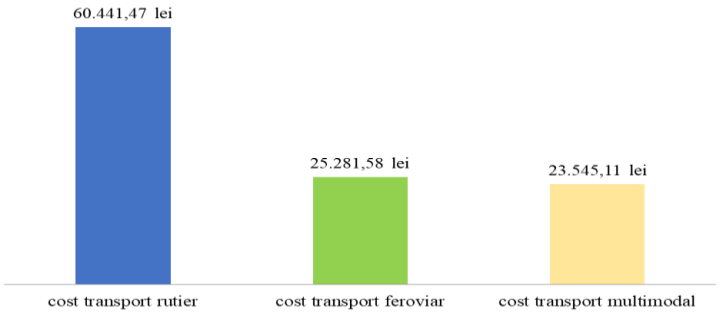
The total cost of multimodal transportation (Cti) is obtained by adding the cost of transportation on the road system (Ct) to the cost of rail transportation (Ctf).

It is observed that rail transportation of the three containers accounts for 90% of the total multimodal freight transportation cost because they cover approximately 880 km by rail and only about 50 km on the road network.



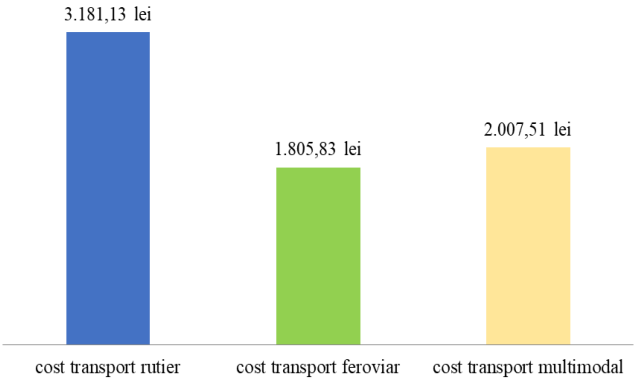
Structure of multimodal freight transportation cost (three containers) on the Lipova-Railport Arad-DP World Constanța route

From the analysis of the results obtained for the transportation of the 56 containers, it is evident that multimodal transportation is the most cost-effective option, while road transportation is the most expensive.



Cost of road, rail, and multimodal transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța route (in lei)

Regarding the results obtained for the transportation of the three containers, it is observed that rail transportation is the cheapest option, while road transportation is the most expensive.



The cost of road, rail, and multimodal transport for the three containers on the Lipova-Railport Arad-DP World Constanța route (lei)

In conclusion, in the analyzed cases where handling costs were not considered, multimodal transportation is cheaper than rail or road transportation when larger quantities of goods are transported. Additionally, road transportation is the fastest mode of transport on the Lipova-Railport Arad-DP World Constanța route, regardless of the quantity of goods transported.

Time required for the transportation of goods, depending on the mode of transport, on the Lipova-Railport Arad-DP World Constanța route (in minutes)

7.3. Efficiency analysis of freight transportation on the Lipova-Railport Arad-DP World Constanța route

7.3.1. Efficiency analysis of rail transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța route

To calculate the efficiency of rail transportation for the 56 containers, the following formula is used:

$$\eta_{tf} = V_m \times \frac{t_f^{-1}}{c_{tf}} \quad [t \times min^{-1}/lei]$$

ηtf – Efficiency of rail transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța ruote [t×min-1/lei]
tf – Time required for rail transportation of the 56 containers of goods on the Lipova-Railport Arad-DP World Constanța route [min];

Ctf – Cost of rail transportation for the 56 containers on the Lipova-Railport Arad-DP World Constanța route [lei].
Vm – Quantity of goods transported in the 56 containers on the Lipova-Railport Arad-DP World Constanța route [t].

7.3.1.1. Analysis of the efficiency of transporting the 56 containers by road, on the Lipova-Railport Arad-DP World Constanța route

To calculate the efficiency of transporting the 56 containers by rail, the following formula is used:

$$\eta_{tf} = V_m \times \frac{t_f^{-1}}{c_{tf}} \quad [t\times min^{-1}/lei]$$

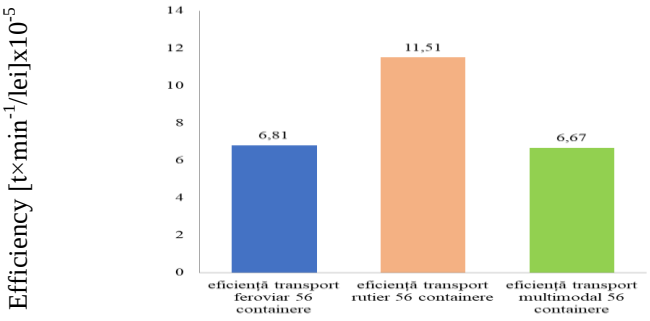
ηtf – Efficiency of rail transport for the 56 containers on the Lipova-Railport Arad-DP World Constanța route [t×min-1/lei]
tf – Time required for rail transport of the 56 containers of goods on the Lipova-Railport Arad-DP World Constanța route [min];
Ctf – Cost of rail transport for the 56 containers on the Lipova-Railport Arad-DP World Constanța route [lei];
Vm – Quantity of goods transported in the 56 containers on the Lipova-Railport Arad-DP World Constanța route [t].

7.3.1.2. Analysis of the efficiency of multimodal transport for the 56 containers on the Lipova-Railport Arad-DP World Constanța route

To calculate the efficiency of multimodal transport for the 56 containers, the following formula is used:

$$\eta_{ti} = V_m \times \frac{t_i^{-1}}{C_{ti}} \quad [t\times min^{-1}/lei]$$

ηti – Efficiency of multimodal transport for the 56 containers on the Lipova-Railport Arad-DP World Constanța route [t×min-1/lei]
ti – Time required for multimodal transport of the 56 containers on the Lipova-Railport Arad-DP World Constanța route [min];
Cti – Cost of multimodal transport for the 56 containers on the Lipova-Railport Arad-DP World Constanța route [lei].



The efficiency of transporting the 56 containers, depending on the mode of transport, on the Lipova-Railport Arad-DP World Constanța route

Considering the parameters used to calculate efficiency, including the quantity of goods transported, costs, and transport times, the order of efficiency for the analyzed modes of transport is: road, rail, and multimodal. Achieving superior efficiency in multimodal transport can only be realized by increasing the speed of rail transport, which would reduce the transport time. This can only be achieved through adequate funding for railway infrastructure modernization works, improving the overall performance of the railway infrastructure. These works have a significant impact on train speed, allowing for an increase in projected speeds. Typically, railway modernization works, being costly, are carried out, especially on European transport corridors, such as Rail Freight Corridor 9 Rhine-Danube.

However, currently, the funds allocated from the national budget for railway infrastructure are insufficient. For example, the funds allocated for maintenance and repair of railway infrastructure are much lower than those calculated by the railway infrastructure manager in Romania.

7.3.2. Analysis of the efficiency of transporting with a single truck with a trailer and in isolated wagons on the Lipova-Railport Arad-DP World Constanța route

7.3.2.1. Analysis of the efficiency of transporting with a single truck with a trailer on the Lipova-Railport Arad-DP World Constanța route

To calculate the efficiency of road transport for the three containers, the following formula is used:

$$\eta_{tr3} = V_{3con} \times \frac{t_{fr}^{-1}}{C_t} \quad [t \times min^{-1}/lei]$$

ηtr3 – Efficiency of road transport for the three containers on the Lipova-Railport Arad-DP World Constanța route [t×min-1/lei]

tfr – Time required for road transport of the three containers on the Lipova-Railport Arad-DP World Constanța route [min];

Ct – Cost of road transport for the three containers on the Lipova-Railport Arad-DP World Constanța route [lei].

Vcon – Quantity of goods transported in one container on the Lipova-Railport Arad-DP World Constanța route [t].

7.3.2.2. Analysis of the efficiency of transporting in isolated wagons on the Lipova-Railport Arad-DP World Constanța route

To calculate the efficiency of rail transport for the three containers, the following formula is used:

$$\eta_{tf3} = V_{3con} \times \frac{t_f^{-1}}{C_{tf2vagoane}} \quad [t \times min^{-1}/lei]$$

ηtf3 – Efficiency of rail transport for the three containers on the Lipova-Railport Arad-DP World Constanța route [t×min-1/lei]

tf – the time required for rail transport of the three containers on the Lipova-Railport Arad-DP World Constanța route [min];

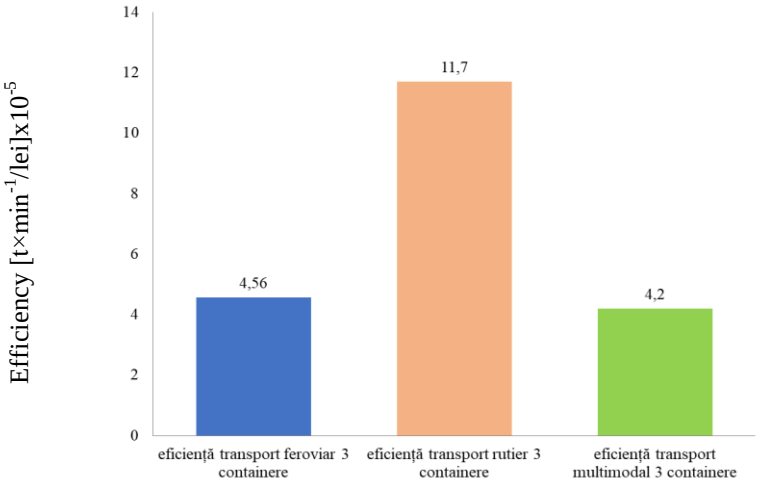
Ctf2vagoane – the cost of rail transport for the three containers on the Lipova-Railport Arad-DP World Constanța route [lei].
Vcon – Quantity of goods transported in one container on the Lipova-Railport Arad-DP World Constanța route [t]..

7.3.2.3. Analysis of the efficiency of multimodal transport with a single truck with a trailer and in isolated wagons on the Lipova-Railport Arad-DP World Constanța route

To calculate the efficiency of multimodal transport for the three containers, the following formula is used:

$$\eta_{m3} = V_{3con} \times \frac{t_i^{-1}}{C_{ti}} \quad [t \times min^{-1}/lei]$$

ηm3 – Efficiency of multimodal transport for the three containers on the Lipova-Railport Arad-DP World Constanța route [t×min-1/lei]
ti – Time required for multimodal transport of goods on the Lipova-Railport Arad-DP World Constanța route [min];
Cti – Cost of multimodal transport for the three containers on the Lipova-Railport Arad-DP World Constanța route [lei].
Vcon – Quantity of goods transported in one container on the Lipova-Railport Arad-DP World Constanța route [t].



The efficiency of transporting the 3 containers, depending on the mode of transport, on the Lipova-Railport Arad-DP World Constanța route

Considering the parameters taken into account for calculating efficiency, including the quantity of goods transported, costs, and transport times, the order of efficiency for the analyzed modes of transport is: road, rail, and multimodal. The conclusion is the same as in the case of analyzing the efficiency of transporting the 56 containers, depending on the mode of transport, on the Lipova-Railport Arad-DP World Constanța route, namely the need to improve the quality of railway infrastructure.

Chapter 8 - Contributions to the streamlining of multimodal employee transportation

One of the long-standing problems faced by employers in the automotive industry has been related to the transportation of employees to the workplace, particularly for distances exceeding 50 km. Despite the construction of industrial platforms that have attracted significant investments and generated new jobs, the necessary connections for transporting employees to these platforms have not been established. Employee transportation to the workplace is vital for the smooth operation of activities in the industrial sector. The availability of the workforce and, consequently, personnel costs are closely linked to ensuring connections between different areas and industrial platforms and factories.

8.1. Case Study: Solutions for streamlining employee transportation to the Dacia Mioveni - area around Bucharest

For the case study, the author selected a route that ensures the connection, through public transportation, of the industrial platform in Mioveni with the human resources basin around Bucharest, including the localities of Brănești, Pasărea, Pantelimon, Voluntari, Otopeni, Mogoșoaia, and Chitila.

Ilfov County recorded the highest population growth (approximately 40%) according to the 2022 Census data. Consequently, a significant portion of the population that previously resided in Bucharest has moved to Ilfov County. The average age of residents in the county is around 40 years, making Ilfov one of the younger counties in Romania[28].

The Mioveni industrial platform encompasses production, logistics, and export activities for Automobile Dacia. Nearly 13,000 employees work at the Mioveni platform. In 2021, the factory produced nearly 257,000 automobiles [29]. Additionally, Automobile Dacia S.A. is the largest Romanian automobile manufacturer and the sixth-largest fiscal contributor. Furthermore, the Mioveni platform is home to 16 factories of companies supplying auto components [31].

8.1.1. Railway transportation on the Brănești-Mioveni route

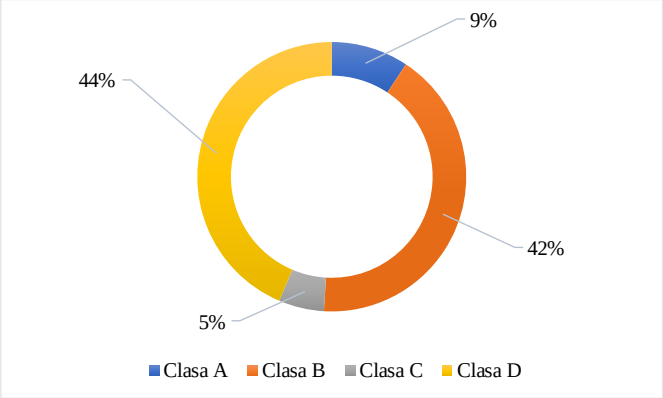
Currently, transportation between Brănești and Mioveni can be facilitated by train. However, railway connection between Brănești and Mioveni has the following disadvantages: the train is scheduled to depart from Brănești at a late hour to transport employees to the Mioveni platform, it only stops at a few stations in the workforce basin around Bucharest, and there is a waiting time of approximately 6 hours and 30 minutes between arrival and departure from Clucereasa to Mioveni.

8.1.2. Railway transportation on the Brănești-Pitești route and road transportation on the Pitești-Mioveni route

Another option is railway transportation on the Brănești-Pitești route and road transportation on the Pitești-Mioveni route. This transportation option has the following disadvantages and cannot be used for employee commuting to the Dacia platform: the train is

scheduled to depart from Brănești at a late hour, the journey is not direct, and there is an approximately 25-minute wait time at Bucharest Nord station, so the train arrives in Pitești.

Additionally, it is observed that on the Brănești-Pitești railway section, the proportion of Class D tracks is approximately equal to that of Class B tracks, in total tracks. Thus, while the maximum permitted speed on Class B railway sections is 100 km/h, on Class D sections, it is 50 km/h.



The proportion of each rail class on the total length of the Brănești-Pitești route

Additionally, on the Brănești-Pitești route, 70% of the railway line is not electrified. Therefore, to reduce pollution, it is necessary to electrify the railway line or use hydrogen-powered trains.

Furthermore, to reach Autogara CNCD SA from Gara de Sud in Pitești, where the routes to Mioveni depart, you can travel by bus. Three routes depart from Autogara CNCD SA to the Pitești-Dacia Mioveni route.

8.1.3. Public transportation on the road system, on the Brănești-Bucharest-Mioveni route

Gazela Transport SRL operates routes on the Brănești-Bucharest route, which depart from Brănești at 05:09 and arrive in the capital at 05:45 [32].

This transportation option has the following disadvantages and cannot be used for employees traveling to the Dacia plant: there is no direct route from Brănești to Mioveni, with a three-hour wait between the route from Brănești to Bucharest and the one connecting the capital to Mioveni, and the station is located at a distance from the Dacia plant. Additionally, the route is operated directly without intermediate stops [33].

8.1.4. Private car transportation, on the Brănești-Dacia Mioveni route

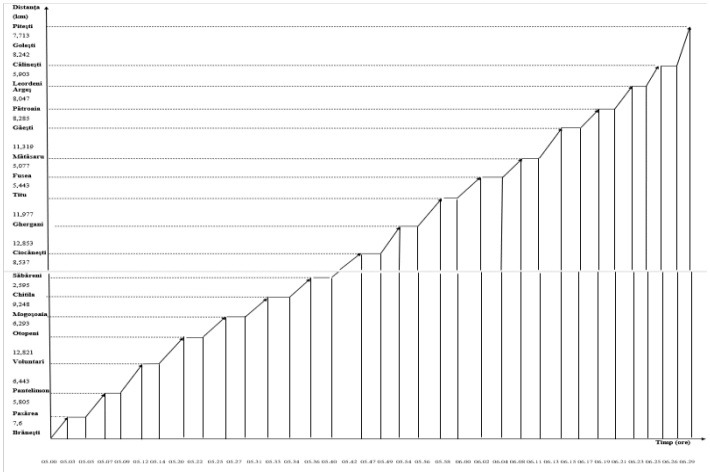
To travel from Brănești to the Militari neighborhood (A1 exit), you cover approximately 30 km. Then, from Bucharest to the Dacia Mioveni Plant, you travel 120 km on the A1 Motorway to Pitești, and subsequently about 10 km on DN 73, between Pitești and Argeșelu, and 5.8 km on DN73D, between Argeșelu and the Dacia Mioveni Plant.

8.2. Employee transportation efficiency solutions on the Brănești-Dacia Mioveni route and return, using multimodal transportation

Since none of the current public transportation options represent an efficient solution for the transportation of employees from the workforce basin in the Capital area, the author proposes train transportation on the Brănești-Pitești route and road transportation between Pitești and the Dacia Mioveni Plant. The employee transportation efficiency solution on the Brănești-Dacia Mioveni route, using multimodal transportation, proposed by the author, starts with the premise that the railway line on the Brănești-Pitești route is modernized, with the lines being of class A. Currently, on this route, there are only 13.405 km of class A railway lines.

8.2.1. Determining departure and arrival times for rail transportation on the Brănești-Pitești route

The author's chosen route involves train connections between the localities of Brănești, Pasărea, Pantelimon, Voluntari, Otopeni, Mogoșoaia, Chitila, Săbăreni, Ciocănești, Ghergani, Titu, Fusea, Mătăsaru, Găești, Pătroaia, Leordeni Argeș, Călinești, Goleşti, and Pitești. In total, the 144.201 km of railway could be covered in approximately 54 minutes without intermediate stops if traveling at the maximum speed of 160 km/h. To calculate the travel time between Brănești and Pitești, the author assumes that there is a 2-minute stop at each of the 17 intermediate stations. This implies that the total travel time between Brănești and Pitești, at maximum speed, is 1 hour and 29 minutes.



Train Schedule for the Brănești-Pitești route

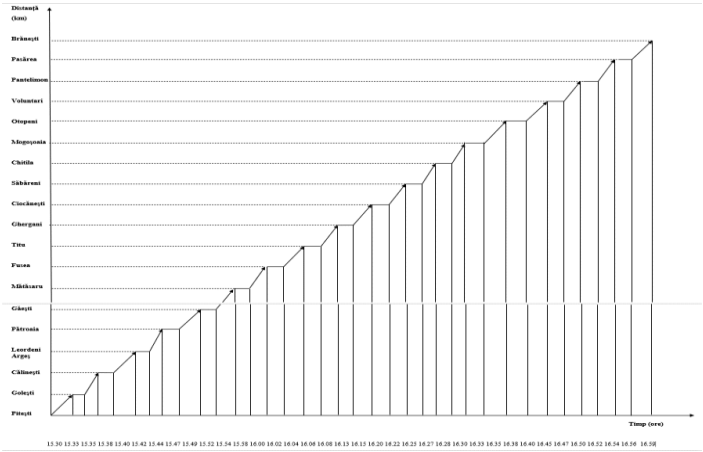
From Pitești, by establishing a direct passenger road transport line, the 15.4 km to the Dacia plant in Mioveni can be covered in about 24 minutes.

As a result, the total travel time between Brănești and the Dacia Mioveni plant is 1 hour and 53 minutes, and the total distance is 159.6 km. In the case that an express road is built between Pitești and the Dacia Mioveni plant, allowing minibuses to travel at a maximum speed of 100 km/h, the 15.4 km could be covered in no more than 10 minutes, reducing the total travel time on the Brănești-Dacia Mioveni route to 1 hour and 39 minutes.

8.2.2. Determining departure and arrival times for rail transportation on the Pitești-Brănești route

It is assumed that the employees' work schedule begins at 07:00 and ends at 15:00. The minibus will depart from the Mioveni platform at 15:15 and arrive at the Pitești train station at 15:25. The train will depart from the Pitești train station at 15:30.

For calculating the travel time between Pitești and Brănești, it is also assumed that there is a 2-minute stop at each of the 17 intermediate stations. This implies that the total travel time between Brănești and Pitești remains 1 hour and 29 minutes, assuming maximum speed.



Train Schedule for the Pitești-Brănești route

8.2.3. Analysis of employee transportation costs to the workplace on the Brănești-Dacia Mioveni route

8.2.3.1. Analysis of employee transportation costs to the workplace by rail on the Brănești-Pitești route, using hydrogen-powered trains

The cost of transporting employees to the workplace on the Brănești-Dacia Mioveni route is calculated by summing the cost of transporting employees to the workplace by rail on the Brănești-Pitești route with the cost of road transportation on the Pitești-Mioveni platform route, using the formula:

$$C_{totalbm} = C_{tfa} + C_{trm} \quad \text{[lei]}$$

Ctotalbm - the total multimodal transportation cost for employees to the workplace on the Brănești-Dacia Mioveni route, rail transportation with hydrogen-powered Coradia Steam train [lei]

Ctfa - the cost of rail transportation on the Brănești-Pitești route with the hydrogen-powered Coradia Steam train [lei]

Ctrm - the total cost of road transportation on the Pitești-Mioveni platform route [lei].

The cost of rail transportation (Ctfa) on the Brănești-Dacia Mioveni route includes the following elements: Ticket fare for the Brănești-Pitești route (TUIbp) [lei]; hydrogen cost (Ch) [lei].

To calculate the cost of rail transportation, the following relationship is used:

$$C_{tfa} = TUI_{bp} + C_h \ [lei]$$

8.2.3.2. Analysis of employee transportation costs to the workplace by rail on the Brănești-Pitești route, using electric trains

In the cost of rail transportation with the Coradia Steam electric train (Ctfe) on the Brănești-Dacia Mioveni route, the following elements are included: ticket fare for the Brănești-Pitești route (TUIe) [lei]; cost of traction electric energy (Ctrac) [lei].

8.2.3.3. Analysis of employee transportation costs to the workplace by road on the Pitești-Mioveni Platform route

Employee transportation to the workplace will be done using Renault Master minibuses, which have low fuel consumption (diesel), specifically 8.1 liters per 100 km [34]. The minibus can transport 17 passengers, plus the driver [35].

It is assumed that all 350 seats of the Coradia Stream train are occupied, which means that 21 Master Bus minibuses are needed for road transportation of employees.

The elements included in the cost of road transportation are as follows: vignette cost and fuel cost.

The calculation of the cost of road transportation for employees to the workplace on the Brănești-Mioveni Platform route is done using the relationship:

$$C_{rbm} = C_{ro} + C_{mbm} \ [lei]$$

Crbm - cost of road transportation for employees to the workplace on the Brănești-Mioveni Platform route with a Master Bus minibus [lei]

Cro - vignette cost per day for road transportation of employees to the workplace on the Brănești-Mioveni Platform route [lei]

Cmbm - diesel cost for road transportation of employees to the workplace on the Brănești-Mioveni Platform route [lei].

8.2.3.4. Analysis of the cost of road transportation on the Brănești-Mioveni Platform route, using a personal vehicle

The author assumes that transportation is done using a Dacia Logan Prestige car, for a single employee. The car has a gasoline consumption of 5.1 liters per 100 km [457]. The distance from Brănești to the Mioveni Platform is 150 km.

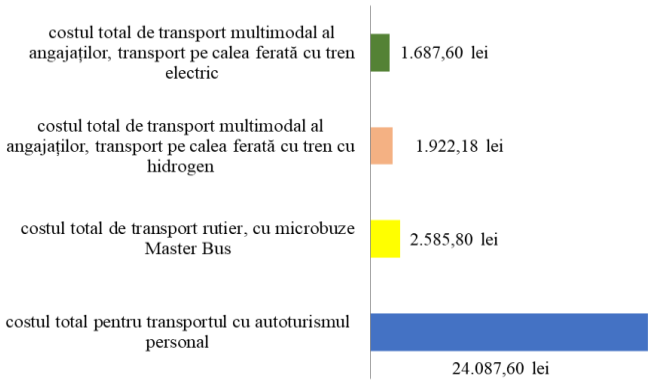
The calculation is done using the formula:

$$C_b = C_{ant} \times P_b \ [lei]$$

Cb is the cost of gasoline [lei]

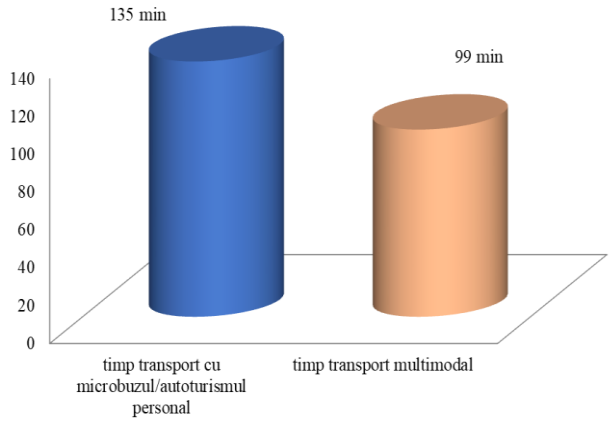
Cant is the quantity of gasoline required for the journey on the Brănești-Mioveni Platform route with a Dacia Logan Prestige car [l]

Pb is the average price of a liter of gasoline [lei].



Cost of transportation for the 350 employees, depending on the type of transport

It is observed that multimodal transportation, in the case where rail transportation is done using electric trains, is the most cost-effective compared to all other transportation options. This is because the cost of electric traction energy is lower than the cost of hydrogen. Therefore, the cost of multimodal transportation, when rail transportation is provided by an electric train, is lower than the cost of multimodal transportation when rail transportation is done with a hydrogen-powered train. The highest cost is associated with personal car transportation. Additionally, multimodal transportation is faster than road transportation.



Transport Time for 350 Employees, Depending on the Type of Transport (min)

8.3. Analysis of the efficiency of the human resources transport service on the Brănești-Uzina Dacia Mioveni route

8.3.1. Analysis of the efficiency of the multimodal human resources transport service on the Brănești-Uzina Dacia Mioveni route when transport is carried out by hydrogen trains

In the case of multimodal transport, the formula used is:

$$\eta_{tm} = \frac{t_{um}^{-1}\, n_p}{C_{totalbm}} \quad \text{[persoane/min lei]}$$

ηtm - efficiency of multimodal transport of employees on the Brănești-Uzina Dacia Mioveni route located on the Mioveni platform when transported by hydrogen trains Coradia Steam
tum - multimodal transport time of human resources on the Brănești-Uzina Dacia Mioveni route located on the Mioveni platform [min];
np - number of passengers transported on the Brănești-Uzina Dacia Mioveni route (350 employees);
Ctotalbm - total cost of multimodal human resources transport on the Brănești-Uzina Dacia route [lei].

8.3.2. Analysis of the efficiency of the multimodal human resources transport service on the Brănești-Uzina Dacia Mioveni route when rail transport is carried out by electric trains

In case the Brănești-Pitești railway line is electrified, and rail transport is done by electric trains, the efficiency of multimodal transport is calculated using the formula:

$$\eta_{tme} = \frac{t_{um}^{-1}\, n_p}{C_{totale}}$$ [persoane/min lei]

ηtme - efficiency of multimodal transport of employees on the Brănești-Uzina Dacia Mioveni route located on the Mioveni platform when rail transport is provided by electric trains Coradia Steam;
Ctotale - total cost of multimodal human resources transport on the Brănești-Platform Mioveni route when rail transport is done by electric train Coradia Steam [lei].
tum - multimodal transport time of human resources on the Brănești-Uzina Dacia Mioveni route located on the Mioveni platform [min];
np - number of passengers transported on the Brănești-Uzina Dacia Mioveni route (350 employees).

8.3.3. Analysis of the efficiency of the road transport of human resources on the Brănești-Uzina Dacia Mioveni route

The formula used is:

$$\eta_{tr} = \frac{t_{ur}^{-1}\, n_p}{C_{totalbm}}$$ [persoane/min lei]

unde:
ηtr - efficiency of employee transport by minibus on the Brănești-Uzina Dacia Mioveni route
tur - road transport time of human resources on the Brănești-Uzina Dacia Mioveni route [min];
np - number of passengers transported on the Brănești-Uzina Dacia Mioveni route (350 employees);
Crtotalbm - total cost of road transport for the 350 employees, with Master Bus, on the Brănești-Platform Mioveni route.

8.3.4. Analysis of the efficiency of personal car transport for human resources on the Brănești-Uzina Dacia Mioveni route

The formula used is:

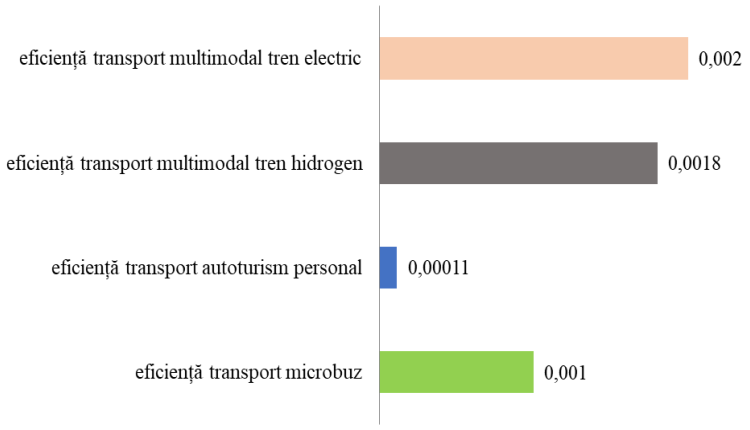
$$\eta_{tp} = \frac{t_{up}^{-1}\, n_{pa}}{C_{tptotal}}$$ [persoane/min lei]

ηtp - efficiency of personal car transport for the 350 employees on the Brănești-Uzina Dacia Mioveni route;
tup - time of human resources transport with personal cars on the Brănești-Uzina Dacia Mioveni route [min];
np - number of passengers transported on the Brănești-Uzina Dacia Mioveni route (350 employees);
Ctptotal - total cost for personal car transport for the 350 employees on the Brănești-Platform Mioveni route [lei].

As a result of the analysis of the obtained results, it is observed that the most efficient mode of transport is multimodal transport when rail transport is done by electric trains. Although hydrogen trains are less polluting than diesel trains, their disadvantage is that there are no charging stations for them in Romania. Additionally, as it is a new technology, the cost of hydrogen is nearly 29 times higher than that of electric traction energy. Therefore, the cost of transport by hydrogen train is approximately 15% higher than the cost of transport by electric train. Hence, the efficiency of multimodal transport when rail transport is done by electric train is superior to the efficiency of multimodal transport when rail transport is done by hydrogen train. However, significant investments are required for electrifying the railway line in this case.

Regarding transport by minibus, its efficiency is lower than that of multimodal transport when rail transport is done by hydrogen train. Thus, the travel time by minibus is longer than the travel time of multimodal transport when rail transport is done by hydrogen train. Additionally, the cost of minibus transport is higher than the cost of multimodal transport with hydrogen trains.

Personal car transport is the least efficient, with the highest cost among all the analyzed options.



Efficiency of employee transport, depending on the type of transport

8.4. Simulations of the online reservation and purchase process of a single travel ticket on the Brănești-Uzina Dacia Mioveni route and return

To develop an application that allows for the online reservation and purchase of a single travel ticket for both rail and road transportation on the Brănești-Uzina Dacia Mioveni route, it is necessary to model the process using modeling languages such as Unified Modeling Language (UML), Business Process Model and Notation (BPMN), or Systems Modeling Language (SysML) [36].

Activity diagrams are used to model the dynamic aspects of a system. They represent an activity broken down into actions that can be executed sequentially or in parallel [37].

Chapter 9 - Final conclusions and key contributions to the development of multimodal transport and industry implications

9.1. Final conclusions

- Transport is a strategic sector of the economy, representing a stimulus for Romania's industrial sector. Industrial activity depends on the mobility of goods and human resources. Additionally, transportation costs account for between 9% and 14% of the total costs of goods and services [7], and any changes in transportation costs have a direct impact on product prices. As a result, companies try to identify solutions to streamline the transportation costs of raw materials and finished products in order to increase business profitability.

  Concerning the mobility of human resources, establishing connections between different areas and industrial platforms directly influences the availability of human resources and, consequently, personnel costs. Given the growing labor shortage in Romania, companies are looking for ways to attract employees from areas near industrial platforms. Hence, transportation solutions for employees to commute to work are being explored.

  However, in Romania, despite the construction of industrial platforms that have attracted significant investments and created numerous job opportunities, the necessary transportation connections for employees have not been adequately established. The connections to industrial platforms are not adapted to the current situation, with even large distances remaining uncovered by public transportation networks. Additionally, there is no alignment between public transportation schedules and the work hours of commuters, nor synchronization of various transportation modes' schedules to facilitate passenger transfers. Consequently, companies are compelled to enter contracts with passenger road transport operators to transport employees and collaborators. These are the main conclusions of the study that addresses the connection, through public transportation, of the Dacia industrial platform in Mioveni with the human resources pool around Bucharest, including the localities of Brănești, Pasărea, Pantelimon, Voluntari, Otopeni, Mogoșoaia, and Chitila.

On the other hand, although online reservation and purchase of travel tickets offer numerous benefits not only to passengers but also to passenger transport companies, Romania lacks a reservation and ticket issuance system for multimodal transportation.

- Multimodal transportation is an efficient alternative to road transport aimed at reducing its carbon footprint. The use of multimodal freight transport can reduce greenhouse gas emissions by 70-80% compared to road transport [38]. Similarly, multimodal passenger transport supports CO2 emissions reduction and traffic decongestion. According to a study by the International Transport Forum, multimodal passenger transport can reduce CO2 emissions by up to 30% compared to unimodal transport [39]. However, in the EU, freight and passenger transport is predominantly carried out by road. For example, in Romania, road freight transport accounts for about 66% of all modes of transport, and passenger transport accounts for 81%. Nevertheless, CO2 emissions from the transport sector constitute a significant share of total greenhouse gas emissions in the EU, with road transport being the most polluting mode. On the other hand, traffic jams in road transport annually cost approximately 0.9-1.5% of the EU's GDP. Therefore, promoting multimodal freight and passenger transport is a priority for the EU, with an emphasis on rail transport, considered an environmentally friendly mode. In addition, for a large quantity of goods, rail transport is cheaper than road transport. This is the result of cost analysis and cost calculations for transporting goods by road, rail, and multimodal transport on the Lipova-Railport Arad (Curtici)-DP World Constanța route. However, on the route analyzed by the author, road transport of goods is faster than by train (10 hours compared to 46 hours by rail or 45 hours using multimodal transport). It should be noted that the average TUI (train unit operating costs) perceived on the Romanian rail network in 2020 is lower than the EU average, but the average commercial speed of freight trains on the Romanian railway is very low.
- Multimodal freight and passenger transport is encouraged through EU policy and, consequently, national policy, through the transposition of EU legislation. Additionally, European and national funds are allocated for the implementation of specific projects. However, different modes of transport are financed differently by the Romanian state and other EU member states, creating a competitive advantage for road transport over rail transport. Furthermore, certain national legislative provisions provide incentives for road transport but not for rail transport. Moreover, underfunding of maintenance and repair works on the Romanian railway has led to a large number of speed restrictions, resulting in reduced train speeds. In these conditions, on the one hand, rail transport operators, despite operating in a competitive market, are not incentivized to renew their rolling stock. Consequently, most locomotives and wagons operating on the Romanian rail network are over 30 years old. On the other hand, companies choose to transport their goods by road due to the long transport times on the rail network, even

though road transport for large quantities of goods is more expensive than rail transport.

- Regarding employee transportation efficiency analysis, on the Brănești-Mioveni industrial platform route, it was found that multimodal transport is the most efficient, especially when rail transport is done by electric train. This analysis is based on the premise that the railway line between Brănești and Pitești is modernized, with Class A tracks and electrification. Currently, there are only 13.405 km of Class A track on this route, and only 30% of the railway line is electrified. It is also assumed that an express road has been built between Pitești and Mioveni, which is currently in the project phase and where minibuses can travel at a maximum speed of 100 km/h.

  While hydrogen trains represent a less polluting option than diesel trains for non-electrified lines, the disadvantage is that Romania lacks hydrogen refueling stations. Additionally, since it is a new technology, the price of hydrogen is almost 29 times higher than that of electric traction energy. Thus, the cost of transportation by hydrogen train is about 15% higher than the cost of transportation by electric train. Therefore, the efficiency of multimodal transportation, when rail transport is done by an electric train, is superior to the efficiency of multimodal transportation when rail transport is done by a hydrogen train. However, significant investments are required for electrifying the railway line.

  In terms of minibus transportation, its efficiency is lower than that of multimodal transportation when rail transport is done by a hydrogen train. Consequently, the travel time by minibus is longer than the travel time by multimodal transportation when rail transport is done by a hydrogen train. Additionally, the cost of minibus transportation is higher than the cost of multimodal transportation by hydrogen train.

  Personal car transportation is the least efficient and has the highest cost among all the analyzed options.

- The conclusions resulting from the analysis of freight transportation efficiency and those obtained from the analysis of employee transportation to the workplace indicate the potential effect of improving railway infrastructure, although there are certain differences between the two types of transportation. Thus, in the case of freight transportation on a section of Freight Corridor No. 9, the current state of railway infrastructure was taken into account, while for employee transportation to the workplace, it was assumed that the railway line had been modernized and that there was an express road between Pitești and Mioveni, where minibuses could travel at a maximum speed of 100 km/h.

  The results confirm that by improving transport infrastructure, the efficiency of multimodal transportation is superior compared to rail or road transportation efficiency.

9.2. Key contributions to enhancing multimodal freight and passenger transport efficiency in Romania with implications for served industrial processes

Theoretical Contributions:

- Elaborating the detailed stages of the research and development methodology that determine the increased efficiency of multimodal transport and gain competitive advantages for organizations in the transportation sector, as well as enhancing the performance of industrial organizations through the transportation of material and human resources.

- Mathematical modeling of the research and development methodology, describing the interaction between organizations in the transportation sector and the competitive external environment, based on the analogy of management processes with a field of forces, as well as the interaction with industrial organizations benefiting from transportation services.

- Determining the efficiency of multimodal transport and conducting comparative analysis with other types of transport, highlighting its influence on the industrial processes served by the transportation of material and human resources.

- Establishing action directions for increasing the efficiency of multimodal transport and, consequently, the economic performance of industrial organizations benefiting from these transport services.

- Characterizing the global transportation sector and that of the European Union in its current stage and estimating long-term development trends until 2030.

- Characterizing multimodal transportation and its contribution to the sustainable development of the European Union and globally, due to the significant reduction in pollution emissions, as well as the implementation of the principle of free movement of goods and people within the European Union.

Practical Contributions:

- Comprehensive analysis of external environmental factors affecting organizations in the transportation sector and their interactions - characterization of the system of factors in the general external environment.

- Comparative evaluation of railway and road transport costs and the analysis of the issue of externalizing these costs in favor of road transport by the state, creating an imbalance regarding competitive advantage in the transportation sector.

- Analysis of solutions for improving multimodal transport, including new technologies for transshipment and real-time monitoring of transported goods.

- Detailed evaluation of the competitive environment of multimodal freight transport in Romania and assessment of this market, aiding transportation sector organizations in formulating competitive advantage strategies.

- Application of SWOT analysis to a generic organization and a representative one engaged in multimodal transport, along with the formulation of solutions for strengthening strengths and improving or eliminating weaknesses, so as to enhance the organization's position in the SWOT coordinates.

- Application of three complementary strategic forecasting methods: relevance tree, scenario method, and content analysis, to identify trends in the railway transport sector with implications for the development of multimodal transport and served industrial processes.

- Application of dynamic analysis, taking into account determined trends in the railway sector, the external and internal environment of an organization primarily engaged in railway transport, which is a crucial component for multimodal transportation.

- Formulation of solutions/measures for strengthening strengths and improving or eliminating weaknesses identified in the internal analysis of a railway sector organization, comparing the graphical representation of the organization's positions in the SWOT system before and after the implementation of these measures.

- Determination of costs and transit times, as well as the efficiency of freight transportation along a nationally relevant route in three transport modes: railway, road, and multimodal.

- Establishment of measures and action directions for improving the efficiency of multimodal freight transport based on efficiency calculations, as well as determining their impact on industrial processes served by this type of transport.

- Determination of costs, travel time, and efficiency for employee transportation along a relevant route connecting a region with a high-growth human resources pool and a strategically important industrial hub for Romania's economy.

- Development of the UML language architecture for an online ticket purchase application and simulations of the online reservation and ticket purchase process for the chosen relevant route, connecting a major industrial hub with a continuously developing human resources pool.

9.3. Future Research Directions

- Currently, Romania lacks a comprehensive strategy addressing multimodal freight and passenger transport that can meet the requirements of economic efficiency and sustainable development. This doctoral work can serve as a starting point for the development of such a strategy at the national level. Therefore, this doctoral thesis can

be a valuable resource for the Ministry of Transport in formulating a Strategy for Multimodal Freight and Passenger Transport.

- Developing an application for online booking and sale of a single passenger travel ticket for multimodal transportation, ensuring human resources for heavily industrialized areas, under efficient conditions.
- Efficient implementation of multimodal transportation for both goods and passengers, as examples of best practices developed within the thesis, on other relevant routes, with a significant impact on the industry.

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