Current Issues of Multimodal and Intermodal Cargo Transportation

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Abstract Freight transport is constantly growing and the forecast is that this trend will continue in the future. The sustainable development of transport requires the development of activities, which yield higher economic and social results while at the same time reduce the negative impact on the environment. In the long term, the sustainable development of transport activities is complex and tied to enormous challenges, difficulties and barriers, related to the development of the technological environment, the social and economic development, the influence of political factors and regulations. One of the central perspectives for the development of the freight transport in Europe is the development of multimodal and intermodal transport. The present chapter reviews some essential issues about the conditions for interaction between the modes of freight transport and the main challenges this kind of transport faces. An overview has been made of the main characteristics of organization and technology in multimodal and intermodal transport, and the related to them commodal and synchro modal transport that have appeared in recent years, as well as the physical internet concept. The application and barriers for modern use of information and communication technologies in multimodal and intermodal transport has been reviewed. An overview of the development of multimodal and intermodal transport in Bulgaria in accordance with the development of international transport

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corridors that pass through the country is carried out. A mathematical model has been developed on the basis of multicriteria optimization with three criteria: direct costs, time and external costs. The transport scheme is presented as an oriented graph line with each point corresponding to a node and each road, connecting nodes i and j, to an oriented weighted rib (i, j) in the graph. Weight c_{ij} is directly connected to the three criteria set. We assume that on each rib transport can be carried out by three modes: waterway, road and rail. If there is no physical connection, the respective weight is assumed to be an infinitely large number. Pareto optimal solutions have been determined under conditions for integer variables and application of a weighting method. To verify the model, a specific task for providing multimodal transport has been solved with the help of Matlab R2017b software and the optimization functions built into the product have been found to be optimal under Pareto solutions, using heuristic approaches for solving a partially integer linear optimization problem.

Keywords Multimodal transport · Three-criteria optimization · Internal cost · Route and time optimization · Freight and passenger transportation

1 Conditions for Interaction and Main Challenges for Freight Transport

1.1 Coordination and Interaction Between the Different Transport Modes

The interaction between the transport modes is such joint activity that is directed towards the achievement of a common goal through the best use of characteristics and resources of the respective modes during the transport processes. It is directly related to the coordination and coherence in functioning of the transport system and its sub-systems.

Most of the freight and passenger transportation is done with the participation of two or more modes of transport. About 80% of the freight, transported by rail is delivered by other modes of transport. About 70% of the freight, delivered to sea and river ports, are transferred for further transportation by rail. Almost all the oil and oil products, which are transported by pipes, are delivered by water, and the bigger part is transferred for further transportation by pipe or road. The road transport practically interacts with all other transport modes.

The points of direct interaction of the modes of transport are the transport terminals (railway stations, river and sea ports, airports, freight warehouses, container sites, etc.), where all transport modes merge. Until recently, legally and physically the transit freight flows of the transportation process have been interrupted in the transport terminals. The freight owner unloads them and prepares new documents, in order to continue their transportation with another transport mode. Or, in other words, in the case of no interaction between the transport modes, each transport terminal becomes an end point for fright tracking. This interruption of the transport chain not only incurs big money and time costs, but also long delays at these points, thus prolonging the time of their transportation to the final destination.

The multimodal mixed transport comes in response to these difficulties. With this kind of transport, there is coordination between the modes for the transportation process, with one document prepared for the entire route—from the starting to the final point, for all the modes of transport involved. With this kind of organisation, the owner is released from performing the necessary intermediate and final reloading operations in the transport nodes.

The organizational and effective interaction between the different modes of transport, comprising the transportation of freight, is achieved through full specification and coordination of the operations. It must be noted that this interaction is a complex process of planning and realization and depends on a number of conditions of economic, technological, organizational, legal and managerial nature.

Organisational and economic conditions of interaction. The transportation plans of the units of various modes, performing mixed freight transportation should be identical. This refers both to the perspective annual plans and the operational transportation plans, which should coincide in volume, nomenclature, terms, points of departure and destinations, names of the organisations, carrying out the dispatch and receiving of freight.

The absolute coincidence of transportation plans for all transport modes that interact in the transport terminals, allows preliminary preparations, concerning the rolling stock, machines and equipment for loading, unloading and handling the freight, work force, work organisation, etc.

In the cases when the identical planning has been disrupted, or there is a discrepancy of the plans on the specific positions for the different modes of transport, carrying out mixed transportation, retention of both the freight and the submitted rolling stock occur due to the functional discrepancy obtained. This also refers to the cases when unplanned freight is fed by on mode of transport.

Technical conditions of interaction. Constructive power unification of the main structural elements of the different types of rolling stock, participating in mixed transportation is necessary. The transport terminals should be planned rationally, coordinating the carrying and processing capacity of the unified transport line, followed by freight and passenger flows. More specifically, the length and positioning of the station tracks (railway deviation) and the quay wall of unloading ships should be coordinating or unified, as well as cranes and other loading–unloading equipment for reloading of freight from ship, railway carriage and car; the power of the handling machines and the capacity of the warehouse; the loading capacity of the railway composition and the capacity of the ship's rolling stock; the loading capacity of the railway carriage and car, the parameters of the tanks and of the overflow trestles; the specialization of the ship, the railway carriages and cars; the sequencing layout of all freight handling sites; unified telephone and other connections between the officials of the operational unit, managing the performance of mixed transportation and belonging to the departments of the various modes of transport.

The technical aspect of interaction of the modes of transport is extremely broad and complex and is subject to further development in practical and theoretical terms.

Technological conditions. The processing of freight in the transport hubs should be carried out by a unified technology, without which it is not possible to reload the freight from one transport vehicle to another quickly and efficiently.

Units of different modes of transport (rail, road, water) function in the transport terminal, each having its own equipment and using its manipulation technologies. For the rational performance of all manipulation operations, it is necessary to unify the technologies used by the different units. This can be done through joint specification of the unified technology and its description in a single document. This document should be approved by the authorized institutions, representing the different modes of transport, which interact in the transport hubs.

In organisational terms, the problem of interaction lies in the development and joint use of a number of documents, regulating the production activity in the transport terminal, instrumental for the organisation and operational management of the work. These documents include: unified contact schedules for the traffic on the lines, connecting the transport terminal; uniform forms for shift work planning; introduction of unified duration, start and alternating of shifts, unified forms for exchange of information on the entire operational production activity, etc.

Management aspects of interaction. Management considerably affects the performance and the results from the joint work of the various modes of transport in the transport hub. In summary, and as the existing experience shows, the best results come when there are unified shifts with representatives of the interacting transport modes.

1.2 Modern Challenges for Freight Transport

The volume of freight transported in the EU is increasing, as a result from the completed European domestic market, the abolition of internal borders, the drop in transport services prices due to the liberalization and opening of transport markets, as well as the changes in the system of production and ware house management.

At the same time, the dynamic transport sector faces a number of challenges. The main ones are: sustainable transport solutions and serious social and ecological restraints; providing a reliable transport service; requests for smaller shipments and their consolidation; higher expectations for the quality of transport services and their integration into flexible ICT systems; increasing fuel costs.

Sustainable transport solutions. Issues like safety, reducing the risk when transporting freight and sustainability of the environment are today's agenda. The transport sector is increasingly placing an important accent on the ecological solutions. Besides, most consignors prefer smart and sustainable transport solutions to the standard ones, which do not take into account the impact on the environment.

Reliable transport services. Transport companies strive to offer reliable services. Although freight transport has a growing market segment, it often lacks flexibility when providing transportation. Ongoing repair and force majeure circumstances cause temporary scheduling of transport. Security is a growing concern in the international logistics. This is due to the fact that in the freight transport process, the freight goes through a number of agents in the supply chain, from the moment when it leaves the export company to the moment it reaches its final destination. One of the problems, ensuing from the visibility of the supply chain, is the risk of fraud.

There are many reasons why delivery to the final destination may be delayed such as the time needed for the release of the cargo and the custom's checks after the release. These checks often cause delays due to problems with the documentation. The freight stays in the terminal longer, which leads to considerable delay costs (which vary in different countries and companies) for the transport operator. This situation is usually outside the control of both the export company and the importer. Besides, there are other external reasons like time, technical problems of vehicles, natural disasters, etc. These delays are one of the reasons why in many cases the final delivery date for the freight would not be met. Besides the delay, it is possible to lese a client, image, etc.

Consolidation of shipments and their grouping due to smaller volumes. It can be noted that most clients reserve smaller volumes with shorter notice. Due to the emphasis on production flexibility, companies are looking for solutions to reduce inventory. This led to increased demand for consolidated and grouped shipments.

Higher expectations for the level of services and integrated, flexible ICT systems. Today digitalization is transforming many industries and the transport industry is no exception. With the advance of technologies, clients expect a higher level of service, including integrated and flexible ICT systems.

Rising fuel costs. The rising fuel costs have a strong influence on the transport sector. Optimising travelling routes and reducing fuel costs is one of the biggest challenges in this sector. In addition, alternative fuels, offering a more optimal solutions for the future are being studied. Some of them include electrical or hydrogen driven vehicles.

Furthermore, the international standardization should be noted, as well as competitiveness, automation of processes; market niche; cost effectiveness, etc.

1.3 Force Majeure Circumstances in Transport and Measures (e.g. COVID 19)

On 16.03.2020 the European Commission published a communication, concerning the guidelines for forming the so called "Green lanes" [1].

The main points in the document are as follows:

- The principle that all internal EU borders should stay open for freight transport and the supply chains for essential products should be guaranteed has been emphasised. The free flow of goods, especially at times of emergency, is in everybody's

interest. The countries should fully comply with and apply the Guidelines for all internal cross-border points. It is necessary to apply a process of cooperation in the whole EU, in order to ensure the transportation and arrival at the destination point of all freight, not just of essential goods such as food and medical supplies.
- In order to preserve the functioning of the supply chains in the entire European Union, as well as the unified commodity market, at every point where there exists or has existed internal border control, the member states are called upon to designate immediately all relevant internal border-crossing points of the Trans-European Transport network (TEN-T), as well as additional ones, to an extent that is considered necessary, as "green lane" border points—for land (rail and road), sea and air transport.
- Passing through the "green lane" border points, with all checks, including health screenings of the transport workers, should not exceed 15 min at the inland borders. The "green lane" cross border points should be open for all freight transport vehicles, carrying such kind of freight.
- Member-states should immediately undertake action for temporary suspension of all types of restrictions for road access to their territory (weekend, nighttime or sector bans, etc.) for road freight transport and the necessary free movement of transport workers.
- Transport workers, irrespective of their nationality and place of residence, should be allowed to cross internal borders. Restrictions for travelling and mandatory quarantine for the transport workers should be abolished without the need for the authorities to undertake proportional and specially adapted measures for minimizing the risk of infection.

On 01.04.2020, Bulgaria published an Action Plan of the Republic of Bulgaria on the Call of the European Commission for applying the Green corridors from the Guidelines for border management measures to protect health and ensure the availability of goods and essential services [2].

The Action plan contains 23 groups of guidelines:

- Treatment of all goods, vehicles and drivers in a non-discriminatory manner;
- Identifying internal border checkpoints on Bulgarian territory under the TEN-T network;
- Passing through the border checkpoints in maximum 15 min;
- Open border passages of the "green lanes;
- Providing opportunities for transporting all kinds of goods and livestock;
- "Minimizing procedures at border crossings;
- Holding health screenings;
- Performing other checks on documents and freight;
- Minimal delay during checks and screenings;
- Effective functioning of the "green lanes" border crossing (Fig. 1);
- Cooperation between the National units for contact with EU member-states, as well as countries outside the EU;
- Lifting of all types of driving restrictions;

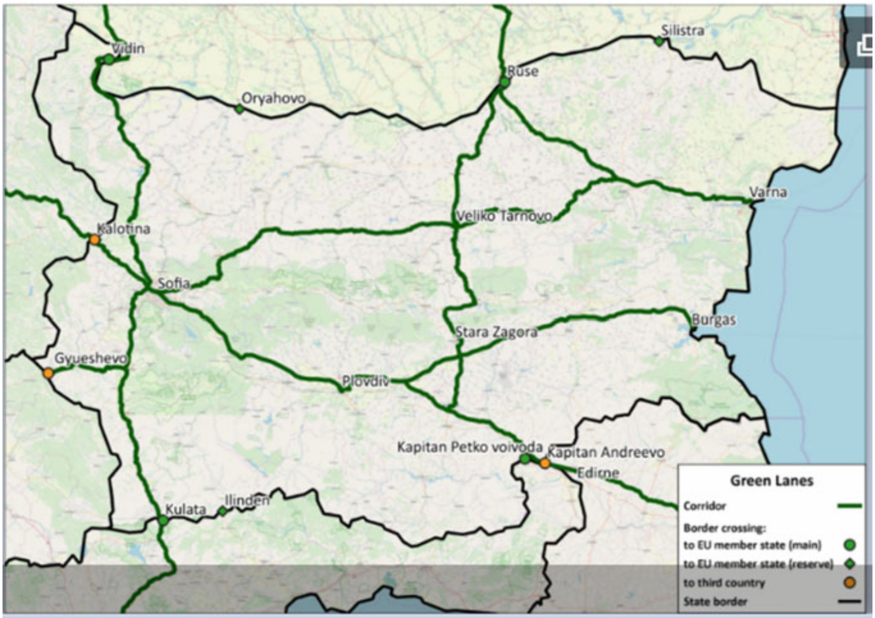


Fig. 1 Green corridors on the map of Bulgaria, crossing the territory of the country

- Availability of appropriate sanitation facilities for transport workers along the main transport routes;
- Creating transit lanes for safe passing of private drivers and their passengers along the TEN-T network;
- Providing free movement in the EU of all workers participating in international transport, for all kinds of transport;
- Lifting of some restriction rules;
- Unobstructed crossing of the borders for the transport workers;
- Establishment of legal capacity;
- Providing health screening for the transport workers and respective subsequent measures;
- Improving the sanitation and measures for disinfection;
- Transport workers and operators on critical and basic supply chains for services should be viewed as one of the priority groups when protective and prophylactic equipment is distributed;
- Cooperation for facilitating the repatriation of transport workers, whose contracts have been terminated;
- Applying all principles for third country citizens as well.

Bulgaria designates the following cross-border points:

- At the border with Greece–Kulata and Kapitan Petko Voivoda, and Ilinden as a backup.

- With Romania, the main border points are At Vidin and Ruse and Oryahovo and Silistra are designated as backups.
- Cross-border points with the countries from the Western Balkans and Turkey have also been designated, with activities for a coordinated approach undertaken by the European Union.
- Between Bulgaria and Serbia is designated the cross-border point at Kalotina.
- With Turkey–Captain Andreevo, and with Northern Macedonia–Gyueshevo.

Going through these "green lane" border checkpoints, including all checks and screenings of the transport workers, should not exceed 15 min at the internal land borders. The "green lane" border crossings should be open to all freight vehicles carrying any type of goods.

On 28 October 2020 EC proposed to expand the approach for green lanes in order to guarantee the effective functioning of multimodal transport in different modes, including rail, water and air, and on 25 January 2021, EC proposed to update the coordinated approach to restrictions on free movement. The member states should strive to avoid stopping emergency travel, and in particular, the movement of transport flows in accordance with the "green lane" system, as well as avoid interruptions along the supply chain by air freight.

During the first month (March), long lines of waiting freight vehicles were noticed at the road transport border crossing points. Thus, for example, on 18.03.2020 at 13:15 h the length of lines [3] were as follows:

- Captain Andreevo—24 km;
- Kalotina—4 km;
- Ruse Danube bridge—7 km;
- Vidin Danube bridge—6 km.

Gradually the situation was normalised.

2 Characteristics of Multimodal and Intermodal Transport

2.1 Main Characteristics of the Organisation and Technology of Multimodal Transport

Up until the 1980s, goods were transported from their point of origin to the consignee mostly by one mode of transport. The development of technologies today allows the use of various types of vehicles in different segments of the routes. To stimulate solutions for efficient and balanced use of transport modes, the inclusion of maritime, inland waterway and rail transport is encouraged, including through providing tax incentives and funding under various programmes [4]. Some countries started to impose restrictions on road transport for environmental reasons, high risk of accidents, busy roads and noise pollution [5].

Table 1 Main content of the EU strategic documentation on transport policy

Strategic document	Content on the use of transport modes
The White Book of 1992 on the future development of common transport policy (COM (92) 494 final as of 2 December 1992)	Changing the balance between the modes of transport is defined as the main goal
The White Book of 2001, "European Transport Policy by 2010—time for decision-making" (COM (2001) 370 final as of 12 September 2001)	The significance of the change in the ratio of the different modes of transport in view of increasing the sustainable nature of the European transport system is confirmed. It is noted that the intermodal transport must be promoted through investments in building stable connections between maritime, inland waterway and rail transport
The White Book of 2011, entitled „Roadmap for achieving a Single European Transport Area—for competitive transport system with efficient use of resources" (COM (2011) 144 final as of 28 March 2011)	The main goal is to reduce greenhouse gas emissions through limiting the increasing level of road congestions and building efficient intermodal connections

The development of multimodal and intermodal transport technologies is part of the European transport policy and has been included in the three main strategic documents of the European Community in the field of transport so far (Table 1).

The first concept of multimodal transport appears for the first time in the concise Oxford English Dictionary of 1980. In 1993, the concept was developed as a container system. In the dictionary, the meaning is defined as transport using more than one mode [6], unlike the earlier situation when different modes of transport operate independently. With multimodal transport, the individual transport modes are offered in a common consolidated mode and become more integrated and coordinated. Multimodal transport is also called "combined transport", but it should be noted that this term is used for a special case of multimodal transport according to the definition, given by the European Conference of Ministers of Transport (ECMT), which has become known as International Transport Forum since 2006.

In the concepts of various authors related to multimodal transport exist differences. This is due to the fact that some of the authors view the process holistically while others view it piecemeal, as well as by individual operations. The term "multimodal transport" characterises the transportation process in terms of its legal and organisational provisions, unlike the terms "combined" and "intermodal transport", which characterise the transportation process, depending on the technological operations performed with the load or with the vehicles.

At present, multimodal transport systems are at the heart of international commerce, with the aim to reduce the total cost for transport and processing within the supply chain, and at the same time, to meet the demand for door-to-door transport services.

The first and only international legal source, containing the term "multimodal transport" and revealing its essence is the UN Convention of 1980 for international multimodal transport of cargo, which, however, has not come into force because it has not been ratified by a sufficient number of countries. Some basic provisions of the document are: international cargo transport; using at least two transport modes; the transport is organised by an international operator, or by an authorised individual who represents the operator; the transport operator is equal to the shipper party under the contract and does not act as an agent, or on behalf of the consignor, or as a carrier, involved in the transport operations; the transport operator assumes responsibility for execution of the transportation contract; the document issued by the transport operator covers the entire route from the shipper to the consignee; the responsibility of the transport operator for the cargo covers the period from the moment of acceptance of the cargo to its delivery to the consignee.

Therefore, according to the convention, multimodal transport can be defined as international transport, executed in two or more different modes, organised by a transport operator, taking full responsibility for the cargo transportation and issuing to the shipper a document for multimodal transport, covering the whole route of the cargo. The movement of the material flow in the multimodal scheme consignor—carrier—consignee can be presented conditionally on Fig. 2.

The Rules "UNCTAD/ICC for Multimodal Transport Documents" have been in force since 1992. They are recommendatory and contain standard conditions of the transport contract, included in the multimodal transport documentation. The contractual nature of the rules does not allow their use in case of occurrence of the circumstances related to loss or damage of the cargo, or violation of delivery times. Today, the legal status of the multimodal transport is regulated by the national, laws or bilateral or multilateral agreements.

The individual legal approaches usually differ in their content and often bring disorder and doubt into the legal mode, regulating the multimodal transport. All this leads to increasing the costs, including those for insurance.

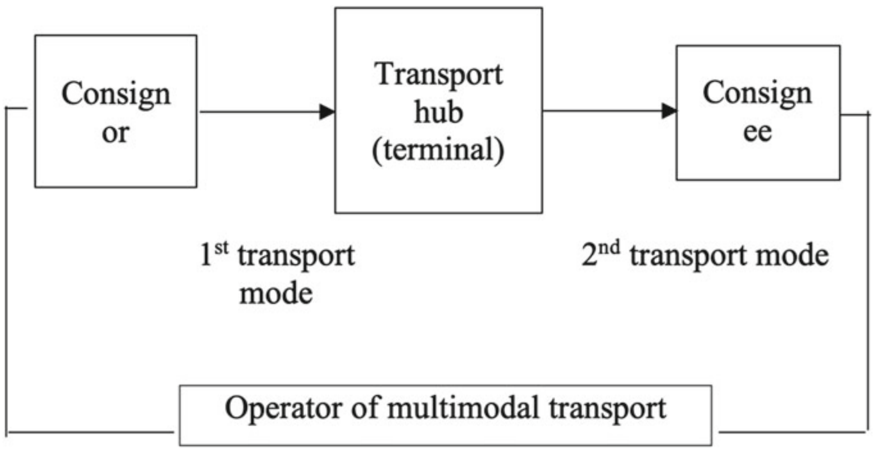


Fig. 2 Movement of the material flow in a multimodal cargo transport scheme

The benefits of multimodal transport are well-researched. Some key advantages, which turn multimodal transport into an attractive opportunity for public and private stakeholders [42], include: saving costs and time by using each mode of transport optimally in each phase of the route; greater return on infrastructure investment; better utilisation of the capacity as a result of optimal use of each mode; lower energy consumption; reducing the harmful effect of transport on the climate and the environment. In the literature about multimodal transport a number of fields have been researched such as: the need of developing multimodal transport networks; comparative analysis of multimodal cargo and passenger transport; cost and time benefits of using multimodal transport [7]. Part of the research is focused on the behavioural aspects, i.e. the perceptions of the end user and the sender [8] and the modal solutions [9–12].

There are a number of studies on the integration of the multimodal transport networks in terms of the end-user [8]. Different methods are used when studying the problems, related to integration of the multimodal transport networks. For example, a case study, focused on cost and time, show the advantages for the expenses and the efficiency of using different route combinations and modes of cargo transport [7]. The model used in this study is based on offers, received from shippers, while calculating the freight for twenty-foot equivalent (TEU) for four different routes, passing through different countries and ports, and using a combination of modes. This model is proposed by [12].

Other studies on multimodal transport are related to the network and are focused on the choice of transport, using probability models with several parameters such as travel costs, loading and unloading time costs [9–12].

2.2 Main Characteristics of the Organisation and Technology of Intermodal Transport

Intermodal transport has developed as a special case of multimodal transport. In the literature, there are different definitions of intermodal transport. Just like multimodal transport, the intermodal version can be viewed as an alternative of single mode transport for long distance travels with large volume cargo [13].

According to the Organisation for Economic Cooperation and Development [14] "Dictionary of Statistic Terms", the intermodal transport is defined as "movement of goods (in the same cargo unit or vehicle) through successive units of transport without processing of the goods themselves when the transport mode changes". Another definition is given in [15], where the intermodal transport keeps the goods in the same cargo unit during its transportation with different types of transport.

The main advantage of intermodal transport solutions is that they have relatively low external costs [16]. According to [17], in the case of intermodal transport by rail, the external costs of tkm are 28% of the external costs in the case of road transport.

The difference in external costs can be even greater since the congestions are not considered in the calculations [16].

Since the intermodal cargo transport is less energy-consuming than the road transport, it has a significant contribution for achieving sustainability in the European transport sector [18]. This is the reason why intermodal solutions are promoted by policies at all levels [19]. The market share of the intermodal cargo transport, however, is not expanding as much as it is expected [20], while going through different stages.

After the advent of containers, intermodal transport has been developing rapidly. The technologies have changed, particularly at the ports, where the work of the stevedores has been transformed from labour-intensive to more automated activities. Consequently, more time has been freed up for ships to sail, instead of being unloaded for days, which leads to a more profitable maritime industry. Carriers and port structures are changing their logistics; hence, the globalisation of industry prospers [15]. With the increase of the number and volume of ships, staying in ports for shorter periods, the intermodal inland transport is also increasing (land and inland waterways transport) [21]. The increase of maritime transport and the improved functionality of seaports can seriously affect land transport [22].

The transition to intermodal transport is a strategy for decreasing harmful emissions and increasing economic growth, thereby changing logistics models and reducing congestion [15, 21]. In addition to reducing emissions, economic growth is realised, due to applying model transfer of goods, which can provide better access to global trade routes. Transport industry, however, is facing many challenges, and one of them is the need of using automobile transport, in which operational factors such as shorter distances and demand imbalances lead to a more effective transportation, but later, this creates problems such as congestion and more harmful emissions. Nevertheless, according to [22], intermodal transport of goods can solve problems, related to the environment, congestion and traffic safety.

The supply chain of intermodal transport is described in Fig. 3.

In addition, transport industry aims at delivering products along the entire supply chain to the end-user with "an appropriate level of service and quality, with the lowest possible costs" [23]. Therefore, the supply chain faces various obstacles, which need to be overcome, in order to meet global sustainability challenges.

The intermodal solutions with using a chain of land rail-automobile transport lead to an increase of transit time, lower reliability, related to delivery by rail transport, higher risk of damage, as well as reduced flexibility [21].

Despite the outlined problems, intermodal transport is the preferred choice when sustainability in transport is targeted. The development of faster trade between ports has led to an increased quantity of goods in global routes, which poses more requirements to transport. Green transport solutions mean sustainable opportunities for transport and choice of various modes within the scope of intermodality, which offers effective and efficient flow of goods along the entire supply chainy. Despite this fact, the modal choice which the stakeholders have to make is difficult because there are various hindrances, influencing it.

The fast-growing global industrialisation and the ever-increasing demand of goods increase the use of different modes of transport, incl. intermodal transport, involving

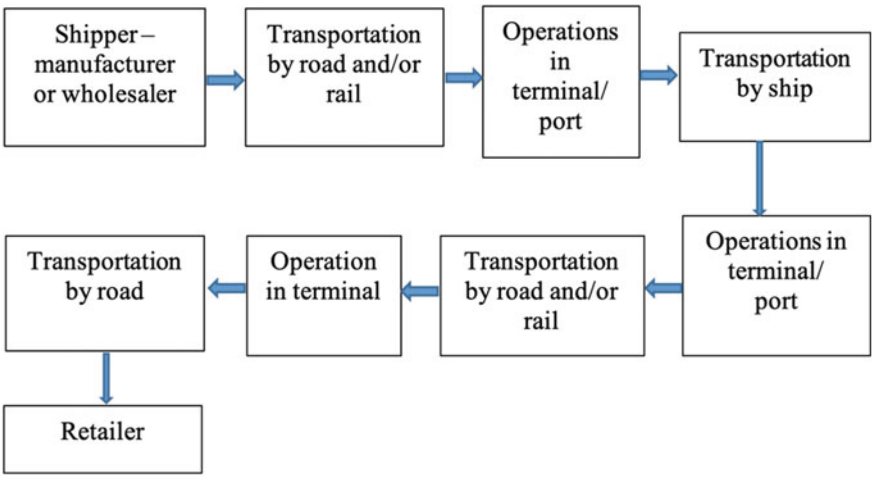


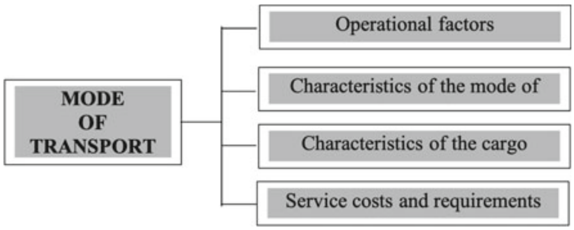
Fig. 3 Model of intermodal transport chain from consignor to retailer

sea, road and rail [23]. From a point of view, goods are transported to longer distances because trade is mainly between developed countries in Europe and North America, North America and Asia, Asia and Europe. Besides, many of the companies have only one global production enterprise [24]. As a consequence, o0f longer transport distances, it is more and more important for the modes of transport to maintain and develop efficient logistics operations all over the world [25].

Although the logistics sector offers several variants of transport, the automobile cargo transport remains the main modal choice in many countries. It is a fact that the use of cargo vehicles is constantly increasing while the rail transport use is reduced or kept at the same level [26]. Nevertheless, intermodal transport is viewed as competitive with the traditional modes of transport, including automobile since the demand for transportation of goods leads to an increase of transport flows, which inevitably calls for cooperation between the various transport modes [25].

When choosing the most suitable mode of transport within the scope of intermodality, we can define a four-stage process. These four stages are related to: operational factors; the characteristics of the mode of transport, characteristics of the cargo, its quantity and the requirements for costs and services, as shown in Fig. 4.

Fig. 4 Mode of transport choice



The modal choice is not easy and is associated with many trade-offs and taking into account of different aspects [26].

There are various analytical models, used for determining the choice of mode, as well as factors, influencing the decision-making. It is important, however, to consider the fact that there are also various trade-offs between these factors and that decision-making depends on the various participants such as freight forwarders, consignees, carriers and logistics service providers [27].

With the raising awareness of climate change and other ecological problems, together with globalisation, environmental sustainability is turning into a competitive advantage in industries and the logistics sector. Congestions and pollution, resulting from the increased freight transportation by road, encourage policy makers, who actively tolerate the change of transport mode [28].

In connection with the development of sustainable transport, many countries are introducing new policies, promoting its development through the use of rail and water transport in the intermodal chain. These sustainable options are developing as alternatives of the most common modes of transport—road and air, which are the least sustainable choice of mode [29].

As far as the literature on intermodal freight transport is concerned, many obstacles are reviewed. In addition to the barriers, mentioned most often in the literature, the supply chain faces other different challenges. The participants in the chain, i. e. forwarders, carriers and society, have different points of view, which justify their decisions when choosing intermodality [30].

Society's point of view is sustainability, the carriers are focused on providing the transport service, and the forwarders—on the business perspectives. They all have the common goal of overcoming the barriers to using intermodal transport, as shown on Fig. 5.

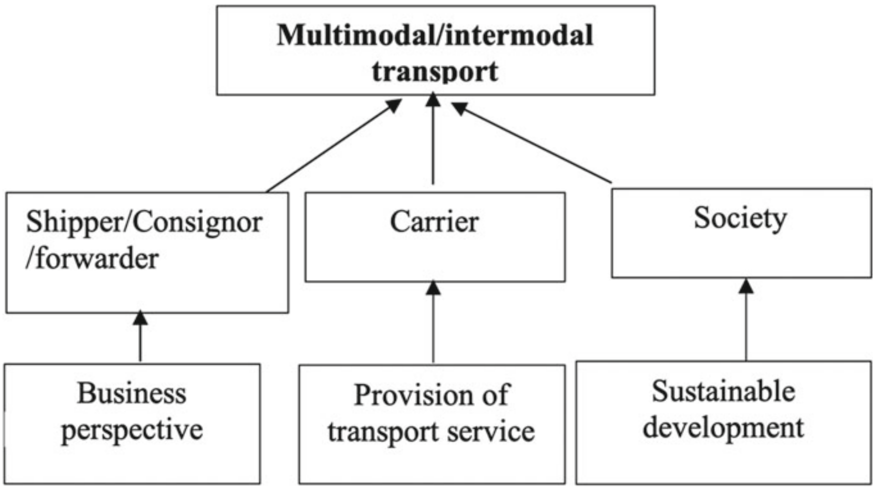


Fig. 5 Perspectives of the participants in the multimodal/intermodal transport

The choices made by the different participants, are not decided in an isolated manner, but rather in the context of the supply chain or logistics, where the different hierarchical levels influence the final decision. This final decision for a change of the mode of transport is affected by some overarching factors, subjected to external pressure, business and logistics strategy:

- "External pressure" can be the change in the user awareness, stricter environmental legislature, increased fuel prices and a growing demand for green solutions such as green products or transport;
- New "business strategies", in which organisations adapt the consumer demands, e.g. more environmentally-friendly solutions as the society's awareness rises;
- "Logistics strategies" are closely related to the business strategy chosen by the respective organisation as depending on the strategy and the different resources available, shippers can choose among the different logistics systems, logistics services suppliers for third countries (3PL), etc. The choice of system will also depend on the level of demand for a given product.

The review of scientific literature on intermodal transportation reveals the availability of various studies in areas such as:

- addressing port logistics, which plays a major role;
- earlier research of intermodal transport has focused strongly on rail transport while current studies include water and road transport to a larger extent;
- topics of political concern, related to climate, environment, congestion and accidents are becoming more and more frequent;
- research on terminals, which are an important part of the intermodal transport chain and play a strong influence on the competitiveness of the intermodal alternatives for freight transport, are considerable.

The problem of distribution of space for storage in container terminals [31] is considered by the authors as they divide it into two levels as models of mathematical programming.

The intermodal freight transport by rail has been reviewed in the literature [25]. The authors claim that with intermodal freight transport, research is in the pre-paradigmatic phase and offer a list of nine research needs, which they consider as prerequisites for the research to move to the phase of normal science.

The modeling of intermodal and international freight networks describes the development of a multimodal network, created and stored in a digital mode, for use in freight transport simulation [32]. The simulation was conducted back in 1997 when studying commodity flows in the USA. The authors describe the development and implementation of a unified, integrated, digital presentation of a multimodal and transcontinental transport network. This network has been built to aid the simulation of approximately five million shipments, directed to freight transport. The document focuses on the route of the tens of thousands intermodal freight transports, reported in this study. The routes include different transport mode combinations—with freight trucks, by rail and water. The GIS technologies were invaluable in the cost-effective construction and maintenance of this network and the subsequent validation of the mode sequence and the choice of route. Nevertheless, the reliance on the intermodal freight transport is most effective outside GIS. The choice of appropriate intermodal routes requires: procedures for connecting the freight warehouses and destinations with the transport network; procedures for modelling the intermodal services in the terminals; intermediate, intertwined transshipment services and a procedure for generating multimodal models, reflecting the relative costs in choosing one mode or another.

Modelling of the total costs of intermodal and multimodal road transport network [20] includes developing a model for analysis of the internal and external expenses when comparing the intermodal and road transport networks. The authors have found that the total costs of both networks decrease in proportion when the "door-to-door" distance increases, which implies great savings. Parallel to this, they have discovered that the total costs for intermodal transport decrease while the road transport costs remain steady with the increase of load volume.

The document examines the combined economic and emission costs among three different transport networks, including an intermodal one with the participation of rail transport, only rail and directly road transport. The aim is to analyse the potential of the scheme with a large capacity of increasing the competitiveness of intermodal transport in terms of total costs. The model developed has been applied under Swedish conditions and with Swedish transport. The findings from the research show that the costs in IRT, compared to those in direct road transport, can be reduced considerably.

The concept of the dry port—connecting the container sea ports with the hinterland [33, 34]—surpasses the conventional use of rail transport for connecting the sea port and its hinterland region. Three categories of dry ports have been defined and the authors claim that when combined, the port and the surrounding city can be relieved from congestions and the logistic solutions for shippers can be improved.

Definition in [33] of Rousseau, from 2009 reads that "The dry port is an internal intermodal terminal, directly connected to a sea port/ports by high capacity vehicles, where clients can leave/take their standardized units, as if directly to/from a sea port".

A case of a fast-developing market of commodities [35] discusses the justification of the networks for the cooperation of hubs and claims that the savings from the scope and those from the range of logistics can be achieved through cooperation in multimodal networks.

In recent years, besides multimodal and intermodal network, the terms co-modal and synchro-modal transport have emerged.

The common part of the definition is that in each of the technologies more than one mode of transport is used [36].

In summary, the special features of each of the various unimodal transport schemes are shown in Table 2.

Additionally, with the development of Industry 4.0, in literature emerged another concept, related to the multimodal mode of transportation—the physical internet (PI). This is a concept of the open global logistics system, which entirely redefines the currant supply chain, business models and value creation models. The concept was first introduced by Prof. Benoit Montreuil from Laval University, Quebec, Canada, and the main idea is as follows [38, 39]: The logistics activities should be organised

Table 2 Main differences in transport schemes

Type of transport mode	Special features
Multimodal	Use of more than one mode of transport with a common transport document and cargo handling
Intermodal	Use of more than one mode of transport and handling of cargo units
Co-modal (co-modality)	Co-modality is defined as "effective use of different modes of transport" [37] Co-modal transport is the combination of ecological modes of transport such as rail, water, container, with road transport, which provides the client with door-to-door supply chain
Synchro-modal	The synchro-modal transport is a mode variant of co-modal transport with parallel use of the available transport modes

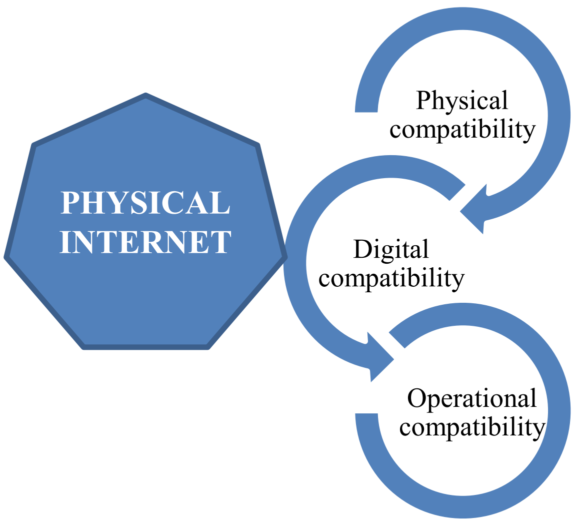
in an open and shared network, not in specialised ones. The application of physical internet is a new era of interrelated logistics. The key word of the concept of PI is the universal interconnectedness, which should guarantee full cooperation between all participants in a supply chain, full compatibility of all implemented technical and technological resources and solutions, and optimal realization of all operations.

With physical internet we consider three interconnections (Fig. 6).

The physical compatibility includes the formation of appropriate smart module units (containers). These cargo units travel optimally through logistic networks.

The digital compatibility provides the opportunity for full communication, based on the Internet of Things (IoT), both between the separate module units and all the elements of the physical internet.

Fig. 6 Types of interconnections in physical internet



The operative compatibility includes the application of certain protocols and procedures for defining domains and priorities when using information in planning, realization and management of the module units.

The physical internet is still at a concept stage. It is necessary to do research at the physical and informational level, as well as the business models.

One of the first challenges is the physical level, which is closely related to the physical infrastructure (standard containers, hubs, roads, etc.). At the information level, the challenges are related to the role of ICT and their correspondence to the business models applied, as well as the degree of intelligence of the cargo units. Redefining the configuration of the supply chain in the business models will lead to a number of changes for which their efficiency and effectiveness should be evaluated.

PI are complex systems and require the involvement of huge technological changes and changes in the business environment. They can be realized only with the active participation of industry since they require large investments.

2.3 Quality Criteria of Transport Services in Multimodal Transport

The indicators, characterizing the quality of services in transport systems can be conditionally classified into four groups (Fig. 7).

The indicators for transport infrastructure efficiency characterize the composition of the transport system and its potential capacity (Fig. 7). In terms of national and regional transport systems, they are called indicators for transport security of territories and are the following: The length and condition of communication roads are an indicator which is included in the transport coverage indicator when comparing transport systems and is a result from dividing the length to the area of the territory. The number of terminals in the system can be evaluated in absolute values for a unit of area, a unit of length of the transport system, etc. The carrying capacity is the maximum number of vehicles, which can pass along a section of highway, railroad, waterway, etc. for a certain period of time. The projected and the real carrying capacity of the infrastructure do not always coincide. In many cases, due to deterioration of the technical conditions of the transport sections, it is necessary to restrict the speed, reduce the time of use for a certain section, creating "slots" for road repairs or closing the traffic on one of the rail tracks (in the case of a multi-rail track railway) or one of the lanes (in the case of a multi-lane road).

The vehicle carrying capacity is the maximum amount of cargo, which can be transported in a certain period on a railroad, road or waterway. The carrying capacity depends on the load capacity. At the same time, when the capacity reserves are exhausted, the load capacity can be increased, if necessary, by increasing the permissible carrying capacity limits of the vehicles used. The concepts *passing capacity* and *carrying capacity* characterize not only the routes but also the transport hubs and terminals. In this case, the passing capacity is determined by the maximum number

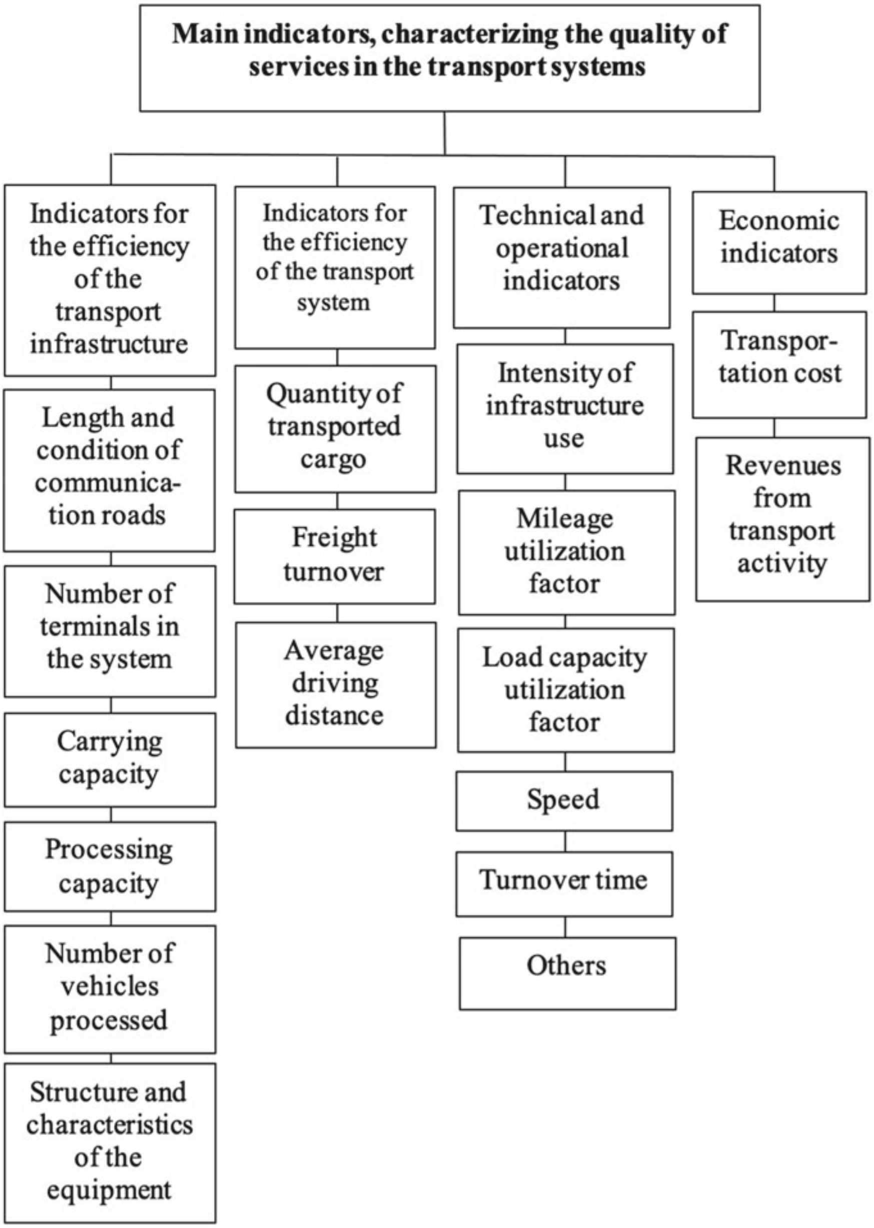


Fig. 7 Indicators, characterizing the quality of services in transport systems

of vehicles, which can be processed in a facility per unit of time and the processing capacity is the amount of cargo passing through the facility. Different number of vehicles, structure and power of the fleet can be used in the process of operation.

New vehicles can be purchased during operation and the old ones could be decommissioned. In a number of cases, the structural characteristics of the equipment are used. In the case of road vehicles fleet such characteristics are the type of vehicles, their operational life cycle, their load capacity. The structure of the terminals can be characterized with their capacity, specialization, etc.

The indicators, characterizing the efficiency of the transport system are the amount of transported cargo, which sum up all transported cargo in every single truck, the cargo turnover (transportation work completed) and the average distance for transporting a unit of cargo. The volume and turnover indicators are applied not only for transportation, but also for processing of cargo in transport hubs, terminals, etc. In this case, they are synonyms (i.e. the terms "port turnover" and "volume of port processing" denote one and the same value, determined by the total amount of cargo received and sent within a certain period of time.

The indicators for technical efficiency characterize some aspects of the efficient use of communication routes and vehicles. The indicators for this group are numerous since they take into account the specific features of the vehicles, the equipment and technologies. The name, form of structure and procedure for calculating such indexes can vary considerably for the various modes of transport.

The technical and exploitation indexes are used mainly for analyzing the efficiency of the transport process organisation and characterize:

- the intensity of the infrastructure use. Indicators such as density, intensity, length of queue, as well as the fact that the goods turnover per kilometer depends on the transport network, are used to assess street capacity. Concerning terminal sites, the exploitation indicators are calculated in tons or containers per square metre of the site area, per metre of quay (for port terminals), per unit of processing machinery, etc.;
- the total and paid mileage of the vehicles. Usually, when characterising the transport system, the average annual mileage of the vehicle and the average mileage with cargo are calculated. A common relative indicator is the ratio of paid to total mileage;
- the average vehicle load for a given period. An example of such an indicator is the ratio between the amount of cargo actually loaded and the average carrying capacity (coefficient of using the carrying capacity);
- speed of movement. For the various modes of transport, the speed indicators are most diverse in terms of their application and order of calculation, even within one mode. Most common are the indicators for technical speed (determined on the basis of the distance covered and the time of movement) and the speed of exploitation (which considers not only the time of movement, but also the stopover time along the route). In terms of the transport logistics, an important indicator is the speed of movement of cargo along the transport network or the speed of communication, which is determined by the transportation distance and the time

interval between the moment of receiving the cargo for transportation and the moment of readiness for delivery to the recipient. The speed of communication can differ considerably from the speed of the vehicles. Thus, if the technical speed of freight trains is 50–60 km/h, then the speed of freight communication can vary from 10 km/h for single carriages to 25 km/h for block trains;
- the number of courses completed in a given period of time or a similar indicator—the time for turnover of the vehicle, i.e. the interval between two subsequent shipments. Under constant operating conditions and maintaining stable cargo flows, the value of this index characterises the efficiency of the transport organisation. If a large fleet is working in changing conditions, the dynamics of the turnover time usually shows a change in the conditions of work, and above all a change in the average range of freight quantities;
- the quantity of loads transported by the vehicle for a given period. This indicator can sometimes be defined in terms of one-ton capacity of the vehicle.

The main indicators, characterizing the economic aspects of functioning of the transport system are:

- transport costs—the costs of the transport operator for a unit of work completed;
- the average revenue percentage—the revenue of the transport operator for a unit of transport service.

The comparison of the prime cost and the average income rate allow to estimate the stability of the transport system.

Some important qualities, in addition to the economic costs and time, are the qualitative elements, which have to be considered when selecting a mode of transport. These are the availability of cargo, speed of transportation, risk of delay, reliability, flexibility, availability of infrastructure, characteristics of good and risk of loss and damages [28, 40]. Concerning the price, water transport is the prevailing choice when it comes to bulk or general cargo, which move a long distance, especially if the speed of delivery is not a leading factor. Another important aspect to be considered is the need to transport the cargo to/from the port, which increases the risk of damage [26].

For the participant in the transport industry, it is imperative to make the right decisions when selecting the mode of transport. Decisions made regarding the choice of mode can affect the logistics system [30].

From the point of view of the transport service user, the following quality indicators for multimodal/intermodal transport can be defined: costs, duration of cargo delivery, guaranteeing the term of delivery, reliability, service flexibility, ensuring cargo storage, ensuring a reliable information system. With multimodal and intermodal transport these indicators face a number of barriers.

According to [41], a real challenge for the shippers is the constant increase of prices, accompanied by the growing awareness of the environmental problems and the increase of fuel prices. In relation to that, the frequency of formation of multimodal and intermodal networks has been growing. At the same time, the price of transport with these modes is increasing as well because of the additional movement of goods and the need of additional processing at the points of mode change. The transport costs play a significant role in the competition between rail and road transport [42], where the rail transport has a competitive advantage only when long distances are involved. This, however, is not common because most of the cargo is transported to short distances and/or is too small to fill up a whole carriage or block-train. [43] also points out that the transport costs are decisive when it comes to choosing a transport mode. The shippers tend to choose the cheapest route for cargo transport with options for intermodal, rail and road mode. Thus, for short distances and small cargo the road transport is the most preferred mode since it is the cheapest in this case, and also because sometimes there is no well-developed rail infrastructure, which limits the flexibility of multimodal and intermodal transport.

Transit time is often one of the most valuable assets for the users as it is measured for the whole transport supply chain, i.e. the transportation from consignor to consignee. In [43], the time is viewed as a barrier to multimodality and intermodality. At the same time, it is stated that those who make the decisions which type of transport to be used are ready to take the risk of loss of or damage to goods as long as the transit time is shorter. This prompts yet again that shorter delivery date is one of the main competitive advantages.

Reliability is another key barrier for the multimodal and intermodal transport chain, discussed in the literature. In [43] it is noted that a mode of transport is chosen if the operator can guarantee its reliability and in time delivery. In a number of publications such as [44, 45], the importance of improving reliability of multimodal and intermodal transport is discussed. At the same time, with multimodal, and mainly with intermodal transport, factors like scheduling and planning have a great influence.

Flexibility is an additional competitive advantage of road transport to the intermodal rail transport—road transport chain. In [43] it is noted that with an increasing demand for cargo transportation and the Just-In-Time concept, the road transport is the preferred mode. This claim is also supported by [37], where it is pointed out that the road transport mode is more flexible than the rail transport. Flexibility is smaller with multimodal and intermodal transport, due to the need for planning and communication management. In [21, 30, 45] the flexibility is viewed in comparison between rail and road transport. Therefore, the current transport management of multimodal schemes should be greatly improved in order to respond to the competitive advantage.

The communication between the various stakeholders in the logistics sector is one of the most important barriers influencing the competitiveness. According to [45], trust, exchange of information, process integration and synchronization of decisions for achieving sustainable cooperation should be established, in order to increase the popularity of multimodal and intermodal transportation. In [21] it is noted that the horizontal cooperation is not enough for the development of multimodal and intermodal transport. The need of vertical cooperation for the creation of a more efficient transport system is discussed. Communication problems emerge due to inadequate exchange of information between the participants, which partly depends on the competition among them and the resistance to sharing valuable information [46]. This competition, however, should be overcome since without cooperation and trust, the development of multimodal and intermodal transport will be difficult to achieve.

2.4 Advantages of Multimodal and Intermodal Transport

Road congestions, environmental pollution, as well as regulations, restricting the number of driving hours for the drivers create a number of problems for the road transport. The situation is complicated even further by provisions on safety, border closures and other force majeure measures (COVID, etc.).

While traditional road transport is facing more problems than ever, water and rail transport remain fully operative. In this sense, using multimodal networks allows the best combination of sea, river, rail and road transport.

Large-scale operations and the use of vessels allow for highly competitive prices while at the same time provide flexible door-to-door solutions (one ship can be loaded with cargo equivalent to 700 freight trucks).

When a multimodal solution is selected, the bigger part of the transport distances is covered by sea, river or rail. In this way the cargo is much better protected and is more safely stored on the ship or railway carriage than on a semi-trailer or trailer in a traffic congestion.

With water and railway transport, the cargo can be moved door-to-door in sealed steel containers with no processing in-between. In this way, the risk of contamination and loss of cargo is reduced. Besides, the containers can be equipped with high security seals.

Many freights transport companies do not have the ability to plan logistics operations in response to the irregularity of freight turnover. Multimodal transport companies can plan this quite efficiently, irrespective of the decrease or increase of turnover. With multimodal transport there is access to options for container storage (including empty ones) in highly secure terminals. In ports, the cargo can be stored free of charge up to 7 days at arrival and departure.

Transport containers by sea provide a more environmentally-friendly alternative to the conventional inland transport with significantly lower CO_2 emissions. In this way, multimodal transport can contribute greatly to reducing the carbon footprint of transport. A vessel can replace up to 700 freight trucks from the roads.

In summary, a conclusion can be drawn that compared to single-mode transport, the multimodal transport has a number of economic, ecological and social advantages (Table 3).

Table 3 Advantages of multimodal organisation of transport

Advantages			
Economic	Environmental	Social	Modal
• Planning is easier due to a greater number of possible variants • Fewer congestions • Higher productivity due to the bigger capacity of long distances	• Fuel savings; • Reduction of harmful emissions • Higher energy efficiency • Fewer external costs	• Bet-ter road safety • Less noise • Re-ducing climate change	• Safer transport • Avoidance of regulatory restrictions for some modes of transport (e.g. traffic ban) • Even distribution of the transport modes • Increasing automation

3 Application of Information and Communication Technologies (ICT) in Multimodal and Intermodal Transport

3.1 Application of ICT in Multimodal Transport

There exists a great variety of ICT applications for the logistics and transport sector, including applications for management and planning, supply chain implementation applications for real-time information sharing in cargo transportation, solutions for management of vehicles and cargo, applications for reporting transport work, which provide various transport data (e.g. time of travel), etc. It has been proven that the application of ICT has positive effects on the flexibility of the supply chain and the economic results.

Due to the many participants and the varying transport modes multimodal transport is quite complex. This poses a number of requirements concerning transport integration. One of the main ways of solving the problem is the efficient and effective digitalization, and particularly, the information connectivity. It provides real-time visibility, efficient data exchange and improved flexibility.

To date, each transport mode creates its own appropriate smart systems, corresponding to the characteristics of its technical and operational indexes and the specifics of its transport network (Fig. 8). Deploying systems such as ERTMS, TAF, ITS and others, creates opportunities for development of land modes of transport (rail and road). Water transport is provided by systems such as VTMIS, RIS and others, air transport—by ATM and others.

At the same time, the information systems are an integral part of the logistics chains, in terms of planning, management and organisation of shipments (Fig. 9).

Both for the individual stages of the logistics process and for each operation a number of examples can be given of successfully developed and implemented information systems.

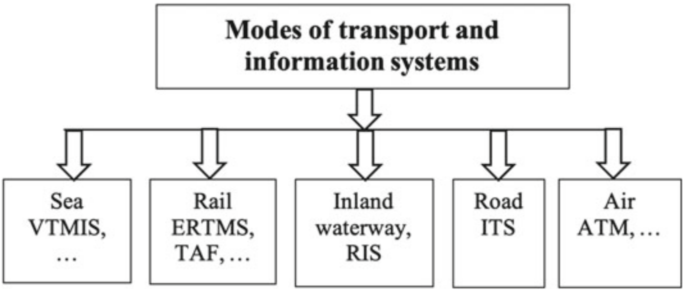


Fig. 8 Main information systems for different modes of transport

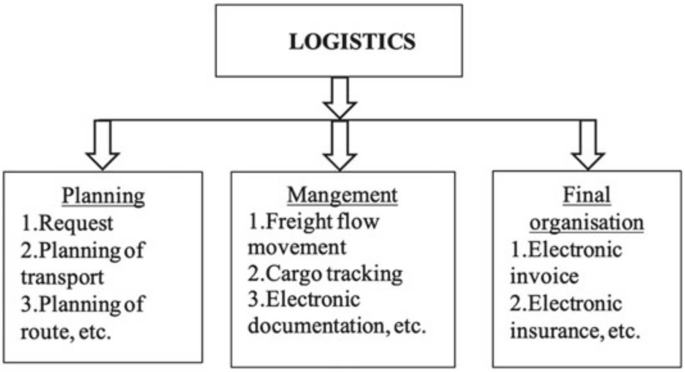


Fig. 9 Information support of logistics operations

In February 2008, to the CMR convention an additional protocol eCMR was introduced, which came into force in June 2011. The electronic protocol provides a legal framework and standards for the use of electronic means of recording a CMR bill of lading. It is expected that eCMR will become mandatory as of 2026. Some of the main advantages of eCMR include: lower processing costs; faster administration with reduced data input, paperless processing, no letter exchange, no paper archives, etc.; faster invoicing; reduction of discrepancies in delivery and acceptance; larger transparency; data precision; control and monitoring of the shipment; real-time access to information and proof of collection and delivery.

Due to its digital nature, e-CMR can easily be integrated with other services, used by transport companies, e.g. custom's declaration or services for transport and fleet management. Switching to an electronic format, companies benefit from the increased overall efficiency of logistics, which leads to improved economic competitiveness. e-CMR can be connected to the eCall system and dial automatically emergency services in the event of an accident.

Since 25 May 2021 a new legal framework is to come into force for eTIR within the TIR convention, which is a new step in support of a completely digitalized system.

The implementation of eTIR will facilitate additionally crossing the borders and will reduce the time for transport while increasing the cargo security.

The concept "Internet for freight", known under the term of "eFreight", is a vision for paperless freight transport processes, in which the electronic flow of information is related to the physical flow of goods. e-Freight refers to the development, which in the future is expected to lead to "Smart freight". This means that the goods will be connected to a wide range of information services, thus automating further the transport management process.

The concept "Self-organising logistics" (SoL)—provides a decentralized coordination of logistics chains, which means that the individual participants in the chain (e.g. consignors, shippers, etc.) make autonomous decisions, based on specific information. SoL have appeared since the logistics processes—planning, storage, reloading, distribution and transport—are becoming more and more automated and autonomous, and there is more accessible local information. The traditional preliminary route planning in the multimodal chain has been replaced by dynamic planning based on real-time information. Instead, if the dispatcher choosing the optimal route, the packages, which are equipped with sensors and communicate through intelligent self-learning systems, will find the best way to their destination alone. The systems know the location of the truck, ship, train or plane and the goods, which need to go to a specified destination, in order to adapt the route or the vehicle any time. If there is congestion, the waterway is blocked, the weather changes suddenly or the consignee changes the requirements, the system can calculate the consequences and suggest the fastest, most accessible and most logical alternative.

Coherence of concepts and strategies for implementing Intelligent Transport Systems (ITS) can contribute considerably to the change in the logistics chain of multimodal transport.

Regulation (EC) 2020/1056 of the European Parliament and the Council of Europe concerning electronic information for freight transport obliges the authorities of the Member States to accept electronic cargo information, specifying the electronic format in which regulatory transport information is to be provided (EfTI), and requires from the European Commission to establish common data sets and information processing procedures. Besides, it aims at ensuring the availability, integrity, confidentiality and security of the data managed. The regulation will come into force in August, 2024. It will establish a legal framework for the operators of road, rail, sea and air transport to share information with agencies in e-format. EC will develop the technical specifications for eFTI platforms by 2022. Following that, the Member States will have 30 months to create electronic platforms for exchange of information. By August 2024, the transport operators will be able to submit electronic information, using a harmonized format in all EU Member States.

Together with the decisions, concerning the coherence, the information systems continue to develop.

Instead of the expensive and complicated integration from point to point of separate systems, web-based systems are designed for participants to share a single system. Similar technological advances accelerated and intensified the development of new e-business models such as the e-market [47]. The bigger part of such technologies in freight business were developed back in the 1990s and the beginning of the twenty-first century and they form the core of the present-day ICT applications, used in the field of transport.

Modern developments in the field of digitalization are connected to a number of newly-developing technologies such as:

- cloud technologies;
- wireless communication technologies;
- Internet of Things (IoT);
- developing web-technologies;
- social networks;
- developing interface technologies (augmented reality, etc.);
- big data technology to support multimodal transport management solutions and blockchain;
- cooperative and intelligent transport systems;
- connected and autonomous mobility;
- integration and artificial intellect;
- others.

The use of these technologies reveals new opportunities for efficient implementation of multimodal transport. This process of digitalization will help to avoid human errors and increase the efficiency through a higher level of automation, which will reduce the time for expedition and the costs.

Cloud technologies. The need to invest in IT infrastructures and purchasing expensive hardware and software solutions as a rule is an obstacle to small and medium enterprises. This can be solved through the use of cloud technologies. With "cloud computing" [48]. ICT systems are hosted by a third party and the consumer companies "get involved and use the resource". Offering greater flexibility, cloud computing provides opportunities for small and medium-sized enterprises to use the respective system (Fig. 10).

Users who use cloud computing, pay only for certain computer resources, when necessary, having access to them on request via a web-based interface, using smart phones, computers or other devices. Software as a Service (SaaS) is turning into a popular way of gaining access to a specific software on request via an internet browser, paying a fixed fee or a subscription to use it. This is a form of shared economy. SaaS has become a common model for delivery of many business applications.

Using cloud technologies, the companies are relieved of the burden of managing ICT applications and can focus on their main business tasks. This is of strategic importance for small and medium-sized enterprises, which can hardly afford or posses no internal resources and experience to implement enough ICT solutions in support of their business needs.

On Fig. 11 an example of a driver-operator interaction scheme with a suitable application is given.

Fig. 10 Cloud technology structure scheme

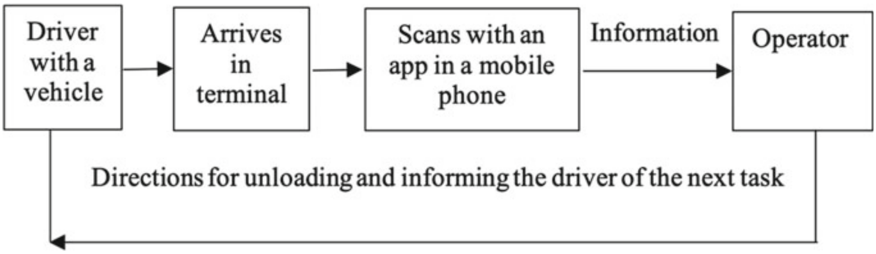


Fig. 11 Scheme of driver-operator interaction

To get information about his next task automatically, the driver should have a smart phone with a GPS.

The application can be expanded for faster customs clearance, tracking loads at all times and instructions for work with hazardous loads.

Wireless/mobile communication technologies. In today's development, there is a constantly growing use of wireless communication technologies (intelligent mobile phones QR code, RFID, telematic tracking, etc.). The use of these technologies allows people and devices to be connected everywhere and any time. This connectivity and network services allow expanded visibility in the supply chains in real time, which is of utmost importance for handling the complexity in multimodal environment.

Transport operators can track containers within the framework of multimodal loading operations and to have access to additional information about the load such as temperature and humidity.

Internet of Things (IoT). This technology is still fragmented, but it is already in the process of completely changing the freight transport industry. The type of technology IoT is using consists of a data base, a reader, a chip and a GPS-based cloud

Fig. 12 Communication systems ("one-on-one" and "one-to-many")

system. These elements interact among each other, creating detailed and valuable information about the transport operations. With IoT, packages and containers send useful information about themselves automatically and autonomously directly to the Internet.

This technology (radio frequency identification) allows the freight industry to monitor its shipments and the conditions of their implementation effectively. Confirmation receipts and barcodes may not require scanning and the technology allows automatic receipt of shipments. The advancement of IoT made it possible for the companies to check on their shipments all along their route not only more easily, but also more efficiently. 5G networks will provide an addition for the expansion of IoT.

Web 3.0 and social networks. The development of web technologies and social networks has changed our way of communication. The transition from "one-on-one" to simultaneous "one-to-many" communication (Fig. 12) is changing the way supply chains are structured and information is shared, thus having significant consequences for securing and implementation of the transport process.

Web 3.0 technologies allow ITS applications to automate data and information exchange and to limit the need of human interaction. The real-time data for transport, including the data on vehicles are automatically merged and processed with algorithms to create new next generation regional operating platforms. Semantic technologies will also prove to be a significant component for supporting the connected vehicle platform. Social networks develop the capacity of multimodal technologies due to the nature of this communication, where people with similar requirements and ideas connect to each other. Social networks of the type "meeting cargo owners/carriers/consumers" can be used. Through the social networks the most appropriate vehicle meeting the requirements for delivery can be selected without for a certain delivery without compromising costs.

The technological platform of social network sites like Facebook and Twitter can be used in the transport and logistics environment to facilitate instant communication between different stakeholders. There are examples of private social networks as well. In the multimodal transport chain, it is important to receive immediate status update for a specific shipment, due to the fact that multiple participants (consignors, consignees, shippers, carriers) are involved in the physical implementation of a shipment. A private social network is used for creating a community where immediate updates and information sharing between different countries in geographical areas can reduce point to point communication time and cost. This concept for a community online portal could be applied in the same way in the context of ports or railway terminals, which often involves complex activities for receiving and dispatching ships or freight trains, as well as management of container parks.

Interface technologies, augmented reality. Advances in interface technology have encouraged a number of new applications. For instance, hands-free driving through voice-activated commands has recently become popular in the logistics industry.

The newly emerging concepts like augmented reality are still in their infancy, but have already been piloted in some industries like retail and construction. Augmented reality (AR), where real world interactions are enriched with virtual images, graphs or other data, can be seen as the next step in improving resource management in port or warehouse settings. Webcams and mobile devices are used to view the projections of goods in live size, including their location before devising a cargo plan.

Big Data systems are technologies for support of multimodal transport management solutions and blockchains. Many ICT technology developments lead to an increasing volume and detail of information. What is important is their efficient implementation. The future of decision support systems (DSS) for multimodal transport management is in real time, considering the dynamic and integrated nature of decision making with enhanced capabilities through the development of ICT technologies. The main efforts are directed to such areas as planning of terminals, transport modes, loading and unloading, route optimization, etc. Trends related to cloud computing and IoT, together with business analyses will further improve the capabilities of DSS and consumer access to the respective functions.

For multimodal transport the application of Big data means more secure supply chains. This is especially important for small and medium-sized enterprises, which despite having no resources can have transport companies, offering Big data to their customers. In this way, they will have faster, more transparent and more personalized access to information about their shipments. They can correct parameters such as the condition or temperature and time of the load, as well as rationalize customs procedures, contracts and receipts. These Big data also increase and improve automation by reducing human errors.

Blockchain technology can enhance transparency in all logistics processes, ensuring the integrity of the data and maintaining confidentiality. This saves time, documents and mediators, especially when considering the complexity of the international freight transport.

Cooperative and intelligent transport systems (C-ITS), for example vehicles, infrastructure equipment, traffic control centres) communication and sharing of information for ensuring efficiency and traffic safety. After May 2022, all new models of automobiles should be fitted with the following advanced systems:

- intelligent speed control;

- anti-alcohol blocking device;
- warning of drowsiness and inattention of the driver;
- advanced warning against distraction of the driver;
- emergency stop system;
- reversing detection system;
- accident recorder („black box”).

Additional systems for freight trucks and buses:

- specific requirements for improving the direct vision of drivers;
- removal of blind spots and systems at the front and the sides of the vehicle, to detect and warn vulnerable road users, especially when cornering.

Connectivity and autonomy reshape mobility as we know it. It includes different levels of aiding the driver and autonomy and varies from functions for aiding the driver such as cruise control to fully autonomous vehicles. The data exchange between the different members of the transport system means that correspondence between demand and supply could be achieved in real time. This will lead to a more efficient use of resources, whether it concerns car sharing, container or railway network. Digital technologies aid the reduction of human errors, which are the most significant reason for accidents. They can also create a multimodal transport system, combining all transport modes in one mobility service, allowing people and cargo to move smoothly door-to-door. Furthermore, they can stimulate social innovations as well, and guarantee mobility for all with the emergence of new participants so they can move door-to-door freely, e.g. economy of sharing. Technology is evolving so fast and the public and private sectors are investing such significant resources in the development and testing of technologies for joint intelligent transport systems (JTS) that there exists a risk of not achieving pan-European interoperability in a timely manner unless a framework is established at European level. This would put European industry at a disadvantage and would delay the deployment of JTS in Europe with all the benefits it brings to transport and society as a whole.

Collaboration, connectivity and automation are not just complementary technologies, but they strengthen each other and will merge completely over time. A good example is the organisation of convoys of trucks, which move automatically and safely at a small distance, using appropriate communication. Connectivity, cooperation and automation combine in order all this to become a reality. But cooperation will be even more needed in the future, when automated vehicles will need to manage safely and efficiently in far more complex road situations.

In a Communication from the European Commission to the European Parliament, the European Economic and Social Council and the Committee of the Regions on 30.11.2016, “The European strategy for joint intelligent transport systems—a cornerstone on the road to joint, connected and automated mobility” was published. The aim of the strategy is to avoid the fragmentation of the internal market in the field of JIT and to generate useful synergies between the various initiatives. It addresses key issues, including cyber security and data protection (especially important for the public trust to technology) and the operative compatibility. It also recommends actions at various levels.

Transport services integration and artificial intelligence (AI)—the applications of AI to transport planning are already growing and activated by machine learning, analyses, predictive intelligence, IoT, automation, etc. This enables large companies around the world to improve multimodal visibility, reduce carbon emissions, increase productivity, improve carrier management and optimize intermodal transport costs.

Some of the technologies mentioned already have wide application (e.g. intelligent sensors, connection technologies) although further development is expected. Other technologies (e.g. artificial intelligence) are still in their initial phase of implementation, but demonstrate a high potential for using.

3.2 Barriers to the Application of ICT in the Transport Industry

The positive role of ICT for improving the overall efficiency, visibility and communication between participants in multimodal transport is unquestionable, but there are also many barriers that we can generally divide into three groups (Fig. 13). *Company barriers* are connected to the internal environment of the company itself. These include economic and financial constraints, human capital constraints and operational activities.

Economic or financial barriers include:

- costs for the investment, necessary for purchasing equipment (e.g. telematic equipment in case of tracking applications);
- long periods for implementing ICT solutions;

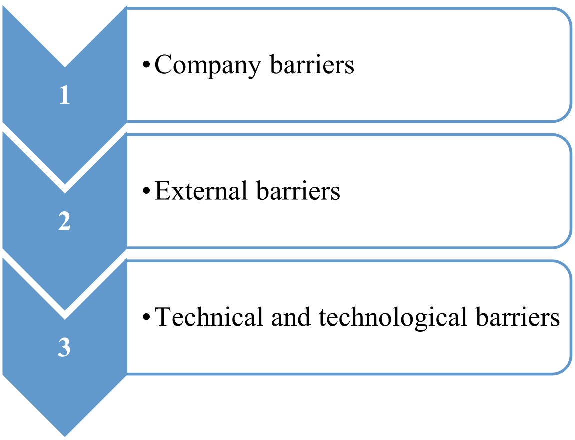


Fig. 13 Types of barriers for applying ICT

- insufficient compatibility between the new ICT solutions and the existing ones in the company, and costs for installing and integrating new ICT solutions with old sytems [49].

Human capital constraints also hinder the adoption and implementation of ICT. These refer to:

- the attitude of the top management of the company. This is connected to the strategic plans and the anticipatory planning horizon, which should take into account the expected changes in technology;
- the insufficient number of ICT specialists in the labour market. The observed growth of the sector exacerbates the need for such specialists;
- insufficient training. Companies not always have the practice to plan training for their staff, often relying on prior knowledge and self-training;
- unwillingness of company staff to change and acquire new technologies. For example, it is common practice for drivers to believe that the introduction of new technology will control them more closely and thus they perceive the latter as an enemy rather than as a tool to facilitate their work.

The operative activities are related to the daily activities of the company, dealing with production and sales of their product, generating of revenue, as well as general administrative and support activities. Insufficient knowledge by managers of the potential opportunities for profits from the implementation of ICT or lack of management on the part of decision-makers hinder the implementation of ICT. Due to the development of still new ICT technologies, very often the effectiveness of their application is unknown or unclear, which limits its acceptance by companies. Previous experience with ICT and the present technological development of the company can influence the decision to use new ICT in its operations. The activities of competitive companies, or partner companies also have a significant effect on the use of ICT. Different level of application for specific companies can be noted, especially with companies of different sizes (e.g. small and medium-sized enterprises and big companies). Small and medium-sized enterprises often have limitations on finance and human resources, as well as expert knowledge of ICT, which reduces the likelihood of using the available resources while big companies have the opportunities to develop applications or platforms by order for their business needs.

Internal barriers are those, in which the attitude of companies to implementing ICT is influenced by the behavior of other participants in the market (partners and competitors), as well as by regulatory and administrative restrictions. The partnership between companies from the supply chain, the attitude of customers to ICT or the reluctance to accept technologies can hinder the implementation of ICT projects in the company's operations. On the contrary, if there is a positive climate and common strategic goals concerning the use of ICT between the members of the supply chain, this can lead to fast implementation of the latest technological ICT solutions. Companies should think strategically about which technology could give them a competitive advantage and how to integrate it with other supply chain members, including fast adaptation to the new scenarios in their business strategy (adaptability and flexibility) [50]. For multimodal transport, the fact that there are different levels of ICT implementation in each mode of transport and between different stakeholders in the multimodal transport chain should also be taken into consideration. The insufficient exchange of information between the participants in the multimodal chain is quite common and could be a barrier for implementing ICT solutions for multimodal transport. The integration between various ICT solutions and technologies, used by different members of the supply chain is also necessary for the efficient implementation of new ICT solutions. Customers can have a strong influence on their suppliers, encouraging them to apply specific ICT solutions, which can improve their communication and differentiate them from others. In [51] environmental insecurity is identified as a factor influencing the perception of ICT technologies, insecurity being understood as unpredictable changes on the side of suppliers or customers, changes in the transport processes or each rapid change, which cannot be predicted in advance. Regulatory and administrative requirements and political solutions can also influence seriously the acceptance of ICT solutions by the companies. For instance, tax decisions or standards approved can restrict the use of ICT използването на ИКТ. The lack of political decisions concerning stimulating the small and medium sized businesses to use ICT can have a long-term effect on digitalization of business processes. Most of the multimodal chains are international and it is possible different states to have different policies, which could affect the approval of ICT.

The technical and technological barriers are the third type of hindrances and they include:

- systems operative compatibility;
- иIntegration of ICT, standardization;
- security and data protection.

Multimodal transport includes different modes of transport and different participants, connected in one coordinated transport system. Technology related barriers stem mainly from a series of difficulties, related to the need from interaction between different connected participants. Issues, related to the lack of homogeneous ICT standards, influence the development of systems for the entire multimodal transport chain. The barrier in implementing ICT can prove to be security and data protection, which is enhanced by the fact that there are numerous participants in the multimodal solutions.

In summary, we can point out that ICT have a great potential for efficient and reliable management in real time and operations of multimodal freight transport, but some strategic, political and company decisions for the implementation of the system and especially for aiding small and medium-sized enterprises.

One good practice is the political decision for financing the development of a European Digital Innovation Hubs network (EDIH). EDIH is a political element for enhancing the digitalization of small and medium-sized enterprises. The initiative is part of the Digital Europe 2021–2027 Programme. The aim is for EDIH to accelerate the wide use of new technologies (artificial intelligence, high performance computation, blockchain, etc.), favouring the development and introduction of innovations.

The role of the future European digital innovation hubs is to provide innovative digital solutions and their integration into the everyday activities of businesses and local administration. The digital innovation hubs are designed to offer opportunities for experimenting and testing new technologies according to the specific needs and activity of each company or institution in the public sector [52]. By April 2021, the existing and planned EDIH in Bulgaria are 11 (Fig. 14), with 5 of them already existing and 6 are at the start of their development and are candidates for EDIH. The distribution is even on the country's territory, with mandatory presence of a university or research institute in the consortium that has initiated the hub.

As an example of a consortium structure (Fig. 15), which is at the core of a DIH, we can point out one of them—the Danube digital innovation hub (DDIH) with a headquarters in Ruse.

Participants in the consortium are:

- University of Ruse;
- Ruse Municipality;
- Danube Association of municipalities along the River Danube;
- Ruse Commercial and Industrial Chamber;

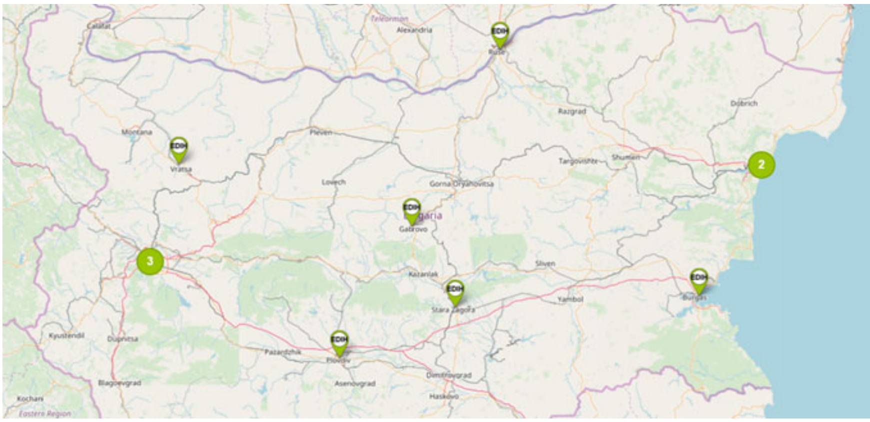


Fig. 14 Geographic location of DIH in Bulgaria

Fig. 15 Structure of the consortium, which founded a DDIH with a headquarters in Ruse

- Bulgarian- Romanian commercial and industrial Chamber;
- Inobridge Business Innovation Centre;
- Musala Soft;
- “Sirma AI”.

DDIH is planned to specialise in:

- Digitalisation of services for vehicles or development of intelligent systems for energy efficiency, decarbonization and safety, including digitsl product supply chains);
- Experimental joint research work for improving systems and products in mechatronic based industries;
- Digital solutions and analytical research expertise (out of the range of e-management) to attract investments in the public sector.

The contemporary development of the information and communication technologies requires adequate actions on their standardization, implementation and development in the transport practice, as presented in [53]. The systems implemented improve the organisation and visualization of the transport process.

Table 4 Goods transported and transport performance by mode of transport (2014–2019)

Mode of transport	2014	2015	2016	2017	2018	2019
Goods transported—thousand t						
Total	114,558	125,498	124,358	136,685	116,644	96,675
Land transport	112,719	123,626	12,190	134,385	114,430	94,279
Waterway transport	1837	1867	2443	2291	2191	2376
Air transport	2	5	5	9	23	20
Transport performance-million ton-km						
Total	33,201	37,789	41,546	42,532	32,923	25,866
Land transport	32,195	36,677	40,263	41,396	31,951	24,662
Waterway transport	1003	1107	1278	1218	956	1188
Air transport	3	5	5	8	16	16

4 Development of Multimodal and Intermodal Transport in Bulgaria

4.1 Volume of Transport Work in Freight Transport in Bulgaria

The total of freight in Bulgaria in the period 2014–2019 is an average of approximately 100 thousand/t (Table 4), at 35.5 million/tkm transport work [54]. The share of transported goods and transport work with land transport is predominant.

The volume of land transport (road and rail) is 95.34% transport work in tkm, with 93.8% for EU 28. Bulgaria is one of the 18-member states, which use inland waterways for freight transport. The modal share of inland waterway transport in the country is 4.59 with 6.2% for EU 28. The share of air transport is insignificant (0.07%). Like in the EU, in Bulgaria the road transport is predominant.

Just as in many other countries, so in Bulgaria road freight transport remains the preferred mode. The reasons for this are related to the relatively small area of the country (111 km^2), the underdeveloped port and railway infrastructure, connected to just a few enterprises, country specific industries, needing only a limited volume of scheduled supplies in short intervals, etc. In recent years a slight decrease of freight and the volume of work done with road transport has been observed. The freight in 2019 was 115.0 million t, and the work performed, incl. domestic and international transport was 20,613.5 million tkm. To compare, in 2012 the freight was 140.4 million t. With rail transport some increase is observed. In 2019, 14.95 million t of freight were transported by rail. To compare, this number for 2012 was 12.47 million t. The work done by rail in 2019, incl. domestic and international transport was 3901.6 million tkm.

Turnover Through Bulgarian Ports

The cargo turnover of the Bulgarian ports is based mainly on import and export of cargo, (Table 5) [55]. For the period 2014 to 2019, there has been an increase of

Table 5 Turnover in river and sea ports and airports

Year	2014	2015	2016	2017	2018	2019
Domestic waterway transport						
Loaded and unloaded freight (thousand t)	4278	4441	5781	5429	5574	5786
Sea transport						
Loaded and unloaded freight (thousand t)	27,970	27,754	29,172	31,441	28,371	31,515
Air transport						
Loaded and unloaded freight (thousand t)	23,101	31,720	33,039	34,837	29,923	–

import and export processed freight in Bulgarian ports and airports. In the domestic river ports along the Danube, the increase is by 19.9%, in sea ports—11.2% and in air transport until 2018 this increase is by 22.7%.

During the last 10 years, from 2010 to 2019, a significant change of import and export has been observed in Bulgarian ports at the Black Sea and on the Danube (Fig. 16). In the sea ports, the import export processed freight maintained their volume with some fluctuations toward an increase by 6.3%, while in Burgas there was a clear trend towards growth by 15.9% from the beginning of this period. With river transport in ports with a small freight turnover there was a trend towards growth in 2019 while in those with a big freight turnover—the trend is reverse, Fig. 17. Thus, for example, in Vidin the growth is by 41%, Nikopol and Somovit—by 51% and Silistra—by 89%. At the same time, in Ruse and Tutrakan there was a 4% decrease, and in Lom, Kozlodui and Oryahovo this decrease is by 23%, compared to 2016 [55]. At Svishtov and Belene the change is insignificant due to the fluctuation observed in this period.

Concerning import and export in Varna and Burgas, in 2019 there was a serious irregularity, Fig. 18. The quantity of processed freight from import in Varna was 4379 thousand t, and in Burgas—10,681 thousand t, which is 2.44 times more. With export the difference is not so big—the export in Burgas is only 4.5% bigger than

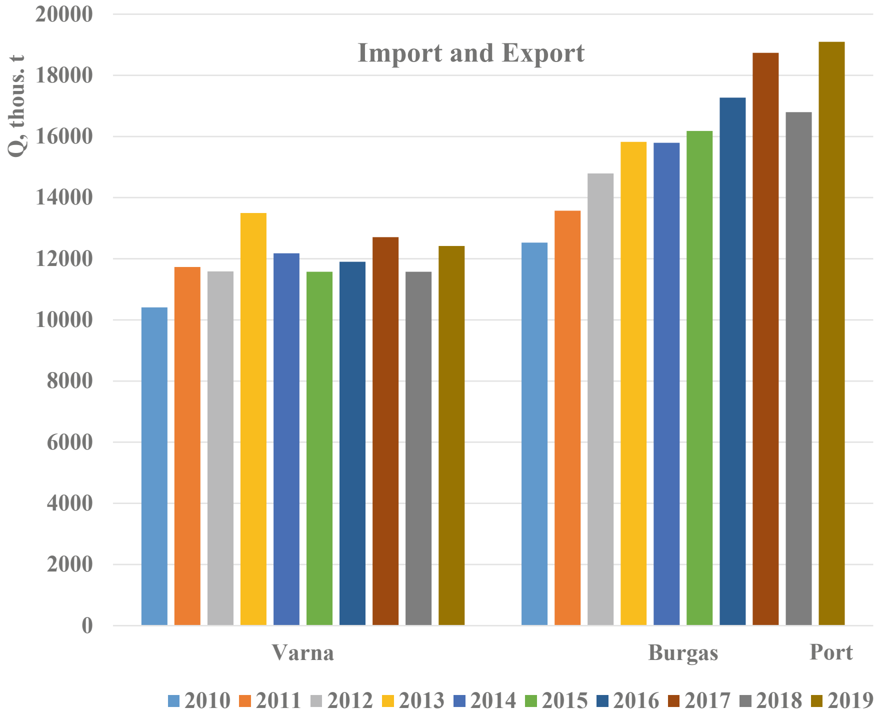


Fig. 16 Total processed freight from import and export in the sea ports of Varna and Burgas

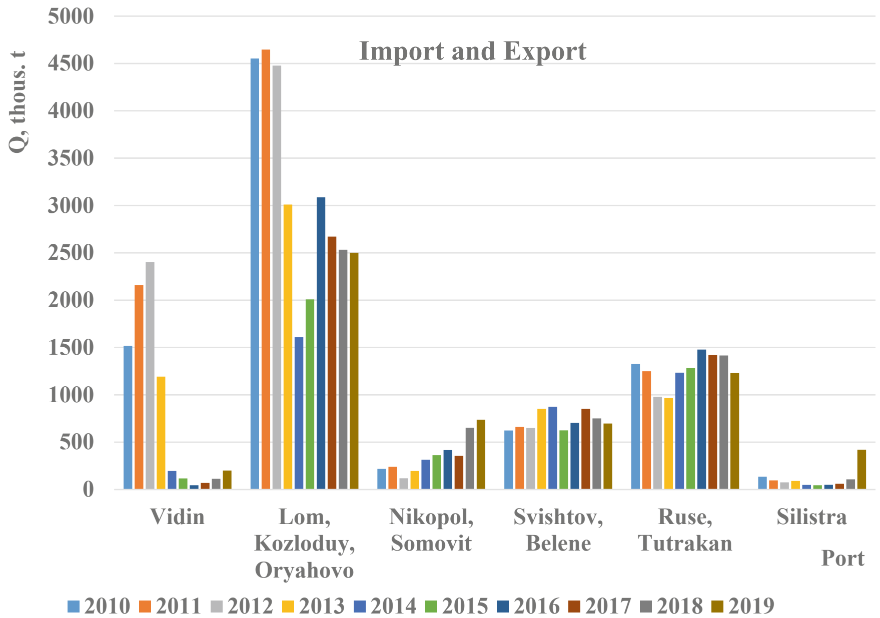


Fig. 17 Total processed freight from import and export in river ports

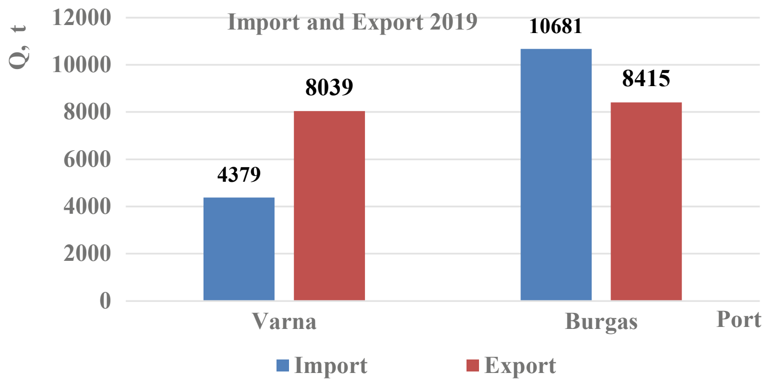


Fig. 18 Processed freight from import and export in the sea ports of Varna and Burgas for 2019

that in Varna. There is a serious difference between import and export in the ports themmselves. In Varna the difference is 45.5% in favour of export, and in Burgas, it is 26.9% in favour of import. This means that the vehicles have a significant amount of traffic without freight. In Varna this is due to the small amount of import, and in Burgas, on the contrary—on the bigger amount of import.

With river ports, for 2019 there was a larger amount of export than that of import in general. The only exceptions were the ports of Ruse and Tutrakan, where the

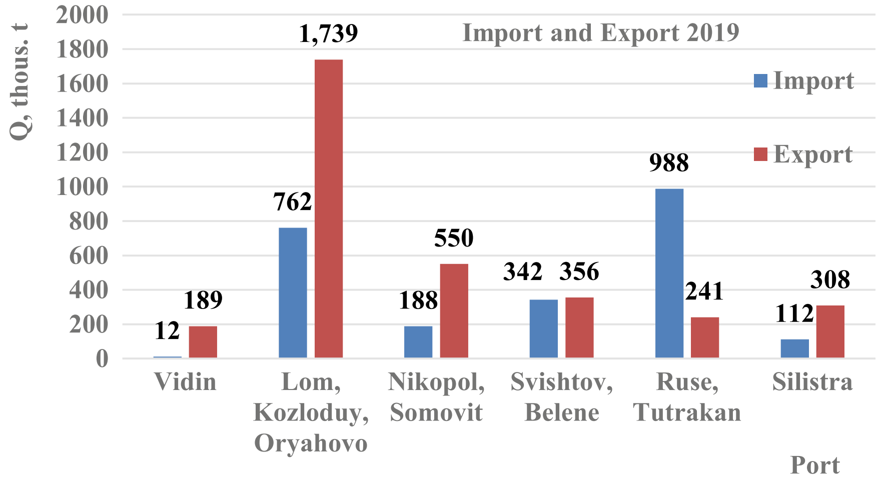


Fig. 19 Processed freight from import and export in the river ports for 2019

import was 988.1 thousand t, and the export—241.1 thousand t, i.e., almost 4 times bigger import, Fig. 19. The biggest amount of processed freight was reported in Lom, Kozloduy and Oryahovo. There the import was 761.6 thousand t, and the export—1739.1 thousand t. In the two end ports for Bulgaria—Vidin and Silistra the amount of work was the smallest.

The reason for this irregularity for 2019 can be determined after analyzing the imported and exported freight by type. The types of freight processed in ports are: liquid bulk, solid bulk, general, container and RoRo. Additionally, the number of containers in TEU and that of RoRo transport, Figs. 20, 21, 22 and 23.

Figure 20 shows that with export in Varna port mainly solid bulk freight is processed—2141 thousand t, and containers—918 thousand t. At the same time in Burgas port the import shipments are mostly liquid bulk—7567 thousand t, which consist of petrol for the refinery in Burgas, followed by solid bulk at 1229 thousand t and general at 1225 thousand t.

With export we have an analogous situation: in Varna port the solid bulk makes the biggest part of processed freight at 5554 thousand t, followed by container freight at 1249 thousand t, Fig. 21. It is because of this irregularity that there is such a big difference between import and export. In Burgas port the liquid freight lead at 4326 thousand t, followed by solid bulk at 2792 thousand t. It is exactly this type of freight that has led to the serious disbalance in import and export in this port.

On Fig. 22 the import is presented by types of freight for 2019 in the Bulgarian Danube ports. The biggest amount of freight was processed in Ruse and Tutrakan, where the work is mostly related to processing of solid bulk freight at 376 thousand t, followed by liquid bulk freight at 319 thousand t, which is mainly fuels for the port in Ruse and general freight at 285 thousand t. Second come the ports in Lom, Kozlodui and Oryahovo. The biggest share there has the RoRo transport at 501 thousand t,

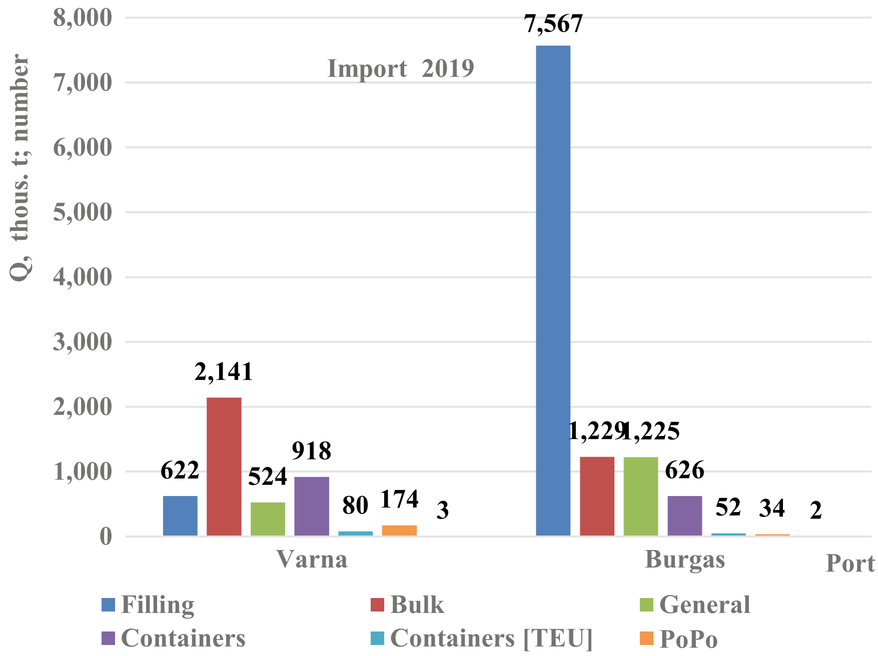


Fig. 20 Total import in Varna and Burgas port by type of loads for 2019

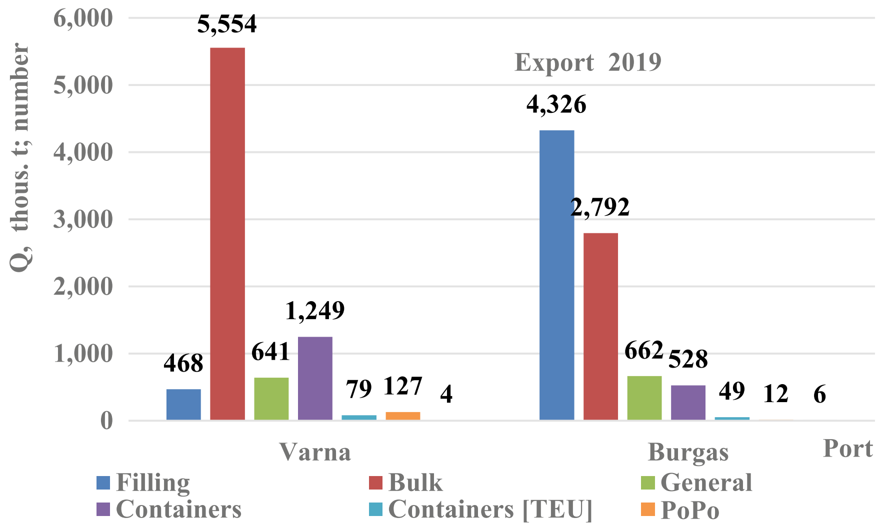


Fig. 21 Total export in Varna and Burgas ports by types of freight for 2019

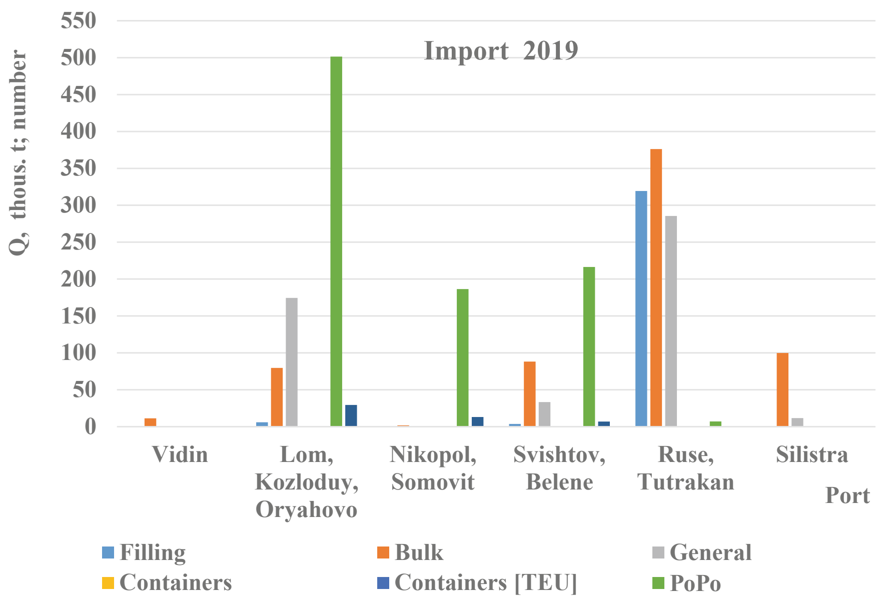


Fig. 22 Processed import and export freight by type in the river ports in 2019

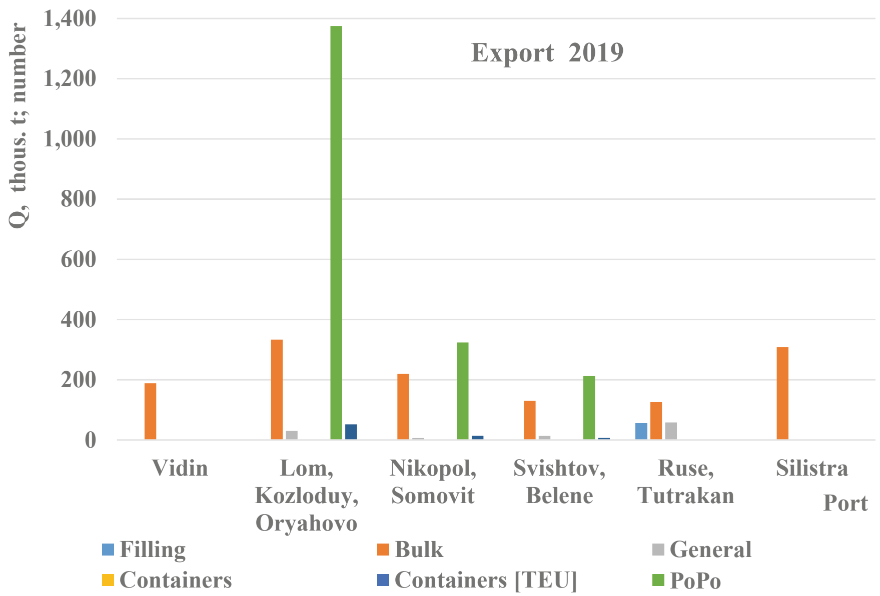


Fig. 23 Processed export freight by types in the river ports in 2019

carried out by freight trucks loaded on ferry across the River Danube from Romnia to Bulgaria, followed by general freight at 174 thousand t.

With export the situation is slightly different. The ports in Ruse and Tutrakan have a very small amount of solid bulk, liquid bulk and general freight for export and this leaves them in the last positions before the port in Vidin at 189 thousand t. Solid bulk freight, Fig. 23. The first position is for the group of ports Lom, Kozlodui and Oryahovo at 1375 thousand t. RoRo freight transport in freight trucks on ferryboat, which have crossed from Bulgaria to Romania. The second position is occupied by solid bulk freight at 334 thousand t, which consist mainly of cereal crops. The freight in the other three ports is analogous, with mostly solid bulk freight in Silistra at 308 thousand t, Nikolpol and Somovit at 220 thousand t, Vidin at 189 thousand t, Svishtov and Belene at 130 thousand t. The second group is the RoRo transport of freight trucks through the ferryboat ports of Nikopol and Somovit at 324 thousand t. And Svishtov and Belene at 212 thousand t.

There is no processing of freight in containers through the Bulgarian ports along the river Danube. There have been single cases of mainly light freight and empty containers in 2015 and 2016 through the group of ports in Ruse and Tutrakan with a volume of 1288 and 470 t import and 1169 and 407 t export, respectively, but after that this activity has ceased.

The choice of transport mode is quite a complex decision-making process, determined by a wide range of factors of economic, social, geographic and psychological nature. It is often the result from a complex process, including both objective and subjective reasons. The objective reasons can usually be identified by quantity while the subjective ones are qualitative [56].

4.2 State of Transport Infrastructure

Road infrastructure. Bulgaria has 19,853 km state owned roads (2015). The average road density is 179 km/1000 km^2, or 2.27 km per 1000 inhabitants [54]. The highway and first-class road coverage of the country is irregular. The road directions East–West are better developed than North–South. Despite the large investments for the development of road infrastructure in recent years, there exist a great number of road sections with traffic intensity close to their пропускателна capacity. The data from the automatic counters (used since 2016 in Bulgaria) show an increase of traffic on all types of roads. The increase of traffic flows on highways for 2019, compared to 2016, is 5.24%, on firs-class roads it is 3.99%, on second-class roads—11.02%, and on third-class roads—2.69% [57].

For improving the connectivity and development of cross-border connections the completion of Struma highway, construction of Ruse-Veliko Turnovo highway and of the tunnel under Shipka peak is of utmost importance. By completing Struma highway, the transport connections with Greece will be improved. The Ruse-Veliko Turnovo highway (of the Core TEN-T network) will provide connection with Hemus

Table 6 Capacity of the main railway lines concerning the speed range

Predominant speed range (km/h)	% of the main railway lines total length
<60	17.4
60–80	41
80–100	24.4
>100	17.2

highway and the Danube Bridge at Ruse (the cross-border connection with Romania). The tunnel under Shipka will pass through the Balkan Mountain range and will povide a connection between North and South Bulgaria in the central part of the country in the direction of the Core TEN-T network "Ruse–Veliko Tarnovo–Stara Zagora–Dimitrovgrad–Marica highway". The projects for the Ruse-Veliko Tarnovo highway and the tunnel under Shipka will contribute to building the connection between the Rhine-Danube Corridor and Orient/East-Med Corridor—Transeuropean transport corridors in the direction North–South.

Railway infrastructure. The total length of the railway lines in the country is 5468 km, of which more than half is with electricity (2870 km). The average density of a railway is 36.3 km/1000 km^2 of territory.

The railway network in the country has a great capacity, but concerning the main network efficiency, it is predominantly low-speed: only 38.8% of the main railway lines length are used with the projected speed. In Table 6, the capacity of the main railway lines concerning the speed range is shown. About 60% are main railroad lines with speed range predominantly up to 80 km/h [58].

For the programme period 2021–2027 the modernization of railway lines along the main directions is to provide reliable transport connections between the main urban centres within the country, connections of Bulgaria with the neighbouring countries and connections between different European countries through our territory. The projects for modernization of the railway line Sofia-Kulata, in the sections Sofia-Pernik-Radomir and Radomir-Kulata, will contribute to considerable improvement of the cross-border connections with Greece. The modernization of the railway line Radomir–Gueshevo and the construction of a railway connection with Northern Macedonia is of considerable importance for the improvement of the railway line connectivity between these two countries. The cross-border connection with Serbia will be improved by the modernization of the railway line Sofia–Dragoman–Serbian border. Launching into exploitation of Danube bridge 2 (Vidin-Kalafat) in 2013 contributed greatly to the improved connectivity between Bulgaria and Romania. It is necessary to modernize the railway sections Vidin-Medkovec-Ruska Biala-Sofia as well.

Waterway transport infrastructure. The development of the sea and river transport is directly connected to the capacity of ports.

Freight capacity of the functioning sea terminals in Burgas and Varna is shown in Table 7.

Table 7 Capacity of sea port complexes

Port region	Type of terminals	Freight capacity (t/year)
Burgas	Port terminals of national importance	31,216,168
	Port terminals of regional importance	2,438,059
Varna	Port terminals of national importance	27,960,681
	Port terminals of regional importance	1,113,487

The main share in the capacity of sea ports belongs to the ports for public transport of national importance.

The port terminals for public transport of national importance in Burgas have the highest total capacity, however about 50% of this capacity in Burgas port is provided by the specialised terminal for liquid bulk freight Rosenec.

The capacity of sea ports for public transport with regional importance is a mere 5.66% of the total capacity of sea ports.

Concerning the capacity by regions for transport on the River Danube, the biggest share belongs to the ports in the region of Ruse—about 50% (Table 8).

Unlike the sea ports of regional importance, the river ports with regional importance have a much higher share—about 42% of the total capacity of the river ports.

Irrespective of the fact that the quantitative parameters of the Bulgarian ports capacity exceed considerably the freight turnover of the past years and demonstrate the availability of spare capacity, many of the quality parameters of the of the services offered do not meet the contemporary requirements and the demand mostly because: the parameters of the quay port equipment do not correspond to the contemporary

Table 8 Annual capacity of river port regions

Port region	Type of terminal	Freight capacity (t/year)
Ruse	Port terminals of national importance	7,261,860
	Port terminals of regional importance	4,110,306
Lom	Port terminals of national importance	3,107,000
	Port terminals of regional importance	2,620,000
Vidin	Port terminals of national importance	2,514,000
	Port terminals of regional importance	2,858,816

trends for navigation and serve as a restrictive factor for large ships due to the insufficient depth of the aquatory and the approach to ports. Other disadvantages are that the territory of some terminals, which is a public state property, does not possess enough rearward warehouses; the different ownership of the port terminals—buildings, warehouses, reloading and transport equipment creates a serious dependence of these terminal on the interest of the individual owners; morally and physically obsolete machinery in the ports and terminals; insufficient specialization to provide the necessary conditions for reloading and storage of structure-determining freight with adequate capacity, highly efficient and competitive work; some of the port terminals and ports with regional importance have no access to the railway network. For some of the ports this is quite negative and the whole freight turnover from and to land has to be carried out through freight trucks. The most negative trend affects the ports and terminals, which are located in urban territories and the whole car flow passes through the streets of the towns, which are usually with a lower capacity and this leads to congestions, risk of accidents and problems for the freight trucks, and hence inefficient work for the transport companies; the intermodal terminals, connecting ports to the railway network are not well developed; the volume of air freight transport is low for the country.

Additional investments are needed for improving the conditions for navigation along the River Danube (as part of the Rhine-Danube Corridor), as well as for improving the safety of navigation in the sea territories of Bulgaria adding intelligent transport systems and equipment.

Bulgaria is among the member-states with poor transport infrastructure. Despite the significant investments with the support of European structural and investment funds, the quality of the roads and the railway infrastructure is rather low.

When providing transport connections, the infrastructure of the countries that border Bulgaria is important. In Table 9 is shown the Global Competitiveness Index 4.0, 2018, ranking 141 countries [59]. The columns of Table 9 are the quality evaluations in each area in the respective state. The efficiency is measured as frequency, punctuality, speed and price (incl. access to services at sea ports for countries without sea access). The connectivity of roads refers to the average speed and straight-line routes, connecting the cities, which together have at least 15% of all the population. Airport connectivity measures the level of integration of the country within the global network of air transport. Sea connectivity evaluates the quantity of services offered by the companies to the linear navigation.

The total complex evaluation of the infrastructure state ranks Bulgaria 68th, with only Northern Macedonia behind it at 84th position.

Concerning the quality of the road transport network, Bulgaria is at the 102nd position with only Romania behind it at 119th position. On the index Railroad density km of roads/square km Bulgaria occupies a good position—26th, behind Sebia (24th) and Romania (19th).

On the index Efficiency of sea port services Greece and Turkey are before Bulgaria at 42nd and 43rd position respectively. Bulgaria is 62nd.

The favourable geographic location, allowing transit transport through Bulgaria is a competitive advantage of the Bulgarian transport system.

Table 9 Global competitiveness index 4.0 2019, rank in 2018 edition

Country	Bulgaria value/rank[a]	Romania	Greece	Turkey	Serbia	North Make-donia
Road connectivity index 0–100 (best)	76.6/67	79.3/55	75.8/73	87.1/34	84.5/43	67/91
Quality of roads 1–7 (best)	3.4/102	3.0/119	4.6/44	5.0/31	3.5/98	3.4/105
Railroad density km of roads/square km	37.1/26	46.8/19	17.4/46	13.3/52	42.7/24	27.1/33
Efficiency of train services	3.1/66	2.8/76	3/70	3.5/56	2.6/82	2.1/91
Airport connectivity score	40,732.7/70	59,903.7/57	232,147/27	558,459/14	27,204.6/76	5203.2/116
Efficiency of air transport services	4.5/79	4.6/71	5.4/35	5.4/31	4.3/88	4.3/87
Liner Shipping connectivity index 0–100 (best)	6.8/99	29.8/58	59.4/28	59.7/27	n/a	0.6/110
Efficiency of sea port services 1–7 (best)	4.3/62	3.9/76	4.8/43	4.7/44	3.1/111	2.4/125
Transport infrastructure	68	61	39	33	46	84

[a]Rank/141

Three of the 10 most important transport corridors of Trans-European Transport Network (TEN-T the pass through the territory of Bulgaria, Fig. 24, with two of them coinciding with the Bulgarian section of the River Danube:

- Corridor 4 (Orient/East-Med Corridor);
- Corridor 9 (Rhine-Danube Corridor);
- Corridor 10 (Strasbourg–Danube Corridor (also known as Seine–Danube Corridor).

Corridors 9 and 10 coincide with the Bulgarian section of the River Danube.

Orient/East-Med Corridor (Fig. 25) passes through Germany, Czech Republic, Austria, Slovakia, Hungary, Romania, Bulgaria, Greece, Cyprus and connects the

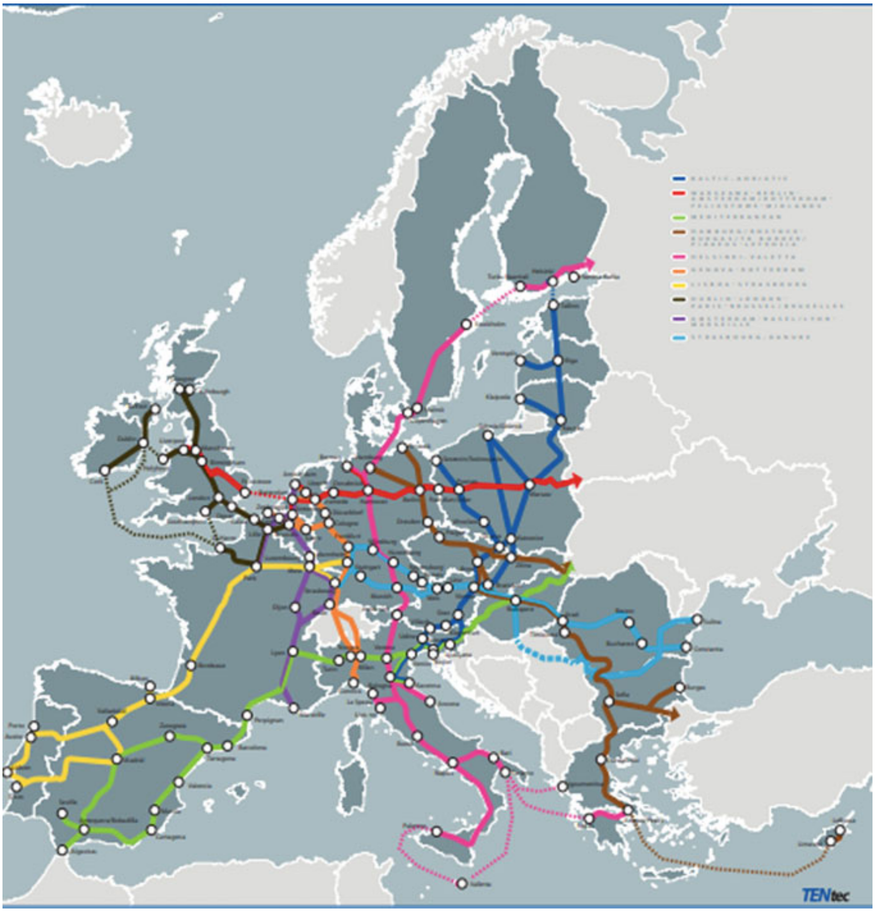


Fig. 24 TEN-T: the core network corridors

sea ports of the North, Baltic, Black and Mediterranean Seas. It includes the Elbe River as inland waterway, which improves the multimodal connections between the North Germany, Czech Republic, the mid-Danube lowland and Southeastern Europe. The total length is 3412 km.

Through the territory of Bulgaria, corridor 4 is in three directions. It passes through Vidin, Sofia, Kulata and continues to Athens, Piraeus, Patra в Greece. The second direction is Sofia-Plovdiv-Burgas, and the third—Plovdiv-Kapitan Andreevo and continues to Turkey.

Along the direction of the Orient/East-Med Corridor the railroad route includes the sections Vidin-Sofia-Kulata and Sofia-Plovdiv-Burgas/Svilengrad (Turkey border). According to the Draft Regulations for the Mechanism for connecting Europe 2021–2027, othe sections "Sofia–Serbian border" and "Sofia–North Macedonian border"

Fig. 25 Layout of the Orient/East-Med Corridor

are also part if the corridor. In the Core TEN-T network the railway directions Mezdra-Gorna Oriahovica and Ruse-Dimitrovgrad are also included.

The highways and first-class roads with European and national importance, whose length is 18.6% for 2019 from the total length of the road network in the country, are part of the Core TEN-T network on the territory of Bulgaria.

Besides the road route along the Orient/East-Med Corridor, the Core TEN-T network includes also the road directions Sofia-Veliko Tarnovo-Ruse and Sofia-Veliko Tarnovo-Stara Zagora-Dimitrovgrad- Marica highway.

Rhine-Danube Corridor (Fig. 26), which provides the main connection East–West through continental Europe, through the Main–Danube canal as its skeleton, connects the central regions around Strasbourg and Frankfurt through South Germany to Viena, Bratisava, Budapest and reaches thr Black Sea, with an important branch from Munich to Prague, Zilina, Kosice and Ukrainian border.

Fig. 26 Rhine-Danube Corridor

Strasbourg–Danube Corridor (also known as Seine–Danube Corridor) (Fig. 27). The route of the corridor is Strasbourg–Mannheim–Frankfurt–Wurzburg–Nuremberg–Regensburg–Passau–Wales/Linz–Vienna–Budapest–Arad–Brasov–Bucharest–Constanta Sulina) Length 2137 km.

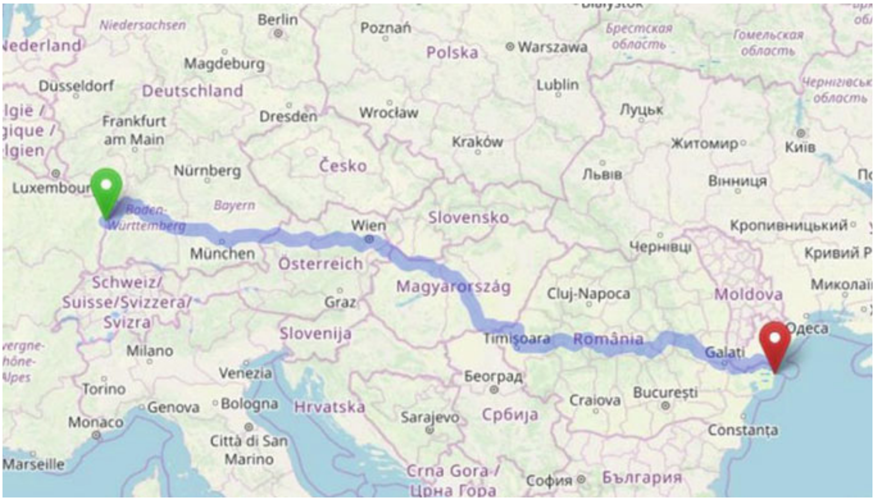


Fig. 27 Strasbourg–Danube Corridor (Danube Corridor)

Table 10 State of the TEN-T core network, Bulgaria

Completion of TEN-T core network 2016			
Road	Conventional rail	High speed rail	Inland waterway
50%	11%	Not applicable	100%

Source DG MOVE TENTec (The statistics reflect the official maps contained in Annex I of Regulation (EU) No 1315/2013. The term completed refers to "existing" infrastructure, which doesn't necessarily mean that infrastructure requirements, as stated in the above mentioned regulation, are already implemented. The time horizon for the completion of the TEN-T core network is 2030)

In Table 10 we can track the completeness of the TEN-T Core Network, Bulgaria. The lowest degree of completeness (11%) has the railway network (as a rule, it exists but does not meet the approved standards). The road network also has a low level of completeness (50%). The inland waterway, the River Danube is evaluated at 100% completeness. In Bulgaria нthere are no high-speed railway lines.

In the Core TEN-T network of the country are included Burgas port and the inland waterway ports Ruse and Vidin. In the Comprehensive TEN-T network are Varna port and the inland waterway ports Lom, Oryahovo, Svishtov and Silistra.

Sofia airport is included in the Core TEN-T network as part of Orient/East-Med Corridor. Burgas, Varna, Plovdiv and Gorna Oryahovitsa airports are included in the Comprehensive TEN-T network as completing the functions of the intermodal transport nodes from the Core TEN-T network.

The transcontinental corridor Europe–Caucasus–Asia „TRACECA", connecting Europe with Central and Far Asia has 13 states are members Armenia; Azerbaijan; Bulgaria; Georgia; Iran; Kazakhstan; Kyrgyzstan; Moldova; Romania; Tajikistan; Turkey; Ukraine; Uzbekistan. At present the TRACECA countries are gradually implementing the Strategy of the IGC TRACECA 2016–2026 [60]. Major traffic flows passing through a corridor formed on the one hand, in Western and Central Europe, and on the other—in Central and South-East Asia (Fig. 28).

On the territory of Bulgaria parts of TRACECA are ports Varna (P8); Burgas (P7), TRACECA routes: (1) Sofia-Veliko Turnovo (Rail and Road); (2) Sofia-Pleven Ruse (Road); (3) Sifia-Karlovo-Burgas (Rail); (4) Ruse-Dimitrovgrad (Rail and Road); (5) Sofia-Kalotina (Rail and Road); (6) Sofia-Gjueshevo (Rail and Road), TRACECA routes main index: (42) Sofia-Plovdiv-Svilengrad (Rail and Road); (43) Sofia-Burgas/Varna (Rail and Road); (46) Varna-Ruse (Rail and Road) и (47) Vidin-Sofia (Fig. 29).

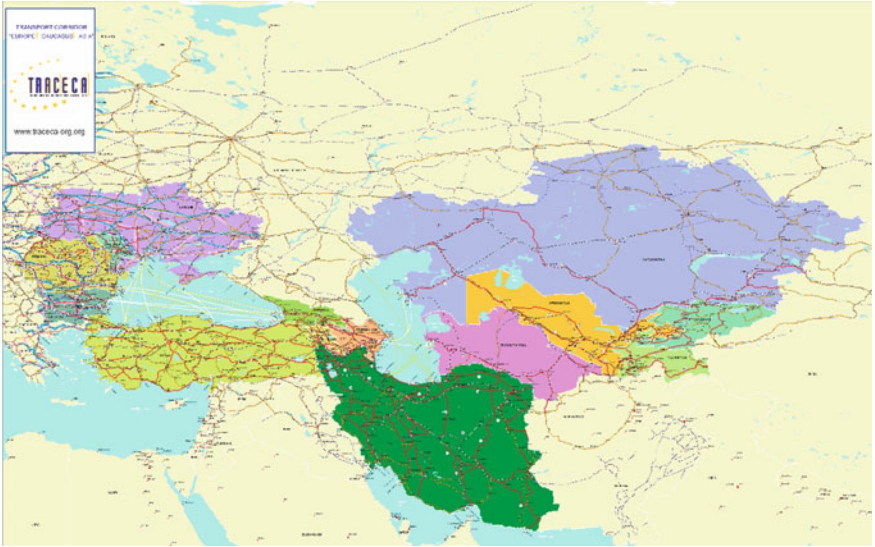


Fig. 28 Europe–Caucasus–Asia corridor “TRACECA”

Fig. 29 TRACECA map Bulgaria

4.3 Development of Multimodal and Intermodal Transport in Bulgaria

Multimodal and intermodal transport in Bulgaria. The future of the transport connectivity of Bulgaria lies not only in the transport sections, but also in the logistics and intermodal transport technologies, which should unite the railroad, port and road transport in a national integrated infrastructure and technology.

The main policies and activities in the country, concerning the development of the multimodal and intermodal transport, are related to the European policy and the main goals set in the strategic documents:

- by 2050 more than half the transport for more than 300 km have to be done by rail or waterway;
- all measures undertaken have to reduce the volume of harmful emissions into the atmosphere to 60%, compared to 1990.

In this direction the EU is working actively towards developing rail and waterway transport in the structure of the European transport, purposefully trying to reduce freight road transport, which will be subject to more and more restrictions along the individual transport corridors while at the same time, the ecological requirements to it will be increasing.

The main routes for domestic and international intermodal transport coincide with the directions from the Bulgarian sections included in AGTC and the directions from the Core and Broadband Trans European transport network. The state of the railway infrastructure for conducting combined transport as a whole does not meet the requirements for providing modern transport services. The development of intermodal terminals, connecting ports with railway network is restricted. The available terminals for container transport were built in the 1970s and 1980s and they do not meet the requirements for providing modern transport services.

There is no national network of modern intermodal terminals to serve the needs of rail and waterway freight transport. A project is planned for building an intermodal terminal in Varna, which will combine waterway, rail and road transport. Another problem is the poor equipment with a specialised rolling stock of the operators. There exist only several operative/logistics intermodal connections. As a whole, it can be summarized that the intermodal freight transport in the country is not developed sufficiently. The main reasons for that are related to the fact that the reloading equipment for national and international container freight transport were built back in the 1970s and 1980s and the reloading equipment available is specialised for processing only large containers. On the other hand, the degree of construction of the country's terminal network is still rather low. To date, Bulgaria has specialised container terminals located in the sea and river ports, one private intermodal terminal in Stara Zagora (Metalimpex) and the newly-built intermodal terminal in Plovdiv (Railway station Todor Kableshkov). The intermodal terminal in Sofia at Railway staion Yana, used by the private operator Ecologistics LtD has been built.

Fig. 30 Terminal at railway station Yana

The terminal at Railway station Yana (Fig. 30) allows the transportation of large volumes of mostly transit freight through a connection with Central and Western Europe on one hand, and Turkey, Greece, the countries from the Caspian region and South Russia, on the other.

Services offered at the terminal: Loading and unloading of containers train-land-car-and vice versa, 20′, 40′, 45′, tank, flat rack; Storage of empty and full containers, a depot for empty ones, repositioning between various ports servicing sea lines; Containerization and decontainerization; distribution door-to-door with container trucks; Repair, washing and rental of containers.

The possibility for granting a concession of the intermodal Ro-La terminal in Dragoman, owned by DP "NKJI", which is not functioning at the moment.

The problem of the degree of construction of the country's terminal network remains a high priority, provided that there is still no functioning intermodal terminal in the capital Sofia despite the strategic position of the city and the considerable freight flow passing through it.

The loads processed in Metalimpex Stara Zagora are mostly imported to the country. The terminal has 7 railway tracks, each with a length of 360 m (Fig. 31). There is storage area for storing loads and containers and tanks, are serviced by 2 terminal cranes with lifting capacity of 40 and 25 t. Metalimpex possesses its own

Fig. 31 Metalimpex terminal in Stara Zagora

truck fleet—about 20 road tractors, transporting containers and other freight to their final recipients on the territory of the country. They also transport empty containers, which are ten loaded on trains to be returned.

Additionally, the terminal has a steam plant for heating tanks with special freight, requiring the maintaining of a specific temperature.

The trains, servicing the terminal, come from Western Europe and Turkey. Different railway operators are contracted for work—DB Schenker, Rail Cargo, Gartner, Bulgarian State railway (BSR) Freight transport, Gopet Trans, Lukoil, etc. Among the shippers are Baier, BASF, Hoyer, etc. All types of freight is shipped such as organic chemistry products, cast iron, iron, metal sheet, pipes, fuels, sand, gravel, etc. Some of the processed loads are rails and crossbars of the companies that are modernizing the railway line Plovdiv-Burgas.

The terminal is located at Todor Kableshkov railway station and is part of railway node Plovdiv (Fig. 32) The terminal provides combined transport from trucks to rail and provides maximum efficiency of the freight flow from and to Central and Western Europe, as well as to the Middle and Far East and even to China.

The approach of trucks to the terminal is directly from the national road network, without passing through settlements. On an area of 71,450 m^2 a terminal site for loading–unloading, a site for storing containers in two rows, an area for damaged containers and equipment, special lots for refrigerating freight units, administrative building for customer services, customs control building and customs warehouse, parking lots for freight trucks and cars, as well as checkpoints.

Fig. 32 Terminal at Todor Kableshkov railway station

4.4 Multi-criteria Optimisation

The evolution of freight transport, the development of technologies and digitalization are constantly changing the nature of logistics and goods supply chain. The factors, which influence the choice of transport mode are different. Usually, the decisions are made based on previous experience, the type of goods transported, the technical and operational characteristics, the distance, the time for transport and the price.

The factors, influencing the choice of transport mode, are related to characteristics of the shipper and the shipment, the geographical and time characteristics and the technical and exploitation indexes of the transport mode (Fig. 33).

In terms of time, for all distances under 200 km road transport is the preferred mode [61]. Rail transport has lower speeds at 18 km/h average for the EU [62].

The operational factors of the modes of transport complement the reasons stated, which determine the choice of freight transport mode. For example, large quantities of heavy solid bulk freight (coal, metals, chemicals, etc.) are transported mainly by rail or waterway. Road transport is more appropriate for smaller freight quantities.

According to a survey held for the European Commission, 11 characteristics of the service can be identified as decisive for determining the mode of transport, especially between road and intermodal mode [63].

- Costs;
- Time;
- Reliability;
- Flexibility;
- Tracking of shipment;
- Infrastructure used (quality, capacity, incl. That of the terminals);
- Freight volume;
- Terminal service;
- Legislature;

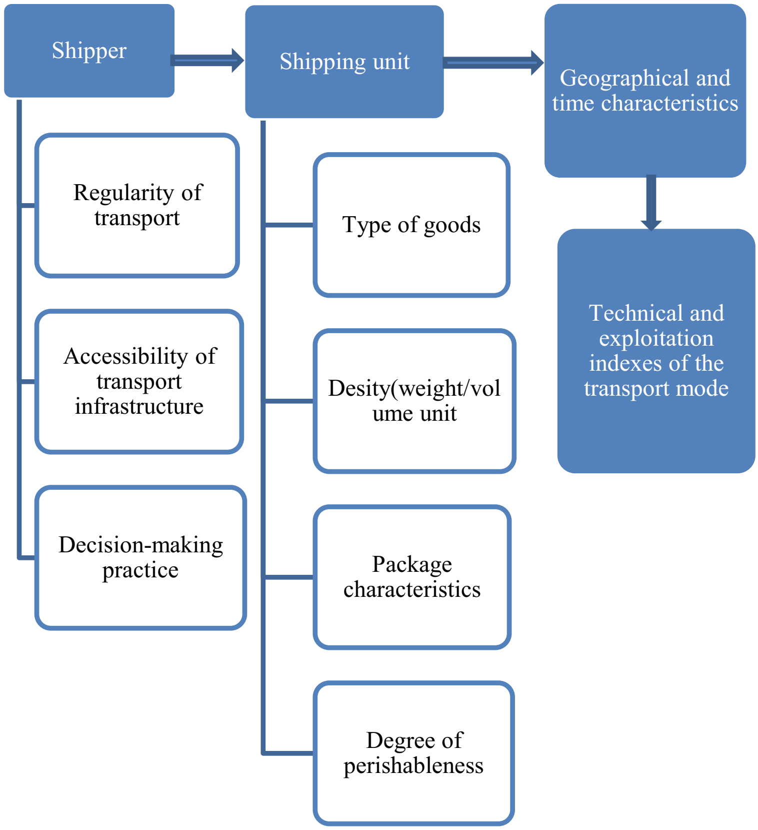


Fig. 33 Factors, influencing the choice of multimodal transport mode

- Safety;
- Security.

The characteristics most frequently used by the shippers for the choice of transport mode are the first two, connected to the criteria minimal costs and minimal time for transporting shipments. Adding to them external costs, we obtain a multi-criteria task with three criteria.

X_1 is starting point.
x_n is end point.
$x_1, x_2, \ldots\ldots x_{n-1}$ are internal transit points (n − 1) with possible transport connections from the modes of transport between them (Fig. 34).

The task is to get from start point x_1 to end point x_n, passing through internal transit points in general. The travel from the starting to the end point can be done along different routes, using different modes of transport between two neighbouring transit points.

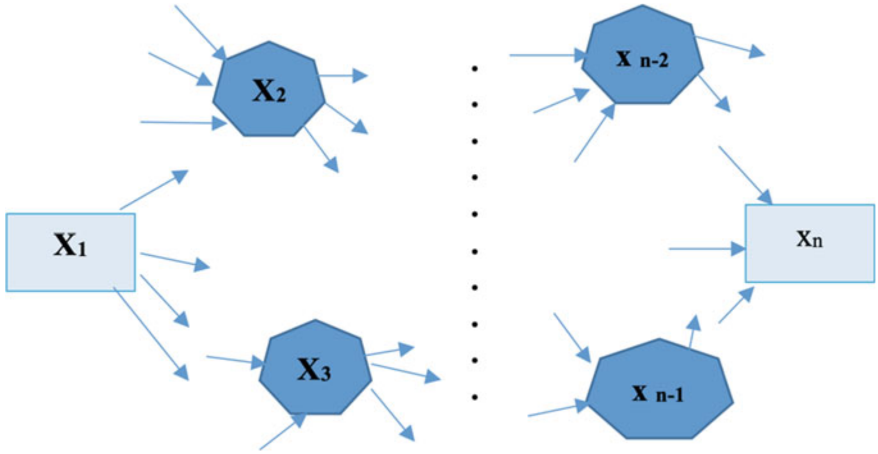


Fig. 34 Scheme of availability of corresponding points with the connections from the modes of transport between them

In the general case, the problem for the multimodal transport can be formulated as a problem seeking a route $\left(x_{1i}^{r_1}, x_{ij}^{r_2}, \ldots, x_{vn}^{r_n}\right)$, where

$x_{ij}^{r_l}$—carrying out transport between ith and jth node with r_lth mode of transport,$r_l \in \{1, 2, \ldots, k\}$, with
$\min(x)[F_1(x), F_2(x), \ldots, F_m(x)]$, where $F_i(x)$ at ($i = 1, 2, \ldots, m$) is ith target function.

In our case m = 3.

To create that mathematical model of the problem, we view the transport scheme as an oriented graph, in which to each point corresponds a node in the graph, and to each road connecting node i, with j, an oriented weighted rib is compared (i, j) in the graph. Weight c_{ij} of the rib is directly connected to the criteria set. In our case three criteria are set; with each directed rib three weights will be initiated for each vehicle with a number k passing along the rib: time of travel c_{ij}^{k1}, price of travel along the rib given c_{ij}^{k2} and the external costs (in conditional units) c_{ij}^{k3} along rib (i, j). If k modes of transport pass between two nodes, then on all three criteria are initiated k weights—$c_{ij}^{11}, c_{ij}^{21}, \ldots, c_{ij}^{k1}; c_{ij}^{12}, c_{ij}^{22}, \ldots, c_{ij}^{k2}; c_{ij}^{13}, c_{ij}^{23}, \ldots, c_{ij}^{k3}$.

The mode of transport with the lowest cost between two nodes according to a given criterion will be called dominant according to the criterion given between two specific peaks. It is possible a vehicle to have the lowest cost on all three criteria between two peaks. In this case, if it is necessary to pass along the rib given, its choice is unconditional.

We assume that transport can be carried out with three modes of transport along each rib: waterway, road and rail.

For each rib (i, j), the weights are $c_{ij}^{11}, c_{ij}^{12}, c_{ij}^{13} - waterway$ $c_{ij}^{21}, c_{ij}^{22}, c_{ij}^{23} - road$ $c_{ij}^{31}, c_{ij}^{32}, c_{ij}^{33}$- rail. In this way, there are three choices of transport mode between two points (two peaks in the graph), as for each of the three one is always dominant (it is possible the same transport vehicle to be dominant for two of the three criteria, as well as for all three simultaneously).

Different matrices can be set as adjacent $C^{k1}, C^{k2}, \ldots, C^{km}$ describing a specific cost with $k^{-\mathrm{t}h}$ mode of transport along the respective ribs.

The adjacent matrices are given depending on the criterion set—a criterion for minimum transport costs, minimum external costs, as well as minimum time for transport. With the three criteria set and the availability of three modes of transport with Z_1, Z_2, Z_3 to indicate the total costs under the first, second and third criteria, respectively (Z_1—total transport costs, Z_2—total external transport costs, Z_3—total transport time). With $c_{ij}^{11}, c_{ij}^{12}, c_{ij}^{13}$ we denote the cost of the first mode of transport. For the respective second and third criterion along the rib (i, j). Analogously to $c_{ij}^{21}, c_{ij}^{22}, c_{ij}^{23}$ and $c_{ij}^{31}, c_{ij}^{32}, c_{ij}^{33}$—the costs with the second and third mode of transport under the respective criteria. Then

$$Z_k = \sum_{i=1}^{n} \sum_{j=1}^{n} c_{ij}^{1k} x_{ij}^{1} + c_{ij}^{2k} x_{ij}^{2} + c_{ij}^{3k} x_{ij}^{3}, \quad k = 1, 2, 3 \tag{4.1}$$

Are the total costs under the three criteria?

The task is to minimize the vector criterion

$$\begin{aligned} Z &= \left[Z_1\left(x^k\right), Z_2\left(x^k\right), Z_3\left(x^k\right)\right] \\ x^k &= \left(x_{11}^k, x_{12}^k, \ldots, x_{nn}^k\right) \end{aligned} \tag{4.2}$$

With restrictions

$$\sum_{k=1}^{3} \left(\sum_{i=1}^{n} x_{ir}^{k} - \sum_{i=1}^{n} x_{ri}^{k} \right) = 0 \quad \forall r = \overline{2, \ldots, n-1}, \tag{4.3}$$

$$\sum_{k=1}^{3} \sum_{i=2}^{n} x_{1i}^{k} = 1 \tag{4.4}$$

$$\sum_{k=1}^{3} \sum_{i=1}^{n-1} x_{in}^{k} = 1 \tag{4.5}$$

$$\sum_{k=1}^{3} x_{ij}^{k} \leq 1 \quad \forall i, j = \overline{2, \ldots, n-1}, \tag{4.6}$$

$$x_{ij}^{k} \in \{0, 1\}, \quad \forall k = \overline{1, 3} \tag{4.7}$$

The unknown variable x_{ij}^k (4.7) accepts value 1, if the route goes through rib (i, j) from node I to node s from node i to node j with kth mode of transport and 0 otherwise. Restrictions (4.4) and (4.5) express respectively that from the start node we should choose just one node and one mode of transport to start to and exactly one node and one mode of transport to get to the end point. Restriction (4.3) is that for all remaining nodes (except the start and end ones) the sum of all modes of transport coming into a given intermediate node, should be equal to the sum of all leaving modes. Condition (4.6) reflects the fact that along a given rib in one direction, only one mode of transport can be selected. Thus, the task set (4.2)–(4.7) is a task of the multi-criteria integer linear optimization, for which the criteria (target functions) are more than one and the solution should be integer (in the specific case—binary variables). The solution can be found via Pareto—optimal solutions. The vector criterion (4.2) is linear and the restrictions (4.3)–(4.6) are linear, which means that the allowable set is convex. Condition (4.7), is a condition for integer variables (or some of them); these are tasks from the so-called class NP-complexity (nondeterministic polynomial time). Pareto-optimal solution in this case is a discrete set and it is not obligatory the points to coincide with points from the Pareto optimal solutions without integer conditions. Given that the allowable area is a convex set, to find the Pareto optimal solutions in conditions of integer of variables, we apply weighing method.

A generalized criterion is constructed as a linear combination of the partial criterion with weights λ^k, $k = 1, 2, 3$ and weight condition

$$\sum_{k=1}^{3} \lambda^k = 1, \quad \lambda^k \geq 0,\ k = 1, 2, 3 \tag{4.8}$$

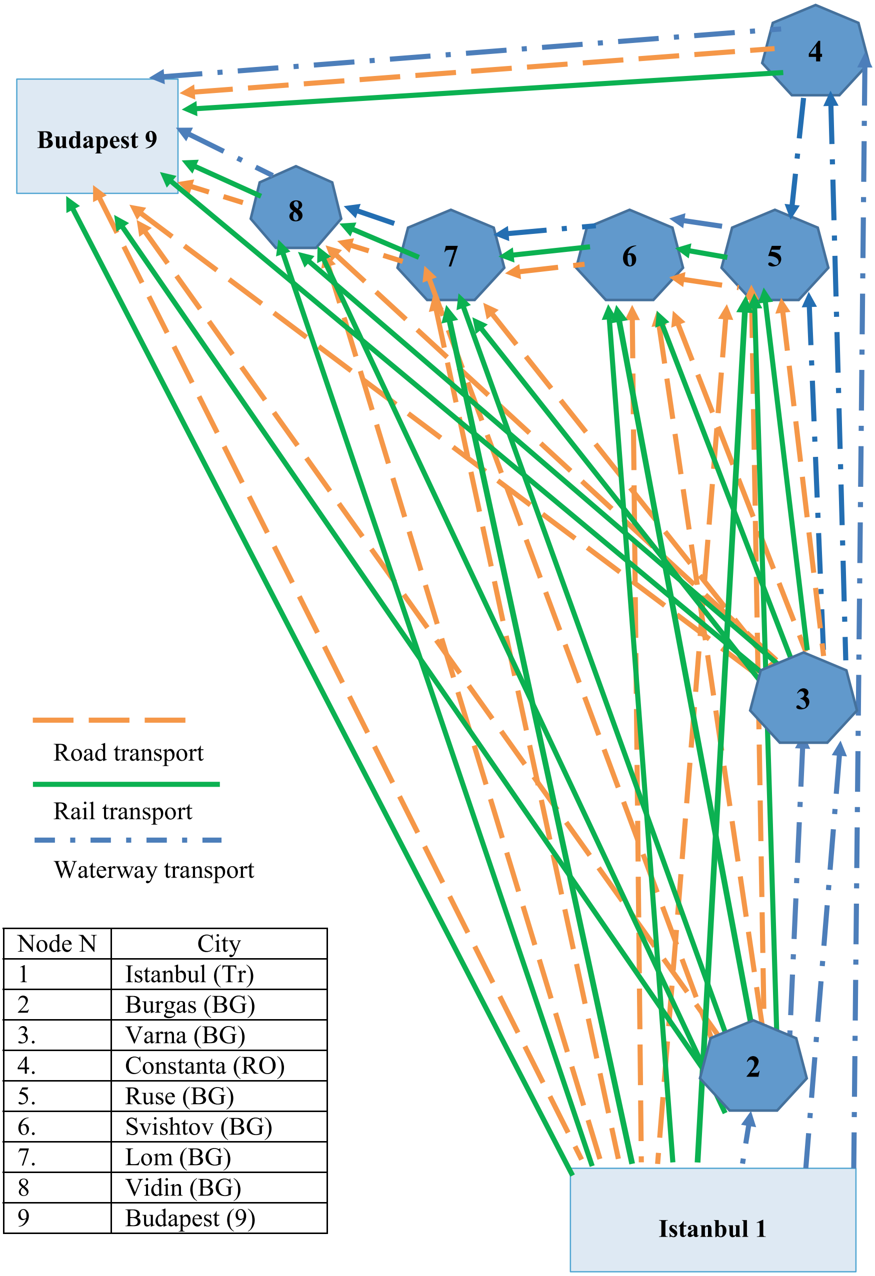
To weights λ^k evenly distributed random numbers are set, meeting condition (4.8) (the area specified with (4.8) is probed). For each random set of weights the one-criterion integer problem is solved

$$\begin{aligned} \min Z = \lambda^1 Z_1 + \lambda^2 Z_2 + \lambda^3 Z_3 = \sum_{k=1}^{3} \lambda^k Z_k = \lambda^1 \sum_{i=1}^{n}\sum_{j=1}^{n}(c_{ij}^{11} x_{ij}^1 + c_{ij}^{21} x_{ij}^2 + c_{ij}^{31} x_{ij}^3) \\ + \lambda^2 \sum_{i=1}^{n}\sum_{j=1}^{n}(c_{ij}^{12} x_{ij}^1 + c_{ij}^{22} x_{ij}^2 + c_{ij}^{32} x_{ij}^3) \\ + \lambda^3 \sum_{i=1}^{n}\sum_{j=1}^{n}(c_{ij}^{13} x_{ij}^1 + c_{ij}^{23} x_{ij}^2 + c_{ij}^{33} x_{ij}^3). \end{aligned} \tag{4.9}$$

At conditions (4.3)–(4.7). The different solutions are selected. They form the Pareto optimal solutions with integer variable coordinates (control parameters).

The following task is solved to check the model.

It is necessary to transport cargo of 1000 t from Istanbul (Turkey) to Budapest (Hungary) through Bulgaria. When delivering the cargo, it is possible to use a road, railway and waterway transport in combinations shown on Fig. 35.



Node N	City
1	Istanbul (Tr)
2	Burgas (BG)
3.	Varna (BG)
4.	Constanta (RO)
5.	Ruse (BG)
6.	Svishtov (BG)
7.	Lom (BG)
8	Vidin (BG)
9	Budapest (9)

Fig. 35 Corresponding points for freight delivery from Istanbul to Budapest graph

Table 11 Freight unit (characteristics)

Cargo	Reinforcing steel bars, length 12 m, diam. 12 mm
Packing	Bundles of unit weight about 2 t
Shipment size	1000 t
Port of loading/parity	FOB/FCA Istanbul, Turkey
Final destination/parity	CFR/CPT Budapest, Hungary

In the calculations, it is assumed that a truck carries 20 t, a train car 50 t, and a sea and a river vessel collect all the cargo in one vehicle. For this purpose, a scheme of route variants is compiled. The start point is Istanbul, and the end point is Budapest. Intermediary points are Burgas (BG), Varna (BG), Constanta (RO), Ruse (BG), Svishtov (BG), Lom (BG), Vidin (BG).

The characteristics of a freight unit are given in Table 11.

In the tables that follow, the direct costs, external costs and time between the corresponding points from the transport scheme are pointed out.

In Tables 12, 13 and 14 are given the direct costs between the corresponding points with waterway, road and rail transport, respectively, considering the costs of port congestion in EUR/t (Table 15).

External costs are reflected in Table 16 (for waterway transport), Table 17 (for road transport) and Table 18 (for rail transport). The external costs in EUR/t with the different modes of transport are shown in Table 19 [64].

When determining the distances between corresponding points, online calculators have been used: for rail transport [65] and for waterway transport (sea and river) and

Table 12 Direct costs between the corresponding points with waterway transport

Freight rate by vessel, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	20	23	25	0	0	0	0	0
Burgas	0	0	0	0	0	0	0	0	0
Varna	0	0	0	0	0	0	0	0	0
Constanta	0	0	0	0	0	0	0	0	22
Ruse	0	0	0	0	0	0	0	0	19
Svishtov	0	0	0	0	0	0	0	0	18
Lom	0	0	0	0	0	0	0	0	17
Vidin	0	0	0	0	0	0	0	0	16
Budapest	0	0	0	0	0	0	0	0	0

Table 13 Direct costs between corresponding points with road transport

Freight rate by truck, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	0	0	0	52	54	62	64	115
Burgas	0	0	0	0	14	16	18	19	85
Varna	0	0	0	0	10	12	14	15	82
Constanta	0	0	0	0	0	0	0	0	72
Ruse	0	0	0	0	0	0	0	0	77
Svishtov	0	0	0	0	0	0	0	0	75
Lom	0	0	0	0	0	0	0	0	73
Vidin	0	0	0	0	0	0	0	0	72
Budapest	0	0	0	0	0	0	0	0	0

Table 14 Direct costs between corresponding points with rail transport

Freight rate by rail, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	0	0	0	38. 4	40	45	47	81
Burgas	0	0	0	0	15	16	18	19	52
Varna	0	0	0	0	11	13	15	16	49
Constanta	0	0	0	0	0	0	0	0	42
Ruse	0	0	0	0	0	0	0	0	47
Svishtov	0	0	0	0	0	0	0	0	45
Lom	0	0	0	0	0	0	0	0	43
Vidin	0	0	0	0	0	0	0	0	42
Budapest	0	0	0	0	0	0	0	0	0

Table 15 Costs for reloading at ports

Transhipment costs, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Discharging from vessel		3	3	3	3	3	3	3	
Discharging from railcar		2	2	2	2	2	2	2	
Discharging from truck		2	2	2	2	2	2	2	
Loading on vessel		2	2	2	2	2	2	2	
Loading on railcar		2	2	2	2	2	2	2	
Loading on truck		2	2	2	2	2	2	2	

Table 16 External costs with waterway transport mode

External costs by vessel, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	1.50	1.77	2.32	0	0	0	0	0
Burgas	0	0	0	0	0	0	0	0	0
Varna	0	0	0	0	0	0	0	0	0
Constanta	0	0	0	0	0	0	0	0	69.30
Ruse	0	0	0	0	0	0	0	0	56.83
Svishtov	0	0	0	0	0	0	0	0	53.76
Lom	0	0	0	0	0	0	0	0	44.40
Vidin	0	0	0	0	0	0	0	0	42.03
Budapest	0	0	0	0	0	0	0	0	0

for the road transport [66]. The time between corresponding points is shown in Table 20 for waterway transport in h/1000 t, Table 21 for automobile in/1000 t with the fleet of cars reflecting the needed road vehicles and Table 22 for rail transport in h/1000 t. In Table 23 the tome for reloading in the ports from the transport scheme is given in h/1000 t, according to documents received by the Bulgarian shipping company Donau Transit. In order for Preto front to be obtained, a single-criteria problem with different weights is solved repeatedly (in this case, the probing was performed with 400 different test points). The one-criteria problem is solved repeatedly, it is integer and large (a total of 243 variables).

Table 17 External costs with road transport

External costs by truck, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	0	0	0	49.84	48.27	64.74	69.82	117.82
Burgas	0	0	0	0	23.65	26.19	49.49	53.52	97.76
Varna	0	0	0	0	17.52	22.34	39.68	45.20	93.64
Constanta	0	0	0	0	0	0	0	0	96.89
Ruse	0	0	0	0	0	0	0	0	77.70
Svishtov	0	0	0	0	0	0	0	0	71.74
Lom	0	0	0	0	0	0	0	0	64.12
Vidin	0	0	0	0	0	0	0	0	59.48
Budapest	0	0	0	0	0	0	0	0	0

Table 18 External costs with rail transport

External costs by rail, EUR/t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	0	0	0	6.26	6.06	8.13	8.77	14.80
Burgas	0	0	0	0	2.97	3.29	6.22	6.72	12.28
Varna	0	0	0	0	2.20	2.81	4.98	5.68	11.76
Constanta	0	0	0	0	0	0	0	0	12.17
Ruse	0	0	0	0	0	0	0	0	9.76
Svishtov	0	0	0	0	0	0	0	0	9.01
Lom	0	0	0	0	0	0	0	0	8.05
Vidin	0	0	0	0	0	0	0	0	7.47
Budapest	0	0	0	0	0	0	0	0	0

Table 19 External costs for the various modes of transport [64]

External costs by transport mode	EUR/tkm
Sea	0.0064
IWT	0.0495
Road	0.0876
Rail	0.0100

Table 20 Time for transporting the total freight with waterway mode

Transit time by sea/river, h/1000t vessel	Istanbul	Burgas	Varna	Constant a	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	61	63	56	0	0	0	0	0
Burgas	0	0	0	0	0	0	0	0	0
Varna	0	0	0	0	0	0	0	0	0
Constanta	0	0	0	0	0	0	0	0	280
Ruse	0	0	0	0	0	0	0	0	273
Svishtov	0	0	0	0	0	0	0	0	268
Lom	0	0	0	0	0	0	0	0	242
Vidin	0	0	0	0	0	0	0	0	228
Budapest	0	0	0	0	0	0	0	0	0

Table 21 Time for transporting the total freight with road mode

Transit time by road, h/1000t (with all truck)	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	0	0	0	184	208	240	240	**278**
Burgas	0	0	0	0	172	197	224	225	254
Varna	0	0	0	0	171	196	223	224	254
Constanta	0	0	0	0	0	0	0	0	182
Ruse	0	0	0	0	0	0	0	0	254
Svishtov	0	0	0	0	0	0	0	0	326
Lom	0	0	0	0	0	0	0	0	254
Vidin	0	0	0	0	0	0	0	0	254
Budapest	0	0	0	0	0	0	0	0	0

Using accurate algorithms, this would take an unacceptably long time and/or unacceptably large memory resource. In order to save time and computational memory, heuristic approaches have been used to solve a partially integer linear optimization problem. With the help of Matlab R2017b software and the optimization functions built into the product are found to be Pareto optimal solutions Table 24.

Table 22 Time for transporting the total freight with rail mode

Transit time by rail, h/1000t (block train)	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Istanbul	0	0	0	0	120	120	120	120	144
Burgas	0	0	0	0	108	120	120	120	120
Varna	0	0	0	0	96	96	108	108	120
Constanta	0	0	0	0	0	0	0	0	84
Ruse	0	0	0	0	0	0	0	0	120
Svishtov	0	0	0	0	0	0	0	0	144
Lom	0	0	0	0	0	0	0	0	120
Vidin	0	0	0	0	0	0	0	0	120
Budapest	0	0	0	0	0	0	0	0	0

Table 23 Time for reloading in the ports from the transport scheme

Transshipment time, h/1000 t	Istanbul	Burgas	Varna	Constanta	Ruse	Svishtov	Lom	Vidin	Budapest
Discharging from vessel		24	24	12					48
Discharging from railcar					48	48	48	48	24
Discharging from truck					72	96	120	120	86
Loading on vessel	24			12	48	48	48	48	
Loading on railcar	48	24	24	12	48	48	48	48	
Loading on truck	96	96	96	48	96	16 8	120	120	

The results from Table 24 should be interpreted in the following way:

In the considered task, in case of variant No.1 only waterway transport is used from the start to the end point. Along the route from point No. 1 (Istanbul) to No. 4 (Constanta) sea transport is used, and then, from No. 4 (Constanta) to No. 9 (Budapest), river transport is used. Here in Constanta port reloading of freight is carried out, in cases where it is not possible for the seagoing vessel to sail on the Danube. We note this fact because there were ships that could sail on the Black Sea and on the Danube, but today they are not used because they failed to establish

Table 24 Pareto optimal solutions and values according to different criteria

Pareto variants No.	First mode transport route	Second mode transport route	Second mode transport route	Direct costs, EUR/t	External costs, EUR/t	Time, h/1000 t	Direct + external, EUR/t
1	[1 4 1;4 9 1]	[]	[]	**47**	**71,62**	336	**118,6**
2	[1 2 1;6 9 1]	[]	[2 6 3]	54	58,55	**449**	112,6
3	[1 2 1;7 9 1]	[]	[2 7 3]	55	52,12	423	107,1
4	[1 4 1]	[]	[4 9 3]	67	14,49	**140**	**81,49**
5	[1 3 1]	[]	[3 9 3]	72	**13,53**	183	85,53
6	[1 3 1]	[3 6 2]	[6 9 3]	**80**	33,12	403	113,1

themselves as an alternative. Under this option, the direct costs are the lowest 47 EUR/t, the external costs are the highest 71.62 EUR/t, as well as the sum of the direct and external costs 118.60 EUR/t. The value of the transport time is also not small 336 h/1000 t. In case the time is not important and the external costs are not considered, then this route is the most economical and suitable. If you are looking for a solution in which the external costs are optimal, then you should choose option No. 5 on route No. 1 (Istanbul)—No. 3 (Varna) by sea and then by rail on route No. 3 (Varna)—No. 9 (Budapest). In this case the costs will be 13.53 EUR/t. The value of the sum of direct and external costs is quite acceptable 85.53 EUR/t, as well as the value of the transport time, which is also small 183 h/1000 t. Only direct costs have a high value of 72 EUR/t. This route can be considered as a suitable alternative.

In order to find the optimal value of the total direct and external costs, then the route should be according to option No. 4, which is performed by sea transport from No. 1 (Istanbul) to No. 4 (Constanta) and then by rail from No. 4 (Constanta) to No. 9 (Budapest) at a cost of EUR 81.49/t. This route also has a minimum delivery time of 140 h/1000 t, although the direct costs are not small 67 EUR/t. In this case, if the delivery time and the total direct and external costs are decisive, then this route is the most suitable.

One of the main reasons for determining the delivery time from the starting point to the end point is the possibilities for loading and unloading at the individual points. In some cases, it turns out that low rates in river ports, the load of wagons in rail transport, as well as the load of a large number of trucks significantly increase the delivery time and this is crucial in the choice of route by freight forwarders. It is suitable, for example, for the delivery time directly from Istanbul to Budapest by rail, which is 144 h/1000 t, and optionally No. 4, it is 140 h/1000 t, which is 2.8% more.

The obtained solutions show that there is no single route along which the values of all three criteria are optimal. Therefore, it is left to the decision-maker (forwarder) to decide which the appropriate route for the transport is.

5 Conclusions

The following conclusions can be drawn:

1. The organizational and effective interaction between the different modes of transport, comprising the transportation of freight, is achieved through full specification and coordination of the operations. It must be noted that this interaction is a complex process of planning and realization, and depends on a number of conditions of economic, technological, organizational, legal and managerial nature. At the same time, the dynamic transport sector faces a number of challenges, which are becoming more complex in force majeure circumstances such as the restrictions on travelling due to COVID 19. The main ones are: sustainable transport solutions and serious social and ecological restraints; providing a reliable transport service; requests for smaller shipments and their consolidation; higher expectations for the quality of transport services and their integration into flexible ICT systems; increasing fuel costs.
2. At present, multimodal and intermodal transport systems are at the heart of international commerce, with the aim to reduce the total cost for transport and processing within the supply chain, and at the same time, to meet the demand for door-to-door transport services.

   In recent years, besides multimodal and intermodal network, the terms co-modal (co-modality is defined as „effective use of different modes of transport") and synchro-modal transport have emerged (the synchro-modal transport is a mode variant of co-modal transport with parallel use of the available transport modes).

   Additionally, with the development of Industry 4.0, in literature emerged another concept, related to the multimodal mode of transportation—the physical internet (PI). This is a concept of the open global logistics system, which entirely redefines the current supply chain, business models and value creation models. The Physical Internet is still at a concept stage. It is necessary to do research at the physical and informational level, as well as the business models.
3. Modern developments in the field of digitalization are connected to a number of newly-developing technologies such as: cloud technologies; wireless communication technologies; Internet of Things (IoT); developing web-technologies; social networks; developing interface technologies (augmented reality, etc.); big data technology to support multimodal transport management solutions and blockchain; cooperative and intelligent transport systems; connected and autonomous mobility; integration and artificial intelligence; others. The use of these technologies reveals new opportunities for efficient implementation of

multimodal transport. This process of digitalization will help to avoid human errors and increase the efficiency through a higher level of automation, which will reduce the time for expedition and the costs.

In summary, we can point out that ICT have a great potential for efficient and reliable management in real time and operations of multimodal freight transport, but some strategic, political and company decisions for the implementation of the system and especially for aiding small and medium-sized enterprises and overcoming the barriers need to be made. One good practice is the political decision for financing the development of a European Digital Innovation Hubs network (EDIH). Building the Danube Digital Innovation Hub (DDIH) with a headquarters in Ruse, Bulgaria is a good example. By April 2021, the existing and planned EDIH in Bulgaria are 11, with 5 of them already existing and 6—at the start of their development are candidates for EDIH. The distribution is even in the country's territory, with mandatory presence of a university or research institute in the consortium that has initiated the hub.

4. The choice of systems for freight transportation depends on a number of factors of economic, social, geographical and psychological nature. The favourable geographic location of Bulgaria and its connectivity with important international corridors from the TEN-T network and TRACECA are good initial conditions for the development of transit transport. At the same time, the poor infrastructure, low volumes of transport work, neglecting the external costs are reasons for slowing down the development of multimodal and intermodal transport. The future of the transport connectivity of Bulgaria lies not only in the transport sections, but also in the multimodal and intermodal transport technologies, which should unite the railroad, port and road transport in a national integrated infrastructure and technology. The mathematical model developed on the basis of multi-criterial optimization with the following three criteria: direct costs, time and external costs allows the efficient planning of multimodal transport.

   Checking the model with Matlab R2017b software and the embedded optimization functions, as well as optimal Pareto solutions, using heuristic approaches for solving a partially integer task of linear programming is a proof of the versatility and efficiency of this task.

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