ANALISYS OF THE INTERMODAL FREIGHT TRANSPORT IMPACTS ON ENERGY CONSUMPTION

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REZUMAT. Transportul este un consumator important de energie neregenerabilă. Totodată este responsabil de efecte negative în mediul social şi natural în care este plasat. Reducerea consumurilor de energie şi a efectelor poluante necesită politici conjugate: de promovare a mijloacelor şi tehnologiilor de transport cu randamente energetice sporite şi efecte externe reduse. Obiectul lucrării de faţă constă în analiza reducerilor consumurilor de energie obţinute în cazul înlocuirii transportului rutier de mărfuri pe distanţe mari cu transportul intermodal feroviar - rutier.

Cuvinte cheie: transport intermodal, consum de energie, consumuri specifice.

ABSTRACT. Transportation is a major consumer of non-regenerating energy. It is also responsible for the negative external effects on the social and natural environment that it resides on. Reducing of energy consumption and pollution needs conjugated policies: promoting energetically high capabilities and low external effects transport vehicles and technologies. The subject of this paper consists in analysis of energy consumption reducing obtained by replacing road freight transport on long distances with intermodal rail-road transport.

Keywords: intermodal transport, energy consumption, energy efficiency.

1. INTRODUCTION

The energy consumption and external effects in transport are more frequently the determinant factor in strategies for restructuring the present modal share. The attention on energy sources and energy efficiency stimulates the research on sustainable transport.

In the global economy, with oil as main energy source (see Figure 1), the transport sector consumed about 3.9 Gtoe (Giga tones of oil equivalent) in 2009 at world level [17]. An analysis of the final end use of energy shows three dominant categories: namely, transport, industry and households. Figure 2 shows that the share consumed by transport was around 32% from the energy supplied in EU-27 [14], [15].

The expansions of the road and air transport, which have oil as main primary energy source, are major factors for rising of the energy consumption. The energy consumption of primary energy within Europe Union (EU-27) was about 1.7 Gtoe in 2009, with a substantial decrease, -5.5 % compared with 2008 [16]. The decrease could be attributed to a lower level of economic activity as a result of the financial and economic crisis, rather than a structural shift in the pattern of energy consumption [14], [17].

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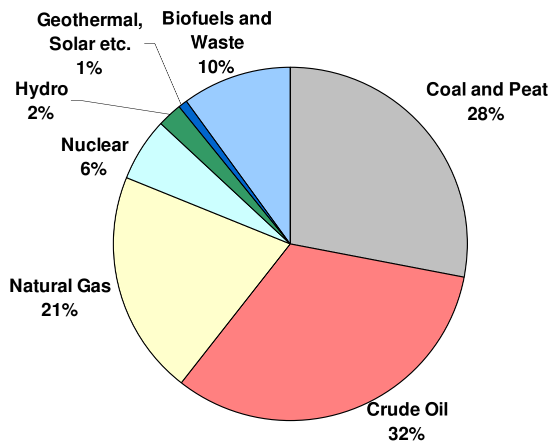


Fig. 1. Share of total primary energy supply in 2009.

In the context of cvasi-stationary energy consumption for the most efficient energetic and non-pollution transport modes (rail and inland waterway transport), road transport is responsible for constantly increasing energy consumption, with more 11% in 2008 than 1998 [13].

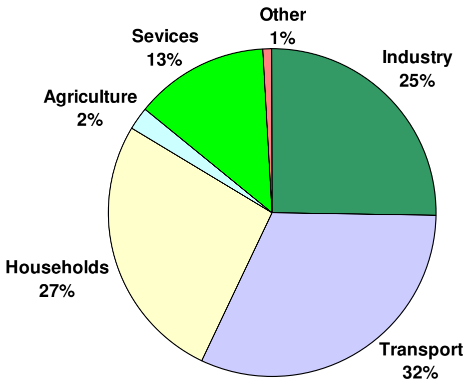


Fig. 2. Final energy consumption in Europe Union in 2009

Comparative analysis of energy efficiency for different transport modes is usually performed function on ratio between energetic consumption (measured in toe) and transport performance (measured in passenger-km or t-km) estimated to satisfy the mobility demand. For this purpose, using the theoretical data offered by vehicle producers, not taking into account the real condition with significant influences on energy efficiency, only partial information could be obtained. For example, an automobile producer indicates a fuel efficiency of 7l/100 km, which means potential 11 gep/passenger-km energy efficiency for 5 passenger /car, but in fact, for urban traffic condition values five times bigger could be obtained [8].

Analysis of data on final energy consumption in transport modal share show that road transport is the main consumer (see Figure 3 [14]), even with advances in transport techniques and technology, aimed at enhancing energy efficiency. The impacts of the technical progress is receded by the increased of road transport intensity [5].

Besides the attributes that raise the attractiveness of road transport, inappropriate land use and financial policies (mostly uncorrelated with existing rail and inland waterway infrastructure and with the capacity of their development) contributed also to the explosive increasing of road vehicles number [8], [10].

The high requests of the users are also responsible for the rising of road transport share, as well as of total transport volume. The development of the „just in time" services and the demand for a wide diversity of products lead to prompt transport flows, with reduced quantities [9], [10]. The inland waterway transport – with reduced commercial speed – and rail transport are adequate for transport flow with significant size and are inadequate for mentioned actual requests.

In this context, which anticipate no significant change in user behavior, solution have to be identified in order to reduce energy consumption and negative environment implication of oil dominated road transportation. Therefore correlated policies are needed to [8]:

- Promoting transport technologies with increased energy efficiency and reduced emission effects;
- Shifting transport flow to the most sustainable transport modes.

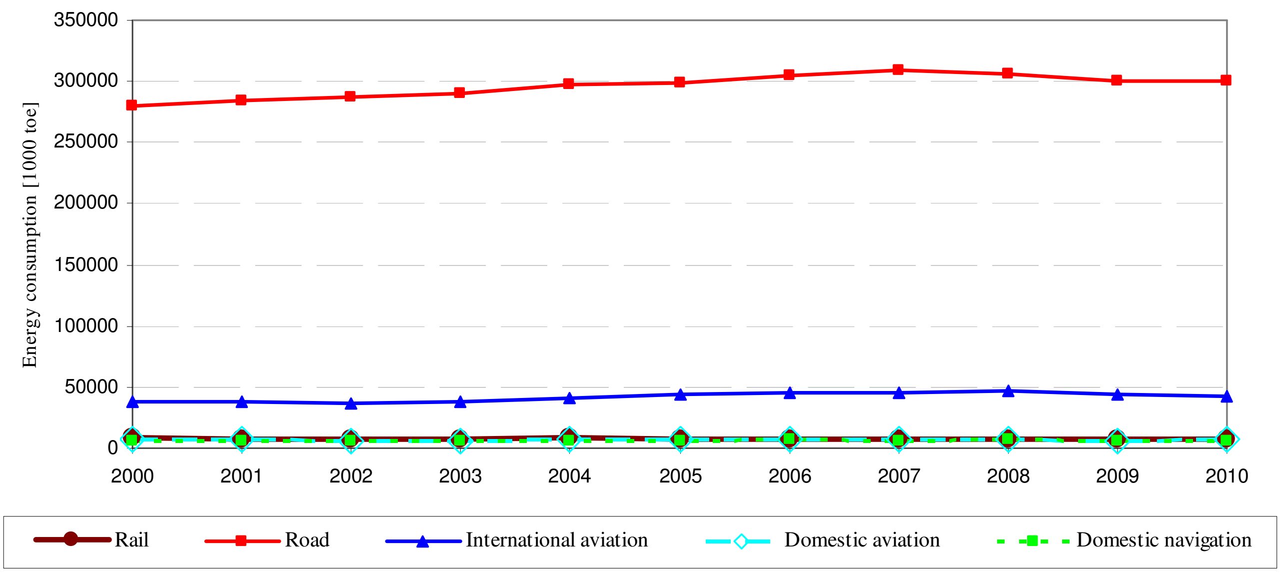


Fig. 3. Energy consumption by transport mode in EU-27, 2000-2010.

The objective of our research is to develop an intermodal rail-road transport model which attracts the road transport on long distances, and offers similar performance of service like unimodal road transport.

It is well-known that the road transport includes light-duty vehicles (such as automobiles, minivans, small trucks), as well as heavy-duty vehicles (such as large trucks). In this paper we address only the freight transport in long distances by havy-duty vehicles and point out the advantages of shifting the long distances freight transport from road to intermodal transport. The basic model of intermodal rail-road transport contains (i) -road network on short distances for last mile distribution or cargo collecting; (ii) - intermodal terminals with special handling infrastructure for transfer processes, and (iii) - rail network on long distance. The next section presents the characteristics of intermodal rail-road transport, and than, in the third section we develop a model to select a multimodal transport network, taking into consideration transport indicators which were computed for different transport routes. For each route category, we compute the energy consumption for a load in both cases, for road-rail intermodal, on one side and for unimodal road transport, on the other side.

2. CHARACTERISTICS OF INTERMODAL FREIGHT TRANSPORT

The road freight transport share is predominant, with severe consequences on environment and energy consumption. In this context, development of intermodal transport is considered solution for a beter modal share balancing.

The research presented in this paper is limited to road-rail intermodal freight transport (see Figure 4), which include the following steps:

1. Freight collecting and road transport on short or medium distances from supplier to initial terminal;
2. Initial terminal transfer and transport flow consolidation;
3. Rail transport for long distances and large quantities;
4. Destination terminal transfer and traffic unit decomposition;
5. Road transport on short or medium distances for freight distribution to customers.

Intermodal transport maximizes the use of the long haul system during the transport, because of the scale economies. Therefore intermodal transport is not a competitive alternative on short distances, since the advantage of using intermodal transport does not arise until the savings in the long-haul system outweigh the additional cost in the terminal and distribution/collection systems.

In order to organize reliable and sustainable intermodal services, which allow the shift of road long haul to rail system and to lead to increased intermodal transport demand, all the above mentioned steps have to be optimized. The intermodal service level depends mainly on terminal location, correlation between capacities of interacting systems, capability of co-operation of transport chain actors [3].

In intermodal terminals transport, flows with different origin/ destination are consolidated on the main route section, in one traffic unit. The advantages of transport flow consolidation are the increasing load factor (which could determine decreasing of specific transport cost and rising of energy efficiency) and incising transport frequency.

Intermodal transport system requires terminals with special transshipment facilities. The modal transfer and operating of the transport flow in intermodal terminals imply additional time and cost. Therefore the efficiency and the location of intermodal terminals are crucial success factors for intermodal transport development.

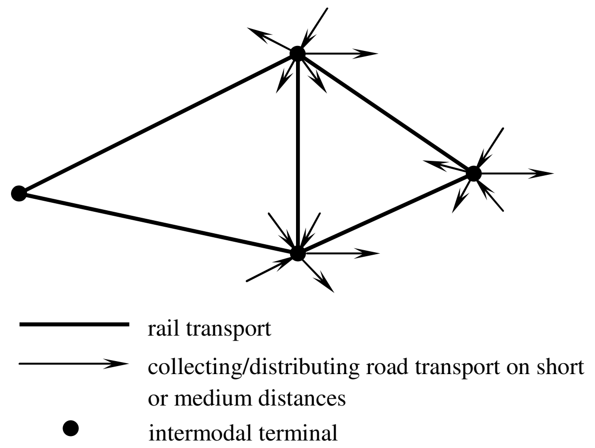


Fig. 4. Rail-road intermodal network.

Design of intermodal network, which allow the shift of road long distances transport to rail system and offer the benefit from the economies of scale of consolidating freight, needs additional research on development of mathematical and simulation models to solve the intemodal terminal location in a structured territory and necessary capacity of terminals. Different types of intermodal transport network models have been proposed [1], [2]. However there is no specific study on how terminal expansion and transport freight policy affect the intermodal transport development.

The next section presents the methodology applied to model intermodal transport network. The developed model is a useful tool to evaluate different pattern of intermodal terminal network and the advantages of intermodal transport comparing with road transport.

3. INTERMODAL TRANSPORT NETWORK MODELLING

General considerations

The aim of our research is to develop an intermodal rail-road transport model which attracts the road transport on long distances, offering level of services comparative with that one of road system. The competitiveness of intermodal transport depends on many factors, as terminal location and its accessibility, terminal transshipment efficiency, rail level of service (e.g. price, reliability, transit time, co-operation relation between participants). Among these, a first step for planning of the intermodal transport and one of the most crucial success factors consists in terminal location. In this section the main steps of intermodal transport network modelling are presented and the methodology applied for selecting potential terminal location is described. Based on the set of proposed terminals, the model of intermodal transport network is developed considering several artificial links having the purpose to connect the two road and rail networks and to build the intermodal routes from origin to destination. The intermodal transport indicators are estimated in relation to set of attributes (cost, time and energy consumption) allocated on artificial links which correspond to technological processes in terminals. The computed values of intermodal transport indicators are compared with unimodal road transport indicators, in case of the same origin-destination relationships.

Solving the terminal location problem needs as data entry a set of potential terminal location. In case of large scale network, the number of nodes is large, and solving of location problem by deterministic methods is difficult [7]. Consequently procedure for selecting a set with the most appropriate nodes for terminal location has to be applied. Figure 5 illustrates the structure of the model for selecting of the potential terminal location [6].

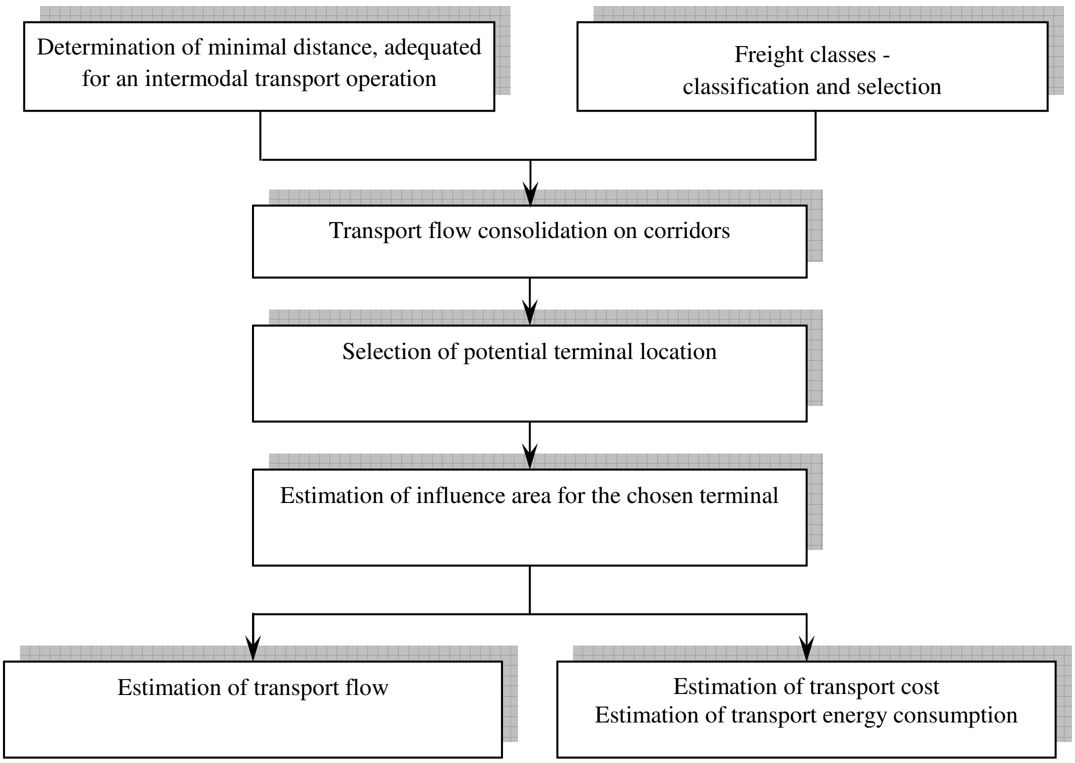


Fig. 5. Flow chart of the procedure applied for estimation of potential terminal location.

After applying of terminal selection procedure, transport demand and cost have to be estimated for each pair of potential terminals. In order to analyze the option of flow consolidation, it is necessary to formalize the intermodal network which allows the transfer from one transport mode to another (road to rail, respective rail to road). The main difficulty consists in including, in an integrated model, the two modal networks (road and railway networks, connecting a common set of nodes with different links) and the features which permit the intermodal transfer. We used GIS procedure to model the intermodal transport network and to solve this issue. The developed model allows evaluating different proposed pattern of intermodal transport network.

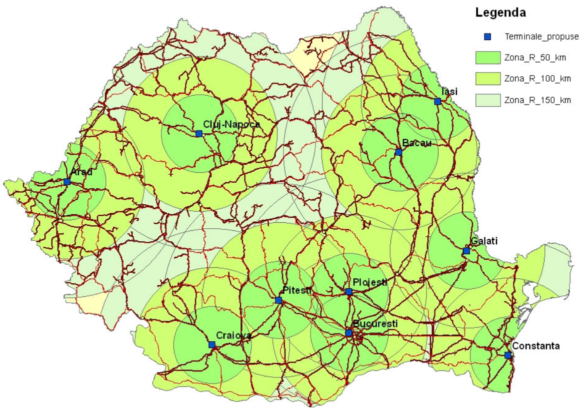
Intermodal transport network modeling with GIS

The method applied to develop an integrated model which includes Romanian road and railway networks and a proposed set of intermodal terminals is described hereinafter. Using GIS procedure available in ArcGIS software, with Network Analyst Extension, intermodal network model was built based on Romanian road and railway network databases. The proposed model was used to compare intermodal versus road transport.

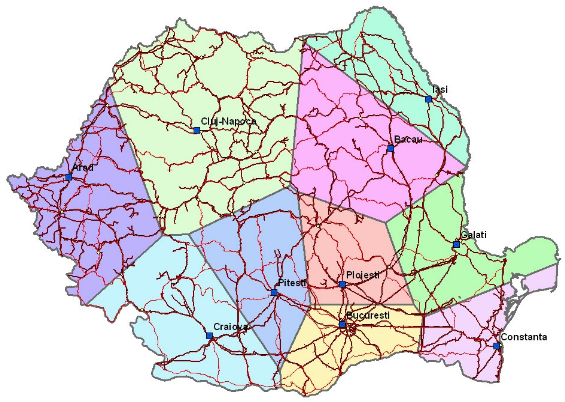
Intermodal transport modeling is an interactive process. The proposed model, described in this section, constitutes a tool for the first step of evaluation of the intermodal terminal network, taking into account the accesibily of the two uni-modal national networks (rail and road).

Due to the lack of available data about freight transport flow at national level, the initial set of potential terminals was selected based on economical data from Statistical Annual of Romania, in 2009 [11]. Figure 6.a illustrates the set of proposed potential terminals, and their influence areas, within the 100 km radius, covering about 24% of Romania area and within the 150 km radius, covering almost all Romania area.

For the set of potential terminals, Voronoi diagrams are used to define the service area of each terminal and to allocate the freight origin/destination to the closest terminal (Figure 6.a).



a. Influence area of proposed intermodal terminals.



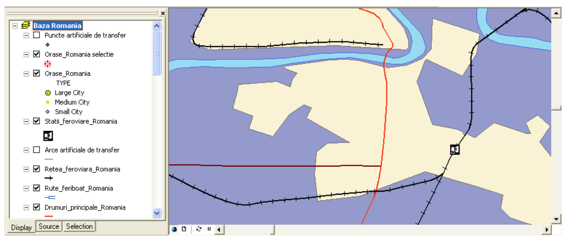
b. Voronoi diagram for proposed intermodal terminals.

Fig. 6. Proposed intermodal terminal network.

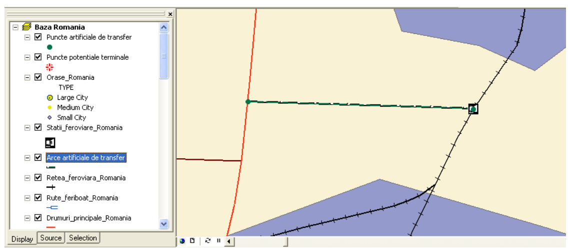
For modeling purpose, the intermodal transport network, the modal transport network and the set of artificial modal connection have to be preliminary designed. The necessary data entry sets are:

- Road network;
- Railway network;
- Railway station;
- Potential terminals;
- Artificial vertex for intermodal transfer;
- Artificial links for intermodal transfer.

All these data sets are initially organized as layers, without topology relation between features (Figure 7.a). To define the connection between modal features, artificial vertex (located on the road component and on the railway component) and links between artificial vertexes have to be edited. The topology of artificial features, necessary to define the connection relation for intermodal network, is presented in Figure 7.b.



a. Modal transport feature layers.



b. Artificial vertexes and links, connecting modal features

Fig. 7. Editing of artificial feature, necessary to intermodal network conexity.

The data entry sets are integrated in GIS complex structure in which relation between intermodal transport network components could be defined. Figure 8 illustrates the structure of integrated data base used to intermodal transport modeling. In the frame of the integrated structure are built the network data sets, with two levels of connectivity, corresponding to modal networks and to intermodal transshipment facilities. Figure 9 shows the data set used to define the connectivity relation.

Based on tables of data sets included in the intermodal network structure, attributes are alocated to the links in the procedure of network data set building. Table 1 presents attribute sets included in intermodal network model. The unit transport cost is assesed considering the cost components in Recordit project [16]. Road transport costs are assesed considering different parameters for collecting/ distributing transport on short distances and for long haul. Unit energy consumption and pollunat emission are computed using the EcoTransitIT procedure [12].

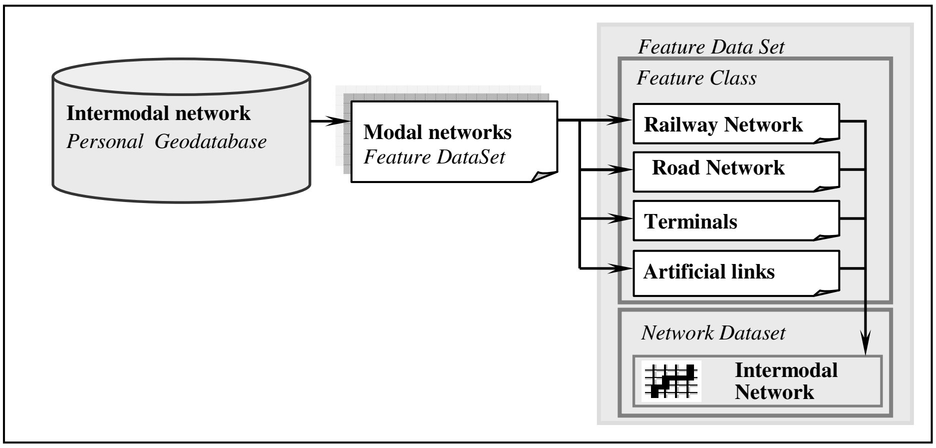


Fig. 8. Structure of integrated data base used to intermodal transport modelling.

The intermodal transport network model is used to calculate the route, in relation with defined attributes for the two cases:

(i) Intermodal transport, with initial collecting road transport to initial terminal, railway transport from the initial terminal to the terminal nearby destination, distributing road transport from the terminal-destination to destination and

(ii) Road transport for the entire route from origin to destination.

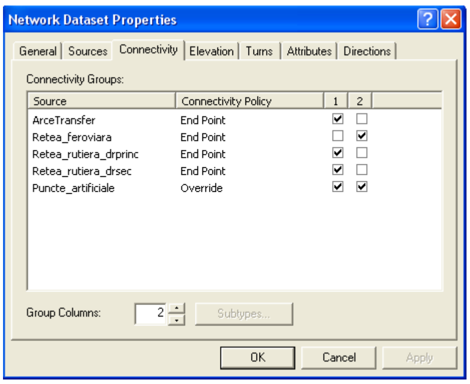


Fig. 9. Intermodal network connectivity relationship.

The procedure for the minimum route finding is developed in ArcGIS - Network Analyst Extension, and includes the following steps:

- Introducing the freight origin point; allocate the origin to the closest node of road network; allocate the origin to the closest transfer facility of the railway network and establishing the terminal-origin;
- Introducing the freight destination point; allocate the destination to the closest node of the road network; allocate the destination to the closest transfer facility of the railway network and establishing the terminal-destination;
- Calculate the minimum route on the railway network between origin-terminal and destination -terminal;
- Calculate the minimum route on road network between origin and terminal-origin; calculate the minimum route on road network between terminal-destination and destination;
- Evaluate the intermodal route indicators, taking into account the initial road section, the railway section, the final road section, the transhipments in terminal-origin and in terminal-destination;
- Calculate the minimum route on road network;
- Evaluate the route indicators for the road uni-modal network;
- Comparing the intermodal transport indicators with those for the road uni-modal transport.

Table 1

Attributes of GIS intermodal network

Feature data class / **Network attributes**	**Road Network**	**Rail Network**	**Artificial links**
Lenght	Lenght	Lenght	Lenght (null value)
Time	Average transport time	Average transport time	Average terminal transfer time
Cost	▪ Average collecting/ distributing transport cost ▪ Average transport cost on long distances	Average transport cost	▪ Transfer cost ▪ Cost of train forming
Energy consumption	Average energy consumption for one unit transport	Average energy consumption for one unit transport	Average energy consumption for one unit terminal transfer
Emission CO_2	Emission CO_2	Emission CO_2	Emission CO_2
Emission NO_x	Emission NO_x	Emission NO_x	Emission NO_x

4. MODEL RESULTS

The developed intermodal network presented in the previous section was applied for the set of porposed terminal represented in Figure 6. Accordingly UIRR statistics, intemodal transport becomes competitive for haulage more than 300 km [20]. This statement could be discussed and needs further analysis, but this is not the subject of the present paper. However, considering the size of Romania area and the national level of the presented analysis, we use this value for minimum length of intermodal transport. For proposed terminal, only the pair origine-destination case railway transport distances are greater than 300 km were selected for study.

For all selected origine-destination pairs, the comparison were made between intermodal transport and road transport. Due to the lack of data about transport flows on the analysed routes, the indicators were calculated for one intermodal transport unit. Therefore the model results analysis is useful to evaluate the advantages of intermodal services, but the complex evaluation of terminal location needs further research, and especially procedure for collecting appropriate transport flow data.

The evaluations of the intermodal transport indicators are made in two assumtions:

- Including road transport on short distances - for each selected terminal, the influence (or service) area is defined for 50 km radius; the average distance of collecting/distributing road transport in this case is considered 25 km;
- Including road transport on medium distances - for each selected terminal, the influence (or service) area is defined for 100 km radius; the average distance of collecting/distributing road transport in this case is considered 50 km.

The intermodal route includes the railway transport between terminal-origin and terminal-destination and the collecting/distributing road transport (on 25 km for first case and on 50 km for the second case). The transport indicators evaluating procedure was iteratively applied for each selected pair of terminals. In order to compare intermodal transport with road transport, the model results are organized in:

- Map of intermodal transport routes, with influence areas of 50 km, respective 100 km radius;
- Chart of distance, time and unit cost variation for intermodal transport, respective for uni-modal road transport;
- Chart of unit energy consumption and pollunat emission (CO_2, NO_x).

In this paper, only the routes with length from 500 to 600 km are presented as an example, in Figure 10 and Figure 11. The coresponding charts are represented in Table 2 and Table 3.

The results analysis for all selected routes reveals that for the length larger than 500 km, the road transport distance is smaller than the intermodal distance; this fact can be explained by the better road network accessibility comparing with all other transport networks.

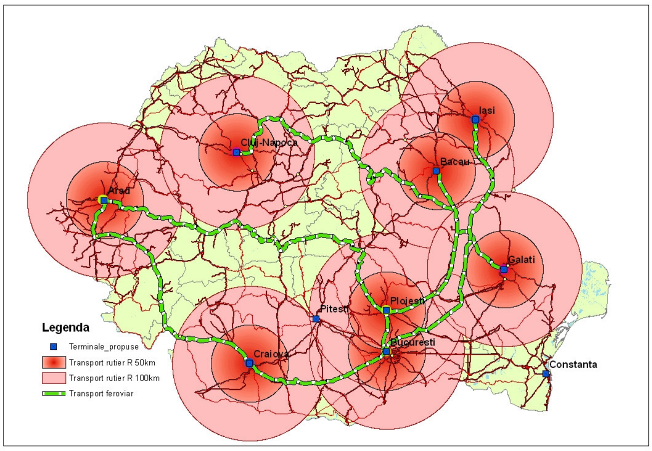


Fig. 10. Intermodal transport routes with rail transport for distances between 500, and 600 km..

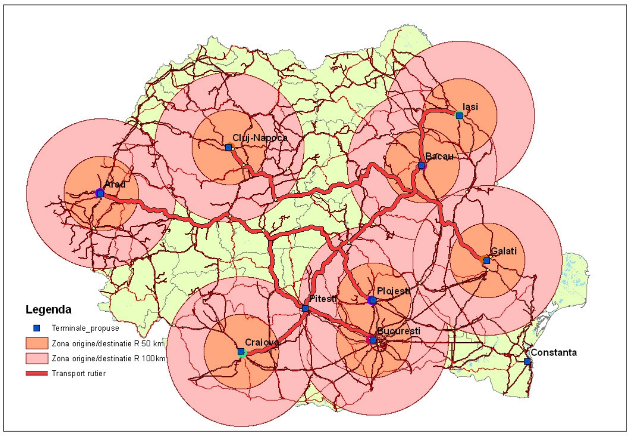
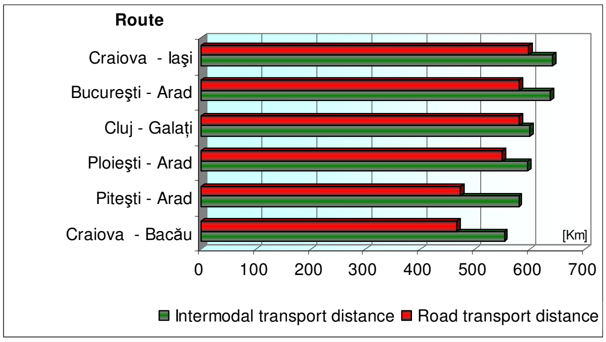
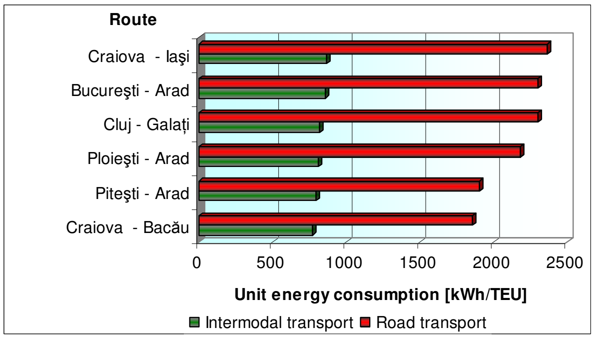


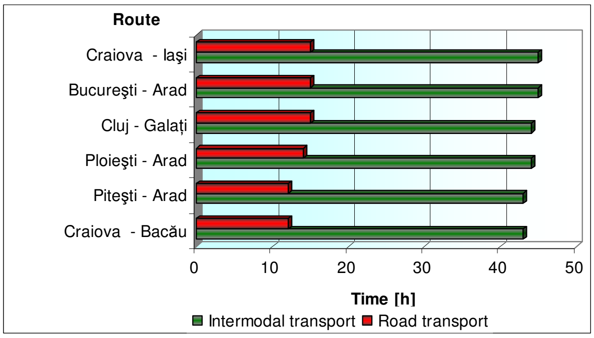
Fig. 11. Road transport routes with origins and destinations of freight inside the influence areas of the selected rail terminals for distances between 500 and 600 km.

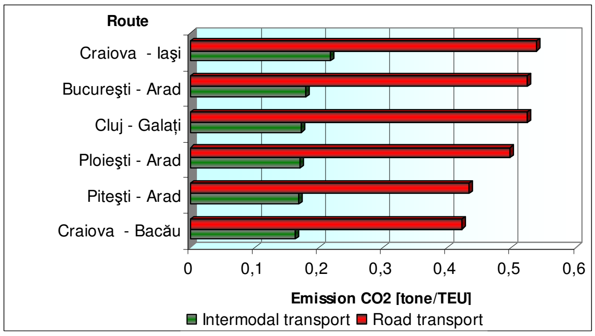
Table 2

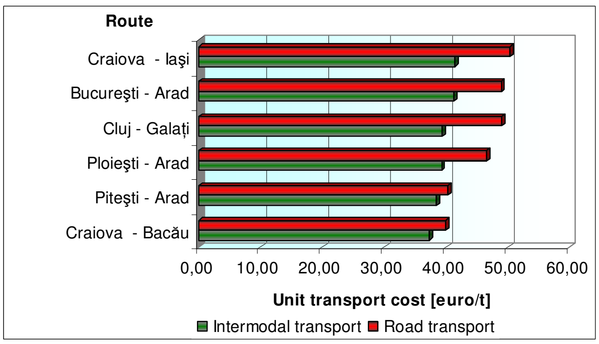
Comparison of the transport routes selected for haulage distances between 500 and 600 km – case of intermodal transport with collecting/distributing road transport inside areas of 25 km average radius











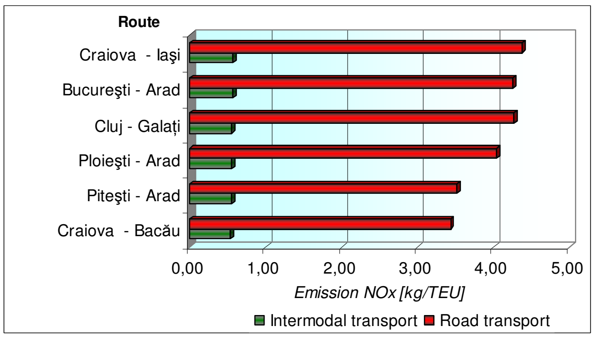
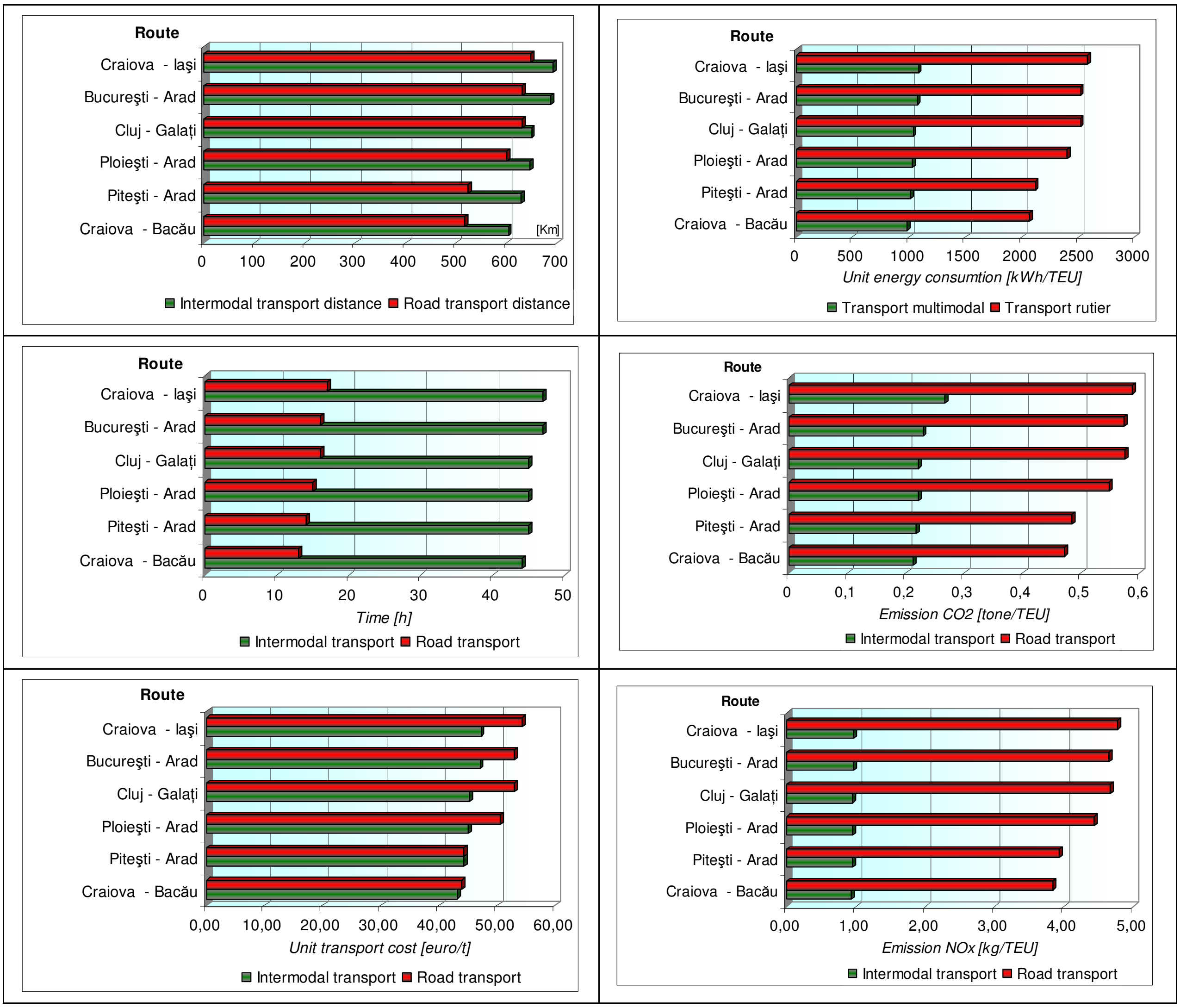


Table 3

Comparison of the transport routes selected for haulage distances between 500 and 600 km – case of intermodal transport with collecting/distributing road transport inside areas of 50 km average radius



For all considered cases, significant differences are obtained between intermodal transport time and road transport time, due to the additional terminal transhipment. This result is perceived as a disadvantage of intermodal transport by customers, but it could be overrised by the cost savings (proved by model results), as well as by planning measures and by fixed deadline for the good deliveris.

Notable results are obtained for energy consumption and polluant emission (see Table 2 and 3). Significant reductions of the energy consumption are obtained for intermodal transport (up to 55%) comparative with all-road transport. This fact proves that intermodal transport shoul be better promoted as solution for energy consumtion reduction in freight transport sector.

5. CONCLUSIONS

The road transport sector is an important consumer of non-regenerating energy. In the context of no significant change in user behavior is anticipate, it is needed to find adequate solutions to reduce energy consumption and negative environment implication of oil dominated road transportation. For that reason correlated policies are needed to promote transport technologies with increased energy efficiency and reduced emission effects.

Intermodal freight transportation is an attractive alternative versus road transport as the latter is not a sustainable service due to traffic congestion, and the generated problems for safety, dependency of fossil fuels, and air pollution.

Terminal location is one of the most important factors of intermodal transport and needs to be considered carefully as it has direct and indirect impacts. The model presented in this paper offers a first level evaluation of terminal location. Althow further researches are necessary for a comprehensive analysis of the terminal location; the developed model is a useful tool for quantifying the advantages of introducing intermodal freight services. The transport routes with better intermodal transport energy consumption indicators, comparative with road transport, could be identified.

Due to the lack of available data about freight transport flows at national level, the estimation and comparison presented in this paper are made for specific values, considering a single transport unit. The real operating conditons (traffic intensity, load factor of traffic units, factor of terminal flow consolidation) influence the final energy efficiency in intermodal transport. Thus the high value of reducing ratio of energy consumption for intermodal transport comparative with road transport could be lightly overestimated for some routes. Eventhogh, significant reduction of energy consumption is posible using the adequate intermodal transport network wich allow the modal shift from road to intermodal rail-road freight movement on long distances.

We consider that the rail-road intermodal transport is adequate solution, at least, because of the following reasons:

✓ Reduction of the negative implications of dominant road freight transport on long distances;

✓ Reduction of the overall energy consumption in freight transport sector;

✓ Efficient use of the existing railway transport capacity, instead of new road infrastructure construction.

Consequently, in our opinion, the intermodal transport development has to be supported through the apropriate strategies and policies by authorities.

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