traffic, transport networks, reliability

Mihaela POPA, Eugen ROSCA, Florin Valentin RUSCĂ*
University POLITEHNICA of Bucharest, Transport Faculty
Department of Transport, Traffic and Logistics
**Corresponding author*. E-mail: florin_rusca@yahoo.com

ON TRANSPORT NETWORK RELIABILITY

Summary. Transport network reliability is defined in relation with the main attributes of the network (e.g. connectivity, topology, state of infrastructure), the traffic characteristics (OD matrices, volume, hourly/day-to-day variations etc.) and with environment interactions (natural event, climatic change). The study of the Romanian national transport network reliability in terms of economic implications, like the growth of the total traveled path induced by functionality/failure of the network components leads to the identification of the road links which, according to the reliability, should be carefully monitored to preserve the attractiveness of the transport network. Using Visum software, the paper presents a methodology to assess the transport network reliability at national level but also useful for urban transport networks.

NIEZAWODNOŚĆ SIECI TRANSPORTOWEJ

Streszczenie. Niezawodność sieci transportu jest definiowana w odniesieniu do głównych atrybutów tej sieci (np. rodzaju połączeń, topologii, stanu infrastruktury), charakterystyki ruchu drogowego (matryce OD, pojemność, godzinowy/dzienny rytm zmian itp.) oraz interakcje ze środowiskiem naturalnym (zjawiska naturalne, zmiany klimatyczne). Badania rumuńskiego narodowego systemu transportu i jego niezawodności w świetle implikacji ekonomicznych takich jak zwiększenie całkowitej przebytej trasy wywołanej przez funkcjonalność lub zawodność komponentów tej sieci doprowadziła do identyfikacji połączeń drogowych, które pod względem niezawodności powinny być wnikliwie monitorowane, aby zachować atrakcyjność danej sieci transportowej. Używając oprogramowania Visum praca prezentuje metodologię oceny niezawodności sieci transportowej na poziomie krajowym. Oprogramowanie to jest również użyteczne dla sieci transportu miejskiego.

1. INTRODUCTION

The concept of reliability is extremely important in assessing the capacity of transport networks to provide continuity in operation. The setting of the transport network reliability function requires the identification of the parameter(s) according to which it is expressed. The main attributes of the network (e.g. connectivity, topology, state of the infrastructure), the traffic characteristics (OD matrix, links' flow, travel time, hourly/day-to-day variations etc.) and the environmental determinants (natural events, climate change) can be element used to define the form of the travel network reliability function.

Transport networks are usually affected by two categories of phenomena that lead to a degradation of the service levels offered [1]:

- variation in the demand for transport services;
- variation in the supply of transport services.

The influence of the last is usually analyzed in the literature. The natural disasters occurring during recent years (e.g. earthquakes, floods, fires), the malevolence (e.g. terrorist acts, sabotages, wars), the spread out of the human habitat and mainly the extension of urban areas and traffic congestion on road networks provided a special interest in the researches on transport networks reliability and vulnerability. The impact of nodes or link disruption could be quite significant. The transport planners or policy makers need methods and decision support tools to evaluate threats to transport networks facilities and to assess the consequences of network functionality disruption and failure of its elements.

Economic, social and environmental benefits come from the possibility to evaluate, manage and minimize the impacts of the transport networks degradation. At urban level, this is translated in reducing users transport costs, alleviation of traffic congestion and negative externalities, trade and social activities continuity.

Although the degradation effects of the system (increased journey time, distance and cost) can be easily determined, the probability of occurrence of these phenomena is difficult to identify. Their classification according to its impact on network begins with terrorist attacks aimed at producing bigger network damage and ends with infrastructure works that are planned and organized so as to minimize the impact.

An important aspect is to balance between the concepts of reliability shaped by the network operator, and the road users' perspective. A holder of the transport infrastructure, respectively an infrastructure operator is interested in identifying the robustness and the system vulnerability. Also, it must continue monitoring the system performances with a special focus on deviations. A network user focuses on the travel time and its variation when an incident occurs.

2. TRAVEL TIME RELIABILITY

The variation of the travel time of users due to the inoperability of the critical road links influences their perception on network performance. The identification of the threshold values above which the travel times lead to the journey refuse is one of the main concerns of engineers in the transport sector. The following methodology assesses the transport network reliability according to the travel time.

2.1. Road transport network modeling

The following principles are used in modeling the road network:

- The network contains the set of nodes which represent important freight traffic origins and destinations. For the particular case of Romania, should be considered the main industrial areas and the main export/import border points (e.g. Dacia Pitesti, Mittal Steel Galati, Constanta Port).
- The network contains the nodes with important personal cars generated and attracted flows. They can be concentrated in the large urban agglomerations.
- To ensure the analysis of all possible routes on the national road network (including road sections which are components of the European corridors), the network contains every possible branch of the same category roads.
- There are included junctions with foreign road networks (road border points).
- There are included points where the transport infrastructure characteristics undergo modifications (line number, capacity, speed etc.).

Due to the complexity of modeling the road network, it is necessary to use specialized software (e.g. VISUM, TransCad) offering user's friendly graphical interface and allowing accurate network representation.

The input database is structured according to specific network model of the software program. Modeling transport networks using VISUM, the input forms requires data about the ex-post demand and the transport offer. As regard to the last category of data, the database will contain information about:

- Nodes, respectively the main crossroad of the road network,
- Links, with information about speed, capacity, length etc.,
- Zones, origins and destinations points (sometime referred to as a centroid),
- Connectors between zones and transport network.

2.2. Framework

The study of the Romanian national transport network reliability in terms of economic implications, like the increase of the travel time induced by functionality/failure of the network components, leads to the identification of the road links that should be carefully monitored for preserving the attractiveness of the transport network. Using Visum software, the paper presents a methodology to assess transport network reliability usable at national transport network level but also for urban transport network.

The network reliability function is computed using the *Equilibrium Assignment* algorithm (fig. 1 [4]). This method allocates the flows according to Wardrop's first principle: "Every individual road user choses his route in such a way that his trip take same time on all alternative routes and that switching routes would only increase personal journey time."[2].

Impedance per network object $Im\ p$ is defined as a function of traffic volume φ.

The objective function of the equilibrium assignment is:

$$OF = \sum_{(i,j)} \int_0^{\varphi} Im\ p(z)dz\ , \tag{1}$$

where the sum is for all links (i, j) in the network.

The lower bound of the objective function is:

$$LB = OF - TEC \tag{2}$$

where TEC is the total excess cost and is equal with difference between total impedance and the hypothetical impedance resulting if all vehicles took the shortest way as OD relation. The relative gap *ER* it is a measure for the excess cost of vehicles that do not take the optimum routes yet in proportion to the total impedance in the network.

To assess convergence criteria we must obtain for ER a value under a specifically threshold, where:

$$ER = \frac{TEC}{LB} \tag{3}$$

The model contains three generic types of vehicles, each one with specific attributes (OD matrices, speed, etc.): car, bus and truck.

The Wardrop's principle leads to an optimal allocation of the individual users on the route, which is different from the network optimum, characterized by a minimum total travel cost.

Although, the last one is more advantageous for the transport network operator, it is more difficult to be obtained in practice. It is more specific for the rail infrastructure operated by a single entity.

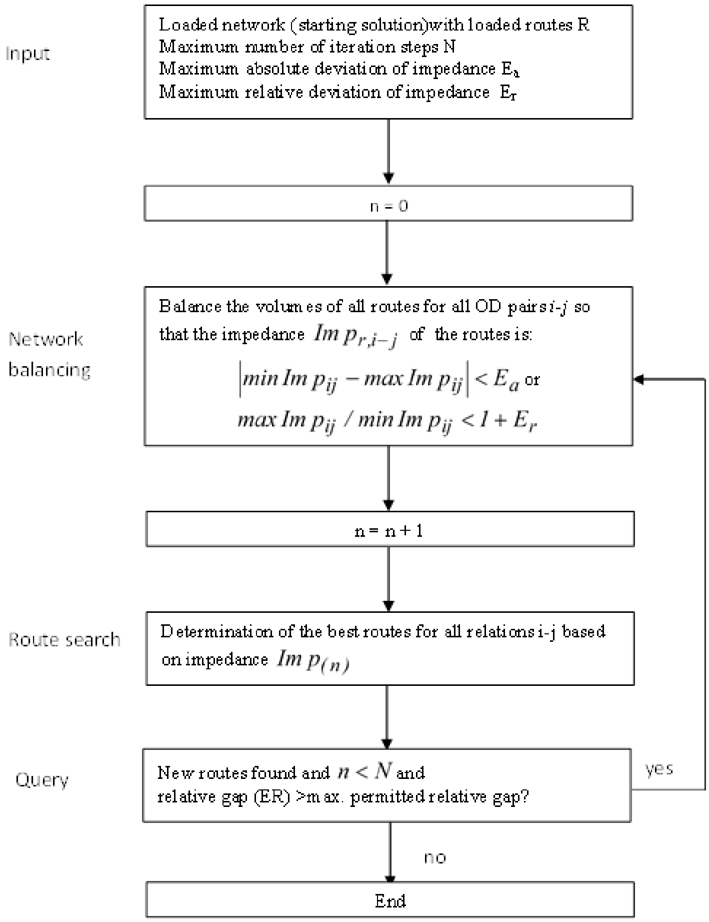

Fig. 1. Equilibrium assignment [4]
Rys. 1. Ocena równowagi [4]

The transport network reliability function is defined as:

$$R = P\left(\frac{T_{inc}^{i}}{T_{inc}^{0}} \le c\right) \tag{4}$$

where R is the probability that the travel time variation is smaller than an upper limit c, T_{inc}^{0}, respectively T_{inc}^{i} are the travel time between O-D pairs for unaffected network, respectively for the network with link *i* inoperable.

The total travel time is calculated with the relation:

$$T_{inc}^{i} = \sum_{s-t} Vol^{s-t} t_{inc}^{s-t} \tag{5}$$

where Vol^{s-t} is the traffic volume between two adjacent nodes s and t, and t_{inc}^{s-t} the travel time between these nodes when the road link *i* is failed.

The algorithm depicted in figure 2 is used to calculate the travel time reliability on the road network.

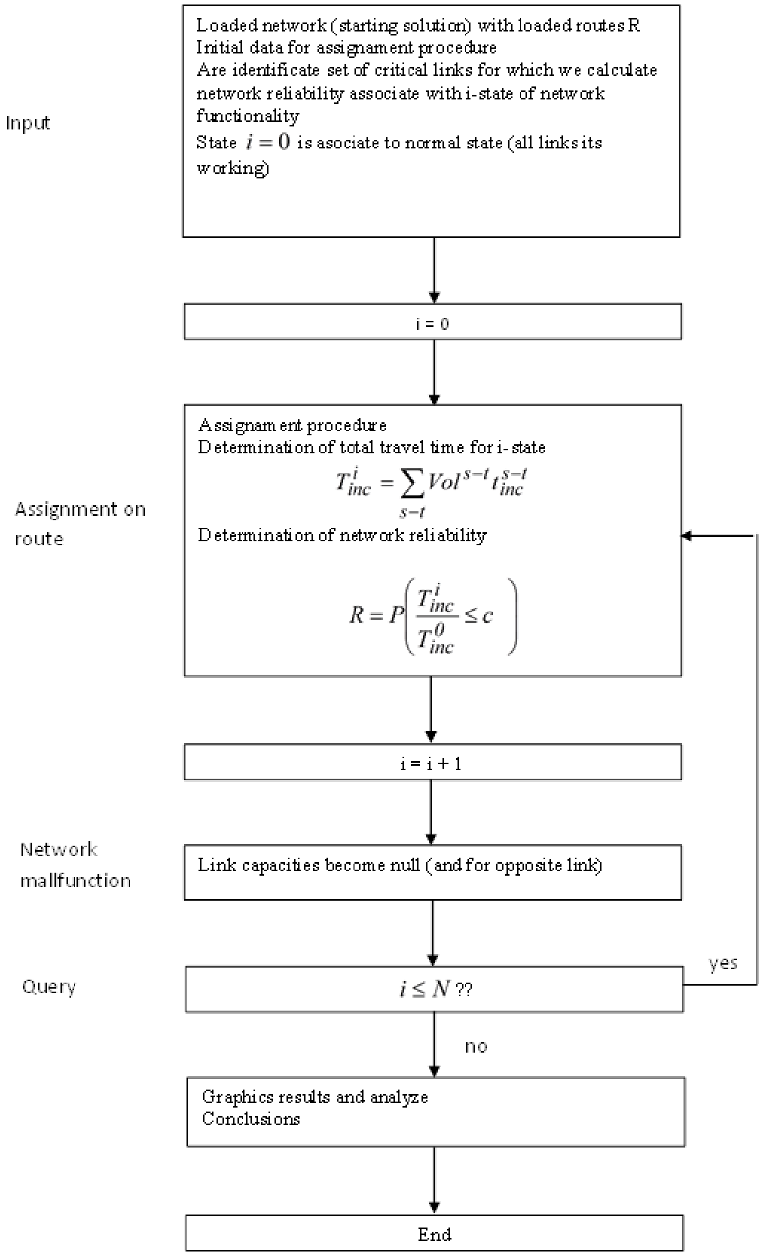

Fig. 2. Travel time reliability algorithm
Rys. 2. Algorytm dla niezawodności czasu podróży

3. CASE STUDY. THE ROMANIAN ROAD TRANSPORT NETWORK RELIABILITY

The polarization of the regional and urban system activities in Romania has increased the phenomena of isolation for many local communities and augmented the duration and distance of access to jobs, health, socio-cultural activities and even sightseeing [3].

The density and the poor connectivity of the road transport network are responsible for its vulnerability to structural, natural and traffic factors. The Trans-Carpathians road network links represent critical infrastructure elements. The disruption of their functionality generates increasing of travel times and feeble network reliability.

The Romanian road network has a length of 82,386 km of which 15,679 km of national roads (6,188 km of European roads), and 332 km highways. The modeled network used in the case study has a total length of 17,530 km including national roads, highways and major county roads. The network is separated by the Carpathian Mountains in two sub-networks connected by three main transport corridors (Olt Valley, Prahova Valley and Oituz corridor). The failure of these links goes to variation in travel times, which can be:

- a negative variation – reduced travel time for links where the traffic decreased due to the path change.
- a positive variation – because of the longer path chosen for traveling between the O-D pairs due to link failure.
- no variation – for the unaffected links.

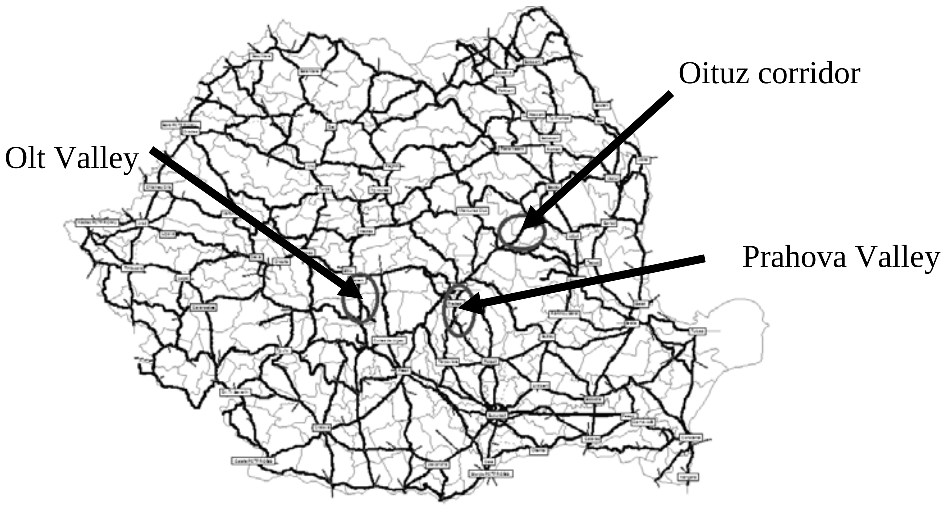

Fig. 3. The national road transport network
Rys. 3. Narodowa sieć transportu drogowego

Olt Valley provides the connection between the southern areas of the country and the NW region. The probability density that the travel time exceeds a certain threshold, respectively the network reliability function is represented in fig. 4 a-b. In this case we supposed analyzed links are closed all day, so equilibrium state is achieved.

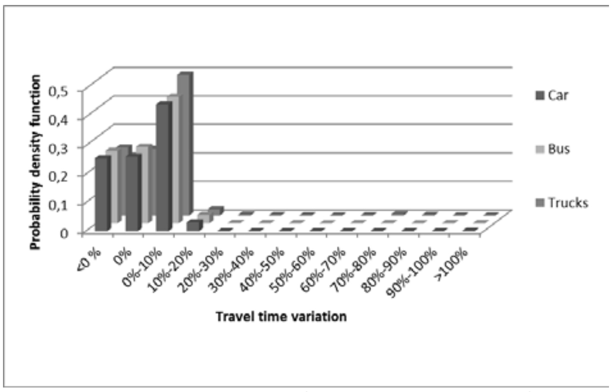

Fig. 4a. Probability density function (Olt Valley failed)
Rys. 4a. Prawdopodobieństwo funkcji gęstości (Dolina Olt)

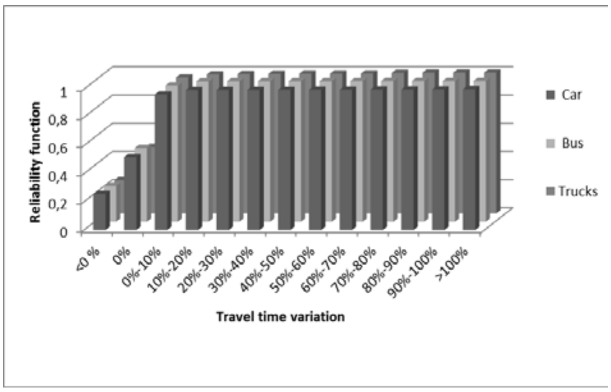

Fig. 4b. Travel time – transport network reliability (Olt Valley failed)
Rys. 4b. Czas podróży – niezawodność sieci transportowej (Dolina Olt)

One concludes that although 47% of all freight vehicles travel time has not changed or improved, there are 49% journeys for which the travel time increased up to 10%.

The Trans-Carpathian link on Prahova Valley is the main access route for the inhabitants of the historic region of Transylvania to the capital city Bucharest. Also it has a great importance for tourism because many mountain resorts are located along this road.

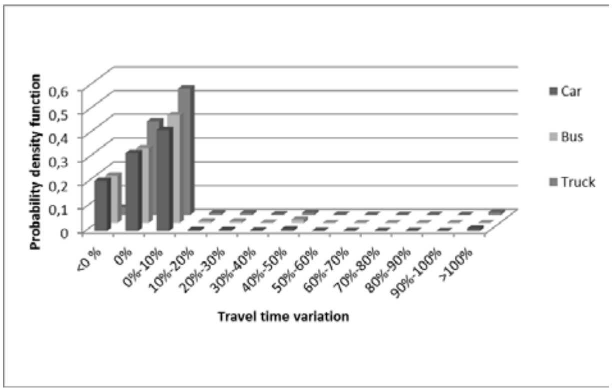

Fig. 5a. Probability density function (Prahova Valley failed)

Rys. 5a. Prawdopodobieństwo funkcji gęstości (Dolina Prahova)

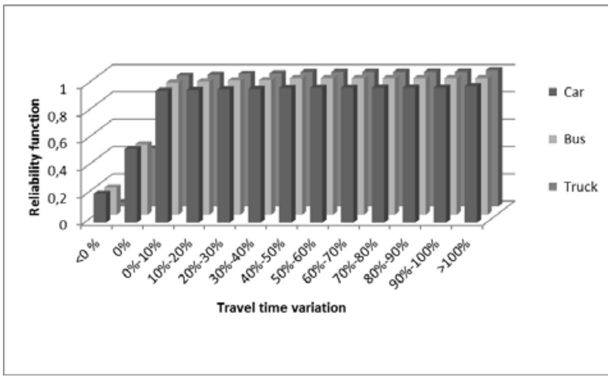

Fig. 5b. Travel time – transport network reliability (Prahova Valley failed)

Rys. 5b. Czas podróży – niezawodność sieci transportowej (Dolina Prahova)

In this case 34% of all freight vehicles travel times remain unchanged, compared to 51% of cars, respectively 54% of busses.

Trans-Carpathian link on Oituz corridor provides connection between the historic regions of Moldova and Transylvania.

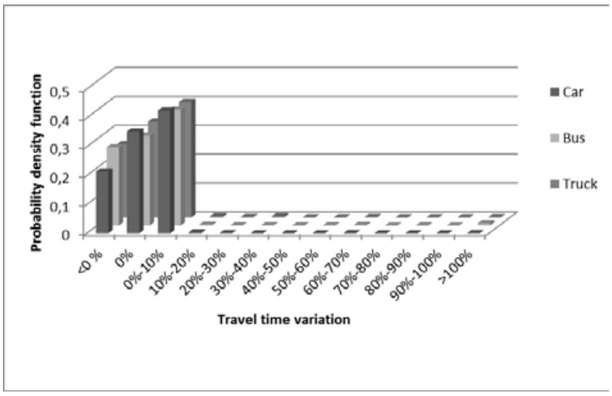

Fig. 6a. Probability density function (Oituz corridor failed)

Rys. 6a. Prawdopodobieństwo funkcji gęstości (korytarz Oituz)

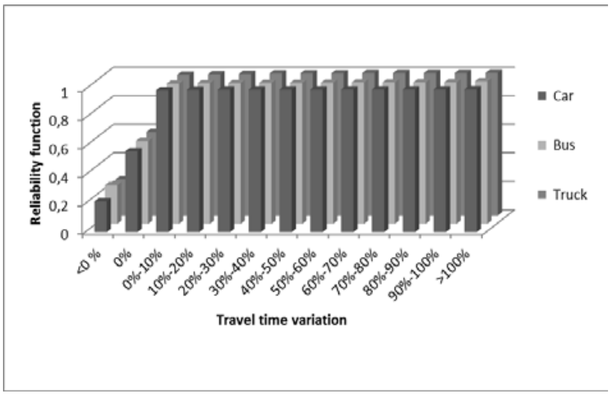

Fig. 6b. Travel time – transport network reliability (Oituz corridor failed)

Rys. 6b. Czas podróży – niezawodność sieci transportowej (korytarz Oituz)

Closing this link leads to the network reliability values ($c<0.2$) higher for freight vehicles and buses (0.99) while for car a value of 0.98 is obtained.

The flows on the transport network for all the four states (whole operable network; Olt Valley, Prahova Valley and respectively Oituz corridor failed) are represented in fig. 7.

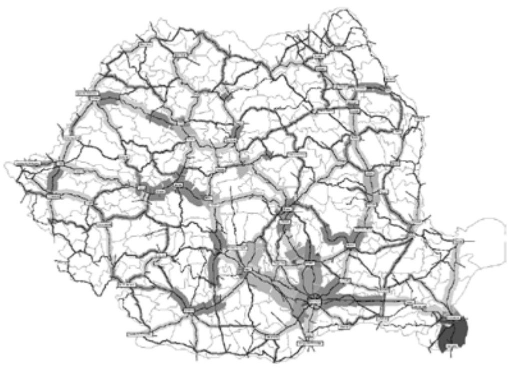

Fig. 7a. Transport network flows (whole operable)
Rys. 7a. Przepływ sieci transportowej (w całości wykonalny)

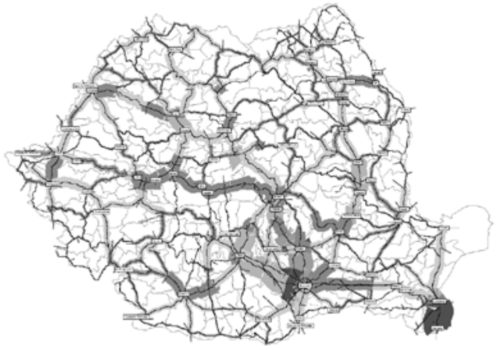

Fig. 7b. Transport network flows (Olt Valley failed)
Rys. 7b. Przepływ sieci transportowej (Dolina Olt)

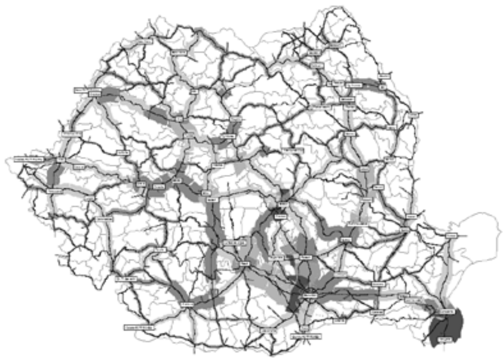

Fig. 7c. Transport network flows (Prahova Valley failed)
Rys. 7c. Przepływ sieci transportowej (Dolina Prahova)

Fig. 7d. Transport network flows (Oituz corridor failed)
Rys. 7d. Przepływ sieci transportowej (korytarz Oituz)

4. CONCLUSION

The road links failure increases the duration of the travel time between some O-D pairs. The hierarchical importance of the Carpathian links is determined by comparing the values obtained for the network reliability for the different thresholds of acceptability. Closing a link of the network leads to improved values of the travel times in the adjacent sections of the link. However, the overall travel time increased for at least 50% of network users, mostly up to 10% of the initial traveling time values. Knowing the probability of variation in travel times between certain limits (probability density) is particularly useful for freight transport that can establish delivery dates much closer to reality.

Bibliography

1. Nicholson A.J., Schmöcker J-D, Bell M.G.H., Iida Y.: *Assessing transport reliability: Malevolence and User Knowledge.* The network Reliability of Transport, Proceedings of the 1st International Symposium of Transportation Network Reliability, Pergamon, 2003.
2. Ortúzar J.D., Willumsen L.G.: *Modelling Transport*. John Wiley and Sons, London, 2001.
3. Raicu S.: *Soluţii interdisciplinare convergente în amenajarea teritoriului şi în structurarea sistemului de transport, orientate către dezvoltarea durabilă şi creşterea calităţii vieţii (TERITRANS)*. Contract nr. 122, Programul Cercetare de Excelenţă – CEEX, 2007.
4. *VISUM 10.0 User Manual-Volume 1*. PTV Traffic Mobility Logistics, 2007.

Received 03.04.2011; accepted in revised form 15.08.2012