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THE UTILIZATION OF THE EFFICIENCY MEASURE FOR THE TRANSPORTATION PROCESSES IN THE ROAD CONSTRUCTION AND MAINTENANCE

Marina Petrunina, Jury Sikerzhicky
Transport and Telecommunication Institute, Latvia

Abstract

Measures of the effectiveness of the transport systems are tightly interlaced with the reliability measures for the transportation processes [1]. In case the reliability measures are uniquely defined, the assessment of the cargo transportation effectiveness could be made by the reliability level. However, in the present time, the reliability measures are defined qualitatively only [2].
In this work, it is offered to define the efficiency measure of the transportation process as the "adequacy of the cargo to some bespoken condition before and after its transportation". And for its quantification we should evaluate the conditions of the roads in the context of the probability of emerging the situations (including accidents) that causes cargo damages. In this work, the following measure for the efficiency assessment of the transportation process and its reliability accordingly, was suggested so called: "safe" travel time - the period of time the vehicle moves along the road according to all the traffic regulations (traffic light signals, speed allowance), if there are no other vehicles (in passing or in oncoming flows) on the road. In case we have any deviation from the "safe" travel time mode of motion, the increase of the probability of accidents emergence or cargo damage (for example, in accordance to Poisson distribution law) takes place. The degree of real travel time deviation from the "safe" travel time could quantify the effectiveness of the transportation processes..
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1 Introduction

During the investigation in the field of improving reliability on surface transport networks, that was developed in 2009, by a group of international experts representing 13 countries under the aegis of the Joint Transport Research Centre of the Organization for Economic Co-operation and Development (OECD) and the International Transport forum, there were defined and recommended some reliability measures for surface transport networks [2].
In the report [2], the journey-time predictability is the defining feature of the reliability. And, on the basis of cost-benefit analyze as a tool, the reliability is defined as: the ability of the transport system to provide the expected level of service quality, upon which users have organized their activities. The key word is "expected". According to the definition, reliability can be improved either by supplying a higher level of reliability, or by changing expectations of the level of reliability. In other words, unpredictability of network performance is the defining characteristic of unreliability. The more random (less predictable) the performance, the harder

it is for the network user to ensure against delays. What the report proposes for incorporating reliability into project appraisal is that the temporal journey time improvement should be split into pure journey time improvement and buffer time (or other temporal reliability measure) improvement for each granulation. The change in time savings benefit then equals the change in pure journey time multiplied be monetary value of time, plus the change in buffer time multiplied by monetary value of reliability [2].
Average time savings should be split into travel time reductions and a reduction of travel time variation. Both of these components should be identified. An appreciation of the traveler types using the link would then enable appropriate values for the components to be applied. This unbundling enables planners to gain insight into the relative levels of reliability benefits. Further, cost benefit analysis will require some quantification of the expected reliability effects of policies. This is a poorly documented field and probably requires some improvement of current traffic forecasting tools and models. Ideally, these tools should be able to provide estimates of future changes in the standard deviations of travel times on links, and model the influence of such variables on travel demand and network use. Above all, because reliability issues are location, user, and time-specific, assessments should avoid applying or repeating the use of a single value for reliability, or applying a value that has been used in one study to a project in another situation. For each project, there are differences in the mix of user groups and time/reliability splits [2].
In this way, it is very difficult to provide recommendations for the road construction and maintenance as the “service quality” measures quantitatively still not defined. And, despite of the existence of numerous amounts of the efficiency measure definitions, still there is no generalized measure defined, as there is no consensus on how reliability should be monitored. So, the identification and the development of such generalized measure is an actual task to solve this problem.

2 Efficiency measure for the transportation process

On the analogy of the method of assessing the reliability shown in Section 1, in this work, there is suggested the following measure for the efficiency assessment of the transportation process – the adequacy of the cargo to some bespoken condition before and after its transportation. To quantify the efficiency assessment of the transportation process, we should evaluate the conditions of the roads in the context of the probability of emerging the situations (including accidents) that causes cargo damages.
Obviously, on the one hand, the travel time for the cargo transportation shouldn’t exceed the manufacturers’ expiration date of the cargo. On the other hand, as it is shown in the researches and after analyzing the factors of accidents emergence [1, 3], the prior as well as most significant measure is the travel time.
In this work, the following measure for the efficiency assessment of the transportation process was suggested, so called: “safe” travel time. The “safe” travel time – this is the period of time the vehicle, during the cargo transportation process, moves along the road according to all the traffic regulations (traffic light signals, speed allowance), if there are no other vehicles (in passing or in oncoming flows) on the road.
In case we have any deviation from the “safe” travel time mode of motion, the increase of the probability of accidents emergence or the cargo damage (in case there exists the manufacturers’ expiration date of the cargo) takes place. And the degree of real travel time deviation from the “safe” travel time could quantify the effectiveness of the transportation processes. The nature of the suggested measure of efficiency is stochastic.
There is offered the method of estimating the “safe” travel time and any deviation from this mode of motion. During the “safe” travel time measurement, the idealized road model is used. For this road model the assessment of the influence of permanent road characteristics set was

made, when the road vehicle moves along the road without any other vehicles (in passing or in oncoming flows) during the travel time.
For defining the real travel time, in the model there are additionally brought random characteristics of the road, for example, like traffic density of the slow-moving and fast-moving vehicles in passing flow, traffic density of the vehicles in oncoming flow etc. Every additional vehicle causes the interferences as well as the delays during the travel time, thus increasing the travel time in general.
For the vehicles' "safe" travel time assessment, in ideal case, it is needed to summarize the time intervals when the road vehicle moves outside the built-up areas ($\sum_{i=0}^{k}\Delta t_{i\_out}$), with the allowed speed V_{out}, and the time intervals when the road vehicle moves inside the built-up areas ($\sum_{i=0}^{m}\Delta t_{i\_in}$), with the allowed speed V_{in}. In this way, it is possible to assess the ideal "safe" travel time (t_{STT_ideal}) in accordance with the following eqn (1):

$$t_{STT\_ideal}=\sum_{i=0}^{k}\Delta t_{i\_out}+\sum_{i=0}^{m}\Delta t_{i\_in}=\frac{\sum_{i=0}^{k}\Delta l_{i\_out}}{V_{out}}+\frac{\sum_{i=0}^{m}\Delta l_{i\_in}}{V_{in}} \tag{1}$$

Where: Δl_{out} - the length of road segment between two neighboring built-up areas;
V_{out} - allowed traveling speed outside the built-up areas;
Δl_{in} - length of road segment inside the built-up area;
V_{in} - allowed traveling speed inside the built-up areas;
k - amount of road segments outside the built-up areas;
m - amount of road segments inside the built-up areas.

The ideal case option assumes that there are no reasons for the road vehicle to change its traveling speed (inside and outside the built-up areas), except allowed one by the traffic regulation rules. For the real "safe" travel time assessment it is needed to take into account the factors that influence the real speed mode of the road vehicle inside and outside the built-up areas. The factors that influence the real speed mode of the road vehicle are as follows: the length of the built-up areas, amount of road crossings on the route and presence or absence of the road junctions on them, as well as the amount of controlled and non-controlled crossings inside the built-up areas etc.
So, during the calculation of the real "safe" travel time of the road vehicle, the following should be considered: the length of the built-up areas as well as the amount of controlled and non-controlled crossings differs from one to another. That's why the calculation should be done separately for each built-up area on the road. For example, the real "safe" travel time spent on road in the built-up area should be calculated as follows, eqn (2):

$$\Delta t_{1\_in}=\frac{l_{1\_in}}{V_{in}(n_{cross\_control},n_{cross\_noncontrol},n_{slow-speed})} \tag{2}$$

where:

$$l_{1\_in}=\Delta l_{no\_cross}+\Delta l_{cross\_control}+\Delta l_{cross\_noncontrol} \tag{3}$$

l_{1_in} - length of road segment inside one (concrete) built-up area;
Δl_{no_cross} - length of road segments inside built-up area between the crossings;
$\Delta l_{cross\_control}$ - length of road segments with controlled crossings;
$\Delta l_{cross\_noncontrol}$ - length of road segments with non-controlled crossings;

V_{in} - allowed speed of the road vehicle inside the built-up area that represents the function of the following parameters:
$n_{cross\_control}$ - amount of controlled crossings inside the built-up area;
$n_{cross\_noncontrol}$ - amount of non-controlled crossings inside the built-up area;
$n_{slow-speed}$ - amount of slow-moving vehicles in the built-up area.

The allowed speed of the road vehicle (the complex function - V_{in}) inside the built-up area can be described by probabilistic indices only.
So, the total real “safe” travel time spent on road in all built-up areas, should be calculated, accordingly, as follows, eqn(4):

$$\sum_{i=0}^{m} \Delta t_{i\_in\_real} = \sum_{i=0}^{m} \frac{l_{i\_in}}{V_{in}\left(n_{no\_cross}, n_{cross\_control}, n_{cross\_noncontrol}\right)} \tag{4}$$

In compliance with the above mentioned example, the assessment of the total real travel time the vehicle spend on the road outside the built-up areas ($\sum_{i=0}^{k} \Delta t_{i\_out\_real}$) will be calculated as follows, eqn (5):

$$\sum_{i=0}^{k} \Delta t_{i\_out\_real} = \sum_{i=0}^{k} \frac{l_{i\_out}}{V_{out}\left(n_{cross}, n_{no\_cross}, n_{slow}, n_{passing}, n_{oncoming}\right)} \tag{5}$$

where: V_{out} - allowed speed of the road vehicle outside the built-up area that represents the function of the following parameters:
n_{slow} - amount of slow-moving vehicles outside the built-up area;
$n_{passing}$ - amount of vehicles on the road in passing flow;
$n_{oncoming}$ - amount of vehicles on the road in oncoming flow.
So, the assessment of the real “safe” travel time (t_{STT_real}) the vehicle spend on the road will be calculated in accordance with the following eqn (6):

$$t_{STT\_real} = \sum_{i=0}^{k} \Delta t_{i\_out\_real} + \sum_{i=0}^{m} \Delta t_{i\_in\_real} \tag{6}$$

As the example of the evaluation of the presence of other vehicles’ influence, outside the built-up areas, procedure of following operations is shown. These operations cause the behavior of the road vehicle and the real travel time outside the built-up areas, accordingly. Received data match the real data obtained on real Latvian road, from Riga to Daugavpils.
As the concrete example of the experiment realization, let’s take the situation of the vehicle overtaking (Fig.1):

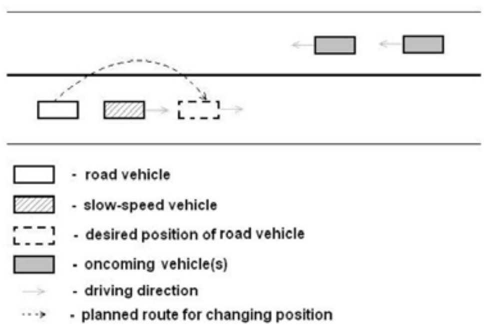

Figure 1 Realization of the overtaking manoeuvre

For the calculation the real travel time spent for the overtaking, the following actions took place:

a The road vehicle meets the slow-moving vehicle moving in the same direction. As the result the vehicle needs to change the speed (to slow down). And the time interval the vehicle moves along the road increases, eqn (7):

$$T_{driving} = t_{usual} + t_{wait} \quad (7)$$

b Before overtaking, the driver needs to be sure in overtaking safety. He needs the time to make the decision. The decision making time consists of the following time intervals: To examine the speed and dynamics of the movement of his and slow-speed vehicles ($t_{ex.SSV}$) + To examine the time necessary to make overtaking and the time before collision with another vehicle (-s) using the same lane of a carriageway and moving in the opposite direction ($t_{ex.col.in\,op.dir.}$) + To examine the possibility of the rear-end collision ($t_{ex.REcol.}$) + To examine the obstruction presence in front of the road vehicle + To examine the obstruction presence in front of the slow-moving vehicle ($t_{ex.obstr.}$) + To make the correct and safe decision (t_{decide}) + Reaction of the nervous system ($t_{reaction}$) + Time for muscular response ($t_{musc.resp.}$), eqn (8):

$$T_{dec.make} = t_{ex.SSV} + t_{ex.col.in\,op.dir.} + t_{ex.REcol.} + t_{ex.obstr.} + t_{decide} + t_{reaction} + t_{musc.resp.} \quad (8)$$

c After the driver makes the decision, the vehicle can make overtaking or stay on the same lane of a carriageway and move in the same direction till the time, all vehicles that move in the opposite direction will pass. If we take overtaking variant, then the following factors influence the time parameters: time for making the overtake (t_{overt}) + time for finishing the overtake ($t_{overt.finish}$) - for slowing and taking the position in front of the slow-speed vehicle), eqn (9):

$$T_{overtake} = t_{overt} + t_{overt.finish} \quad (9)$$

So, for overtaking realization we should take into account the sum of all the time intervals of the described actions in a, b, c, eqn (10):

$$T_{\sum overtake} = T_{driving} + T_{dec.make} + T_{overtake} \quad (10)$$

In the same way, the other situations were realized in the model (the appearance of oncoming traffic flows, the amount of road vehicles in the oncoming traffic, the appearance of the slow-moving vehicles, the amount of the vehicles in the traffic flow moving in the same direction etc.). But due to the limited page amount of the paper work, only one example is shown. From the shown example, it is possible to identify a number of parameters that are random variables, thus they could be described statistically only:

- amount of slow-moving vehicles;
- intensity of slow-moving vehicles;
- amount of vehicles in oncoming flow;
- density of the oncoming flow;
- probability of the lack of obstructions behind;
- probability of the lack of obstructions in front of the road vehicle;
- probability of the lack of obstructions in front of the next vehicle, etc.

The mathematical modeling was realized in the technical computational environment Matlab, to verify the procedure of the assessment for the efficiency measure of the transportation process. There were made calculations for the ideal “safe” travel time and the real “safe”

travel time. Distribution lows of random variables, such as: amount of slow-moving vehicles, amount of vehicles in the passing flow and amount of vehicles in oncoming flow, were taken normal.
The results are shown on following bar graphs, where the ideal "safe" travel time is marked and noted (Fig.2 and Fig.3):

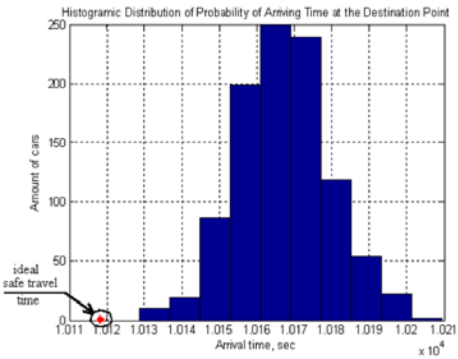

Figure 2 The bar graph of the real and ideal "safe" travel time distribution under initial statistical characteristics of the road

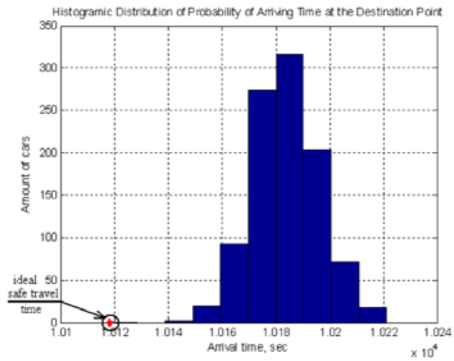

Figure 3 The bar graph of the real and ideal "safe" travel time distribution under changed statistical characteristics of the road

As it is seen from the bar graphs, the ideal "safe" travel time significantly differs from the real one. Thus, the comparison of the real and ideal "safe" travel times, clearly enough characterizes the effectiveness of transportation process on the road. There is also exists the possibility to adjust the features that are used in the model. That allows formulating the requirements for the change of road characteristics on the road designing stage, to increase the efficiency of transportation process

3 Conclusion

In case, there are known some statistical data (for example, amount of vehicles in oncoming flow, amount of slow-moving vehicles etc.) for specified region or state on the road construction and maintenance stage, it is possible with provided model to get the average travel time for the vehicles as well as to assess the possibilities of the road under initial data. Moreover, it is possible to give recommendations for additional traffic lanes, road junctions or detours of the built-up areas to increase the effectiveness of transportation process and to improve the reliability of surface transport networks on the road in general.

References

[1] Pliss M., Petrunina M.: Models for the Estimation of the Effectiveness of the Logistic Activity of the Transport Enterprise, 7th Interntional Conference "RELIABILITY and STATISTICS in TRANSPORTATION and COMMUNICATION" (RelStat'07), Riga, Latvia, Transport and Telecommunication Institute, pp.194-198, 2007.

[2] Summary document of Transport Research Center of the OECD and the ITFnternational Transport Forum: Improving Reliability on Surface Transport Networks. http://www.internationaltransportforum.org/jtrc/infrastructure/networks/ReliabilitySum.pdf

[3] Brilon W., Geistefeld J., Regler M.: Reliability of freeway traffic flow: a stochastic concept of capacity, 16th International Symposium on Transportation and Traffic Theory, Maryland, USA, pp.125-144, 2005.