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Remote Evaluation of Road Transportation Process

Nadezhda A. FILIPPOVA

Roman N. ZAIKIN

Dmitry B. EFIMENKO

Filippova, Nadezhda A., *Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia.*
Zaikin, Roman N., *Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia.*
Efimenko, Dmitry B., *Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia*.*

ABSTRACT

The article is devoted to development of a decision-making algorithm for transportation of goods by road based on the method of online remote assessment of the state of the cargo and the transportation process without human intervention. The development of the algorithm is based on the use of transport telematics and experimental study, the objective of which was to reveal capacity of navigation devices to fix accelerations that occur during vehicle movement.

The developed methodology allows to automatically make decisions aimed at saving resources. The article describes the steps of operational remote assessment of the state of the cargo, as well as the decision-making algorithm based on the information received.

A scheme of information interaction of the cargo transportation process participants is described, in which an analytical center is designated, the task of which is to calculate the force acting on the cargo and compare the calculated force with the strength characteristics of the material from which the cargo is made.

The situational task of delivering goods to several points is described. To visualize the situational task, a cargo delivery route was constructed to compare planned indicators with actual ones, adjusted using the analytical center.

This article describes the prospects for the use of tools of transport telematics, consisting in increasing the effectiveness of cargo safety control during transportation.

Keywords: *transport, road transportation, transport telematics, assessment, condition, cargo, transportation, saving, resources.*

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*Information about the authors:
Filippova, Nadezhda A. – Ph.D. (Eng), Associate Professor at the Department of Road Transportation of Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, umen@bk.ru.
Zaikin, Roman N. – Senior Lecturer at the Department of Legal and Customs Regulations of Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, td@madi.ru.
Efimenko, Dmitry B. – D.Sc. (Eng), Professor, Associate Professor at the Department of Legal and Customs Regulations of Moscow Automobile and Road Construction State Technical University (MADI), Moscow, Russia, ed2002@mail.ru.

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For the original Russian text of the article please see p. 258.

Background. Application of modern technology and tools of transport telematics allows to obtain information that can be used for various purposes, particularly to improve quality of road cargo transportation. Transportation of finished products is the final link in the supply chain, so this stage can be called the most important and responsible [1, p. 152]. When delivering finished products, cargo damage often occurs due to unforeseen traffic situations that provoke drivers to make sharp maneuvers.

To date, there is no single decision-making methodology based on operational remote monitoring of the transportation process and the state of the cargo [2]. This is the cause of consequent overspending of resources occurs. Damaged cargo is sent to the destination point and only there damage received during transportation can be detected. More rational is the option providing for quick detection of damage and an automatic decision to redirect the vehicle to the next point, if the cargo intended for that point is in good condition. To solve this problem, preliminary assessment of the state of the cargo is necessary, which will allow real-time decisions to be made aimed at saving resources. The development of such a mechanism is possible based on technology and tools of transport telematics, having necessary functionality to collect and transmit information about the parameters of the transportation process.

Objectives and research methods

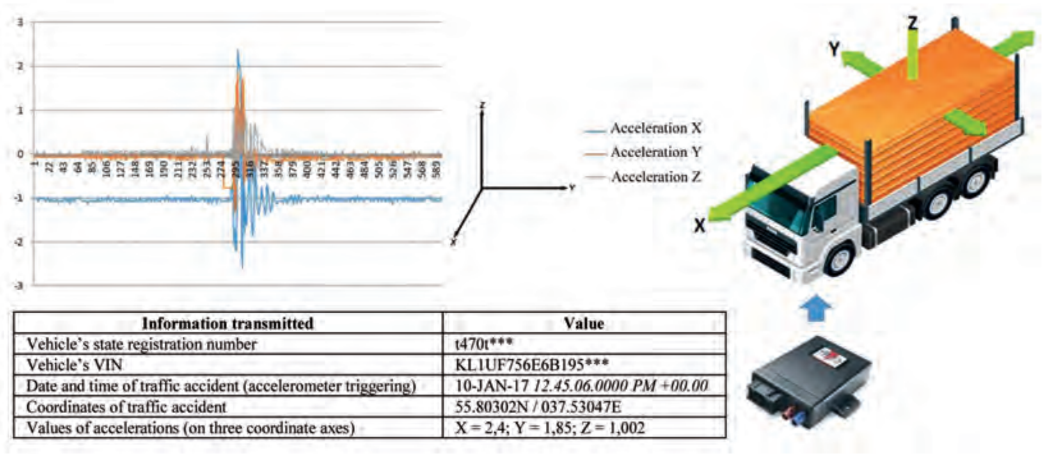
To improve the process of road cargo transportation, a hypothesis was put forward about the possibility of an operational analysis of the dynamic parameters of the car's movement, in order to assess the effect of the resulting accelerations on safety of goods. This article is based on an experimental study, the purpose of which was to describe the capacity of the navigation units and devices to fix and record accelerations that occur while the vehicle is moving.

As an experiment, a traffic accident was simulated on a specialized dynamic test bench. A navigation and communication unit was fixed to the platform, the platform accelerated, then hit an obstacle, after which the accelerometer recorded the accelerations arising from the impact along three coordinate axes. Finishing the process, the navigation and communication unit transmitted information about the dynamic parameters of the incident to the database. As a result of the experiment, the database received information, the final display of which is shown in Pic. 1. This report may be available to a wide range of users, since the experiment confirmed the possibility of transmitting information in real time to the specified database.

Description of the proposed method for assessing the condition of cargo and the transportation process

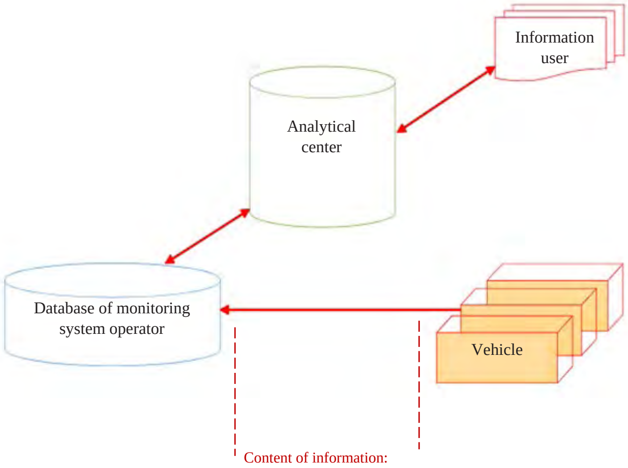
In addition to standard functions related to monitoring the vehicle's location and speed, an accelerometer is integrated in the navigation and communication unit, which can record accelerations that inform about the dynamic parameters of transportation [3] (Pic. 1).

Often, information about accelerations that occur in three planes of the coordinate



Information transmitted	Value
Vehicle's state registration number	t470t***
Vehicle's VIN	KL1UF756E6B195***
Date and time of traffic accident (accelerometer triggering)	10-JAN-17 *12.45.06.0000 PM +00.00*
Coordinates of traffic accident	55.80302N / 037.53047E
Values of accelerations (on three coordinate axes)	X = 2,4; Y = 1,85; Z = 1,002

Pic. 1. Recording accelerations, acting on the cargo during transportation.



- Vehicle's state registration number.
- Vehicle's VIN.
- Date and time of traffic accident occurrence (date and time of accelerometer triggering).
- Coordinates of traffic accident (latitude/longitude).
- Values of accelerations in three planes of the coordinate system (x; y; z).

Pic. 2. Chart of data exchange.

system does not find application, but it has huge potential associated with controlling the dynamic parameters of vehicle movement. The separate existence of these data is not of significant interest, since in logistics there is no exact, understandable, and reasonable numerical definition of phrases «state of cargo» or «damage to cargo». If we take into account the fact that acceptance of cargo is often carried out on the basis of visual inspection of the transport packaging, then the available data may be sufficient for test application of the technique, which will be discussed below [2].

Description of the elements of the method of rapid assessment of the state of cargo and the transportation process

The proposed method for assessing the state of the cargo and the transportation process using telematics consists in the analysis of information received from the navigation and communication unit and the comparison of the received information with reference values of the strength characteristics of the materials from which the cargo is made. The method of operational assessment of the state of the cargo is based on two elements:

1. *Fixing accelerations* (inertia forces) acting on the cargo during transportation (carried out by a navigation and communication unit installed in the car) (Pic. 1) and transmission of information (Pic. 2).

2. *Analysis of compliance of the current traffic parameters* with standard parameters, based on the physical and mechanical properties of the transported goods (carried out by the analytical center).

The recorded effective inertia is compared with the reference value of the physical and mechanical properties of the material (Table 1).

Assessment of the state of the cargo is carried out on the basis of comparison of the inertia force arising during movement of the vehicle with the elasticity force of the material. In this regard, provided that the inertia force exceeds the force tending to return the body to its original state, deformation of the material will be observed, i.e. the condition for destruction of the material is $F_i > F_{elas}$.

Development of a decision-making algorithm for transportation of finished products in the supply chain

It is necessary to deliver the goods from the warehouse to n objects sequentially (in the ascending order of their numbers) located on a pre-established route. During movement, a cargo of mass $m_{(j)}$, $j = 2, \dots, n$, intended for the j-th object, may be damaged. And it is advisable for the vehicle driver to find out about this in a timely manner, so that he can adjust the route on time and not call at the specified object,

Table 1

Comparison of the calculated value of the effective inertia force with the normative reference force of elasticity of the material (example)

No.	Material from which the cargo is made	The name of the indicator of the physical and mechanical properties of the material	The calculated value of the effective inertia force F_i*	The standard value of the elastic force of the material F_{elas}**
1	Glass	Ultimate strength (MPa)	21 MPa	15 MPa

* Current parameters (calculated value of the inertia force acting at the time of transportation) of F_i ($F_i = m \cdot a$, where F_i is inertia force; m is the cargo mass; a – acceleration).

**Standard parameters (reference value) of F_{elas} elasticity force (the force that arises in the body as a result of its deformation and tends to return it to its original (initial) state).

while saving both fuel costs and time to deliver the goods to other objects. If the damage is associated with overloads caused by sudden braking, a navigation and communication unit mounted on the car can help the driver in identifying damaged goods.

Preliminary, before leaving for each i-th section of the route, $i = 1, 2, ..., n\text{-}1$, connecting neighboring objects, $j = i + 1, ..., n$, an i-map of acceleration limits $A_{lim(i,\,j)}$ is developed. The calculations are based on the following considerations:

- the cargoes in the semitrailer of the car are placed sequentially so that products marked with larger numbers (cargo numbers correspond to object numbers) are located closer to the driver's cabin, and cargoes with lower numbers are closer to the rear side;
- on the i-th run, $i = 1, ..., n\text{-}1$, during sudden braking with acceleration $a_{(i)}$ the j-th cargo $m_{(j)}$, $j = i + 1, ..., n$ is affected by the resulting inertia force of all previous cargoes, determined by the formula:

$$F_{in(i,\,j)} = a_{(i)} \cdot \textstyle\sum_k \cdot m_{(k)},\ k = i, ..., j\text{-}1; \qquad (1)$$

- damage to the cargo occurs if this inertia force $F_{in(i,\,j)}$, acting on the j-th cargo is greater than elasticity force $F_{elas(j)}$ of this cargo:

$$F_{in(i,\,j)} > F_{elas(j)}. \qquad (2)$$

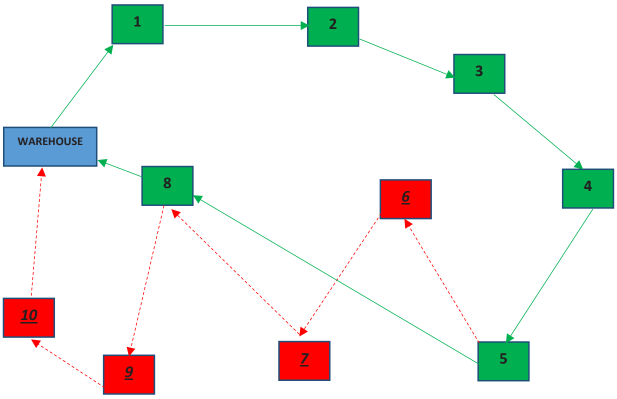
Comparing relations (1) and (2), it is easy to determine the acceleration limits $A_{lim(i,\,j)}$, exceeding which at the i-th stage of the route will lead to damage to the j-th cargo:

$$A_{lim(i,j)} = \frac{F_{elas(j)}}{\sum_k \cdot m_{(k)}},\quad k = i, ..., j\text{-}1;\ i = 1, ..., n,\ j = i + 1, ..., n. \qquad (3)$$

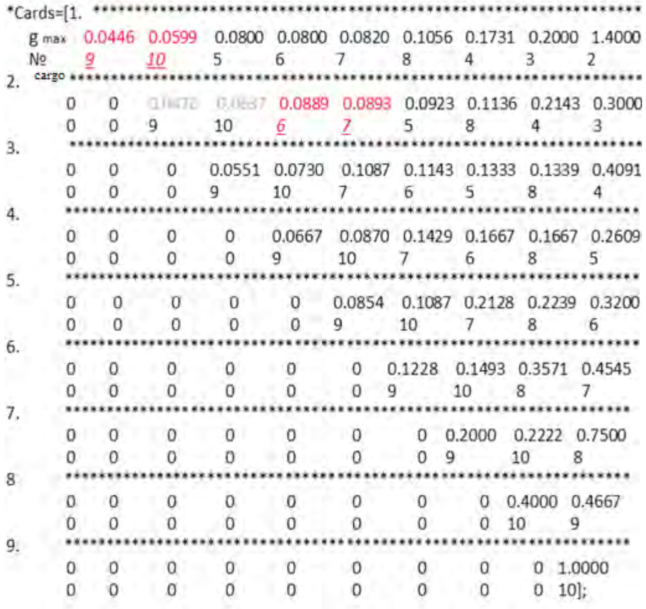
Note. Formulas (3), which determine the maximum allowable acceleration of braking $A_{lim(i,\,j)}$, were obtained for a rather «rigid» arrangement of goods in a road container. And therefore, in practice, these maximum allowable accelerations may turn out to be even greater. And, therefore, the values determined by formulas (3) might be increased by about 10–15 percent.

On (n-1) maps of the route section of the supply chain issued to the driver, $i = 1, ..., n\text{-}1$, the acceleration limits $A_{lim(i,\,j)}$ determined by formula (3) are arranged in ascending order with the indication of cargo numbers, damageable when exceeding the corresponding acceleration:

$$A_{lim(i,\,j\cdot(1))} <= A_{lim(i,\,j\cdot(2))} <=...<= A_{lim(i,\,j\cdot(n-i))},$$
$$i = 1, ..., n\text{-}1, j\cdot(1), j\cdot(2), ..., j\cdot(n–i).$$



Pic. 3. Scheme of delivery of finished products.



```
*Cards=[1. ************************************************************
   g max  0.0446  0.0599  0.0800  0.0800  0.0820  0.1056  0.1731  0.2000  1.4000
   №      9       10      5       6       7       8       4       3       2
2.  cargo ************************************************************
       0     0   0.0472  0.0687  0.0889  0.0893  0.0923  0.1136  0.2143  0.3000
       0     0   9       10      6       7       5       8       4       3
3.     ************************************************************
       0     0     0     0.0551  0.0730  0.1087  0.1143  0.1333  0.1339  0.4091
       0     0     0     9       10      7       6       5       8       4
4.     ************************************************************
       0     0     0     0     0.0667  0.0870  0.1429  0.1667  0.1667  0.2609
       0     0     0     0     9       10      7       6       8       5
5.     ************************************************************
       0     0     0     0     0     0.0854  0.1087  0.2128  0.2239  0.3200
       0     0     0     0     0     9       10      7       8       6
6.     ************************************************************
       0     0     0     0     0     0   0.1228  0.1493  0.3571  0.4545
       0     0     0     0     0     0   9       10      8       7
7.     ************************************************************
       0     0     0     0     0     0     0  0.2000  0.2222  0.7500
       0     0     0     0     0     0     0  9       10      8
8      ************************************************************
       0     0     0     0     0     0     0     0  0.4000  0.4667
       0     0     0     0     0     0     0     0  10      9
9.     ************************************************************
       0     0     0     0     0     0     0     0     0  1.0000
       0     0     0     0     0     0     0     0     0  10];
```

Pic. 4. Map of acceleration limits for the sections of the supply chain of finished products.

In fact, it is desirable to deliver all the loads to the objects without any damage, without exceeding at any stage the minimum braking acceleration determined in advance and indicated in the corresponding acceleration map. If some cargo nevertheless turns out to be damaged, then upon arrival of the transport to the object after unloading the required remaining cargo, the damaged cargo will also be unloaded, but only if it is accessed. Otherwise, the vehicle is sent to the next object with damaged cargo. In more detail, the actions of the driver and movers in different situation are considered using a specific example.

The algorithm allows one to construct maps of accelerations limits for any number of routes to objects *n*, arbitrary allowable masses of goods $m_{(j)}$, and the corresponding elasticity forces $F_{elas(j)}$ of these goods.

Description of the situational transport problem

The situational problem is a description of the process of delivery of goods from a warehouse to 10 objects sequentially located on a predetermined route (Pic. 3). To analyze the compliance of the current traffic parameters with the normative, a map of maximum allowable accelerations for route sections was planned (Pic. 4).

The input data of the situational transport problem:

- $n = 10$ is the number of process steps (total number of delivery points);
- $m = [10; 20; 22; 23; 25; 22; 20; 15; 10; 5]$ is a line of phased masses of delivered goods;
- $F_{elas} = [5; 14; 6; 9; 6; 8; 10; 15; 7; 10]$ is a line of elasticity forces of transported goods;
- Abr = fixed acceleration.

Let us suppose that at the first stage, acceleration of braking at some point in time turned out to be Abr = 0,06 g. As follows from the planned map of accelerations 1 (* Cards = [1; Pic. 3]), corresponding to the first section of the route, such acceleration leads to damage to goods with numbers 9 and 10. Since they turn out to be blocked by previous loads 2–8, the driver with all remaining goods moves to the second facility. However, consulting acceleration map 2, corresponding to the second stage of the route, he does not pay attention to accelerations leading [12; 13] to damage to already written off cargoes. Let now us suppose that during the second stage he had to brake sharply, bringing the braking acceleration to Abr = 0,09 g. This led to damage to goods with numbers 6 and 7. They also are stored in the depth of the container, and, as in the previous case, after unloading at the second facility, the driver goes to the third with all the damaged goods, not paying attention to accelerations of the map 3 leading to damage to already damaged goods. Further, we believe that the sequential move to the fifth object takes place without complications. And already at this object, it is possible to finally unload damaged cargoes 6 and 7. From the fifth object, the driver goes to the eighth object, focusing on the acceleration map 8 (naturally, in doing so, he pays no attention to the accelerations leading to damage to the cargoes 9 and 10). And as follows from this map, at the eighth stage there are already no constraints, violations of which would lead to damage to the cargo 8. After completing unloading, the driver returns to his base.

The map of maximum accelerations displays delivery points for which goods were damaged during transportation (Pic. 4).

On the supply chain of finished products (Pic. 3), dotted lines mark those routes that have lost relevance due to previously identified damage to goods destined for 6, 7, 9, and 10 unloading points.

When comparing planned indicators with actual, there is a reduction in costs regarding:

- *planned* number of finished products delivery points: 10;
- *actual* number of finished products delivery points: 6;
- *planned* number of finished products delivery routes: 11;
- *actual* number of finished products delivery routes: 7;
- *cost reduction* (reduction of the length of the route): 36 %.

Thus, improving assessment of the state of the cargo during road transportation using the specified situational example is appropriate, since it allows to reduce costs of delivery of finished products.

Conclusions.

The proposed method may be in demand, since a wide range of users are interested in analyzing the state of the cargo, including customs authorities which need this information to improve operational actions [4]. For transport companies will have the benefit to be able to monitor safety of the transportation process to maintain competitiveness by reducing the risk of cargo damage [5]. The method will allow insurance companies to quickly obtain the necessary information for examination of a vehicle's motion parameters to confirm occurrence of an accident, as well as to obtain information about cargo damage, which will minimize the risk of financial losses associated with fraudulent activities [6]. Besides, the method may be the foundation for improving the procedure for processing insurance cases and creating effective mechanisms for resolving disagreements between parties to the insurance contract [7]. Consumers of transport services will be able to have a clearer idea of the quality of service provided by transportation companies to choose the most suitable and safe company in the future [8; 9].

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