Virtual cargo security model in digital logistics

D B Efimenko and R N Zaikin
Moscow Automobile and Road State Technical University (MADI), Leningradskiy ave. 64, Moscow, 125319, Russian Federation
E-mail: td@madi.ru

Abstract. The object of research is the security of cargo in case of alteration of vehicle traffic parameters. The necessity of this research is explained by the lack of methodology and practice in applying the data provided by the navigation communication units installed in vehicles. It is proposed to apply the navigation data in the cargo security monitoring. The research theoretical significance lies in the possibility of creating a virtual online model of cargo’s condition during transportation in real time. The research practical significance lies in the possibility of creating a key element in the system of digital logistics designed for analyzing and monitoring supply chains in terms of transportation quality and cargo security. Practical application of the proposed conclusions will provide for improvement of the sphere of cargo transportation monitoring, the sphere of settling losses; it will facilitate speeding up the processes of goods damage assessment and mutual settlement of accounts; it will present valid evidence in litigation.

1. Introduction
Digital logistics presupposes high awareness of the ongoing business processes in the sphere of cargo transportation. Nowadays there are a lot of decisions for organizing quality cargo transportation which are connected with developing of methods for advanced supply chains analytics and monitoring, among other things. Due to the fact that the main indicator of the quality of carriage is the security of the cargo, it is imperative to improve cargo security assessment, taking into account high speed, efficiency and accuracy.

The existing systems of cargo security assessment used during auto transportation have their own advantages and disadvantages. The result of the performed analysis of the modern technical means of cargo condition control are the features pointing to the possible ways of improving control systems. The revealed disadvantages were divided into 3 groups:

1. Methodological disadvantages: there is a lack of a system assessing the threats of vehicle dynamical parameters depending on the cargo features which arise during transportation; there is a lack of quantitative damage assessment system of a consignment depending on the arising road accidents.

2. Technical disadvantages: large amounts of data to be transferred in real time in case of video registration; unstable position of electronic seals affecting the possibility of correctly identifying the emergency situation; seals, trackers, impact indicators are dependent on the built-in power cell; impact indicators have limited usage possibilities.

3. Organizational disadvantages: there is a lack of a single source of information and of an analytical center for processing the data on cargo security provided by navigation communication units installed in vehicles.
2. Methods
One of the main reasons of cargo damage is the exceeding longitudinal, transverse and vertical acceleration which arise during cargo transportation by truck. Exceeding longitudinal acceleration occurs due to abrupt acceleration and braking; exceeding vertical acceleration occurs when driving on poor quality roads, and exceeding transverse acceleration occurs in case of exceeding speed of entering into a turn, which may sequentially lead to the turning over of the vehicle with cargo. The suggested methodology is based on comparing the dynamical traffic parameters of the truck with the physical and mechanical properties of cargo and packaging; a navigation communication unit which is designed to be installed in vehicles is suggested as a device which will record the data on the dynamical parameters of the transportation process.

3. Results
Take transportation of glass as an example of assessing damages which occur as a result of exceeding the normative acceleration. In case of exceeding longitudinal acceleration cargo may shift vertically; the data for damage assessment is presented in table 2. As a result of exceeding vertical acceleration which may occur when passing pits the vertical rows of the transport pack may be damaged. In this case the vertical force of inertia which applies to the cargo when passing through the pit is calculated using the formula given in table 3. In case of exceeding speed of entering into a turn a displacement of cargo may occur and the vehicle may turn over. In order to evaluate the possibility of the vehicle turning over formulae for maximum allowable speed of making a turn are used and are given in tables 4 and 5. The maximum allowable speed of making a turn for an articulated lorry is calculated using the formulae in table 6.

| №  | Material          | Parameter name              | CURRENT PARAMETER Calculated value during transportation | NORMATIVE PARAMETER Reference value |
|----|-------------------|------------------------------|----------------------------------------------------------|-------------------------------------|
|    |                   |                              | Fi (mPa)                                                 | Fe (mPa)                            |
| 1  | Glass             | Maximum durability           | 21                                                       | 15                                  |
| 2  | Cardboard         | Maximum durability           | 21 (resistance to pressing)                              | 0.8 - 8                             |
| 3  | Normative parameters (reference value) - Fe |                            |                                                          |                                     |
| 4  | Current parameters (calculated value) - Fi |                          |                                                          |                                     |
| 5  | Formula for current traffic parameters - Fi=ma |                         |                                                          |                                     |
| 6  | Condition for material breakage - Fi>Fe |                          |                                                          |                                     |

Table 1. Comparison of cargo features with recorded force of inertia value.

Table 2. Longitudinal acceleration damage assessment.

|                                      |                                    |
|--------------------------------------|------------------------------------|
| Number of transport packets (pc)     | 33                                 |
| Gross weight of 1 (kg)               | 210                                |
| Total gross weight of all transport packets (kg) | 6 930                            |
| Overloading recorded by the device (acceleration) (g) | 2.5                               |
| Material of cargo                    | glass                              |
| Overall description of cargo         | decorative glass sheets            |
| Physical and mechanical properties of glass (maximum durability) | 15 mPa                            |
| Gross value of 1 transport packet (EUR) | 3000                              |

|                                      |                                    |
|--------------------------------------|------------------------------------|
| Losses (kg)                          | 5 040                              |
| Losses (EUR)                         | 72 000                             |
| Losses (RUB)                         | 6 433 920                          |
| Total losses in consignment (%)      | 72.7                               |
Table 3. Vertical acceleration damage assessment.

| Calculated values |  |
|--------------------|---|
| Weight of 1 cargo box | 18 kg |
| Number of boxes in a transport packet | 12 pieces |
| Acceleration recorded by the device | 1.8 g |
| Material of cargo | Glass |
| Material of package | Cardboard |
| Fe of cardboard | (0.7-1.2) mPa |
| Formula for calculation | $F_{iv} = a g M (P_v - 1)$ |
| Vertical acceleration (g) | $a g$ |
| Weight of cargo in a container, transport packer, kg | $M$ |
| Number of vertical tiers | $P_v$ |
| Condition for material breakage | $F_i > F_e$ |

| Result |  |
|--------|---|
| Package damage (pc) | 8 |
| Package damage (67%) | 67 |

Table 4. Variant No.1 of assessing the possibility of vehicle with cargo rollover.

| Calculated values |  |
|--------------------|---|
| Center of mass height | 0.7 m |
| Track | 1.8 m |
| Radius of turn | 70 m |
| Formula for calculation | $V_m = \sqrt{\frac{g R B}{2 h}}$ |

| Condition for rollover |  |
| $\frac{J_y}{g} > \frac{B}{2 h g}$ |

Result (maximum allowable speed of making a turn, speed of the vehicle rollover) $V_{over} = 101$ km/h
Table 5. Variant No.2 of assessing the possibility of vehicle with cargo rollover.

| Calculated values                                      |  |
|--------------------------------------------------------|---|
| Laden vehicle center of mass height                    | 1.7 m |
| Track                                                  | 2.04 m |
| Recorded vehicle speed                                | 24 km/h |
| Radius of turn                                         | 7 m   |
| Formula for calculation                                | $V_m = \sqrt{\frac{gRB}{2h}}$ |

Result (maximum allowable speed of making a turn, speed of the vehicle rollover) $V_m = 23$ km/h

Figure 1. Comparison of the recorded speed values with the calculated maximum speed values
Table 6. Calculation of articulated lorry overturn.

Formula for maximum allowable speed of the articulated lorry’s link (Vcr.h.). Applies individually to each link of the articulated lorry and is determined by the equation of the overturning moment to the restoring moment.

\[
V_{cr.h} = \sqrt{\frac{Rg}{h}} \left( \frac{B}{2} + \frac{1}{E_y} \right)
\]

| Part of route | Parameters | Actual parameters |
|---------------|------------|-------------------|
|               | ax Vy(max) | az                |
| 1-2           | ≤ 0,7      | 86,4 km/h ≤ 1    |
| 2-3           | ≤ 0,7      | 86,4 km/h ≤ 1    |
| 3-4           | ≤ 0,7      | 73 km/h ≤ 1      |
| 4-5           | ≤ 0,7      | 73 km/h ≤ 1      |
| 5-6           | ≤ 1        | 73 km/h ≤ 1      |
| 6-7           | ≤ 1        | 73 km/h ≤ 1      |
| 7-8           | ≤ 1        | 86,4 km/h ≤ 1    |
| 8-9           | ≤ 1,2      | 73 km/h ≤ 1      |
| 9-10          | ≤ 1,2      | 23,04 km/h ≤ 1   |

- dangerous turning speed;
- exceeding maximum allowed speed while turning;
- part of route with exceeding longitudinal or vertical acceleration;
- part without exceeding acceleration;
- turning without exceeding acceleration

Figure 2. Assessment of transportation quality on the route. Map of the vehicle’s movement compliance to the recommended parameters.
4. Conclusion
By using the suggested methodology during transportation the values of dynamical traffic parameters of a vehicle can be calculated in advance and presented as a map of maximum allowable acceleration and speed for the parts of the route presented in Figure 2. Cargo security can be traced remotely and efficiently by using the navigation communication unit as the main source of data on dynamical traffic parameters of a vehicle. The suggested methodology allows for creating a virtual model of cargo condition alteration control in real time. Practical use of the suggested theses lies in improving the sphere of settling losses, mutual settling of accounts and cargo transportation quality control. The suggested system can potentially be applied in developing an intellectual system of cargo security in autonomous vehicles.

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