Prospects of development of land driverless trucks

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Abstract. The paper is dedicated to the problem of creation and efficient use of driverless trucks. It also contains general analysis of foreign experience and development trends. The concept of FSUE “NAMI” for development of a platoon of driverless trucks for cargo transportation between specialized terminals on public roads is provided. A road train with virtual couplings where the lead vehicle has a driver and the rest are driverless is proposed as a base for the driverless platoon. The platoon is formed by such road trains, which ensures extended functional features, including the possibility to form platoons of road trains from different logistics centers and with different destinations, quick reforming of the platoon in the logistics centers, possibility to split the platoon when driving on public roads, higher precision of control over the platoon during driving, etc. It is also shown that in order to improve the efficiency of cargo transportation, driverless cargo platforms (trucks) shall be designed without a cabin. The paper also considers the ways to reduce the price of driverless trucks by creating a special road infrastructure, which will allow transfer of the most expensive subsystems of driverless vehicles to such infrastructure. Upon that, the following subsystems will remain within the driverless chassis: navigation, communication, chassis control and ADAS. It is noted that creation of such infrastructure will require high investments, therefore, gradual implementation of such systems is seen as rational. It is shown that the most appropriate area for these purposes is transregional cargo transportation. It is noted that the economic reasons for implementation of the proposed concept are as follows: significant reduction of the number of drivers; significant simplification of the driverless platform control system and reduction of the price of subsystems; no need for the driver’s cabin within the driverless platform; fuel economy when driving within a platoon. Power unit options for driverless cargo platforms are investigated and the reasons for selection of a particular power unit are given.
1. Introduction
Creation of driverless vehicles (DLV) and driverless vehicle control systems (DLVCS) is a priority task in global automotive industry. Such types of vehicles can be rather various and different. Foreign automotive manufacturers are developing DLVs including passenger cars, buses, in-plant or in-factory vehicles, trucks, farm vehicles, special-purpose vehicles, etc. The most intensive development activities are underway in the USA, Japan, Germany and Sweden in such corporations as General Motors, Ford, Toyota, Volkswagen, Audi, BMW, Volvo, etc. According to experts' forecasts, DLV integration would enhance efficiency, decrease cargo-and-passenger transportation costs, ensure traffic safety, reduce a quantity of motor vehicle collisions (MVC), cut down on operational fuel consumption, reduce travel time and minimize emissions of hazardous substances and greenhouse gases into the atmosphere.

Currently, the level of development of foreign DLVs ensures their automatic driving without human intervention on the highways with a good road infrastructure, road marking and without intersections. The DLV is controlled by the driver when driving within the city with intersections and traffic lights and also when driving on roads in winter under icy and snowy conditions. The main type of information generated in the DLVCS is a surrounding situation and vehicle positioning data. Depending on configurations of computer vision systems, the digital, infra-red, laser and ultrasonic scanning of the territory and barriers is implemented in the DLVCS. The data received from computer vision system sensors are holistically analyzed by their priority. Following the analysis results, the control unit transmits commands to actuators, which perform autonomous driving of the DLV according to the developed algorithms and software.

It should be noted that activities related to driverless trucks are especially intensive overseas. Using driverless trucks within the truck platoon (truck convoy) is seen as promising and in prospect is expected to have the following results:

- road safety improvement, as this would lead to minimization of the negative impact of human factors being statistically the main reason of almost 80% of MVC;
- fuel saving up to 20%;
- increase in transportation efficiency by 1.3-1.4 times;
- provision of comfortable working conditions for drivers inside the driven trucks;
- minimization of harmful effects on the maintenance staff and environment;
- reduced need in a large pool of professional drivers with high remuneration;
- possibility to integrate driverless transport systems in technological processes of enterprises including, first of all, large transport and logistic centers, ports, etc., providing their continuous and round-the-clock functioning.

The examples of driverless trucks being developed by the leading global companies are presented in figure 1.

The Volvo driverless truck platoon control system - Safe Road Trains for the Environment (SARTRE) - makes it possible for several vehicles to move on the road within the organized platoon (convoy) - figure 1i [5]. The vehicles follow the lead vehicle which is the truck driven by a professional driver. The vehicles line up to keep the distance of 6 m from each other and fully repeat the movement of the lead truck. In the course of movement, each vehicle can leave a convoy at any time. Volvo's best practices and deliverables in the field of active safety systems, including adaptive cruise control, are used for the SARTRE system creation. At present, such convoy is at the stage of operational tests.

The principles of development of driverless trucks are practically the same as that of passenger DLVs [8-14]. For fuel-saving purposes, the Japanese state organization - New Energy and Industrial Technology Development Organization (NEDO) - developed the platoon of four trucks, which move at the distance of 4 m from each other. When driving in the platoon, aerodynamic air resistance for the following vehicles decreases, thus, fuel consumption by driverless trucks is reduced - figure 1g.

The problem of truck performance and capacity increase is of high-priority. In general, development of driverless trucks is conducted based on modern classical designs of trucks. At the same time, with creation of perspective driverless trucks, the focus on classical configuration solutions cannot
significantly increase labour efficiency in the transport sector (by 1.34 – 1.54 times as specified in "Transport Strategy of the Russian Federation until 2030").

Figure 1. Driverless trucks of the leading global manufacturers: a) Otto driverless truck; b) Inspiration driverless truck (Inspiration Truck) by Freightliner; c) Volvo-Renova driverless garbage truck; d) BMW DLV with Connected Drive Connect; e) Volvo FMX underground driverless truck; e) driverless truck based on KAMAZ-5350; g) Japanese driverless trucks; h) Mercedes-Benz Actros semi-autonomous vehicle platoon/convoy; i) Volvo DLV platoon/convoy (with Safe Road Trains for the Environment); j) Scania driverless truck platoon; k) DAF driverless truck platoon; l) MAN driverless truck platoon.
2. Concept of creation of driverless truck platoon

Prospects of logistic transportations are based on transport and infrastructure technologies development. At present, foreign and domestic transport enterprises introduce modern logistic technologies of cargo transportation and handling: telecommunication systems for cargo transportation maintenance, terminal systems for cargo transportation, door-to-door (house-house) transportations, etc.

According to various estimates [15], the transportation costs amount to 20 - 70% of total logistic expenses, at that, the share of transport costs in the price of goods is different and depends on the product type: 2-3% - for electronics, 5-6% - for food, 7-12% - for vehicles and equipment, 40-60% - for raw products, 80-85% for mineral and construction products. According to experts' calculations, integration of information systems could increase the average vehicle speed by 10-30 km/h.

From the perspective of cargo transportation organization, there is a promising step to combine the DLV and truck platoon concepts. As a result, we are dealing with the two types of transport systems and infrastructure for them as follows:

- "road train" with a virtual automatic coupling;
- truck platoon (incl. virtual links);
- intelligent logistic center.

The main difference between the road train with virtual automatic couplings and the truck platoon with virtual links consists in the number of vehicles included. It is proposed to introduce the following quantitative indicators: for the road train with virtual couplings – from 2 to 5 vehicles, for the truck platoon – 2 and more road trains with virtual couplings. At present, the road train with only three mechanical links is already a vehicle which is complicated in control and development (Fig. 2b), and the truck platoon consisting of a large number of trucks (Fig. 2a) requires a large number of drivers, given the fact that they need to substitute each other in the course of driving.

Figure 2. Modern truck platoon and road train: a) truck platoon; b) three-link road train with mechanical couplings.

In order to ensure modularity and unification, it is suggested that a perspective truck platoon must consist of several road trains with virtual links (virtual automatic couplings) inside of and between them. At that, there is a possibility of platoon uncoupling in the following cases:

- driving across intersections, railroad crossing (road trains (trucks) must drive along one after another);
- maneuvering (also when driving in the city and among other vehicles).

Thus, the road train with virtual couplings is a key item and module of the driverless truck platoon. Accordingly, a different amount of driverless road trains with virtual couplings may be used to form the driverless truck platoon. They may be taken from various logistic centers and intended for different destinations. Truck platoon formation is necessary to organize a joint movement of driverless road trains along highway sections that are comparably long and common for all vehicles.
Let's consider the composition and purpose of such a road train. It consists of several DLVs with virtual automatic couplings, at that:

- the lead vehicle has a driver;
- the driven vehicles are driverless (following behind the lead vehicle, maneuvering under tight space conditions, turning movements/U-turns by separate driverless vehicles, etc.);
- driverless truck platforms are to ensure two main driving modes: automatic driving within the road train and maneuvering, which is controlled by operator.

Reformation of logistic centers in terms of their role and purpose (which will make it possible to exercise effective management of transportations) is required for new categories of vehicles.

- driverless road train and truck platoon formation / reformation;
- vehicle maintenance;
- change of drivers and operators of lead vehicles.

For ensuring the effective formation and reformation of driverless road trains and truck platoons, separate logistic centers must exchange information that will make it possible to focus on general cargo traffics by accepting and sending the driverless vehicles. It is proposed to change the roles of professional drivers. The road train and truck platoon are controlled by a driver and an operator whose task is to monitor correct functioning of all systems providing autonomous driving.

Besides, it is necessary to change the nature of activities fulfilled by drivers and operators accompanying them, ensuring fulfilment of functions in the local territory. During the working shift, they move a truck platoon from one point to another at a distance of several hundred kilometers. After that, the driver and operator are replaced by other colleagues who continue to move the truck platoon further up. The previous ones get a possibility to have a rest and start their way back with another truck platoon. On return, they finish their shift and have a possibility to have a rest at home before picking up a shift again.

Thus, the truck platoon consisting of driverless vehicles (Fig. 3) is designed for cargo transportation between specialized terminals, at that, the driverless vehicles must be driven on public roads. The main requirement defining the driverless vehicle image is that the driverless vehicle platoon must be a part of the traffic, i.e. move along depending on other vehicles movement, traffic lights, road signs, etc.

![Figure 3. NAMI's prototype road train with the driver-operated lead truck and driverless links with virtual couplings.](image)

The truck movement organization systems built that way will ensure the movement of driverless truck platoons and road trains with virtual automatic couplings. Virtual couplings between the driverless trucks will ensure movement of a large number of vehicles, lane-changing, turning movements, U-turns, driving across intersections, driving together with other vehicles on the road, setting and fulfillment of various tasks related to cargo transportation. The driverless vehicles integrated in one platoon can follow the lead vehicle, and at the same time, they have capabilities for some types of autonomous driving: change the distance when necessary, pass a sharp turn, U-turn, get to the unloading / loading point, etc. All of these will allow to reduce the transportation costs and increase efficiency thereof.

When developing perspective driverless trucks, it is reasonable to consider the design of the driven driverless truck without a driver's cabin, with the traction module and motion control system (MCS)
arranged within chassis dimensions. In such configuration, the length of the cargo platform of the
driverless truck can be extended almost to the front border of the frame due to the driver's cabin absence.
The maximum extension of the cargo platform of the driverless truck is also possible when using the
electric drive. Implementation of the electric driverless truck design without a driver's cabin makes it
possible to extend the cargo platform on average by 20 - 30%.

Today, the price of the DLV control system can reach up to $100,000, though the system reliability
is far from perfect. Striving for higher reliability will cause further increase in price, which is one of the
constraints for mass introduction of DLVs. Increasing the DLV production volumes will allow
significant price decrease, but will not solve the problem. This constraint can be overcome only by
creating a specialized road infrastructure, which shall ensure the following functions of DLV in
minimum configuration:

- DLV identification (information subsystem);
- road situation monitoring (computer vision subsystem);
- real-time transmission of data on road situation to DLV (communication subsystem).

Introduction of such road infrastructure will allow to transfer the most expensive DLV subsystems
to the infrastructure, while the driverless chassis will feature only the following functions:

- Navigation and orientation / positioning (navigation subsystem);
- Acquisition of information on the situation from the road infrastructure (communication
  subsystem);
- Calculation of the trajectory and routing based on the information received from the
  infrastructure (chassis control subsystem);
- Collision prevention (ADAS).

Such approach will allow reduction of the price of the DLV control system down to $2,000-$3,000
(even before mass implementation), while the stationary system reliability will be higher than that of a
moving object.

It is obvious that creation of such infrastructure will require high investments and long time for
debugging and refinement; therefore, it is reasonable to introduce and refine such technologies
gradually. The most appropriate area for these purposes is transregional cargo transportation. First, the
price of the control system will be minor compared to the price of the truck, and second, such automation
will have a significant economic effect due to the transportation cost reduction.

The economic reasons for introduction of the proposed concept are as follows:

- significant reduction of the number of "accompanying" drivers;
- transfer of the main infrastructure subsystems (computer vision, operating (control) center,
  communication system) to the lead truck vehicle;
- significant simplification of the driverless platform control system and reduction of the price of
  subsystems (down to $2,000-$3,000);
- no need for the driver’s cabin within the driverless platform (including life-support subsystems);
- fuel economy when driving within a platoon (up to 10-20%);
- easier maneuvering (in remote control mode) and, as a result, relaxation of requirements for
  logistic terminals.

It is proposed to implement the cargo transportation automation concept stage by stage. At the initial
stage, before the DLV road infrastructure deployment, creation of a "mobile infrastructure" for the
driverless cargo platforms is required. The mobile infrastructure shall be installed onto a special truck,
which shall be the lead vehicle of a road train with virtual couplings. The driverless cargo platforms
shall strictly follow the lead vehicle automatically, keeping the minimum safe distance. The lead vehicle,
which is controlled by the driver, shall feature main subsystems of the mobile infrastructure and an
operating (control) center of the road train with virtual couplings.
3. Rationale for choosing the power unit for driven driverless trucks
Since the lead links of the road trains feature virtual couplings, it is necessary to solve the issue of power supply of these links when driving within the platoon. In the short term, three solutions can be considered: diesel ICE, combined power unit (plug-in hybrid) and electric platform (Fig. 4).

![Figure 4. Driven electric driverless truck: 1 – chassis; 2 – batteries; 3 – steering gear electric drive; 4 – electric machines; 5 – electronic motion control unit; 6 – video cameras; 7 – radars; 8 – lidar.](image)

Running 400…700 km per shift is typical for regional transportations. Currently, there are no affordable and available electric power accumulation technologies, which would make it possible to use electric vehicles for regional cargo transportation in terms of economic feasibility (Table 1).

**Table 1.** Calculation of 500 km run of the road train driven link (in electric mode, on a single charge, at the speed of 85 km/h, with the fully loaded weight of 35 t).

| Description                                                                 | Value            |
|----------------------------------------------------------------------------|-----------------|
| Required power capacity of the battery                                     | 620 kWh         |
| Battery weight                                                             | 3,100 kg        |
| Battery cost                                                               | $315,000        |
| Battery cost with 30 kWh Range Extender: (battery power capacity – 440 kW, battery weight – 2,200 kg) | $220,000        |
| Battery cost with 50 kW Range Extender: (battery power capacity – 320 kW, battery weight – 1,600 kg) | $160,000        |

Besides, charging of the battery making such runs possible will demand either a long time or high current loading networks, reducing charge efficiency and battery service life. The lifespan of accumulators will not provide for them without replacement during the entire operating life of the truck, which equals to the run of up to one million kilometers and more. Therefore, the alternative mid-term solutions might be the Combined Power Units (CPU), which have a rechargeable battery making it possible to drive several dozen kilometers in electric mode under certain conditions. Usage of a diesel engine without an energy recuperation system will not provide the required level of energy efficiency.

Heavy-load vehicles and road trains are characterized by a large weight, relatively low resistance to a steady movement within the low and medium speed range and high diesel efficiency in a wide range.
operational range. In this regard, a considerable fuel saving is possible for these types of vehicles due to recovery or recuperation of vehicle kinetic and potential energy. The regenerative braking system of category "B" according to the classification of UNECE Regulation No. 13 shall be used to realize the full recovery potential. This means that the recovery system functioning is fully coordinated with service brake system and active safety systems functioning. A significant effect of energy recovery may be expected when driving in the mode of "acceleration / deceleration" cycles. Such mode is typical for cities or suburbs which heavy-load vehicles can pass only in transit. When driving on highways, the recovery energy may be accumulated as a result of speed decrease in turning movements or other service decelerations and also when driving downhill. As for heavy-load vehicles, it is possible to accumulate a significant amount of energy after several decelerations. When driving across the city or in suburbs, especially in traffic jams, it is possible to switch off the ICE for a certain period of time. Another variant is to consume the recovery energy for additional power take-off. First of all, this refers to refrigerator trucks. According to publications, road trains with the weight of around 32 t consume up to 20% of fuel for operation of an additional diesel engine actuating the refrigeration unit supply generator. Using certain generating unit parameters known from publications and technical materials, it is possible to calculate that 15% of average fuel consumption by the road train without a refrigeration unit (about 35 l / 100 km) correspond to about 5 kg of additional fuel consumption per 100 km. With the average speed of 60 km/h and energy recovery of 150 … 200 kW (typical capacity of a traction electric machine for hybrid vehicles of this type), the vehicle must drive 6.5…8.5% of the route in the recovery mode in order to save 15% of fuel. The required capacities may be provided either by 0.25 … 0.35 m/s² service decelerations (for example, speed decrease when turning) or by 1.5…2-degree downhill driving or by combination thereof.

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