Economic efficiency of innovations in construction: the use of the pilotless equipment

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Abstract. The developments in the field of pilotless transport and equipment act as one of the modern and most perspective directions of the development of modern science and technology. The vehicles, equipped with the system of automatic control, are able to move in the space on the basis of the set algorithm of actions and the instant analysis of the surrounding situation. Thus, they have great prospects of the use in various spheres and will allow to lower the expenses of human labour, accident rate and fuel consumption. The identification of prospects and directions of the use of the pilotless and automated vehicles in construction projects is carried out in this article on the example of road construction. Studying of the existing developments of the pilotless equipment has already allowed to simulate the process of carrying out some earthwork with the use of (Unmanned aerial vehicles) UAVs. As the introduction of the pilotless vehicles and equipment demands some investment expenses, the economic efficiency of the project is calculated. The result of the calculation of the economy, gained with the use of the pilotless equipment has proved the efficiency of such investments.

1 Introduction

One of the modern and extremely perspective directions of the development of science and modern technologies, which is able to find its application in various branches of the economy, is pilotless transport. The vehicles, equipped with the system of automatic control, able to move and perform certain functions without direct participation of the human, can find their application in both in passenger and freight transportation, during performing construction works, production operations, etc. In spite of the fact, that a car without a driver is still a fantastic phenomenon for many people, there are some examples of successful introduction of pilotless vehicles.

Unmanned aerial vehicles (UAVs) are used in archeology for exploring of the territory, video surveillance and aerial photography, in the military and prospecting purposes. The considerable prospects of the use of UAVs for geological exploration, for cargo delivery, for carrying out inspection of various systems (for example, during inspection on the existence of damages to various structures), for the survey of remote and dangerous objects are noted. UAVs can be also used for monitoring of the process of carrying out any works.

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For example, they are being used for determining of the conducted volumes of works in construction. Considerable prospects of the pilotless and automated vehicles are also available in road construction. The identification of prospects and directions of the use of pilotless and automated vehicles in construction projects is the objective of this research.

The market of pilotless vehicles and equipment develops quite promptly, integrating various spheres and branches. So there are already independent Integra robots-bathyscaphes, intended for research of the underwater area, semi-automatic stackers of bricks and even pilotless combines, seeders, tractors and cars [1, 2, 3].

Drones are actively used in construction. They are observed near construction sites more and more often. They are used for studying of the construction site and monitoring of the construction process. The most successful producers of the pilotless equipment for construction are Komatsu (the company uses drones for obtaining images, which will be used for 3D models of buildings with actual sizes of the real construction object) and 3D Robotics (the producer of construction drones with the use of technologies of the complemented / virtual reality) [4, 5, 6].

Automation of work is more and more necessary in the 21th century. Toughening of nature protection norms, the shortage of labour and aspiration to innovations push the progress to modernization of the construction road equipment.

Let us consider the main advantages of pilotless and autonomous construction road vehicles:

1) the use of the automated equipment provides safer working conditions. According to the International Labour Organization there are about 60,000 fatal accidents annually in the construction sites around the world. That means that one fatal accident takes place in this sector each 10 minutes [7]. Actually, about 17% of all the accidents, causing death in a workplace (one of six cases) happen in the construction sites. Safety is the main motivation for automation of construction sites, as it assumes replacement of human work with the equipment. There are also other incentives for the introduction of drones for the implementation of activity in construction and operation of roads:

- the increase in productivity;
- operational coherence of the equipment operation during construction by the means of communication through the uniform centre of information processing.

2) optimization of expenses. Reduction of expenses is reached because of optimization of consumption of fuel and maximum coherence of production operations, that leads to the decrease in terms of performance of work, the efficiency of logistics increases due to expeditious transmission of data on positioning of various objects (including the construction equipment), thanks to the existence of the system of drones.

3) while the pilotless construction equipment will lead to the fact, that some volume of labour will be released, new category of working professions will appear. New classes of vacancies, which will include the operators, piloting the equipment far off, and also the experts, able to analyze and interpret the data, obtained by drones, will be created.

Advantages of the use of the pilotless equipment force to assume, that its introduction gradually will become a necessary condition of the maintenance of competitiveness of the largest construction companies, because it creates the conditions, promoting cost cutting and construction terms cutting and also provides the increase in the efficiency of the use of information modeling technologies in construction (BIM) due to adding some information on the arrangement of objects and amounts of completed work to the model.

The main types of the automated (pilotless) technology and the possibility of its application in construction are considered in this research, the process of construction with the use of the pilotless equipment is simulated.

2 Terms and Methods

The methods, which have allowed to achieve a stated purpose of the research (identification of prospects and the directions of the use of the pilotless and automated vehicles in construction projects) have been used by the authors. We will consider these methods and we will define their role in the research.

The first stage of any research is the analysis of the situation, studying of the problem and assessment of the condition of the object of the research. At the first stage of the presented research the wide analysis of developments of various companies in the field of the pilotless equipment and the main directions of their practical application was carried out. The analysis of some open information sources, available both in the Internet, and in printed media, was carried out by the means of such method as the analysis of documents.

Identification of some modern developments in the field of the pilotless equipment and the analysis of opportunities of their use in construction allowed to simulate the process of construction with the use of the pilotless equipment on the example of road construction. Respectively, such method of scientific research as modeling was applied by the authors. However, the initial investments, allowing to pass from manual control with the equipment to automated one, including development or purchase of the specialized software and the installation of the corresponding technical devices directly on the construction equipment, are necessary for the realization of the process of construction according to the developed model.

The existence of some initial expenses and the need for investments also proves the need of application of the methods of the investment analysis within this research. In this case the model of cash flow was constructed and the net discounted income was calculated. The payback period for the investment expenses was calculated.

3 Results

We will consider the main types of the pilotless equipment, used for construction of roads and such structures as bridges, overpasses, tunnels, etc., revealed as the result of the analysis of a wide range of sources. The research center Advanced Highway Maintenance and Construction Technology Research in the University of California in Davies tries to identify the most dangerous works on the road and to create the cars, able to do such works automatically.

The pilotless equipment can serve for partial or full automation of the process of check of defects, which inevitably arise during construction or maintenance of tunnels. Such equipment increases safety, carrying out inspections in dangerous conditions instead of the human inspector. Manual and (visual) survey by the human is replaced with more exact methods, using mechanical, electronic and robotic systems and data processing, provided by cameras, laser, sonar, etc.; the programmed pilotless operational transport carries out such tasks much more effectively, than the human. For example, the developments on creation of the independent road operational equipment for cleaning of tunnels, scanning and search of cracks are conducted by ultrasonic, laser, touch and other methods. For example, the vehicle, able to conduct independent diagnostics of tunnels, with the use of the remotely-controlled vehicle and robotic hand Mitsubishi PA-10, is tested within the Japanese ROBINSPECT and TunCostract projects [8, 9].

The Japanese equipment manufacturer Komatsu uses drones for functioning the pilotless construction equipment. Besides, the company has developed and has presented several excavators and bulldozers [10, 11] working without a driver (operator). Machines operate together with drones, which transfer the three-dimensional shooting of the area in the site to the on-board computer. Navigating with this map, the excavator can dig a hole or a trench of the necessary depth and width, and the bulldozer can move necessary amount of soil from one place to another.

The drones, developed by the company, allow to perform the whole complex of works: to distinguish the construction site, to estimate the volume of earthwork, to make the district map for better orientation of the pilotless equipment in the territory, where the road construction activity is carried out. The photos, received from the UAVs cameras are transformed to three-dimensional maps, which demonstrate where and how much ground the construction car has to transfer and how the following stage of construction has to look. That is, these developments lead to the fact that the most hard and labour-consuming earthwork will be performed by the robotic construction equipment according to the algorithm set in advance and under the observation of the removed operator. The use of such equipment, made by the company, is relevant for large-scale road construction in the remote and especially dangerous sites.

Besides pilotless excavators, the Komatsu equipment also includes pilotless dump trucks. The dump truck moves without turns with the identical speed, as thanks to the lack of a driver cabin, the optimization of freight distribution among 4 wheels is made and speed of the movement back and forth (about 64 km/h) equal. This type of equipment also works with the assistance of drones and the operator, acting far off; however, the plans of the company include full automation, so that the human factor would be necessary only in the emergency situations.

Volvo Company, which is also engaged in production of the construction road equipment, wishes to make its power supply electronic. The company provided the hybrid wheel loader LX1 with a potential for the increase in fuel utilization efficiency for 50%, reduction of carbon emission to 95% and the total cost of the maintenance for 25%.

Volvo has been engaged in development of independent and semiautonomous cars in partnership with some universities for more than ten years [12]. The cars pass tests in actual practice of maintenance now, and the wheel loader is being used by the Swedish company, which works at the asphalt plant.

Thus, there are some operations within implementation of projects of road construction, which can be carried out by the pilotless construction equipment, which will allow to lower labour costs and to lower fuel expenses. Besides the pilotless equipment can be used for dangerous types of works, that will also reduce the quantity of accidents, will minimize the possibility of any human mistake, when performing operations.

On the basis of the analysis of the existing developments in the field of the pilotless road construction equipment, the process of the road construction, based on the maximum use of the pilotless equipment was simulated (figure 1) [13]:

• At the first stage the 3D map of the existing territory is created with the use of laser scanners, special stations, mobile mapping and aerial photography with the use of unmanned aerial vehicles and drones (in certain cases with the use of robot planes).

• At the second stage civil engineers create the territory development plans, which will be transformed to 3D models.

• At the third stage independent cars are located in the site, and sensors, cameras and the global navigation satellite system (GNSS) as well as GPS are used for positioning of the equipment in the site. The software uses the data, transferred from the heavy equipment, in real time and also the three-dimensional map of the existing area on the website.

• At the fourth stage the three-dimensional model from the website in turn, is going to instruct the equipment, where to go and how ground to dig out, how to arrange bulldozer edges for sorting, in what territories to stack asphalt and in what volumes, etc., all the actions are carried out, taking into account the set parameters.

Stage	Performed works	Technology	Results
Stage 1. Creation of the 3D map of the construction site surface	Aerial photography and mobile mapping	Unmanned aerial vehicle, laser scanners, special stations of data reception	Detailed 3D model of the construction site
Stage 2. Creation of the construction site plan	Processing of the data, received at Stage 1	The determined algorithms and the specialized software	The construction site plan, transformed to the 3D model
Stage 3. The use of the model, correction of the equipment location	Expansion of the systems of the use of the materials, received at Stages 1 and 2	Sensors, cameras, GPS, GNSS	The equipment, prepared in the scanned site, the existence of the three-dimensional map
Stage 4. Automatic planning and work in the construction site	Movement of the ground, carrying out other earthwork, asphalt laying, etc. depending on the task	Pilotless equipment is used directly, taking into account the technologies, applied in the previous sites	The performed works, according to the parameters, set initially

Fig. 1. Model of the road construction process, based on the maximum use of the pilotless equipment.

According to the presented model of the use of the pilotless equipment in road construction, it is possible to conclude, that the use of the pilotless equipment in road construction can be actively applied within the preparatory stage and performance of earthwork now.

While the equipment works, it sends data on the performed works, therefore the software constantly updates the 3D map to reflect constantly changing environment, concerning the conditions of the area and the site. The equipment also transfers data of telematics; generally these are the diagnostics data in real time from different components of the equipment, such as speed, fuel usage, engine temperature, etc. Similar monitoring in real time allows the operator to provide maximum efficiency of the equipment maintenance.

There are some arguments in favor of the use of pilotless vehicles and equipment in different fields of activity. However, it demands the additional expenses because of the connection of certain equipment and software. Respectively, the estimation of economic efficiency and the attractiveness of investments is necessary, as any investor has to be confident, that the invested funds will be returned, and the investment it will be profitable during the limited period of time.

We will consider the economic efficiency of the use of the pilotless equipment on the example of the automated road construction equipment: BobCat S250 mini-loader [14].

Automation of BobCat S250 mini-loaders will have the same technology of integration of the software and means for pilotless functioning. The cost of automation of the car is about 700 thousand rubles. The automation assumes the installation of the Lidar device 15], some sensors and cameras, GLONASS and GPS systems and also some specialized software. The equipment is removable and can be used depending on the needs by different devices.

Implementation of this investment project will demand the conclusion of partner agreements with the companies, which are engaged in the development of algorithms and software for incorporeal vehicles, such as Yandex, Uber, Google Cognitive Technologies [3, 16, 17, 18]. According to the conditions of partner agreements, the company will carry out periodic updating of the software, which cost can be estimated previously as $300 per unit of the equipment annually.

The calculation of economic efficiency of investments will be carried out, taking into account, that according to the traditional way of work digging works are carried out within 12 months, 8 hours a day, the total amount of the expenses, connected with one driver compensation is about $1,400 per a month.

Let us assume, that we need to perform digging works for the subsequent laying of asphalt. According to producers, the expense of fuel when unloading, loading and cargo transfer make 6.4 litres per machine-hour. The cost of one litre of diesel fuel in Russia at the moment of this work preparing is about $0.6.

We will calculate the payback period of the investment project and the net discounted value from its implementation (table 1):

• The data are provided in table 1 for one vehicle. The investment costs are made by one-time purchase of "Lidar" and the accompanying equipment, such as cameras, satellite systems, etc.

• The cash flow, created during the project implementation makes the economy on the salary of the driver of the specified type of equipment.

• The current expenses include:

1) The cost of creation of the special software, equal $300 per the equipment unit, annual updating of the system of the same cost is also considered.

2) fuel usage, expected as the multiplication of the duration of the working day (8 working hours), fuel expenses (6.4 litres per 1 machine-hour) and costs of gasoline.

3) 20% of the fuel usage economy, arising thanks to the use of the GLONASS/GPS systems at the expense of optimization of works and movements, when using special equipment [19].

• Net operating income (cash flow from operating activities) makes the difference between the cash flow, created during the implementation of the project, and the current expenses.

• Cash flow from operating and investment activities in turn makes the sum of net operating income (cash flow from operating activities) and investment costs.

• The discount rate is defined as the sum of the key interest rate and the risk level in 10%, thus it made 17.25% per annum or 1.44% monthly.

• Net pure discounted cash flow or NPV is calculated as the cash flow from operating and investment activities, divided into the sum of 1 and discount rate in the degree, depending on number of the period

• Accumulated discounted cash flow represents the total values of the pure discounted cash flow of all the periods.

Discounting of cash flows on the presented project for 12 months is carried out. As a result it is possible to conclude, that the project is investment attractive, as it has the positive accumulated cash flow in the 9th month making up $194 per an equipment unit, and in the 12th month it makes up $3,445.15 per the equipment unit.

Table 1. Payback period of the investment project and the net discounted income from its implementation, $

Number of the period (month) of implementation of the project on introduction of pilotless technologies	1	2	3	4	5	6	7
Investment costs	-10,294						
Cash flow, formed during implementation of the project (the economy of financial resources)	1,340	1,340	1,340	1,340	1,340	1,340	1,340
Current costs	367	72	72	72	72	72	72
Net operating income (cash flow from operating activities)	974	1,268	1,268	1,268	1,268	1,268	1,268
Cash flow from operating and investment activities	-9,320	1,268	1,268	1,268	1,268	1,268	1,268
Discount rate (17.25% per year), %	1.4	1.4	1.4	1.4	1.4	1.4	1.4
Net discounted cash flow (NPV)	-9,188	1,232	1,215	1,198	1,181	1,164	1,147
The accumulated discounted cash flow	-9,188	-7,956	-6,741	-5,544	-4,363	-3,199	-2,052
Number of the period (month) of implementation of the project on introduction of the pilotless technologies	8	9	10	11	12		
Investment costs							
Cash flow, formed during implementation of the project (the economy of financial resources)	1,340	1,340	1,340	1,340	1,340		
Current costs	72	72	72	72	72		
Net operating income (cash flow from operating activities)	1,268	1,268	1,268	1,268	1,268		

Cash flow from operating and investment activities	1,268	1,268	1,268	1,268	1,268		
Discount rate (17.25% per year), %	1,4	1.4	1.4	1.4	1.4		
Net discounted cash flow	1,131	1,115	1,099	1,084	1,068		
The accumulated discounted cash flow (NPV)	-921	194	1,293	2,377	3,445		

Thus, calculations have confirmed, that the projects, connected with introduction of pilotless special equipment and its automation are attractive from the investment point of view because of the essential economic return, expressed as the economy on the salary of drivers of the specialized equipment and also as the optimization of fuel consumption.

4 Discussion

Development of the technologies, connected with the work of self-driving cars and equipment goes fast. In many countries there are realistic plans of introduction of pilotless vehicles and their use in the field of public transport and also when performing various operations, especially with the repeating actions – loading and unloading works, cargo transportation, repair work, works on performance of road marking, etc.

The separate developments have to be gradually implemented in the mass use; however, the assessment of investment attractiveness of the implementation of such projects certainly has to proceed.

The estimation of the efficiency of replacement of the piloted snow-removing equipment and the watering equipment by pilotless equipment can become the following investigation phase, as this equipment usually follows the standard routes, set in advance, besides the use of such equipment is much more convenient at night, which is easily if not a human but a robotic complex operates the vehicle.

However one of obstacles of the use of such equipment in the roads is the lack of the settled legal aspect as well as traffic regulations, considering the availability of pilotless automotive equipment. Respectively, it is necessary to carry out the considerable work, directed to the creation of opportunities for mass implementation of the pilotless equipment. And a considerable part of works has to be carried out at the state level:

1) it is necessary to understand the responsibility and the degree of guilt in case of failures of the system; namely, to decide in which cases the producer will be responsible for fault of the software, in which cases the operator will be responsible for the incompetent management, which caused a road accident, in which cases the producer of the construction car will be responsible for technical failures;

2) it is necessary to create the infrastructure, in particular, uninterrupted providing with the high-speed Internet in the territories of the use of the pilotless equipment, which is necessary for instant assessment of the situation in the road, availability of marking and road signs;

3) it is necessary to normalize testing and approbation of the similar equipment, to create special polygons for carrying out safe tests.

5 Conclusion

Robotization and automation of production processes gains the increasing steam around the world. It allows the companies to increase their productivity, to lower costs and to exclude influence of negative sides of the human factor on the executed tasks. This research was devoted to the analysis of modern developments in the field of the pilotless construction equipment, as well as the opportunities and the prospects of its use during implementation of construction projects.

During the research the authors succeeded to carry out the following objectives:

1) to define and analyse the existing projects of the use of the pilotless equipment in road construction;

2) to simulate the process of road construction with the use of UAVs on the basis of the existing developments in the field of the pilotless construction equipment;

3) to carry out the assessment of economic efficiency of the use of the pilotless equipment in road construction.

According to the results of the analysis it is possible to conclude, that the integration of pilotless and autonomous transport and the use of robotic technologies is already possible in road construction already and will be economically effective.

Besides the revealed economic effect, the pilotless equipment will allow to minimize the danger for human life, especially when performing dangerous types of works, as all the processes will follow strictly set algorithms, on the basis of the automated means of the analysis of versatile information.

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