DOI: 10.65322/j.srd.05192026.50

DEVELOPMENT OF AUTOMATED CONTROL SYSTEMS AT THE CONSTRUCTION STAGE (USING LINEAR OBJECTS AS AN EXAMPLE)

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Abstract. *Improving production processes based on information modeling technologies in the construction of linear objects and researching the 3D (Trimble Grade Control) system to determine the economic efficiency of this system, the speed and quality of work, as well as creating an automated road construction management system based on 3D leveling and 3D design technologies and creating a simulation model. An automated control system was investigated. The economic efficiency of applying a 3D leveling project during the reconstruction of the "Vilyuy" federal highway section with the preparation of the foundation for asphalt paving has been calculated. It was established that economic efficiency increased due to increased speed and improved quality of the work performed. The operation of an automated control system for constructing linear objects is demonstrated. Information modeling technologies were studied. A system of processes for constructing linear objects is described. The effectiveness and advantages of using 3D leveling technology in road construction management production were identified: a threefold increase in the speed and quality of final leveling work; the exclusion of site processing (only in the event of project changes); the abandonment of planning and geodetic work; interactive calculation of land work volumes; and an increase in the manufacturer's operational efficiency. The introduction of information modeling technologies allows for the improvement of the production process organization model. Theoretical and experimental research, the development of new technical solutions, and the development of new designs for machines and working parts are relevant areas for improving machines for the construction of linear objects.*

Annotatsiya*. Chiziqli obyektlarni qurishda axborot modellashtirish texnologiyalari asosida ishlab chiqarish jarayonlarini takomillashtirish va ushbu tizimning iqtisodiy samaradorligi, ishlarning tezkorligi va sifatini aniqlash uchun 3D (Trimble Grade Control) tizimini tadqiq qilish hamda 3D nivelirlash va 3D loyihalash texnologiyalari asosida yo‘l qurilishini boshqarishning avtomatlashtirilgan tizimini yaratish va imitatsion modelini yaratish. Avtomatlashtirilgan boshqaruv tizimi tadqiq qilindi. Asfalt yotqizish uchun poydevorni tayyorlagan holda "Vilyuy" federal avtomobil yo‘li uchastkasini rekonstruksiya qilishda 3D nivelirlash loyihasini qo‘llashning iqtisodiy samaradorligi hisoblab chiqilgan. Bajarilgan ishlarning tezkorligi va sifati oshishi hisobiga iqtisodiy samaradorlik oshganligi aniqlandi. Chiziqli obyektlarni qurishni avtomatlashtirilgan boshqarish tizimining ishlashi ko‘rsatiladi. Axborot modellashtirish texnologiyalari o‘rganildi. Chiziqli obyektlarni qurish jarayonlari tizimi bayon etilgan.*

Аннотация. *Совершенствование производственных процессов на основе технологий информационного моделирования при строительстве линейных объектов и исследование 3D-системы (Trimble Grade Control) для определения экономической эффективности данной системы, скорости и качества работ, а также создание автоматизированной системы управления дорожным строительством на основе технологий 3D-нивелирования и 3D-проектирования и разработка имитационной модели. Исследована автоматизированная система управления. Рассчитана экономическая эффективность применения проекта 3D-нивелирования при реконструкции участка федеральной автодороги "Вилюй" с подготовкой основания под укладку асфальта.*

DOI: 10.65322/j.srd.05192026.50

Установлено, что экономическая эффективность повысилась за счет увеличения скорости и улучшения качества выполняемых работ. Продемонстрирована работа автоматизированной системы управления строительством линейных объектов. Изучены технологии информационного моделирования. Описана система процессов строительства линейных объектов.

Key words: *automated control, linear objects, technological corridors, 3D system, satellite GNSS receiver, motor grader, bulldozer*

Tayanch so‘zlar: *avtomatlashtirilgan boshqaruv, chiziqli obyektlar, texnologik yo‘laklar, 3D tizim, sun’iy yo‘ldosh GNSS qabul qilgichi, avtogreyder, buldozer*

Ключевые слова: *автоматизированное управление, линейные объекты, технологические коридоры, 3D-система, спутниковый GNSS-приемник, автогрейдер, бульдозер*

Introduction. Automated systems are constantly improving in the direction of intellectualizing the process of constructing linear and field objects. The development of new technical solutions, the conduct of theoretical and experimental research, and the development of new machine designs and working parts are relevant areas for improving machines for the construction of linear objects [1–2].

Literature review. Recent research in road construction has increasingly focused on the integration of automation, Building Information Modeling (BIM), digital design, and machine-control technologies. Hu et al. [1] emphasize the role of BIM-based information management in improving the extraction, organization, and use of construction data. Studies on BIM implementation also show that digital models can support coordination and process management throughout the construction lifecycle [5, 11–14]. In road construction, information modeling is particularly relevant because geometric parameters, terrain data, design elevations, and construction operations must be coordinated with high accuracy.

Automation of road construction processes has developed from conventional surveying and manual control toward intelligent machine-control systems. Kolbasin and Gumerov [15-27,29] discuss the automation of road construction operations, while Selevtsov [28] and Shishmarev [30] describe automation as an important means of improving the organization and efficiency of technological processes. These studies provide a theoretical basis for applying automated control to road-building machinery, including motor graders and bulldozers.

A separate group of studies concerns automated and intelligent control of construction machinery. Research on vibratory rollers and paving equipment has examined dynamic behavior, control parameters, and automated operating systems [2–4, 6, 7, 9]. Zhang et al. [8] investigated an unmanned rolling compaction system, while Wolf et al. [10] considered autonomous off-road robotic operations in road construction.

These studies demonstrate the broader transition from operator-dependent processes toward automated and data-supported machine control. Digital terrain models and 3D machine-control systems are especially important for grading operations. BIM and digital modeling technologies allow design information to be transferred to construction machinery, while GNSS-based positioning and sensors provide information about the actual position of the working equipment. The literature indicates that combining digital models, positioning technologies, sensors, and automated control can reduce dependence on manual surveying and improve the consistency of construction operations [13, 18, 22–24].

Despite these developments, the practical implementation of 3D machine-control technologies requires evaluation under actual road-construction conditions. The available literature provides substantial evidence concerning BIM, automation, intelligent control, and digital construction, but the effectiveness of integrating these technologies into the operational

DOI: 10.65322/j.srd.05192026.50

organization of specific road-construction projects remains an important practical issue. Therefore, the present study focuses on the application of a Trimble Grade Control 3D leveling system and its influence on the organization, productivity, accuracy, and duration of roadbed preparation.

Research methodology. The study uses a case-study and comparative research design to evaluate the application of an automated 3D leveling system in road construction. The research is based on the construction and reconstruction processes described for the A-380 "Guzar–Bukhara–Nukus–Denau" highway section in the Bukhara region. The investigated section was 1.3 km long, with a required implementation period of 21 calendar days and a target construction accuracy of ±2 cm.

The methodological framework combines analysis of the technological process, comparison of construction organization, and evaluation of operational performance. First, the configuration and operating principle of the Trimble Grade Control 3D system were examined. The system includes GNSS-based positioning, slope and height sensors, an onboard display/control unit, and a digital 3D project model. The position of the machine working equipment is determined relative to the digital design surface, allowing the operator or automated control system to maintain the required elevation and slope.Second, the organization of roadbed preparation using 3D machine control was compared with a conventional construction arrangement. The comparison considered the number and type of machines, the number of personnel involved, the need for surveying and setting-out operations, the duration of work, and the quality of the completed surface.

Particular attention was given to the reduction of manual geodetic operations and the elimination of repeated processing of the construction surface.Third, productivity and time performance were evaluated using the available production data. The study compares the standard shift productivity with the productivity achieved using the 3D leveling system and considers the duration required to complete the investigated road section.

The economic and organizational effects are interpreted through changes in equipment utilization, labor requirements, surveying operations, material use, and construction time.Finally, the obtained observations were used to assess the practical effectiveness of integrating 3D leveling, GNSS positioning, digital design, and automated machine control into road-construction operations. The methodology therefore combines technical analysis with a comparative assessment of production organization and provides a basis for evaluating the applicability of automated control systems to linear construction projects.

The aim of the work is to investigate the Trimble Grade Control 3D leveling system for constructing linear objects, the economic efficiency of this system, the speed and quality of work execution, and to study technologies used in the field of information modeling for constructing linear objects [3-7]. A simulation model was constructed to study the main processes of constructing linear and field objects. In order to improve the quality, accuracy, and speed of road construction work, control over planning processes, and the operation of road construction machinery (RMS) as a whole, the authors put forward the idea of creating an automated road construction management system (ADS) based on 3D leveling and 3D design technologies [8-10]. The essence of this system consists of three main components:

- development of a geographically linked 3D model of the project [11];
- creation of a cloud storage system, the 3D model of which can be remotely uploaded to the EMS, as well as the organization of functions for the interactive receipt and transmission of data about its actual operation [12];
- Installation of a set of high-precision geodetic receivers and inclimetric sensors on the HMM, as a result of which the HMM will see and determine the position of its working part relative to the loaded 3D model on the ground and will be able to switch to an automated operating mode [13].

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These systems are currently being actively developed and used in road construction worldwide; they are installed on various types of road loaders: motor graders, bulldozers, concrete and asphalt pavers (Fig. 1) [14].

In general, two types of such systems are widely used today:

1. Based on the installation of robotic tacheometers - a more expensive technology, but more accurate (precision is measured in millimeters).
2. The second type is with GNSS receivers.



Figure 1 Opportunities for 3D leveling at the construction site

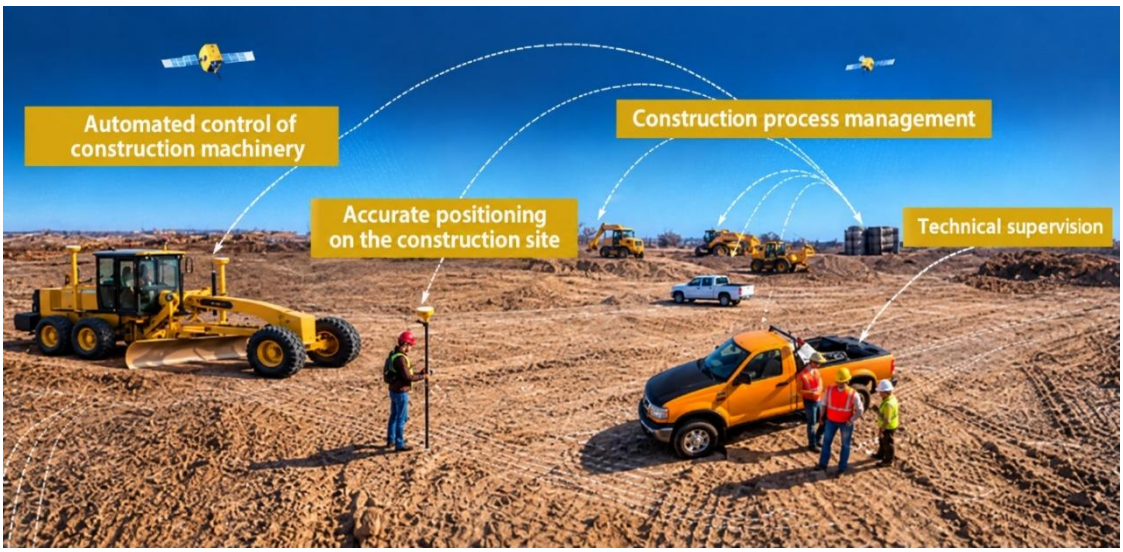

Fig. 2. 3D leveling capabilities at the construction site

In systems of this type, the remaining technological part and the principle of receiving geodetic corrections from the base geodetic station are common [18]. The main set of 3D systems includes: a hydraulic set, sensors responsible for compensating for the slope and inclination of the mast, a dashboard where all working data, designs, axis lines, and markings are stored, as well as, as mentioned above, a set of 2 types of geodetic equipment [19-21]. Currently, 3D systems include automatic technical control of road construction machinery (Central Control System for Road Construction Machinery) [22]. These systems are used for roadbed laying with autograders and bulldozers, as well as for profiling pavement layers with autograders [23]. System maintenance is carried out exclusively by a service engineer (technical specialist) of the supplier company [24]. Currently, there are not many of them, as not everyone is capable of installing, adjusting, and qualifiedly training the engineering and technical personnel and operators of the customer

DOI: 10.65322/j.srd.05192026.50

company (Fig. 2, a-c) 1 [25, 26].



a *b* *c*

Figure 3. Construction machinery equipped with a 3D automatic control system for road construction machinery: a - excavation of unsuitable soil to design marks; b - pouring of road pavement to design marks; c - excavation device with a motor grader to design marks

Today, there are many manufacturers of such systems in the world, produced in Europe, Japan, and China. Today, the most popular leveling systems in Uzbekistan are those from companies such as Trimble, Leica and Topcon [27]. For example, DST 3D systems at "Bukhara Oil Company" Bukhara Oil Refinery LLC are equipped with Trimble Grade Control. It was introduced to the local market by the company Saitek until 2022. Based on the experience of using these systems when performing work at LLC facilities, the "Bukhara Oil Refinery" and Trimble leveling systems have proven themselves reliably in advance. They operate stably, are easier to connect and control, and can be adjusted to the required elevation mark using the onboard computer or the driver's joystick computer according to the results of the slope and height sensors.

This eliminates errors caused by the "human factor," especially when performing final layout work at night, achieves satisfactory work accuracy, and allows for a significant increase in productivity and a reduction in costs for inert materials, fuels and lubricants, as well as labor [28, 29].

Overall, Bukhara Oil Refinery LLC is currently designated as the next technological platform in the Road Construction Department, incorporating a large set of interconnected technologies.

The main components of the hardware and software complex of the Road Construction Department (DCD) are presented in Table 1.

Table 1

Key components of the software and hardware complex

Component of the software and hardware complex	Description
3D CAD (CAD)	Automated 3D modeling and design system
ASU	Automated system of actual accounting and planning
COMBAT	Intelligent transport system with automated control with road construction equipment
3D leveling	Automated control of machinery and construction processes

A special technical infrastructure is created for the operation of the system at the facility,

DOI: 10.65322/j.srd.05192026.50

the main components of which are:

– Installation of the base geodetic station.

– placement of telecommunications equipment for rapid transmission of production data (office-field, field-office).

Designers work with two-dimensional models of construction objects. These are technical documents, plans, and drawings. BIM (Building Data Modeling) design differs fundamentally from traditional design work: the difference lies in the technological, planning, structural, and operational characteristics of the architectural object, which are integrated into a single information field (BIM model) [30-32].

Let us consider the effectiveness of applying a 3D leveling project with the preparation of a base for asphalt paving during the reconstruction of the 228-315 km section of the A-380 "Guzar - Bukhara - Nukus - Denau" highway passing through the Bukhara region (Table 1).

The task of the work supervisor is to prepare the foundation for the reconstruction and asphalt paving of the section of the federal highway A-380 "Guzar – Bukhara – Nukus – Denau," passing through the Bukhara region (Fig. 3).

The length of the section is 1.3 km, the required implementation period is 21 calendar days, and the required quality of work is +/- 2 cm.



Fig. 4. Construction process of the federal highway A-380 “Guzar - Bukhara - Nukus – Denau” passing through the Bukhara region: *a* - excavation of the reconstructed section of the highway to design markings;*b* - prepared foundation for laying the road surface

During the construction of this facility, due to the constant movement of machinery on the road, the work was complicated by extremely tight conditions; therefore, the only solution was to organize work using handrails (working with handrails significantly increases the volume of leveling work, while the constant movement of machinery creates a risk of knocking down the leveling piles). By using a 3D leveling system, we were able to prepare the base with an accuracy of +/- 2 cm from the project (within 20 days) and transfer it to the contractor. The deployed GNSS receiver, equipped with a loaded 3D model and a 3D system, helped promptly resolve disputes "on-site" with the customer service, the construction supervision service, and relevant contracting organizations, proving the quality and accuracy of the completed planning. When using machinery equipped with a 3D leveling system, it is not required to mark areas and paths with stakes. During the comparative analysis of the enterprise's productivity and organization," and on the section of the federal highway A-331 "Guzar – Bukhara – Nukus – Denau" passing through the Bukhara

DOI: 10.65322/j.srd.05192026.50

region, three units of road construction equipment were deployed in a two-shift mode by the Bukhara Oil Refinery JV LLC together with one road foreman, and 17 units of road construction equipment were deployed in a two-shift mode by the related contracting organization together with 13 production personnel, including: a chief engineer, a site supervisor, seven road foremen, and two geodetic teams (geodetic + surveyor) (Table 1). 3). The duration of work on a 1.3 km road section by the Bukhara Oil Refinery LLC was 20 days (Fig. 4).

Table 2

Refundance of investments made in 3D leveling systems (3D leveling system restoration)

Norm per shift, m3	Performance, %
690	100
1100	162

Table 3

Comparison of the performance and organization of the Road Construction Department of LLC "Bukhara Oil Refinery" with the contracting organization*

	The AD section of the A-380 "Guzar - Bukhara - Nukus - Denau" highway passing through the Bukhara region		Interplate blood pressure (IPT)	
ICH composition	Traffic engineer Total: 1 person.		1. Chief Engineer 2. Precinct officer 3. Seven Masters (on the line) 4. Two geodetic brigades (geodetic + surveyor) Total: 13 people.	
Techniques used	1 3D motor grader 1 3D bulldozer 1 dirt wheel	1 syllable	1 motor grader 6 bulldozers Roller 2 1 3D motor grader 7 excavators	6 syllables
Perform work due date	20 days, including regular federal traffic and working with "takings"		About a year	
Quality of work performed	Vertical surface leveling was performed without the greader operating with a tolerance of + \ - 2 cm. Road in satisfactory condition, with temperatures exceeding 0 degrees for two seasons, regular transit traffic, and "winter delivery"		Road in unsatisfactory condition after temperatures exceeding 0 degrees for two seasons and regular non-use	

*After the DSU of the facility was completed - "The reconstruction site of the A-380 'Guzar - Bukhara - Nukus - Beynov' highway passing through the Bukhara region - the construction contracting organization purchased five sets of 3D leveling systems for Topcon heavy machinery from Baykal-Optika LLC.

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The construction of the inter-field road by the contracting organization took about a year. Identified results and advantages of using the Road Construction Department during the execution

DOI: 10.65322/j.srd.05192026.50

of works.

- Increasing the speed and quality of finishing work by 3 times;
- exclude the processing of the object (only in case of project changes);
- abandonment of planning and geodetic works;
- interactive calculation of the volume of earthworks;
- increasing the work efficiency of the master/worker.

Analysis and results. An automated control system for the construction of linear objects was investigated. The economic efficiency of applying a 3D leveling project during the reconstruction of the A-380 "Guzar - Bukhara - Nukus - Denau" federal highway section passing through the Bukhara region with the preparation of the foundation for asphalt paving has been calculated.



Figure 5. 1.3 km section of the A-380 "Guzar - Bukhara - Nukus - Denau" highway passing through the Bukhara region

The possibility of using 3D leveling systems in the reconstruction of the section of the federal highway A-380 "Guzar – Bukhara – Nukus – Denau" passing through the Bukhara region with the preparation of the base for asphalt paving has been demonstrated. The use of 3D leveling systems will help Bukhara Oil Refinery LLC work with massive memory arrays, increase the speed and quality of final planning work, eliminate the need for site reconstruction, eliminate geodetic planning work, and provide an interactive calculation of the volume of earthworks. Thanks to the measurement of the 3D leveling system, it was possible to prepare the foundation within 20 days and hand it over to the contractor, whereas the project (Fig. 5).

Conclusions and suggestions

3D system *Trimble Grade Control* and information modeling technologies were investigated. A description of the system of processes for the construction of linear facilities at Bukhara Oil Refinery LLC was provided. In order to improve the processes of organizing the construction of linear facilities at Bukhara Oil Refinery LLC, it is planned to introduce information modeling technology. Effects and advantages of application in production have been identified

3D leveling technology R&D works:

1. Increasing the speed and quality of finishing work by 3 times.
2. Economic efficiency of this system.
3. Exclude the reconstruction of the facility (only in case of project changes), abandon planning and geodetic works, interactive calculation of the volume of earthworks, and increase the efficiency of the foreman's work.

DOI: 10.65322/j.srd.05192026.50

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