BIM of transport infrastructure – practical aspects of data collection for DTM creation

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Abstract. Road industry is moving towards the “Digital road” concept, and BIM of transport infrastructure is an integral part of it. Objects of transport infrastructure have linear structure required a special approach to their accurate coordinate description for proper digital terrain model creation. Approaches of railway and motor road experts to this issue is described. Implementation of mobile laser scanning and aerial photo survey using unmanned aerial vehicles for digital terrain model creation is discussed. Strengths and weaknesses of those two data collection methods are analyzed.

1. Introduction
Building Information Modelling (BIM) is a process involving various tools and technologies for generating and managing information on construction project across its lifecycle. Worldwide many countries are making efforts at the state level on developing and implementation of BIM standards. According to [1], the USA and the Great Britain are a bit ahead of other countries in this process [2–5]. It is important that main part of developed BIM standards cover mainly requirements for industrial and civil construction while BIM standards for infrastructure construction projects are under development. The article is focused on BIM in relation with transport infrastructure, i.e. railways and motor roads.

General trend in Russia today is moving towards so-called digital economy. There are publications describing what it means for railway [6–7] as well as motor road [8] industries. Although railways and motor roads differ by their organization, operation, methods of maintenance, etc., there is one common goal for both industries within “digital road” conception – implementation of BIM approach for all stages of the road life cycle.

Important part of BIM infrastructure project is Digital Terrain Model (DTM) of the territory where the road is located. Such DTM should have sufficient resolution to visualize all basic elements with required accuracy and detail. We would discuss practical aspects of DTM creation taking into account Russian specifics connected with using national coordinate systems.

Rail and motor roads have a narrow linear structure; their length may exceed hundred and even thousand kilometers. Nevertheless, BIM projects normally start at design stage and cover shorter lengths (few dozens of kilometers or less) provided those particular BIM projects are to be combined all together at later stage during road operation.

There was a number pilot BIM projects in Russia using different surveying methods of data collection for DTM creation. Among traditional surveys using GNSS and optical instruments modern technologies of mobile laser scanning and aerial photo survey by unmanned aerial vehicles (UAVs)
have been used for data collection what had significant impact on the result from point of accuracy and productivity.

Another important issue for assembling separate local BIM projects into bigger one is unified coordinate description of long linear object such as rail or motor road. For this purpose, there should be a number of known points along the road determined in some coordinate system(s). Selection of coordinate system also does matter. Existing national coordinate systems of Russian Federation such as SK-42, SK-95 or regional MSK (local coordinate systems) have some limitations to describe long linear object properly. Both railway and motor road industries undertaken some actions in this respect as described below.

2. Ensuring the unity of coordinate description
As already mentioned national coordinate systems of the Russian Federation such as SK-42, SK-95 or regional MSK do not allow one to describe long linear object properly, because those systems use mapping projection Gauss-Kruger having significant distortion in lengths at the borders of mapping zones. If the length of the project territory exceeds several dozens of kilometers, distortion may be at sub-meter level or even more. The distortion level also depends on object orientation. In particular, distortion in North-South direction is minimal while in West-East one it is maximal. In addition, the points representing SK-42, SK-95 and regional MSK coordinate systems at Earth’s surface (reference GGS points) have not sufficient positioning accuracy. Moreover, the density of existing reference GGS points is not enough in some regions for solving surveying tasks at high level of accuracy. All that together does not allow getting precise DTM of a long linear object using the current reference GGS point’s setup.

It is possible to overcome the described problem with SK-42, SK-95 and regional MSK by using new national global geodetic coordinate system GSK-2011, but density of reference points determined in GSK-2011 is not enough yet.

That situation is not acceptable for transportation industry, especially for design, construction and operation of high-speed railways. As a result, since 2008 Russian Railways (RZD) are developing and implementing their own corporate high accuracy coordinate system (VKS) [9]. In 2015, RZD developed and implemented Code of Practice [10] describing general requirements, rules of creation and use of the VKS. According to [10] VKS consists of the following components:

- Differential GNSS sub-system.
- Geodetic reference network (OGS).
- Communication segment.
- User segment.

Differential GNSS sub-system consists of:
- Permanent GNSS reference stations network.
- Network (computation, control) center.

The geodetic reference network consists of:
- Base stations – geodetic centers to install permanent or temporary GNSS reference stations; distance between base stations is within 50 km.
- Main control points – geodetic centers to install temporary GNSS reference stations; distance between main control points is within 4–5 km.
- Intermediate points – geodetic centers to install surveying equipment during surveys; distance between intermediate points is within 250–750 m.

Communication segment includes:
- Fixed communication channel – used to deliver satellite information from reference stations to network center.
- Mobile radio channel – used to deliver differential corrections from network center to mobile user equipment.

The user segment includes GNSS equipment of VKS users.
RMS error of the relative position of adjacent OGS points should not exceed 8 mm in plan and 5 mm in height (in the Baltic system of heights 1977) [10]. OGS points had been determined in different coordinate systems – ITRF2008, regional MSK, as well as special railway local coordinate systems.

It is important to note that accuracy requirements to operation of railways differ from those to motor roads. In particular, in motor roads segment there is no necessity to maintain road surface in design position over road lifecycle, also there is no need in monitoring high-accuracy position of moving vehicles in real time. At the same time, implementation of modern surveying technologies as well as development of preliminary BIM standards by the state company “Avtodor” resulted in understanding necessity of creation the corporate reference surveying network (named VOGS) having sufficient density of high-accuracy reference points along the roads comparatively to existing GGS setup [11]. Later general definitions and requirements to VOGS have been included into organization standard [12].

According to [11–12] VOGS consists of the following components:

- Network of frame stations.
- Network of benchmarks (or control points).

Frame stations ensure high-accuracy connection of VOGS to global coordinate systems ITRF2008 (international) and GSK-2011 (Russian). Centers of frame stations have to be permanently mounted at buildings with open sky view and availability of AC power connection to enable 5-days continuous GNSS observations; distance between frame stations is within 300 km.

Benchmarks have to be mounted by pairs into concrete foundations of road structures; the distance between points in pair is within 800 m while distance between pairs is within 30 km.

RMS error of the relative position of adjacent VOGS points should not exceed 20 mm in plan and 25 mm in height. VOGS points have to be determined in different coordinate systems – ITRF2008, GSK-2011 and regional MSK.

Currently VOGS segments had been created at several highways (M-1, M-4, M-11) operated by the state company “Avtodor” with total duration of approximately 2000 km.

Both VKS of RZD and VOGS of the state company “Avtodor” generate high-accuracy coordinate reference for effective implementation of advanced data collection methods for DTM creation.

3. Data collection methods

There is a number of methods enabling productive data collection. For big territories, technologies of airborne laser scanning and digital photography provide maximal productivity of the survey, but for quite small territories (few dozens of km) which we are talking about in the relation with BIM modelling at motor road design stage those methods are not reasonable from economical point of view. Alternatively, mobile laser scanning (MLS) method looks like most effective for such applications. MLS technology is developing rapidly resulting in permanent increasing of density, range and productivity of the survey. That is why MLS is widely accepted by the road industry specialists.

Another measurement technique to be discussed is air photo survey using UAVs. That method is also developing very fast demonstrating big potential for BIM data collection applications. It is obvious that every measurement technique has both strong and week points. Let us analyze MLS and UAV methods in more detail.

3.1. MLS survey

MLS technology has a number of advantages (strong points) comparatively to traditional surveying techniques [13]. Among those are:

- Rapid collection of enormous volumes of highly dense accurate geo-referenced data.
- Possibility of acquiring data with survey-grade accuracy at traffic speeds.
- Possibility of acquiring data in the form of 3D point clouds.
- Possibility of acquiring both laser-based and image-based measurement data.
In [14] the analysis of possible MLS applications for different stages of motor road lifecycle is provided. According to conclusions of this analysis, it is reasonable to use MLS for the following stages of road lifecycle:

- Design – engineering surveys.
- Construction – building control, executive survey.
- Operation – monitoring of road infrastructure, monitoring of road pavement.

In 2015, the company “Geoproektizyskaniya” LLC performed MLS of M-4 highway section to make DTM for subsequent repair of the pavement at this road section [15]. Part of DTM combined with the design alignment model is shown in Fig. 1.

![Figure 1. Part of DTM combined with design alignment model](image)

According to [15], application of MLS technology in this project allowed to reduce milling volumes by 40.3 % resulting in savings of 4.35 million rubles.

Among weak points of MLS technology, we should mention dependence from weather conditions (rain, snow, water at road surface, etc.) and presence of obstacles not allowing to “seeing” surface behind them. Because the laser-scanning system itself is located not so high above the road surface, such obstacles as noise protection structures, other vehicles, etc. could reduce the range of MLS effective operation.

### 3.2. UAV survey

Aerial photo survey using UAVs is the data collection method developing rapidly from year to year. A wide range of different options for UAV’s configuration make this method extremely flexible. Depending on the requirements, there may be selection from multiple options – airplane or helicopter type of vehicle, type of engine affecting the range of operation, resolution of photo camera, type of onboard GNSS equipment, etc.

Aerial photo survey using UAVs has following advantages:

- Rapid collection of big volumes of geo-referenced data.
- Flexibility to select proper vehicle configuration depending on range and accuracy requirements.
- Significant cost savings comparatively to operated aerial surveys.
- Easy operation, easy remote pilot education.
- Possibility to map territories from the top avoiding limitations for terrestrial surveys (such as obstacles for visibility, etc.).

In [16] there is description of the road construction project where the UAV’s data collection method was tested for monitoring of construction process. In this test, cost-effective helicopter-type UAV DJI Phantom 4 Pro having reasonable camera resolution was used. The tested road segment is 600 meters in length; it was surveyed twice with 3-weeks interval (Fig. 2).

For DTM accuracy estimation a set of control points measured by GNSS and electronic total station has been used. Accuracy estimation demonstrates RMS of 2.5 cm in plan and 3.0 cm in height [16].
In general, among weak points of UAV’s technology there are: dependence from weather conditions (rain, snow, strong wind, etc.), complicated procedure of getting flight permission, restrictions for flights in some areas (for instance, near airports), safety issues of flights over operated highways and living districts (in case of UAV’s brake and drop), etc. Nevertheless, aerial photo survey using UAVs has very positive perspectives for data collection applications in relation with BIM of transport infrastructure, especially in combination with other data collection methods such as MLS.

4. Conclusions

Both railway and motor road industries are moving towards implementation of the “Digital road” concept. BIM of transport infrastructure is an integral part of this concept. It turn, detailed and accurate DTM is an integral part of the road information model. By this reason, particular efforts should be made to ensure the unity of linear objects coordinate description. Modern technologies of MLS and aerial photo surveys using UAVs can improve significantly productivity and accuracy of DTM creation process. Due to weaknesses of every single technology, it seems reasonable to combine MLS and UAVs data collection methods for DTM creation.

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