COMPARISON OF METHODS TO MAP SELECTED TRAFFIC MARKINGS ON FIRST CLASS ROADS IN THE CZECH REPUBLIC

V. Šafář [1]*, J. Karas [2], P. Černota [3], J. Pospíšil [3]

[1] Research Institute of Geodesy, Topography and Cartography, v.v.i., 250 66 Zdiby, Czech Republic - vaclav.safar@vugtk.cz
[2] Upvision Ltd., Klikatá 18, 158 00 Praha, Czech Republic - jakub.karas@upvision.cz
[3] Technical University of Ostrava, Faculty of Mining and Geology, Department of Geodesy and Mine Surveying, Czech Republic - pavel.cernota@vsb.cz
[3] Technical University of Ostrava, Faculty of Mining and Geology, Department of Geodesy and Mine Surveying, Czech Republic - jiri.pospisil@vsb.cz

Commission I, WG I/7

KEYWORDS: Mobile mapping, UAV, aerial photogrammetry, mapping methods analyses, BIM

ABSTRACT:

The article presents conclusions of a comprehensive analysis of pilot data collection using four mapping methods. To validate mapping methods and procedures, we selected three ten-kilometer sections of the first class roads with different geomorphological, vegetative and transportation properties. All sections were measured by aerial photogrammetry using GSD=4cm, mobile laser scanning equipment linked with cameras, by geodetic surveying methods, and one section was also measured by UAV. The tested methods mapped selected features of vertical and horizontal traffic markings on the first class roads. The traffic marking measuring sets were analyzed from the perspectives of personnel, time, data, costs, and technological and organizational aspects. All the mapping methods were verified as mentioned above starting from work preparation phase, its terrain realization, captured data processing and detailed analysis, concluding with stating the advantages and disadvantages for each mapping method. One of the analysis outputs was proposals to change and refine road administrator's regulations. The mapping methods were compared with geodetic measurements. Analyses were also carried out in the context of creating digital data in 3D for the realization of BIM (Building Information Modeling) digital data in connection with the concept of the European Parliament and Council Directive 2014/24 / EU on Public Procurement, and Czech Government Decree 682 on the Concept of Implementation of the BIM Method in the Czech Republic of 25 September 2017 and Decree 958 of the Government of the Czech Republic of 2 November 2016 on the importance of BIM for the construction engineering and proposal of further steps to introduce it in the Czech Republic.

1. INTRODUCTION

1.1 Objective

The objective of the research team membered with experts from four Czech companies (PRIMIS Ltd.., VARS a.s., GB-geodézie Ltd. a Upvision Ltd.) and consultants from the VSB-Technical University of Ostrava, Department of Geodesy and Mine Surveying, was to analyze a pilot data collection and records verification of selected traffic markings of first class roads. The study describes mapping methods and related personal, time, data, financial, technological, coordination and required organizational links. Selected mapping methods were verified from the phase of mapping preparation work, via terrain mapping, processing of the obtained data to a detailed analysis. We also mutually compared the mapping methods stating their advantages and disadvantages. The work builds on Decree 958 of the Government of the Czech Republic of 2 November 2016 on the importance of BIM for the construction engineering and proposal of further steps to introduce it in the Czech Republic.

1.2 Mapping methods

Roads are usually mapped using geodetic survey, photogrammetry, laser scanning and mobile mapping methods. The required accuracy of the mapping methods was not set for the purposes of this comparison, but each method was supposed to render results of utmost accuracy when maintaining a reasonable cost/accuracy ratio.

1.2.1 Geodetic survey methods in road mapping: Geodetic survey mapping methods are listed below. Considering the capacities and accuracy of the contemporary electronic tachymeter, the first fifth mapping methods are reduced to the polar method in practice. The second used method in testing the accuracy and road mapping procedures was a measuring method using GNSS.

- Polar method
- Orthogonal method
- Forward intersection
- Intersection from distances
- Combined intersection
- Methods using GNSS

1.2.2 Methods of above-ground mobile mapping using photos and laser scanning: The measurement procedures related to above-ground mobile laser and photogrammetric instruments are very convenient for mapping and taking inventory of roads. However, to measure and process surveying results for mapping purposes, only such mobile laser scanning units, processing or graphic programmes, procedures and

---

* Corresponding author

measurement processing may be used, which ensure that the final accuracy complies with the expected $RMSE_{xyz}$

1.2.3 Photogrammetric mapping methods: For the purposes of the test, photogrammetric mapping methods were divided as manned aerial photogrammetric methods and remotely piloted aircraft systems (RPAS). RPAS was used only in the locality "Plateau".

1.2.4 Principles of mapping method verification: When mapping, accuracy of mapping is checked based on the statistical principles and respecting the fact that mapping verification must be carried out using different measurements (or methods in the case of comparing photogrammetric methods and laser scanning methods). It is advisable to check the mapping by other workers who are not biased by the initial mapping quality. The mapping accuracy is evaluated by comparing the mapping with geodetic survey methods in line with the principles below:

- Maximum coordinate error u_{xy} is determined as the double of the mean coordinate error m_{xy}. The maximum deviation in distance is determined as the double of the mean distance m_d.
- Maximum positional error u_p is given by the relation $u_p = \sqrt{2} \cdot u_{xy}$.
- When assessing the acquired coordination accuracy of a newly measured detailed survey point of planimetry as calculated in second point, the accuracy is considered as satisfactory when the selected mean coordinate error calculated by means of least square method is smaller than the maximum coordinate error u_{xy} as calculated in point first point. In case of a set of more than 20 newly measured detailed survey points of planimetry, at least 40 % of selected mean coordinate errors must be smaller than the basic mean coordinate errors m_{xy}
- The number of points to be checked is usually 5% of the mapping detailed survey points.

1.3 Calibration of instrumentation

An important requirement for mapping procedures is to use calibrated instruments, which is also subject to valid laws of the Czech Republic. The total station was calibrated, including the determination of an additive and multiplicative constant and related measurement uncertainty. Angel calibration procedures are related to the calibration of horizontal and vertical angles of total stations. The calibration of GNSS systems was carried out using the state position measuring standard of the Czech Republic – owner of trigonometrical net for testing is Research Institute of Geodesy, Topography and Cartography, v.v.i. Aerial cameras used in the manned aircrafts were calibrated in the manufacturing company Vexcel. Non-surveying cameras used in the RPAS test were calibrated in the non-surveying photo processing programmes.

2. DESCRIPTION OF THE TESTED LOCALITIES

2.1 Locality "Upland"

The locality "Upland" is a first class road I/19 from the town Žďár nad Sázavou, km 170, to the town Nové Město na Moravě, km 180, of a total length of 10 km. The road goes through a hilly terrain. A small section near the crossroads in the direction of Veselíčko is an access road to a complicated crossroads. The section includes the urban zone of

Radvaňovice, several crossroads and numerous road markings. In general, it is a road of medium to heavy traffic with many blind horizons. The traffic does not exceed 4000 vehicles a day. It is a medium complicated locality in terms of the number and complexity of Selected Road Infrastructure Equipment (SRIE) and traffic as well as in terms of used surveying methods.

2.2 Locality "Forest"

The locality "Forest" is a part of a first-class road I/19 from the municipality of Štěpánov nad Svratkou, km 201, to the village of Hodonín, km 208, with the total length of 9 km. 90% the road section goes through forests. A part of the road falls in the urban zone of the municipality Štěpánov nad Svratkou. The road is not very busy, and the mapped features are not many. Forested sections are difficult to survey using all the tested mapping methods. As for the number and complexity of SRIE and traffic, it is a simple locality. As for the used survey methods, it is a very complicated locality, namely for photogrammetry and mobile mapping, as the road goes through a forest. The daily traffic is about 2500 vehicles.

2.3 Locality "Plateau"

The locality "Plateau" is a first-class road I/50 from the town Slavkov u Brna, km 11, to the town Bučovice, km 20, of a total length of 9,5 km. The road goes through open country. It is a road in the rural area with numerous crossroads, bus stops, frequent road markings and extremely heavy traffic. As for the number and complexity of SRIE and traffic, it is a very complicated locality. As for the used geodetic survey methods, it is a very complicated locality with a daily traffic amounting to 16 000 vehicles. Considering photogrammetry and mobile mapping methods, it is a simple locality.

3. DESCRIPTION OF MAPPING PROCEDURES

This section describes the applied instrumentation and mapping procedures in the tested localities.

3.1 Technological description of geodetic survey method

Between 1 August 2017 and 15 September 2017 we measured the features (detailed survey points) of horizontal and vertical traffic markings in all the three tested localities. We used Trimble S6 Oneman total station, and instrumentation to measure GNSS - GPS Trimble R4. The survey was executed using RTK positioning using GNSS apparati (in sections without trees). In sections with a trees (without a quality GPS signal), measurements were made with the total station. A geodetic point field was determined using traverses oriented on both ends. From the polygon points, detailed survey points were measured using the polar method. Sketches were not made as the measured points were surveyed including codes for automatic drawings or 3D models. Each feature of the traffic marking was photographed to make the road inventory. Each detailed survey point is documented by its calculation method and determination accuracy. Based on the measurements and list of coordinates with codes defined for selected types of horizontal and vertical traffic markings, drawings from the supplied geodetic survey TXT files were loaded into the prepared database. In its structure, the database corresponded to the required data model of Ředitelství silnic a dálnic České republiky (Directorate of Roads and Motorways of the CR). The data may be visualized using QGIS software. In the final map output, the vertical traffic markings have 37 attributes in the

geodatabase, including photos of vertical road signs. In the horizontal traffic markings, each feature has 27 attributes, including the used colour, its reflectivity, date of last coating, etc. The road surface area is expressed and described using 25 attributes. The road safety features, such as crash barriers and handrails, also have 25 attributes.

3.2 Technological description of mobile laser-scan mapping

The mobile mapping data were collected on 1 September (locality "Plateau") and on 8 September 2017 (locality "Upland" and locality "Forest"). The data were collected using MOMAS (MObile MApping System) system placed on a ramp pulled by a car (Škoda Yeti). The system comprises of the so-called control unit, to which are connected a monitor and keyboard to control the whole system and monitor the functionality of the discrete devices. There is also a measuring unit equipped with GNSS/INS system to determine position and orientation, two laser scanners, two digital cameras and one spherical camera. The control unit is connected to the car battery and backup battery. An external odometer is also connected to the system. A detailed description of MOMAS system follows:

- GNSS/INS system to determine position and orientation of the mobile mapping system (two-frequency GNSS receiver, GPS+GLONASS L1/L2, frequency 10Hz
- Inertial measurement unit (IMU), frequency 200Hz
- 2 laser scanners (VQ250) for 3D documentation of the area of interest, maximum scanning frequency 600kHz (2x300kHz), 200 lines/s (2x100lines/s), FOV 360°, accuracy 5mm
- 2 digital cameras for a detailed photo documentation of the area of interest, resolution 5Mpx (2452x2056), max. 8 photos/s, FOV 80°x65°
- 1 spherical camera (Ladybug 5), 6 partial cameras, resolution 6x5Mpx (sphere 30Mpx), FOV 36
- 1 external odometer

Based on the required accuracy of the output mobile mapping data, it was necessary to do targeting and subsequent initial point (IP) survey. These points were measured twice in the open country in one-hour intervals using GNSS RTK – radio (locality "Upland" and locality "Plateau"), where the base station was placed on the net densification point of the Czech State Triangulation Network with a verification to at least one neighbouring point. In the forested area (locality "Forest") the initial point coordinates were determined using the combination of GNSS measurements and a traverse. The own data collection using the mobile mapping system was preceded by planning an optimal time for the data collection. Inter alia, we considered suitable climatic conditions, number of satellites above the locality and traffic density. In the given locality we selected a suitable site to begin and terminate data collection (open country with the highest number of satellites as possible), where we carried out a static observation of at least 5 min (at the beginning and end of data collection) and IMU calibration. At each locality, the data were obtained via two passages (each time in opposite direction) at car speed 40 - 45Km/h. The set laser frequency was 300kHz. Images were taken each 4m.

3.2.1 Trajectory calculation: The first step in POSPac programme was the calculation of a trajectory, along which the mobile mapping system moved. The calculation is based on the differential GNSS calculation. For such purposes, we used a virtual reference station of CZEPOS network and reference

station of TopNet Network (Žďár nad Sázavou). The coordinates of the reference station are given in the coordinate system ETRS89. The output MOMAS data are also defined in this coordinate system. When calculating the trajectory, combined are data from the GNSS receiver, inertial measurement unit and odometers, thanks to which the trajectory may be reconstituted in places of GNSS signal dropouts – e.g. when passing through the heavily forested locality "Forest".

3.2.2 Laser point cloud generation: The calculated trajectory was imported into a project in RiPROCESS software. The raw data acquired in the field were used to generate and georeferenced a cloud of laser points. For further processing, the cloud was converted into a standard format LAS 1.2.

3.2.3 Generation of images: Based on the calculated trajectory and exposure timing of the different spherical images and photos of a higher resolution, the images were georeferenced in POSPac and RiPROCESS programmes.

Figure 1- composed spherical image from LadyBug5 camera south-eastern edge of the town Nové Město na Moravě

3.2.4 Point cloud processing: The outcome of the above mentioned processes are laser point clouds in the format LAS1.2 and trajectory records. The data contain inevitable errors from using the systems. If the measurement dropouts exceed the permissible error, it is vital to improve the spatial and altitude data accuracy via smoothing the laser data to initial points. Prior to smoothing, the laser point clouds had to be divided into logical portions of adequate sizes. This process occurs in Microstation V8i programme with TerraScan add-on. The point cloud divided into irregular tiles (due to uneven data density) was compounded into a project for MDL applications of TerraScan and TerraMatch. In such applications, semi-automatic processes searched for distances in the laser cloud, corrections of the passages were determined and the corrections were applied subsequently. In the point cloud, geodetically surveyed ground control points were identified automatically and partially manually, absolute corrections were determined and the corrections were applied along the whole point cloud. This way, we reached the correct position and altitude of the point model representing the geometric conditions of the ground and engineering structures in the localities of interest.

3.2.5 Evaluation of inventory data from a laser point cloud: The smoothed laser point clouds were transformed into the state coordinate system (SJTSK, Bpv) and the required road inventory features were evaluated in the Microstation V8i programme. The coordinates of the evaluated feature points were exported as txt files divided into vertical and horizontal road markings, and as safety barriers. These points were imported into PanoramaGIS programme (by GB- geodézie Ltd.), where inventory data were filled in. The data were completed into the final inventory geodatabase in ArcGis.

3.3 Technological description of manned aerial photogrammetric mapping

3.3.1   Targeting of initial and check points: Prior to recording, the locality was targeted and monumented for ground control points (GCP). The signal size of the ground control points and check points was sufficient, and clearly interpretable at the signal size of average 2.5 multiple of GSD, i.e. circa 10cm. Figure 2 gives the targeting of the initial point No. 8000 in the locality "Upland". It is suitable for the initial point to be placed on a wider flat surroundings of the initial point (at least 20 pixels) so that they were correctly interpreted, pointed, identified via computational procedures, and correlated in all images where shown. An important requirement limiting the quality of the final mapping of traffic markings detailed points is the correct distribution of ground control points in the line locality of the tested roads. The distribution and position of the targeted initial points in the locality must be planned with respect to the borders of the final mapping, orthophotos and digital ground surface model, or its traffic markings features. The position of the points is planned for the sake of comparison and measurability on at least 4 aerial photos. In the course of targeting work, road video records were made from a car travelling at the speed of 50km/hour in order to fill the geodatabase and road inventory attributes.

Figure 2 – targeting of the initial point No. 8000 on the south-eastern edge of the Locality "Upland"

3.3.2   Photoflying of localities: Aerial photos with GSD=4 cm was carried out by means of aircraft Cessna 340 with registration OK-MIT. The used camera was Vexcel UltraCamXp installed in a gyro stabilization mount SOMAG GSM 3000. The camera is connected to GPS/IMU via IGI AEROcontrol-IITM.

3.3.3   Aerial triangulation: Having developed the aerial survey photos, a locality project is compiled, followed by the definition and setting of basic parameters to calculate aerial triangulation (AT) and determine the parameters of external photo orientation. Next, all the initial points are checked manually in all photos, where these occur. The next is the correlation process of automatic search of photo tie points and the calculation of external orientation parameters in all the photos of the locality. The final calculation of AT was executed in Photo-T programme.

3.3.4   Mapping the horizontal and vertical traffic marking features:
Based on the calculated elements of external orientation and requirement for the evaluation of horizontal and vertical markings features with all their attributes, the features of traffic infrastructure were evaluated in the stereoscopic regime using digital stereoscopic stations in MicroStation V8. During the evaluation, information on the mapped infrastructure feature parameters were added gradually. It was recorded in tables*.xls,

which were subsequently used to build the final database *.dbf and make drawings *.shp.

3.3.5   Conversion of DGN into SHP and completion of dbf: The geometry of all features was exported from the auxiliary *.xlsx files and *.dgn files of MicroStation V8 format acquired via merging all drawings of the stereophotogrammetric evaluation in the given tested section (from node to node). The built-in function "Export to Shapefile" of ArcGIS software was used for the export into shp format. In the vertical traffic markings, the geometry was exported simultaneously with marking the name and sign boards sequence in the given stationing. The discrete features of the vertical traffic markings were divided according to types (prohibitory, warning, etc.) in the course of stereophotogrammetric evaluation based on different types of cells. The name and order of the different sign boards on the stationing were attributed manually after merging all drawings of the tested locality in the given tested section according to the information from video records in MicroStation software. In the horizontal traffic markings, the geometry was exported simultaneously with marking the names of horizontal traffic markings of different names and broken line cadences. In the given tested sections, the markings were manually divided into different layers in MicroStation based on the information from video records. The geometry was exported and marked safety markings in the given tested section. Next, the features were divided manually based on the safety markings types into different layers in MicroStation software according to the information from video records. After the data export into the shp format, a required data model was made for each layer using ArcgisModelBuilder (automatic creation of an empty attribute table adhering to data types and names of different data items).

3.4 Technological description of the mapping work using remotely piloted aircraft systems

Having completed the premarking prepared for the manned aircraft with 10 premarked initial points, on 3 August 2017 the locality "Plateau" was scanned between 07:35 and 09:20 CEST using an unmanned aircraft MaVinciSirius (registration OK-X003N) in three overlapped blocks. The aerial work permit is registered with the Civil Aviation Authority of the Czech Republic (number 0003/LPUA). The used camera was Panasonic Lumix GX1 of 14mm focal point, Live MOS (CMOS) chip and resolution of 4592x3448 pixels. When imaging, the sky was clear, the temperature was 20°C, wind 4 m/s with air gust of up to 6 m/s. Each of the three flights lasted for the maximum of 25 minutes (a total of 75 min). A total number of 1175 photos were taken with the longitudinal overlap of p=80% and lateral overlap of 70%. The mean altitude above ground was 216 m. The nominal resolution was 5 cm/px

3.4.1   Preparation and planning of aerial imaging. The aerial assault was planned as a series of 3 flights covering the areas of interest so that each flight did not exceed the maximum time of flight for the used unmanned aircraft with a time reserve of 5 min in case of unexpected complications as well as to comply with the VLOS limit subject to the specifications of aerial work permit. The flight plan was prepared automatically in the relevant MaVinci Desktop software supplied by UAV.

3.4.2   Airspace restrictions: Before the aerial imaging, the area of interest was checked for potential airspace restrictions (with regard to the flight altitude we checked the following airspace: CTR/MCTR, ATZ, LKP, LKR, LKD). Before the

flights we also enquired about potential NOTAM news for the given locality.

3.4.3   Imaging: Imaging was carried out early in the morning, while the weather forecast was checked continuously for the localities in question (particularly the numerical model Aladin used by the Czech Hydrometeorological Institute and server Windguru.com). The time of imaging was decided the evening before flight. In case of unfavorable weather forecast the evening before imaging (more than 20% probability of rain, limited visibility, wind over 8 m/s), the aerial work for the forthcoming day was cancelled.

3.4.4   Take-off and landing sites: The take-off and landing sites were selected during the planning stage as the workers had a clear overview of the local topography based on the field reconnaissance and knew about possible restrictions. The sites were selected especially with regard to the requirement of permanent pilot's visual contact with the aircraft during the flight and with respect to the site safety considering obstacles on the ground.

3.4.5   Data checks and back-ups: After each flight, the photos were checked on the camera display as for quality (exposition, sharp definition, contents) and quantity (an expected number of photos per the flight length). About 400 photos were taken during each flight. After the 3 consecutive flights, the photos were copied from the memory card to two hard discs and the memory card was formatted.

3.4.6   Preparation of images for photogrammetric processing: After the flights, the so-called matching in MaVinci Desktop software was carried out, which logged the data acquired during the aerial photography to the photos. This permitted a visual check directly in the field, whether the whole area was photographed and whether no problematic sites occurred, namely due to imperfect overlaps. Another flight was carried out after such check in the field. Next, we filed all the photos and exported them, including their external orientation, into special photogrammetric software AgisoftPhotoscan to be processed. There occurred the whole process (align, point cloud, mesh) of automatic correlation and identification of determined ground control points for the area surveyed in the S-JTSK coordinated system and calculation, all the way to the export of required data – orthophotos and digital model of the ground surface in the form of a point cloud.

4.   COMPARISON OF THE TESTED MAPPING METHODS

With regard to GSD imaging (4cm), the requirements for the measurement of coordinates of targeted and monumented initial points in all the tested localities corresponded to the accuracy of building net densification point controls of SJTSK network. All the monumented and targeted points entering the photogrammetric processing of mobile laser scanning were taken using GNSS methods, namely the static method of 5-minute observations at each point with double measurements of the given point with at least a 90-minute delay to allow for the change of the GNSS satellite images. The requirements for RMSE points were set on the half value of the scanned GSD, i.e. 20mm in position and 25mm in altitude.

4.1   Comparison of detailed point mapping accuracy

To compare the accuracy of the different mapping methods in the different localities, we selected several types of features. The first entities to compare were discrete, unambiguously pointable, interpretable and determinable points acquired by all mapping methods. In horizontal road markings, a typical comparison point is the end of the continuous traffic line, horizontal road marked lane corner, road markings corner, or start of a direction arrow. An analogous comparison was also executed with vertical road markings, which themselves indicate a position via the intersection of the sign pillar with the ground (soil or concrete). The second type of entities was the evaluation of the positional, altitudinal, and spatial accuracy or distances of horizontal road markings mapped by the different mapping methods. To evaluate the positional and altitudinal accuracy of the surveying methods on the tested first class road sections, the following procedures were used and discrete points of horizontal, vertical and safety road markings were defined:

- An empty DGN file in the SJTSK coordinate system was loaded with points exported as a text file from the primary dgn files of each mapping methods (photogrammetric (PHTGM), mobile mapping (MM) and geodetic surveying GS)). Three dgn files were made this way, which contained all the points from the dgn drawings as outputs of each mapping method. The dgn files were processed in colour (PHTGM is blue, MM in green, and GS in brown;
- We opened the dgn PHTGM file, while referring to the MM and GS mapping results. The other reference raster data were orthophotos with GSD 5cm;
- We opened an xlsx. file. Observing the dgn files over orthophoto, we selected ordered triads and recorded them into an xlsx sheet. We progressed from the west to the east of each locality. To compare the discrete points of the horizontal road markings, we selected easily interpretable points in the field and point clouds for all the mapping methods;
- The procedure was analogous with the vertical road markings;
- Having ordered the triads from the whole locality, we
- selected points to be compared from the dgn exported text file and put them in an xlsx table;
- The data exported into an xlsx table were evaluated as discrete elements as differences of the geodetic surveying method minus the results of the photogrammetric mapping method (GS-PHTGM) and as differences of the geodetic surveying method minus the results of mobile mapping (GS-MM). We calculated the coordinate deviations and related RMSE. Next, we calculated the differences, deviations and RMSE between the photogrammetric mapping method and mobile laser mapping (PHTGM-MM).
- The acquired data were also plotted into charts.

Table 1 gives the values of root mean square errors (RMSE) when comparing the GS-PHTGM methods and GS-MM methods, when the geodetically surveyed discrete point coordinates are taken as the initial values unburdened by inner errors. For the sake of completeness, the right section of the table gives a mutual comparison of two contactless mapping methods, i.e. photogrammetric and mobile mapping. The comparison included over 1120 points in all the three localities.

GS-PHTGM (average of all tested localities)			GS-MM (average all tested localities)		
	Horizontal traffic marking features	Vertical traffic marking features		Horizontal marking features	Vertical traffic marking features
RMSExy	0,058	0,130	RMSExy	0,111	0,141
RMSEz	0,058	0,110	RMSEz	0,040	0,141
RMSExyz	0,085	0,170	RMSExyz	0,118	0,200

Table 1. Comparison mapping methods

4.2 Comparison of the mapped feature lengths using different mapping methods

Besides comparing the accuracy of position and altitude of the different mapped features and the final geodatabase, we also compared the completeness of the data set acquired via the different mapping methods. The differences in the number of features and the lengths of the horizontal road markings lines are caused by the different lengths of the mapped sections. For the sake of an objective evaluation of the different mapping method potential, the starts and ends of the sections in the different localities were not set uniformly. The different teams were left to freely interpret the work load from the submitter's task. In particular, there were pronounced differences in the individual mapping technologies' approach to collection road network ("sucking area" - access to main road subject to mapping), the starts and ends of which were not determined exactly. The outcomes of the comparison of the number of evaluated features using the different mapping methods are the following statements:

- With regard to the uncertainty of the start and end of the sections, the team did not measure identical lengths when using different mapping methods;
- The results differ with regard to the fact that the teams using different mapping methods began measuring the different features at unclearly defined points, defined on the road either by a coordinate or stationing;
- Having chosen identical mapped surface areas and mutually consolidated the areas from different mapping methods to an identical area and distance, it may be stated that using different mapping methods the road markings line lengths differed up to 0.05% in length;
- Minor differences in the lengths of the crash barriers and handrails were caused by different evaluations of their end points in the point clouds and aerial images.

4.3 Comparison of the number of evaluated mapped features using different mapping methods

Having corrected the mapping for identical starts and ends and excluded the measurements in collection road network ("sucking area") of diverse sizes in the locality "Upland", the mapping methods rendered the results below:

- geodetic surveying determined 98 stationings,
- mobile mapping measured 100 stationings,
- photogrammetry measured 91 stationings (without using video records)

4.4 Comparison of the mapping methods from the organization-technological point of view

The tested mapping methods have their advantages and disadvantages. As for the organization-technological point of view, the methods may be compared as for:

4.4.1 The duration of preparation works: When using the geodetic surveying methods to map common first class roads, the work may start from day to day if transport engineering precaution (TEP) is not needed. Mobile mapping technologies come second in this respect as only ground control points need to be targeted and surveyed (in the case of more complicated conditions) on the road, and data may be collected subsequently. When using laser mapping, a ten-kilometer section may be surveyed two days after activation, or order. The last comes the aerial photogrammetry as first, it is important to carry out premarking, and get coordinated with the air traffic control authorities and wait for suitable weather for imaging. From the activation to implementation, imaging of a ten-kilometer section takes about six days.

4.4.2 The number of people (professions) for a successful task execution: Using the geodetic surveying method, it is vital to involve three experts – surveyor, data base producer rendering the data into dbf for SHP, and an unbiased expert to check the final data processing. In mobile mapping, at least four professionals need to be involved (surveyor to measure the ground control points, who is usually also the mobile mapping car driver, a raw data base producer (calculations of trajectories and cloud adjustment), an expert to process point clouds into dbf for SHP, and an unbiased person to check the final processing. Photogrammetric methods need at least eight professionals: a surveyor to survey the initial points, aircraft flight planner and navigator (in one person), pilot, expert to develop digital images, expert for aerotrinagulation, aerial image analyst, expert to process images into dbf for SHP, and an unbiased person to check the final processing.

4.4.3 The instrumentation (owned or rented): In the geodetic surveying methods, it is sufficient to have a car, quality instrumentation to measure GNSS, tachymeter, computer for data processing (the costs, including software, fall below 25.000€ – without the car). As for the mobile laser mapping, the instrumentation is identical to the geodetic mapping methods. On top of that, it is also necessary to get a laser-scanning apparatus, high-performance computer and special-purpose software to evaluate the point clouds. The costs are about 400.000€. For photogrammetric mapping, the instrumentation needed by a geodetic surveyor is topped with an aircraft, camera with add-ons, special-purpose software for data processing, large data storage for data filing and storing. Such technologies start at 1.200.000€.

4.5 Comparison of mapping methods as for processing time

As for the time needed to process and provide the final data, outputs and reports using the different mapping technologies, we must point out that only the geodetic surveying method is proportional to the length in kilometres (or hours). As for time intensity, both the contactless mapping methods (PHTGM and MM) greatly depend on the size or length of the mapped road. For illustration, in aerial imaging the number of images is not relevant as for development from RAW format to the processing format as a hundred images take the same time as one thousand images. When arriving at the site of imaging, there is not much

difference in imaging ten kilometers of roads or one hundred of kilometers. What does matter is the cost of one image in the locality or the cost of labour per one kilometer of road.

4.6 Comparison of the mapping methods as for costs

Table 2 may be used to compare the costs and limit capacities. The financial intensity of data acquisition in MM is influenced by the requirement for the ground control point surveying. In case the spatial accuracy of features entering the geodatabase was reduced to 0.14 m, it would be possible to greatly reduce the costs skipping the requirement for ground control point targeting before surveying, or stipulating ground control point measurements only in localities where the accuracy using MM was obtained. This way, costs reductions of as much as 40 % per one kilometer of road may be achieved. Using PHTGM costs may also be reduced via skipping the ground control points from the technology. Smaller reductions may be achieved by changing the image resolution from 5 cm to 7.5 cm, or 10 cm, but at the expense of not being able to see/ process certain road markings. On the other hand, more geodetic surveying will be needed and costs will rise there. In general, the differences in image resolution (5 cm or 7.5 cm) is minimum as the aircraft travels an identical distance along the road (shorter flight at higher GSD may mean a reduction of 10 % in time and corresponding financial savings).

Financial cost of mapping methods and capacities - average of all three localyties in Euro								
	GS		MM		PHTGM		RPAS	
	min	max	min	max	min	max	min	max
Summary prices of three localities	8120	11600	8800	13400	10400	13200	1800	2340
Price per kilometer	280	400	300	462	360	455	160	220
Minimal length of tender (in km)	1		10		100		5	
Maximal capacities per year/one unit in km	400		2500		2400		700	

Table 2. Comparison of the mapping methods as for costs

5. CONCLUSIONS

When measuring the distances between a point measured geodetically and lines produced by contactless mapping methods, the biggest distances are 8.5cm (where 90% of the distances are from 4.5cm to 8.5cm in mobile mapping). However, 80% of the distances in the locality Slavkov-Bučovice is up to 4.5cm (in photogrammetric mapping it is almost 90%). The differences in the evaluation of horizontal line road markings are caused by the character of the contactless methods.

In photogrammetry the pointing to the surveyed point is direct, i.e. the photogrammeter places the measurement mark on a real object in the stereoscopic model. The final pointing error is thus an error of the maximum setup in the stereoscopic model, which is 1/3 to 1/2 of GSD in the subpixel observation. In this case, imaging with GSD=4cm, it is 1.3 to 2cm. The remaining deviations from the geodetic surveying, or from the real position in the field, are caused by the remaining deviations of aerotriangulation calculations.

In mobile mapping, the points and lines are pointed and interpreted from point clouds. Each point from the cloud is pointed by a laser fixed to a car. If the car goes at the speed of 45km/h, as in this test, one rotation (one section measured by laser) is 12.5cm from another at the laser mirror rotation speed of 100/s. With regard to the fact that the instrumentation described in 3.2 has two lasers, it may be said that point sections in the real terrain are described as profiles with step 6.25cm. In the direction of laser rotation is density between

points only 14mm. Such data are continuous sections along the direction of the car's passage. With regard to the pseudo-random character of the measured points towards the real objects, the pointing and interpretation of the line points is burdened with interpretation error from the point cloud at the level of 1/3 to 1/2 laser rotation value, i.e. 2 to 3cm perpendicularly to the direction of travel, and 3 to 4cm along the direction. These rather constant deviations caused by car travel may be easily removed either by a slower passage (the reduction in speed shall lead to an increase in measured sections) or increasing the laser measuring frequency (the market currently offers MM systems with lasers with almost triple higher mirror rotation and three times higher number of pulses, i.e. two to three times 'denser' data at identical car speed). Research outputs were used during implementation of the project "Integration of IoT data sensory platforms into GIS systems in the framework of Smart City e-services" (PV 10437), that was supported from the State budget through the Ministry of Industry and Trade. The major findings and recommendations are summarized below and in Table 3.

- When compared to the geodetic surveying, the average distances of horizontal road markings are 43mm in PHTGM, and 86mm in MM when using lines mapped from point clouds.
- When compared to the horizontal road markings geodetic surveying, RMSE is 58mm in PHTGM (at the altitude of 58mm) and 111mm in MM (at the altitude of 40mm).
- The contactless mapping methods (PHTGM with GSD=5cm and MM) are practically identical (95mm) measuring the horizontal road markings and comparing the spatial deviations with geodetic surveying. In the vertical road markings, MM is more accurate.
- The geodetic mapping method ensures collection even in relatively difficult terrain such as for example unclean road surface. However, when comparing the line between the reinforced and the unpaved edge of the communication, the line interpretation (grass x asphalt) have the difference in these measurements up to 45mm.
- Geodetic surveying may be used in relatively short sections without prominent increase in unit price (c. from 1 km of surveying length, a standard kilometre price may be used).
- The major disadvantage of geodetic mapping methods for first class roads is the staff safety. This may be eliminated using TEP, which means that data collection becomes longer and more expensive. The most troublesome is the surveying of the centre line, which may be partly replaced using an automated generation of centre lines from the side guide lines. The mean differences in the partial measured centre lines and the generated road axes were: Štěpánov nad Svratkou – Hodonín – 1.96 cm; Žďár nad Sázavou – Nové Město na Moravě – 1.56 cm; Slavkov u Brna – Bučovice – 1.8 cm.
- At traffic cuts, or any errors when painting the centre line, entering the road to survey the direct lines or arrows cannot be avoided.
- It is recommended to do a detailed evaluation of horizontal road markings (Road and Motorway Directorate of the Czech Republic,2017) and determine the procedures leading to the accurate definition of their surveying, which in some cases is not defined precisely.
- It is advisable to comply with the accuracy set by regulations (Road and Motorway Directorate of the Czech Republic,2017) to survey features on consolidated surface for the purposes of SRIE road inventory taking and consider whether this accuracy (0.03m) is needed.

- Taking the inventory of first class roads and requiring the accuracy of 0.03m (position and altitude) without the initial point field and single RTK measurement, it is not possible to guarantee the accuracy by geodetic surveying that would have to be implemented (Decree No. 383/2015 Coll).

- The major disadvantage of contactless mapping methods, particularly PHTGM, is their inadequate accuracy of SRIE position and altitude determination in forested and vegetation shadowed areas. In this case, MM must use ground control points to arrange the laser point clouds, and the photogrammetric method does not identify or measure the vertical and horizontal road markings covered by vegetation, or measured horizontal road markings incompletely. This disadvantage may partially be eliminated by acquiring a georeference video record to add the missing SRIE. This, however, means that PHTGM and MM must be combined.

Performance and safety parameters		Photogrammetry	Mobile mapping	Geodetic surveying
	km)	Good	Good	Acceptable
	Mapping of wider relationships	Good	Bad	Acceptable
	Financial intensity	Good	Good	Good
	Surveying speed	Good	Good	Bad
	Processing speed	Acceptable	Acceptable	Good
	Data collection degree of safety	Good	Good	Bad
	Surveying extent of unit group of given mapping technology	Good	Good	Bad

Table 3. The major findings and recommendations

REFERENCES

Road and Motorway Directorate of the Czech Republic, 2017: https://www.rsd.cz/wps/portal/web/technicke-predpisy/datove-predpisy (10 May 2018)

Decree No. 383/2015 Coll, Czech State Administration of Land Surveying and Cadastre https://www.cuzk.cz/Aktuality-resort/2016/20160104-vyhlaska-c-383-2015-a-c-384-2015.aspx (10 May 2018)

	Evaluated parameter / item description			Photogrammetry	Mobile mapping	Geodetic surveying
	Good	Acceptable	Bad			
Integrity of data series	Open country			Good	Good	Good
	Forested sections			Acceptable	Acceptable	Good
	Lawn and planting			Acceptable	Good	Good
	Urban zones			Good	Good	Good
Accuracy – RMSE	In position – discrete horizontal traffic marking points			0.058	0.111	0
	In position – lines of horizontal traffic markings			0.051	0.078	0
	In position – features of vertical traffic markings			0.130	0.149	0
	In altitude – discrete horizontal traffic marking points			0.058	0.040	0
	In altitude – lines of horizontal traffic markings			0.073	0.053	0
	In altitude – features of vertical traffic markings			0.110	0.117	0
	In 3D – discrete horizontal traffic marking points			0.085	0.118	0
	In 3D – lines of horizontal traffic markings			0.090	0.095	0
	In 3D – features of vertical traffic markings			0.170	0.189	0
Outputs	dgn			Good	Good	Good
	shp			Good	Good	Good
	DTM			Good	Good	Bad
	DSM			Good	Acceptable	Bad
	Point clouds from MM			Good	Good	Bad
	Orthophoto			Good	Acceptable	Bad
	Panoramatic images (video) from MM records			Acceptable	Good	Bad
	Video records of routes			Acceptable	Acceptable	Acceptable
	Photodocumentation of traffic markings			Good	Good	Good
	Data volume			Acceptable	Bad	Good
Project size	Small-size projects (units of km)			Bad	Acceptable	Good
	Medium-size projects (tens of km)			Acceptable	Good	Good
	Large size projects (hundreds of			Good	Good	Acceptable