Research to justify the perspective use of individual coordinate systems for contiguous objects modelling with the case study of Moscow - Saints Petersburg railway

Aleksei Portnov[1]

[1]Moscow State University of Geodesy and Cartography, Moscow, Russia

Abstract. The science of cartography should provide a historical mission, that is navigation, and also meet modern agendas including significantly expanding opportunities for BIM technologies, integrating functions of GIS and CAD systems. In this regard, cartography should be considered a fundamental basis for modern trends while creating digital twins of spatial objects. The practical part of the provided experiments included data collecting aimed at Moscow - Saints Petersburg railway infrastructure, the calculation of optimal parameters of the oblique Mercator projection in the Hotine version for the given object, and the construction of a 3D railway track model.

This research investigated the principles of unique cartographic projections, strictly focused on the certain functioning objects.

The research can helps many users and designers of digital twins of spatial objects pay their attention to the applied cartography specifics concerning these issues and also take into account the recommendations while creating Building Information Modelling (BIM) and Infrastructure Information Modelling (IIM) as well.

Introduction

The peculiarity of this research lies in the approach which regards the investigated object as infrastructure projects, not as local objects. Many scholars consider the relevance of creating digital twins, but the current scale of development still proves the remaining mismatches between software and innovative modelling capabilities based on BIM technologies. Large number of studies indicates [1] limited software opportunities to implement BIM.

One possible reason is the absence of projection solutions that can provide accurate navigation and take into account the Earth surface curvature while creating digital twins and linking of BIM projects geodata with state mapping and real estate accounting systems.

Therefore, if compared to BIM projects, for infrastructure objects it is more important to transfer geometric properties from the physical surface to the plane and back. That is the matter for the relevance to use individual coordinate systems.

Operation failures of critical infrastructure facilities (Italy 2003, European countries 2006) [2] strongly motivate to precisely create infrastructure models (power grids, in particular). In order to support risk analysis and emergency response planning, critical infrastructures must be modeled and displayed in 3D.

For instance, in real time networks of geosensors generate a huge amount of three-dimensional spatial and temporal data [3], orienting the development of BIM models to possess properties of data measuring systems. However, as noted in reference [2], neither the existing models of engineering networks nor the international standards for their modelling contain rules and recommendations for the integration of various infrastructure projects.

In this connection, the objective of the given study is to create a single high-precision coordinate space as the basis for the design and operation of Information modelling systems (digital twins) for infrastructure facilities.

Obviously, the design and operation of such objects suggests that the advantages of GIS systems should be combined with CAD systems, since the former is effective for managing geodata and web applications, while the latter is effective for managing construction data and civil information. A combination of both is essential for the efficient data and information management [4].

Data

The research was based on the example of Moscow - Saints Petersburg railway; the distance along one railway track axis made up 644666.00 km (on the WGS84 ellipsoid), the total length of all tracks, taking into account the station infrastructure, railroad hauls, etc., made up 1702825.59 km.

The latitude and longitude values which characterize the object geographic location are given in Table 1.

Table 1. Geographic scope of the railway location

	L scope, degrees	B scope, degrees
Min.	30,36182	55,77731
Max.	37,65807	59,92867

The commercial significance to consider local topography in modelling of objects was assessed using SRTM photo-surveying (GMTED2010 open data), interpolated to the cells with the dimension of 10m, 1km, 10km. In order to build digital terrain models the research used the following: ArcGis and the dataset in the form of Moscow - Saints Petersburg railway pickets, obtained as vector geodata of the OpenStreetMap project. The projection distortions were calculated using QGIS software.

Research

As noted before, there is a great difference between creating digital twins of local objects and infrastructure models. The BIM model is projected on the plane in the single local reference system, that is the coordinate system. Infrastructure objects that like BIM models

also possess the capacity of physical and information nondivisibility, are difficult to be designed in the single local space. This is primarily due to:

– incomparability of design geometrical dimensions on the plane and on the Earth surface;

– the fundamental necessity to use information about infrastructure models in the professional work of many agencies of local governments and regions that operate with projection coordinate systems.

Researches on BIM technologies not so sufficiently disclose such issues as the transfer of engineering projects to GIS system. So Junxiang Zhu and his co-authors [5] omit one noteworthy aspect about the projection in question while creating shape files that contain information about the coordinate system, and what is most importantly, how engineering projects in a local coordinate system are exported to GIS, because in this case, the project should already have parameters of the projection, or the mechanisms of affine transformations must be used. Therefore, the question of how different BIM geometry will be while exporting to GIS, is quite interesting and it should be studied.

In this case, there is a problem of how to create an object information model comparable to the required accuracy and ease of use [6] . And this is one of the serious matters of the entire geoinformation science development.

Fundamentally for mathematical cartography, it is possible to display any model on the plane. So, for instance, using the Russian National Standard in cartography, the railway line can be represented in two systems, Figure 1.

Fig. 1. The layout of the object relative to the 6-degree zones SK-42 (SK-42 is the state system of geodetic coordinates based on the Krasovsky reference ellipsoid).

However, it should be obvious that to solve the tasks of information modelling of such objects, this method does not suit due to significant distortions of geometric properties [7]. For example, Table 2 shows the values of the geometry distortions of the objects under study while transferring geometry from the WGS84 ellipsoid to the horizontal coordinate system of SK-42.

Table 2. Length of railway tracks when displayed in different coordinate systems

Coordinate system	The total length of railway tracks according to the SK-42 zoning, м	
	Zone 6	Zone 7
SK-42	1703334,02	1705247,80
WGS84	1702825,59	1702825,59
Distortions, м	508,43	2422,21

It is also possible to use local coordinate systems that have a 3-degree zone. This step reduced the distortions to 150 m, but the problem to lead the railway through four regions remained: Leningrad Region (Saints Petersburg), Moscow Region (Moscow), Novgorod Region, Tver Region, and this will not ensure the whole project to be implemented.

Taking into account the specifics of infrastructure projects that have a significant length relative to their width, oblique cartographic projections [8, 9] are mostly preferable for their display with BIM metric space. This particular projection provides the smallest distance between infrastructure elements and the projection axis. The principle of using oblique projections is shown in Figure 2 where the oblique reference frame {e1/, e2/, e3/,} replaces the normal reference frame {e1, e2, e3,} due to the rotation around the 3-axis ellipsoid denoted by Ω in ascent (the right ascension of the ascending node) while the rotation around the intermediate 1-axis by i (the "inclination").

a)   for horizontal coordinates

b) for spatial coordinates
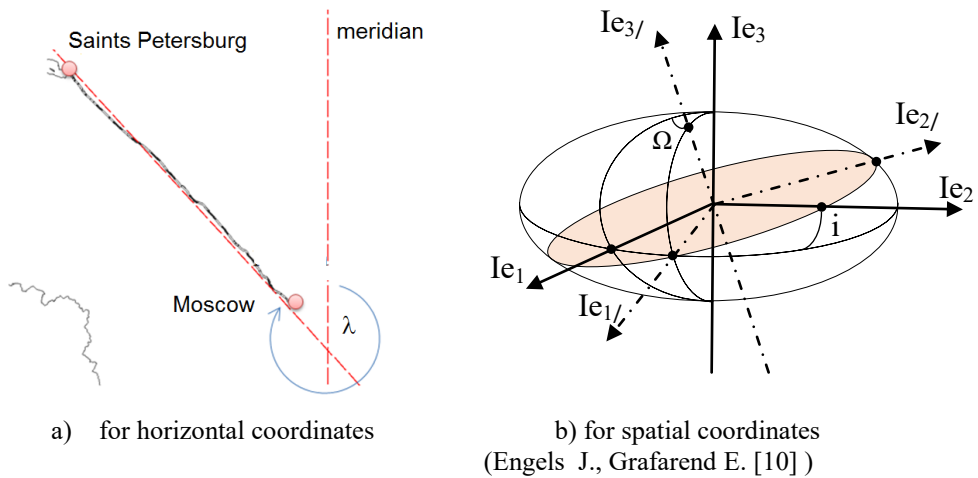(Engels J., Grafarend E. [10])

Fig. 2. Scheme of the axis repositioning for oblique projections relative to the original meridians

The optimal parameters of the oblique projection axis are quite successfully calculated using the least-square method as the algorithm that guarantees to calculate the least deviation of a set of infrastructure elements from the straight line, which is the projection axis.

Aimed to calculate the optimal values of the projection parameters, the following second-order algorithms were used: Levenberg-Marquardt Algorithm, Trust-Region and its

modification Trust-Region DOGLEG, which are one of the most common and effective optimization methods.

All algorithms used showed good convergence (Table 3) due to the positive definite Hessian matrix. It is worth being noted that Levenberg-Marquardt algorithm should be recognized as the best, the implementation of which made it possible to obtain the smallest deviations of the characteristic points of railway transport objects from the projection axis. Features of reconciliation of algorithms types for finding optimal values of target functions is an independent research task.

Table 3. Minimum distance from theoretical projection axis

	Number of feature points	Levenberg-Marquardt	Trust-Region	Trust-Region DOGLEG
Leningrad Region (Saints Petersburg)	545	0,0333911982	0,0333726929	0,0334084152
Novgorod Region	387	0,04331319567	0,0433217447	0,0433091966
Tver Region	774	0,0545134980	0,0545183781	0,0545145595
Moscow Region (Moscow)	356	0,0789784545	0,0789759848	0,0789977434
Total	2052	0,1296251638	0,1296262631	0,1296265803

In GIS, such optimal values are specified in the form of the azimuth (λ) of the meridian inclination, or by the coordinates of two points (as shown in Figure 2 a) and in Table 4) and the coordinates of the projection center.

Table 4. Optimal parameters of oblique projection for the given object

Projection length	Coordinates of the center, B	Axis points, L	Axis points, B
1702831,21	58,92568	29,0000	60,6763
-	-	38,0000	55,5886

The given parameters provide a minimum distance of no more than 10.70 km of railway infrastructure elements from the line of zero distortion - the projection axis. In metric form, the difference between the lengths on the sphere (1,702,825.59 m) and the proposed projection (1,702,831.21 m) made 5.62 m.

This allows the ability to display objects on the plan and conduct geodetic surveys with the scale accuracy of at least 1: 2000 throughout the entire length of the object, which is more than 600 km.

Discussion

In a number of global projects, studies have shown that successful and intensive implementation of BIM technologies did not result in the expected system evolution, which is noted in the article [1] and was also indirectly confirmed in the work of Susanna Vass, Tina Karrbom Gustavsson [12]. Until now, there remains an obvious gap between BIM and GIS in their complex application, especially at the design stage [13].

The presented results of the applied research have proved one of the possibilities to expand the scope of their application due to the proposed method of coordinate adaptation of BIM and GIS projects. The research showed that it is necessary to comprehend the peculiarities

of GIS-systems use in information modelling. So for those who conduct information models for accurate navigation, for engineering problem solutions, for the creation of cyber-physical systems to monitor objects with a significant length, it is necessary to design individual coordinate systems.

The proposed solutions will be a worthy argument while implementing three-dimensional systems for the design and accounting infrastructure facilities, creating a unified information platform for many services (for example [13]) and users throughout the entire life cycle of facilities.

Further steps in the evolution of information modelling largely depend on the creation of digital twins of the infrastructure for large monopolies and state structures, which will be the driving force to create a sustainable digital eco-system of countries.

Acknowledgements

Reference

1. Gulnaz Aksenova, Arto Kiviniemi, Tuba Kocaturk and Albert Lejeune (2019) From Finnish AEC knowledge ecosystem to business ecosystem: lessons learned from the national deployment of BIM, Construction Management and Economics, 37:6, 317-335, DOI: 10.1080/01446193.2018.1481985

2. Becker T., Nagel C., Kolbe T.H. (2011) Integrated 3D Modeling of Multi-utility Networks and Their Interdependencies for Critical Infrastructure Analysis. In: Kolbe T., König G., Nagel C. (eds) Advances in 3D Geo-Information Sciences. Lecture Notes in Geoinformation and Cartography. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-12670-3_1

3. Maiorov A.A., Materukhin A.V. Analysis of existing technologies used to process streams of spatio-temporal data for modern information measurement systems //Measurement Techniques. 2017. Volume 60, Issue 4, pp. 350–354 DOI: https://doi.org/10.1007/s11018-017-1200-9.

4. Trisyanti, S. W., Suwardhi, D., Murtiyoso, A., and Grussenmeyer, P. (2019) Low cost web-application for management of 3d digital building and complex based on BIM and GIS, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci., XLII-2/W17, 371–375, doi.org/10.5194/isprs-archives-XLII-2-W17-371-2019.

5. Junxiang Zhu, Xiangyu Wang, Mengcheng Chen, Peng Wu,Mi Jeong Kim. Integration of BIM and GIS: IFC geometry transformation to shapefile using enhanced open-source approach. Publication: Automation in Construction. Publisher: Elsevier. October 2019. https://doi.org/10.1016/j.autcon.2019.102859

6. Yuju, H., Peng, H., Yanian, W. et al. Mathematical basis for large scale GIS and terrestrial digital products. Geo-spat. Inf. Sci. 4, 35–41 (2001). https://doi.org/10.1007/BF02826922

7. Portnov A. M. (2021) Coordinate basis adaptation of cataloging of unified immovable complexes included into the Russian-Chinese initiative project "One Belt – One Way" (by example railway transport). J. Phys.: Conf. Ser. 1715 012054. DOI: 10.1088/1742-6596/1715/1/012054.

8. John p. Snyder. Space Oblique Mercator Projection. Mathematical Development. Geological survey bulletin 1518. Library of Congress catalog-card № 81-607029

9. John W. Hessler. Philip lee Phillip society occasional paper series №.5. Library of Congress. Washington. D.C.2004 Geography and map division.

10. Engels, J., Grafarend, E. The oblique Mercator projection of the ellipsoid of revolution IE2a,b. Journal of Geodesy 70, 38–50 (1995). https://doi.org/10.1007/BF00863417

11. Lee, J., & Zlatanova, S. (2008). A 3D data model and topological analyses for emergency response in urban areas. In S. Zlatanova & J. Li (Eds.), Geospatial information technology for emergency response (ISPRS book series) (pp. 143–168). London: Taylor & Francis Group.

12. Susanna Vass & Tina Karrbom Gustavsson (2017) Challenges when implementing BIM for industry change, Construction Management and Economics, 35:10, 597-610, DOI: 10.1080/01446193.2017.1314519

13. Zhiliang Ma, Yuan Ren. Integrated Application of BIM and GIS: An Overview. Procedia Engineering. Volume 196, 2017, Pages 1072-1079 https://doi.org/10.1016/j.proeng.2017.08.064.