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A MODEL TO DETECT CARTOGRAPHIC BASE CHANGES AFFECTING THE MAP UPDATE

Lina Papšienė[1], Kęstutis Papšys[2], Jelena Vaitkevičienė[3]

[1]Vilnius Gediminas Technical University, Saulėtekio al. 11, LT-10223 Vilnius, Lithuania
[2,3]Vilnius University, M. K. Čiurlionio g. 21/27, LT-03101 Vilnius, Lithuania
E-mail: [1]lina@rytai.lt (corresponding author); [2]kestutis.papsys@rytai.lt; [3]jelena.vaitkeviciene@gf.vu.lt

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Lina PAPŠIENĖ, *BSc., MSc.*
Date of birth: 1975.
Education: BSc. (1993–1998), MSc. (1998–2000) from the Department of Geodesy and Cadastre, Faculty of Environmental Engineering, Vilnius Gediminas Technical University.
Affiliations and functions: PhD student at Vilnius Gediminas Technical University.
Research interests: generalisation and harmonisation of spatial data, spatial data infrastructure.
Publications: author of six scientific articles, two conference papers.
Present position: head of the Spatial Data Department at SE GIS-Centras, member of the council of the Lithuanian Association of Surveyors, member of the Lithuanian Association of Cartographers.

Kęstutis PAPŠYS, *BSc., MSc.*
Date of birth: 1975.
Education: BSc. (1993–1997), MSc. (1998–1999) from the Faculty of Natural Sciences, Vilnius University.
Affiliations and functions: PhD student at Centre of Cartography, Faculty of Natural Sciences, Vilnius University.
Research interests: GIS methods for the management of natural, social and ecological hazards, generalisation of spatial data, spatial data infrastructure.
Publications: author of four scientific articles, one conference paper.
Present position: head of the Information and Technology Department at SE GIS-Centras, member of Lithuanian Association of Geographers, member of the Lithuanian Association of Cartographers.

Jelena VAITKEVICIENE, *BSc., MSc., PhD*
Date of birth: 1976.
Education: BSc. (1994–1998), MSc. (1999–2000), PhD (2000–2005) from the Centre of Cartography, Faculty of Natural Sciences, Vilnius University.
Affiliations and functions: senior geodesist at Vilnius University 1998–2000, lecturer at Kaunas University of Applied Sciences 2005–2006, lecturer at Vilnius University 2008–2010, senior specialist at Vilnius University since 2010.
Research interests: nautical and aeronautical charts, thematic cartography.
Publications: author of 12 scientific articles, six conference papers.
Present position: head of Spatial Data Management Group, member of Lithuanian Association of Cartographers.

Abstract. Spatial data of cartographic bases are often used for nautical and aeronautical charts, reference maps, or other thematic maps. Traditionally, such spatial data sets of different scales are created apart from each other, are stored in different databases, and, in many cases, have no relations. This makes the update of the spatial data a complex and costly task. Meanwhile, automatic detection of changes in spatial data, when older versions of data are compared to more recent version of data, saves time in this process. To model such a process, two major tasks are solved, namely, detection of a change in spatial data and identification of its significance to answer whether the change detected is significant enough that an update of the data will be effective. The model also takes into account the requirements for spatial data, the scale of the data, and update methods.

Keywords: spatial data, spatial objects, changes, map updating, scale, generalisation, GIS.

1. Introduction

The past decade saw the creation of large national spatial reference data sets, where variety of data and levels of detail depend mostly on scale. They store various thematic spatial objects identifying natural and anthropogenic objects of terrain such as hydrography, various land-use areas, built-up areas, buildings, transportation networks, etc. These spatial data sets are used in planning, in management, and as a cartographic base for the preparation or representation of other thematic spatial data or maps. A cartographic base is the main source for the analysis of terrain for various purposes with the use of applications based on geographic information system (GIS) technologies (Pincevičius *et al.* 2005, 2006).

The high volume of spatial data sets causes national mapping agencies (NMAs) problems with the preparation, update, and technical maintenance of spatial data. Frequently, spatial data sets having various scales and the same theme happen to be updated separately from each other. This may sometimes result in different information in the data of various scales. However, even with the consistent update of spatial data sets (when data having a larger scale are used in the preparation or update of spatial data having a smaller scale), the update of smaller-scale data becomes, at the end of the process, out-dated.

Moreover, the quick update of spatial data is affected by three major factors. First, real objects of terrain are ever-changing as a result of natural and anthropogenic phenomena. This suggests that spatial data sets are always irrelevant and thus must be updated as soon as possible. Second, the scope of the use of geographic information systems is constantly increasing. Consequently, the use of GISs is directly related to spatial data, since using irrelevant data to solve geographic tasks may lead to an unreliable result (Ramirez 1996). Third, methods of automatic data capture and innovative GIS software allow spatial data sets to be quickly updated. With various possibilities of automatic data capturing (e.g. remote sensing, GPS), information on spatial objects may be captured in a short period of time. GIS software allows such data to be used for the effective update of spatial data sets.

The update is usually done by interpreting the most recent raster data. During this process, the changes between existing spatial and raster data are defined manually or semi-automatically. Research has been conducted over the past decade to automatically exclude objects and detect differences between spatial data and image data (Hoffmann *et al.* 2000; Knudsen, Olsen 2003; Jung 2004; Walter 2004, Matikainen *et al.* 2004) and between different spatial data (Goesseln, Sester 2003; Comber *et al.* 2004, Huabin 2009).

Concerning a cartographic database, update costs can be reduced if larger scale data already updated is used in this process by automatically comparing the data of different periods and identifying relevant changes. Detection of spatial object change is the process of identifying differences between objects at different times. The main goal of such a task is to detect significant changes (Richard *et al.* 2005) affecting spatial data updating.

2. Regularity of update of cartographic base

Spatial data of cartographic databases is stored in several scales: e.g. 1:10,000, 1:50,000 and 1:250,000 in Lithuania (Papšienė, Papšys 2011) and 1:10,000 and 1:50,000 in Belgium (Bayers 2010). Different update methods are often used with spatial data having different scales, with the update intervals being different as well. For example, in Lithuania, data at a scale of 1:10,000 are updated constantly, while those at the scales 1:50,000 and 1:250,000 are updated on a 5-year basis or even more. However, new regulations that came into effect in 2010 require Lithuanian mapping agencies to update national reference data of all scales on a regular basis. This means that any change, appearance or disappearance of a real object on the terrain (e.g. the building of a new road, demolition of a building, cutting down of a part of a forest) should affect the modification of data on all scales. To meet these requirements, it is important to improve methods and processes of updating spatial reference data, which would allow identifying changes in objects at larger scales and transferring, generalising and integrating those into a spatial data set of a smaller scale (Tab.).

Table. Updating spatial reference data in Lithuania

Scale	Source data	Update methods	
		(present)	**(future)**
1:10,000 *Base scale*	Ortho-photo maps Field measurements	Vectorisation Integration	Vectorisation Integration
1:50,000	Reference data at the scale 1:10000	Initial automatic generalisation Manual generalisation Vectorisation	Automatic generalisation
1:250,000	Reference data at the scale 1:50000	Initial generalisation Manual generalisation Vectorisation	

As table shows, larger scale national reference data must be used in the update of smaller scale reference data. Larger scale data should also be employed to update the cartographic base of thematic spatial data sets or maps. For example, to update the cartographic base of aeronautical maps at a scale of 1:20,000, one should use national reference data at a scale of 1:10,000. Moreover, available data from a larger scale cartographic base can be employed to update smaller scale spatial data (Fig. 1). Anyhow, in both cases larger scale data must be updated; otherwise, the update process has no purpose.

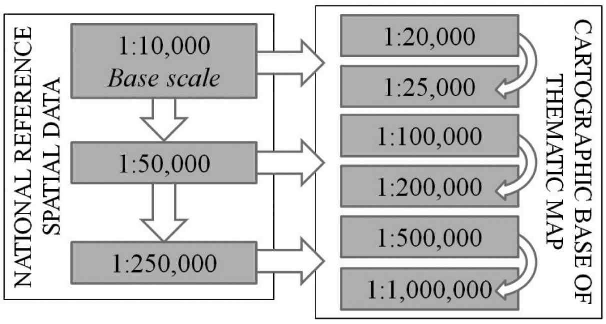

Fig. 1. Example of source data for generalisation depending on scale of spatial data (map) in Lithuania

3. Spatial data generalisation

The update of the spatial data of a smaller scale cartographic base often includes the generalisation of larger scale spatial objects, during which process the amount of information is reduced and the representation of complex object is simplified, retaining significant elements and eliminating insignificant elements of the characteristics of the object.

The benefit of methods for the generalisation of spatial data was recognised in the 20th century, and in a few decades various algorithms were developed to carry out different generalisation tasks.

In reducing expenditures for work, NMAs seek to automate the creation and update of spatial data. There are several reasons prompting the use of automatic procedures:

1. First, it saves time, which is necessary to manually smaller scale update maps. For example, the Swiss NMA Swistopo needs at least one and a half or even three years to fully update reference spatial data and maps based on the latest orthophotographic view (Kreiter 2006). The situation in Lithuania is similar. It takes one to one and a half years to manually update spatial reference data at a scale of 1:10,000 based on orthophotographic views. Then, the update of smaller scale data follows, which is completed in approximately a year up to a year and a half.
2. The second reason is the qualification and subjectivity of the specialists who manually create and update spatial data. This will result in different results achieved by different specialists (Kilpelainen 2000).
3. The third reason is the place accuracy of spatial data, which is lower when generalisation of spatial data is performed manually than when it is performed automatically (McHaffie 2002).

Many years of research evidenced no standardisation of generalisation operations and terminology. Thus, in defining generalisation processes, various scientists were guided by their own research results (Cecconi 2003). For example, A. H. Robinson (Robinson *et al.* 1995) identified only four generalisation procedures, whereas R. McMaster and S. Shea defined as many as 12 different functions of generalisation (McMaster, Shea 1992). The latter classification distinguishes two types of transformations: ten operations for graphic representation of spatial objects and two functions for attributive characteristics of objects:

1. Spatial transformation: simplification, amalgamation, refinement, displacement, smoothing, merging, exaggeration, aggregation, collapse and enhancement.
2. Attribute transformation: classification and symbolisation.

The choice for appropriate operations for specific generalisation tasks depends on various factors. The scientific literature defines three of them, namely, advanced analysis of a situation, type of spatial object (e.g. road, forest), and map scale (Cecconi 2003). In the update of the cartographic base in general, when larger scale data are used, the following generalisation methods can solely be used for the process (Fig. 2):

1. *Selection* of objects by using defined descriptive and/or geometric attributes (e.g. rivers longer than 10 km, buildings larger than 25 m^2).

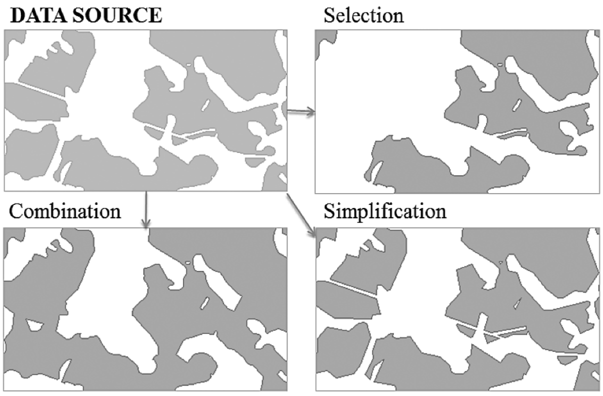

Fig. 2. Spatial data modification after generalisation

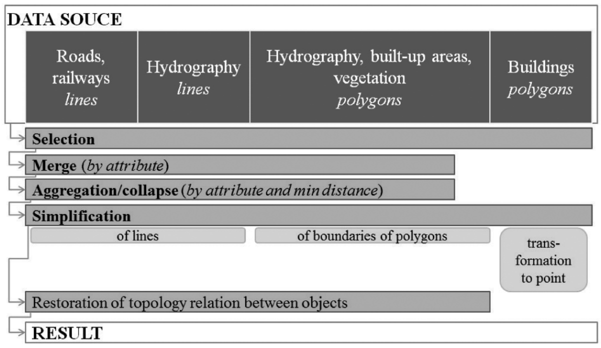

Fig. 3. Concept of generalisation of reference data

2. *Combination* of objects with the same attributes and minimum distance between them, and allowable minimum area of the objects.
3. *Simplification* of object configuration (geometry) by using defined maximum deviation and tolerance and allowable minimum area of the objects.

4. Concept of generalisation of spatial reference data

When the update of spatial data includes automatic generalisation, the update process has to be described in detail. This is necessary since generalisation is an irreversible process, and the result achieved may not live up to expectations at all. Specification of the process of generalisation covers a few stages (Papšienė, Papšys 2011).

1st stage. *Determination of requirements for spatial data* (density, resolution of geometry). This needs to be done because with no specific requirements or specifications of data, it is impossible to properly model generalisation. For example, it may appear after generalisation that the generalisation algorithm applied does not take into account requirements of minimum distance between neighbouring vertexes.

2nd stage. *Selection of methods of generalisation and determination of parameters of generalisation* that will allow obtaining a result satisfying the requirements of the 1st stage.

3rd stage. *Determination of the priority of the methods selected*. This is necessary for the generalisation of the right data. For example, without the selection of spatial objects that should be represented at a smaller scale, the process of generalisation will take a lot of time in comparison with the generalisation of selected objects only.

As a rule, the generalisation of spatial reference data follows the order of the processes as presented below (Papšienė, Papšys 2011) (Fig. 3):

1. Consolidation of spatial objects with the same qualitative unique characteristics (*conditional*).
2. Aggregation of spatial objects with the same qualitative unique characteristics according to defined minimal distance between objects (*mandatory*).
3. Reduction of the density of spatial objects (*mandatory*). Additionally, spatial objects may be divided into specific territories (e.g. city, towns and rural) before the reduction process (*optional*).
4. Simplification of spatial objects according to defined requirements (*mandatory*).
5. Smoothing of simplified spatial objects (*optional*).
6. Restoration of topology between related spatial objects (*conditional*) (e.g. two objects with a common boundary will, most probably, lose it after simplification, and it will have to be restored).

5. The principles of identifying changes in spatial data

Generalisation in the update of spatial data allows to generalising all objects or only those changed. In the first case, we are dealing with absolutely new objects (a new data set) having no relation with the earlier version of the object. For this reason, no earlier specific corrections, e.g. those made manually, are retained. In this case, practically no time needs to be invested into object analysis in order to identify the places requiring the update. Nevertheless, such an update requires rather great:

1. Technological resources, since all spatial objects are created anew.
2. Human resources, since all newly created spatial objects need to be reviewed to evaluate the quality of generalisation. Depending on the number of cases when objects were generalised improperly, those objects are corrected manually or a new process of generalisation is initiated.

The process of updating spatial data will take less time in a second case than in the first because only the objects that have been changed are generalised. For that reason, this case has more advantages. It is however important to invest in the modelling and development of a mechanism to detect and evaluate the changes in spatial objects.

Larger scale spatial objects before and after updating are compared during identification of the altered spatial objects. If generalisation is used to update smaller scale spatial objects, it is important to answer a few questions in the comparing process (Fig. 4).

- Has an attribute of the spatial object changed?
- Has the minimum distance between the spatial objects changed?
- Has the configuration (geometry) of the spatial object changed?
- Is the spatial object new?
- Has the spatial object been deleted?
- Will the altered spatial object be generalised?

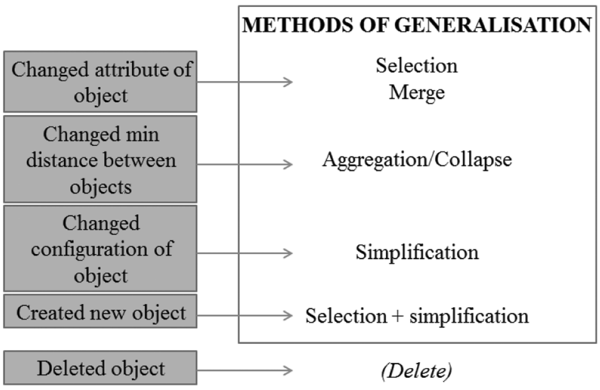

Fig. 4. Relation between detected change and process of generalisation

Upon detection of places of change in spatial objects, one must find objects with altered geometry (configuration) and/or attribute. Furthermore, to identify how significant the change in an object is, one should know in advance the requirements for smaller scale spatial data. First, whether the updated object may be of interest at the smaller scale must be defined, that is, whether the object has the same attributes as spatial data of the same theme at the smaller scale. For example, there is a change in configuration of an unpaved road. If, however, a smaller scale map covers only paved roads, such a change would have no effect whatsoever on generalisation. If, on the other hand, the altered object has the necessary attributes, evaluation must follow as to how significant the change in its configuration is. For example, an object vertex that moved by 1 meter in the initial data will not be seen in renewable spatial objects at a scale of 1:50,000.

6. A model to detect changes in a cartographic base

Preparation of a model to detect changes in a cartographic base was preceded by analysis of national spatial reference data at scales of 1:10,000, 1:50,000 and 1:250,000, as well as of data requirements and their specifications of creation and update processes currently in use.

The cartographic base includes various spatial objects that may have different types of changes. For that reason, there are two types of procedures for detecting and evaluating changes in the model: identification of a change in attributes and identification of a change in configuration (geometry). Both cases include:

1. Establishing the relationship between comparable spatial objects: via unique identification of objects or via spatial join.
2. Comparing the source data (larger scale spatial objects) of the same spatial data set and the same territory before (*sdata.v1*) and after (*sdata.v2*) the updating process.
3. Comparing update source data (*sdata*) and renewable data (smaller scale spatial objects) (*udata*) of the same territory.
4. Evaluating the effect of the detected change (*Change.udata*) in the spatial object on the renewable data (smaller scale spatial objects).

The detected change in a spatial object is significant if it may affect the update process of smaller scale spatial objects. Such detected changes are grouped (falling under no more than two groups) by type of effect:

- effect on the creation and integration of a new spatial object (*Create New Object*);
- effect on the update of an attribute of a spatial object (*Update Attribute*);
- effect on the update of the configuration (geometry) of a spatial object (*Update Configuration*);
- effect on the deletion of spatial data (*Delete Object*).

The model to identify changes in spatial objects affecting the update of map data includes a set of processes.

1. Establishing the relationship between source data before and after updating.
2. Search for changes:

a) analysis of related spatial objects (*sdata.r*) and selection of the spatial objects that change after updating. Spatial objects with altered attributes fall under *Group A1* and spatial objects with changed configuration belong to *Group A2*;

b) selection of the spatial objects (*sdata.v2*) after updating that have no relation with the spatial objects before updating. These objects fall under *Group B*;

c) selection of the spatial objects (*sdata.v1*) before updating that have no relation with the spatial objects after updating. These objects fall under *Group C*.

3. Analysis and evaluation of objects from groups A1, A2, B and C:

a) analysis of the spatial objects from groups A1, B and C and selection of objects with suitable attributes. Other objects are removed from the groups;

b) analysis of the spatial objects from group A2 and selection of objects with significant changes in configuration (geometry). Other objects are removed from the groups;

c) analysis of the spatial objects from groups B and C and selection of objects with suitable attributes of geometry. Other objects are removed from the groups.

4. Establishment of the relationship between spatial objects from groups A1, A2, B, and C and renewable data (smaller scale spatial objects) (*Change.udata.v1*).
5. Analysis of spatial objects from groups A1, A2, B and C that are related to renewable data. The spatial objects from groups (Fig. 5):

a) A1 and B are identifying places for the updated attributes of spatial objects;

b) A2 identifies places for the updated configuration of spatial objects;

c) C identifies places for deletion of spatial objects;

d) analysis of spatial objects from groups A1, A2, B and C that have no relation with renewable data. The spatial objects from groups A1, A2 and B are identifying places for the creation of new objects.

A conception of the model is represented in figure 6.

Significant changes in source objects are detected by using a defined parameter of change in value (e.g. area, length). Additionally, the expected size of the change in the object after generalisation has to be evaluated. Minimal allowable change in the spatial object depends on the scale of cartographic base or map (this scale affects the resolution of the map) and specific uses (Fig. 6). For example, the graphic resolution of printed maps is higher than the screen resolution of Web maps. Therefore, visible change in the first case will be less than in the second.

Significant changes in configuration (geometry) have to be done in the specific order (Fig. 7).

1. Union of spatial objects from *Group A2* before and after update. Selection of changes in the geometry of the object (only part of the object is changed) (*A2.changes 1*).
2. Creation of buffer zones around source objects before update (*Buffer 1*). The size of the buffer depends on the specified resolution.
3. Selection of changes in the geometry of the spatial objects inside the buffer zone (*A2.changes 2).*
4. Simplification of the changes in the geometry of the object (*Simplify Object*).
5. Creation of buffer zones around updated objects (*Buffer 2*). The size of the buffer depends on the specified resolution.
6. Selection of changes in the geometry of objects outside the buffer (*A2.changes 3).*

7. Conclusions

Updating spatial data sets is complicated and time-consuming work. An optimal data renewal process should include only the changed objects in the update. This paper describes principles and actions to detect significant changes in spatial objects that affect the update of spatial objects. The model that is prepared provides the possibility to compare the data of different periods and identifies relevant changes in the attributes and/or configuration (geometry) of spatial objects. The model can also identify places where spatial objects have to be created or deleted. The model that is described provides a framework to develop the model to detect changes in a cartographic base that affect the update of related spatial objects.

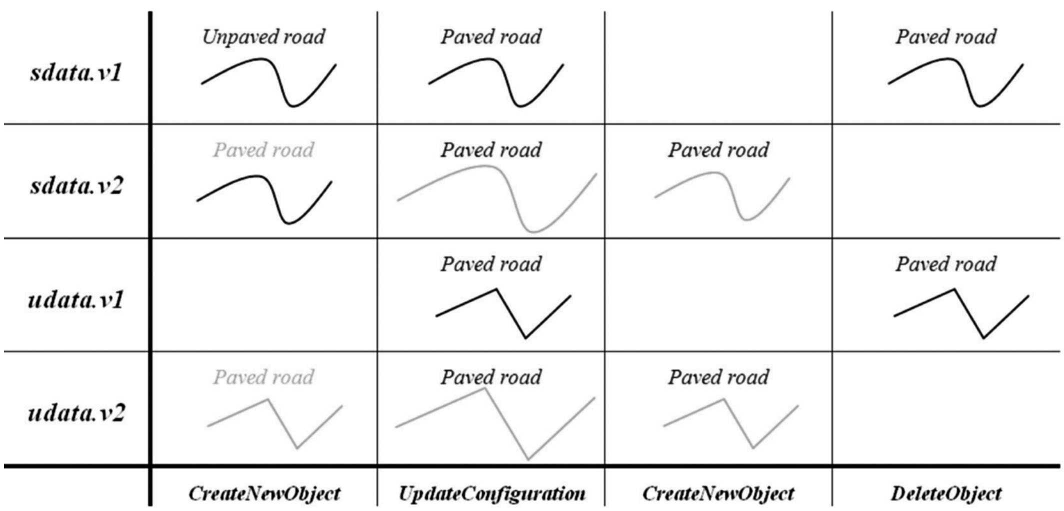

Fig. 5. Examples of the relationship between type of object change and type of object update

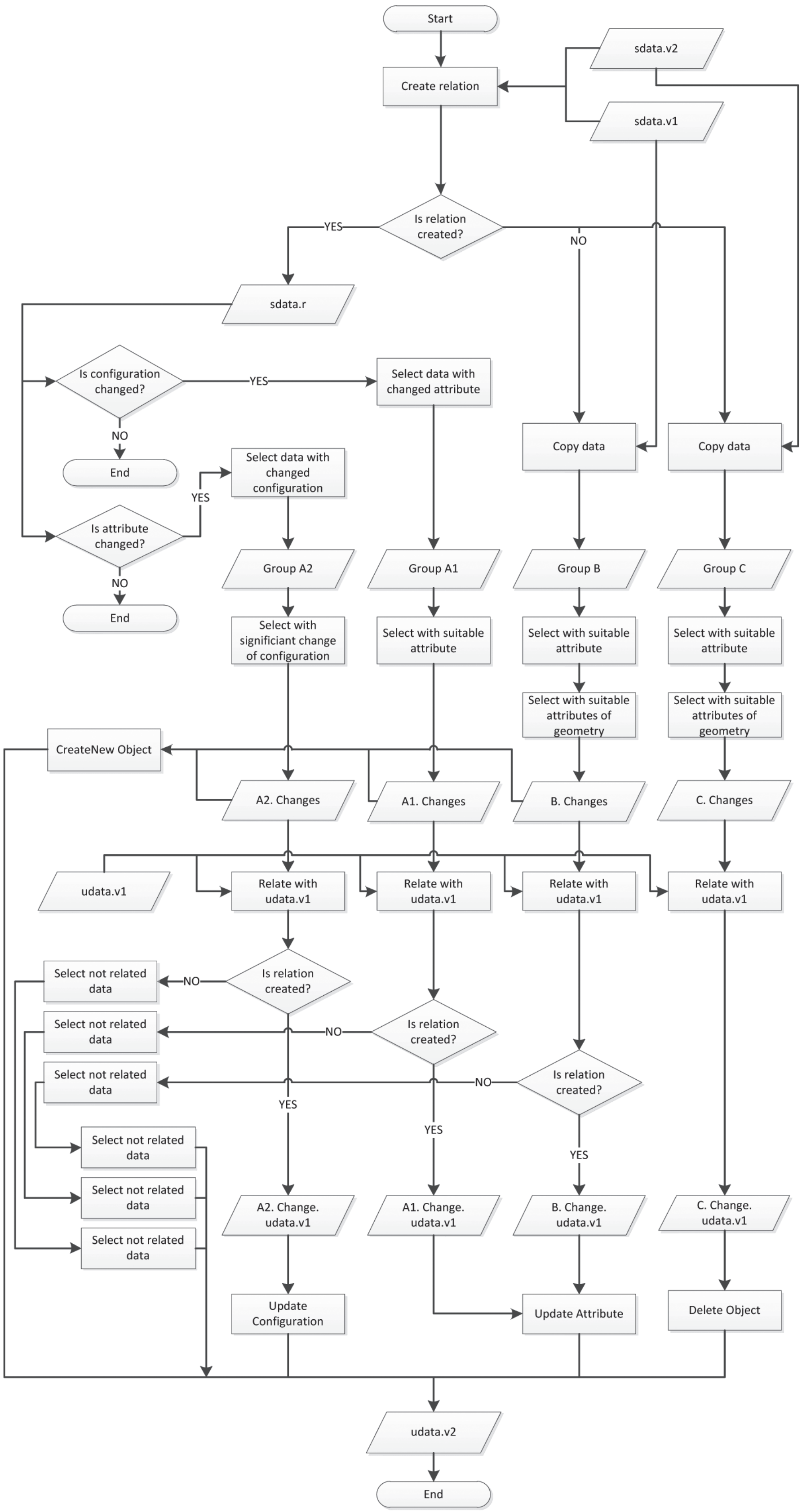

Fig. 6. A model for detecting changes in a cartographic base

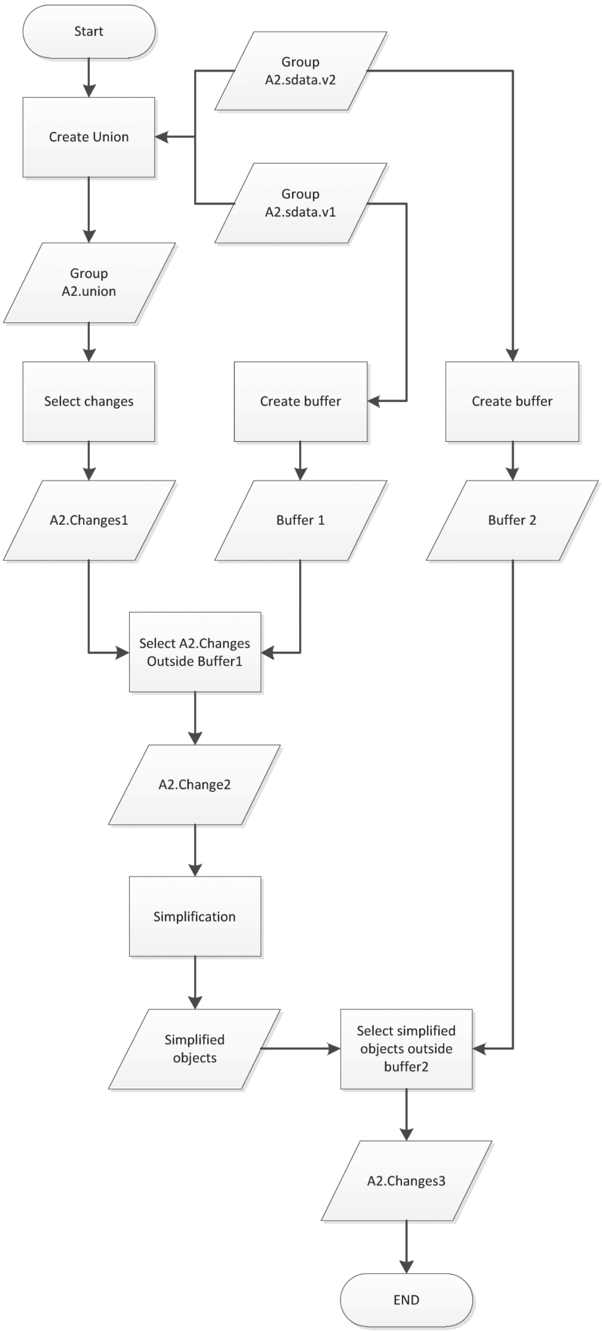

Fig. 7. The processes for determining significant changes in the geometry of spatial objects

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