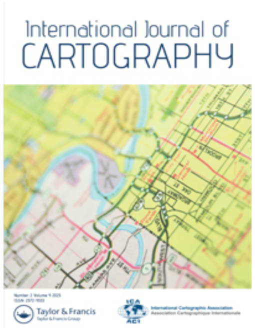

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Possibilities of systematizing cartographic rules

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ABSTRACT

Map production is currently based on the use of digital geographic data and advanced software tools for their processing and visualization. The source digital geographic data requires modification according to written and unwritten rules prior to its use for map creation. Both written and unwritten rules then govern the actual processing of the maps. This article suggests a systematization of the rules that are used in the whole technological cycle of map creation. The proposed system of rules is processed into the design of a knowledge ontology database intended for solving especially collapses and other complicated situations in the creation of topographic maps. It focuses on problems that are time-consuming to solve by manual cartographic processing and whose automation has a great potential to bring capacity savings in topographic map creation.

RÉSUMÉ

La production de cartes repose aujourd'hui sur l'utilisation de données géographiques numériques et d'outils logiciels sophistiqués pour le traitement et la visualisation des données. Les données géographiques numériques initiales doivent être modifiées en fonction de règles écrites et implicites avant leurs utilisations pour la création de carte. Ce sont autant les règles explicites que les règles implicites qui guident le processus de conception cartographique. Cet article propose une systématisation des règles qui sont utilisées lors du processus technique complet de création de cartes. Le système de règles que nous proposons est transformé en conception d'une base de données ontologique des connaissances conçue pour résoudre spécifiquement les disparitions et autres situations complexes rencontrées lors de la conception de cartes topographiques. Ce système se concentre sur des problèmes qui sont longs à résoudre lorsqu'ils sont traités de façon manuelle et pour lesquels l'automatisation a un grand potentiel de gain lors de la création de cartes topographiques.

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Cartography; cartography rules; generalization; knowledge database; ontology

Introduction

Geospatial data and information at all levels of details (LoD) are in high demand by all types of users, from the general public to public administration and industrial applications to scientific and research teams. One of the critical characteristics of geospatial data that is

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demanded by users is its high timeliness. Therefore, geospatial data creators and providers strive for the shortest possible update cycles, which for some feature groups can be several days or even hours.

One of the important user groups of geospatial data are map creators themselves. On the one hand, this group is a consumer of data and, on the other hand, it ensures that user demand for paper or electronic visualized geospatial data is met using cartographic procedures and rules, while ensuring the requirement for high timeliness. However, cartographic production is not as flexible as the updating of geospatial data models regarding the updating of the content of the maps provided.

On one side, data of the highest accuracy and detail are required for computer applications and control systems, while on the other side, geographic data are visualized in the form of a 'map base' which, in additional to accuracy and detail, is also subject to the requirement of (visual) legibility. This is practically a combination of the three mutually contradictory requirements of content completeness, positional accuracy and map legibility on maps scale of 1:25,000 and smaller used mainly for state government and military purpose.

It is therefore the most essential task to set the correct procedures and parameters of cartographic generalization and visualization in relation to the purpose and use of the final map. However, it is always necessary to resolve the issues related to how to use the data coming from source database and their appropriate reduction, and at the same time how to formally define the generalization rules. The following text briefly presents one possibility how to solve the issues raised.

Generalization rules

In generally, generalization rules can be defined in many different ways, which are usually related to both data generalization in GIS data models and generalization in the cartographic sense. If only map outputs are taken into consideration, then this involves, for example, suppressing unnecessary details to recognize important patterns, ensuring the usability of the map for the end user, ensuring a visually balanced and pleasing presentation, etc. (Mackaness & Ruas, 2007). Cartographic generalization rules are used to create all types of maps, but their complexity and detail varies.

The most complicated cartographic generalization procedures are used for topographic maps, where on the one hand there is a requirement to maintain maximum accuracy and detail in the representation of the map content. On the other hand, their scales do not allow to fully using all the properties of the original underlying digital geographic data from the source databases that are used to create the topographic maps. In especially, the position of features and usually their shape cannot be fully preserved, as well as all their thematic properties cannot be preserved and display.

The definition of '*Cartographic Rules*' (Cartographic Rules, Cartographic Conventions or Cartographic Constraints) is currently used for defining the generalization and visualization procedure of data sets. In the scope of map creation technology, cartographic rules are usually used to define the procedure and control of the cartographic generalization (Beard, 1991; Hallie, 1999, 2003; Hallie & Weibel, 2007). In general, these are rules that define how the output of the visualization should look like, i.e. they define the target states and relations of the map elements. For example, those watercourses are displayed starting from 2 cm in length, electric power lines start and end at a building or pole symbol, etc. These rules are in fact declarative – they set a target state and are usually stated without a description of how to achieve that target. This allows for flexible modelling, but on the other hand often results in an inconsistent approach and the possibility of reaching even a few dozen 'correct' solutions. As an example of the definition of cartographic rules:

- Cartographic rules not only specify the basic properties and superimposing of cartographic symbols, but they may also define rotations, displacements and even or geometry manipulations of symbols with exactly the same goal as in traditional computer-assisted cartography (Iosifescu et al., 2009).
- Cartographic representation rules lead to a quality topographic map (CartouCHe, 2012).
- Cartographic rules are sets of rules have evolved regarding the selection and placement of text – particularly in relation to topographic maps (ICSM, 2020).
- A set of rules for designing and building a symbol key, i.e. for creating the appearance of a map (Voženílek et al., 2011).

The comprehensive approach to symbolization and generalization rules can be found in Defence Topographic Map for 1:50,000 Scale (DTM50) Data Product Specification (DTM50 DPS) (DGIWG, 2020), where the Portrayal Catalogue is defined as 'symbol descriptions, symbol rules, labelling rules, generalization rules, finishing rules and additional informative guidance associated with feature portrayal on hardcopy topographic maps.'

In the case where the creation of maps in digital technologies is assumed, cartographic rules and generalization rules are usually expressed. For example, by means of numerical indicators (usually limiting values of length, area, etc.), which are no longer related to the specific scale of the map, but are related to the units in which the features in the data models are geometrically determined. This then allows the application of especially selection criteria, which can be found e.g. in the Data Product Specification 1:25,000; 1:50,000 and 1:100,000 Scale MGCP Topographic Map (DPS MTM) or in the Defence Topographic Map for 1:50,000 Scale (DPS DTM) see (DGIWG, 2020; MGCP, 2017). However, despite their high degree of systematicity and precision in definitions and descriptions of use, including rules for resolving element conflicts, the method of generalization, etc., they again remain mostly declarative.

If generalizing the conclusions from the survey of the rules used, it can be stated that:

- many rules are formulated only as verbal formulations without the possibility of its systematized writing;
- the search and identification of a cartographic situation, its solution and the application of individual cartographic rules strongly depend on the experience and professional skill of the cartographer;
- the solution of a cartographic situation is not always a straightforward process,
- there may be several correct or acceptable solutions;
- as a rule, it is a complex solution of several interrelated cartographic situations.

There is, however, a way to systematize cartographic rules in a way that minimizes their declarativeness while also allowing them to be adapted to a higher level of automated map production. The aim is to prepare cartographic rules for formalized recording and then convert them into digital form and store them in a knowledge base.

Approaches to rule systematization

In general, all cartographic rules define two basic sets of requirements:

- *map readability requirements*, which can be called general cartographic rules;
- *map content requirements*, i.e. rules linked to the specific purpose and use of the resulting map. These rules are specific to particular sets of map features, the size and importance of individual map features and their interrelationships (Drozda & Augustýn, 2016).

By generalizing these requirements, it is possible to propose a general definition of cartographic rules: 'Cartographic rules are a set of principles for creating a map image with the aim of producing a complete, positionally correct and, above all, easy-to-read map.'

Current maps are in most cases created from spatial data stored in data models. Therefore, it is advisable to consider cartographic rules not only from the point of view of the actual creation of a given type of map, but it is also necessary to consider the rules that govern the collection of data for the source data models from which the maps are created, or the rules used to select the data necessary for the creation of a particular map (cartographic model) from the source databases. In the case of such a complex approach to map creation, it is possible to work with generalization

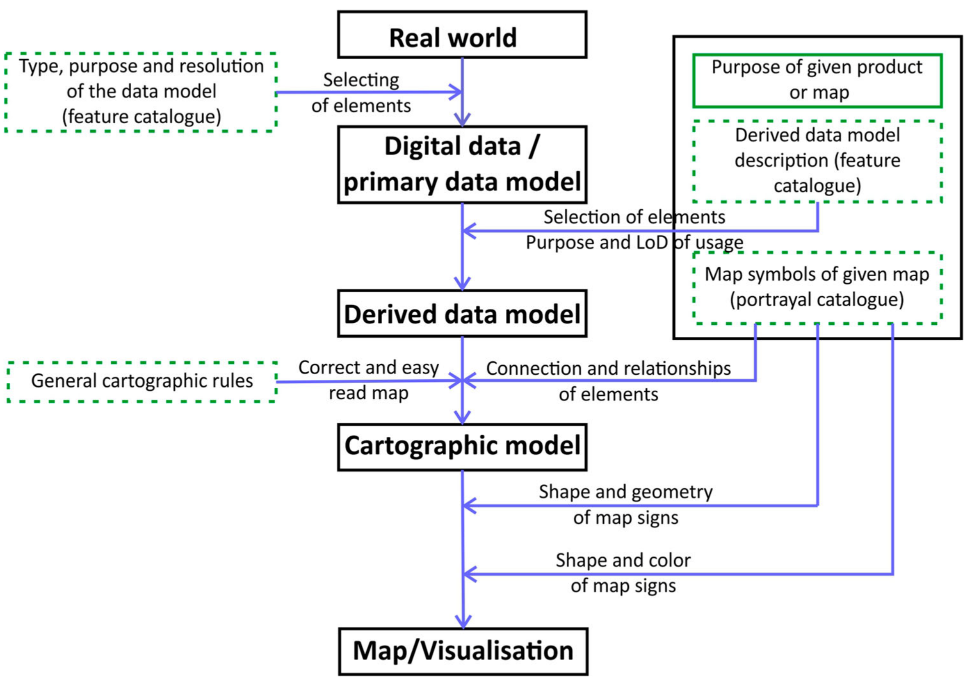

Figure 1. Using rules for map creation in the process of map production.

rules for map creation, whose basic technological scheme and places of application of rules for its creation can be expressed by a diagram (Figure 1). In order to express the completely general procedure from primary data collection to the creation of a specific map, rules for the initial generalization of objects are included. Generalization rules for the creation of derived data models, which may not even be the subject of cartographic visualization, are also included. The degree of generalization here is typically applied according to the feature catalogue of the derived data model in which the LoD is defined. However, when maps are created, it is necessary to work with the portrayal catalogue of given map type.

If an entire system of data collection and map production is considered, it is useful to classify the generalization and cartographic rules and then create a system from them.

Criteria for the classification of cartographic rules

Collecting many available historical and current generalization rules that have been and are contained in specifications for map production (map symbol keys, their additions, general formulations on the approach for the production of the content of a given map type, etc.), different forms and applications of each rule were identified. Nevertheless, it is possible to systematize the rules in a way, which makes them easier and more clearly defined. This systematization can be approached, for example, according to criteria such as the form of their recording and the purpose of their use and the purpose of their use, which is directly linked to their application in the technological step, i.e. in which phase of map production the rules are applied.

According to the *form of their recording,* they can be divided into *written and unwritten*, or *textual and graphical*. The *written rules* are mainly the content of binding standards for map production, which are part of map symbol keys or guidelines for map creation (CUZK, 2015; DGIWG, 2020; MOCR, 2008). *Unwritten rules* can be considered as *advice and experience* passed on by more staff that are experienced or even guidance from responsible editors. These cartographic rules are very difficult to capture and process, and it is usually up to the given cartographer to apply them. Other unwritten rules are *general known and obvious facts and relationships.* For example, it is not possible to find in any available material or in a list of map symbols, a rule that a ferryboat must be on a watercourse, but in manual processing no cartographer would ever think of moving a ferryboat out of a watercourse. However, for automated processing, these rules must also be described and applied in the generalization.

According to the *purpose of the rules*, they can be divided into *feature, model* and *cartographic* rules. *Feature rules* are mainly applied in the primary data collection for the source data models and are used to specify the geometry of features and their attributes. Feature rules are usually part of the guidelines for the creation of primary data models, for example for the Multinational Geospatial Co-production Program (MGCP) (MGCP, 2012) or for the Basic Geographic Data Base – ZABAGED (CUZK, 2020a). *Rules for model* generalization are mainly defined for generalizing the content of primary data models when deriving data models with a lower LoD. Their main purpose is to define procedures for selecting features, simplifying their geometric properties and attributes (Zhang, 2012). Cartographic rules are then implemented to create cartographic models for a particular map type and to symbolize these models. These rules are usually described in a general manner in cartography textbooks and are specifically applied in guidelines for map creation, such as Symbol Placements Rules, Label Placement Rules or Finishing Rules (DGIWG, 2020).

Proposal of systematic cartographic rules

Based on a detailed analysis of the content of the particular groups of rules, their importance for cartographic production and the way they are used, it is possible to define four groups of cartographic rules:

(1) Rules for creating the content of source databases, which define the geometric, thematic and topological properties of the features when created in the relevant data models of spatial databases – Digital Landscape Models (source DLMs, primary data model). According to these rules, the primary data model is created as an abstraction of the modelled reality with the application of basic generalization schemes, such as selection criteria for recording the geometry of features, classification procedures for defining their thematic attributes and guidelines for linking features to each other according to defined topological rules. Requirements for the accuracy of the determination of the geometry of features defined by the required resolution level of the model being created are also provided. These rules can be described collectively as *rules for features generalization*.

(2) The rules *for creating the content of derived digital models* consist mainly in the application of generalization schemes for *model generalization*, i.e. for reducing the geometric, topological, and thematic properties of the initial features of the primary data models in order to create a digital model according to the specified requirements, usually with a lower resolution level in the geometry and thematic of the newly created features (secondary DLMs). The model generalization rules in particular define the level of simplification provided by the target resolution level of the secondary digital model. The simplification can be at the level of the whole model, a group of features or even for individual features. The actual simplification can involve both the geometry of the features and the reclassification of the features. However, the topology of the features must not be damaged during model generalization. This generalization is often carried out almost automatically with minimal or no human intervention. To its description, catalogues of operators for the given types of features are usually elaborated, in which the parameters of the used tools are given. The rules used are generally called model generalization rules.

(3) *Cartographic rules* that ensure the readability and comprehensibility of the resulting map and that result from the perceptual and cognitive properties of the map features in the used map symbols and the guidelines for their interpretation. These rules are mainly implemented in the design of the map symbols or in the design of individual map features and their implementation is usually part of map style libraries. Together, these rules can be referred to as *map symbols design rules*.

(4) *Rules of cartographic generalization*, describing the approach to solving the content of a map created in a given map symbols key in a particular space and at a particular scale, or in a particular scale range. These rules deal in particular with simplifying the geometry of features of cartographic models, or adjusting their position in

conflict points with other features so that the resulting map respects the cartographic rules. Cartographic generalization rules can be further divided into two groups:

(a) *general cartographic rules* applicable to the creation of a given map type. These are mainly rules for features conflicts, selection and simplification;
(b) *cartographic rules related to a specific map symbol*, i.e. rules specific to individual map symbols, the size and importance of individual map elements and their mutual relationship.

All of these rules must be considered as a system that extends through the entire process from the creation and updating of the source spatial databases to the final map, and in many cases cannot be considered as separated processes. However, the rules of cartographic generalization are described in more detail in the following part of the article.

More than 120 situations were used in the compilation of the generalization rules, which were identified directly during the physical production of the state topographic maps at scales of 1:10,000 and 1:25,000 (ZM10, ZM25). All situations were processed and described in cooperation with the production site of the state mapping agency. For each situation, a separate card was prepared with an evaluation of the cartographic rules used, possibly with an additional description. For each evaluated situation, the source data model (primary data model) and the final portraying of map 1:10,000 are displayed as well as text description of cartographic rules used (Figure 2). All situations are stored in database.

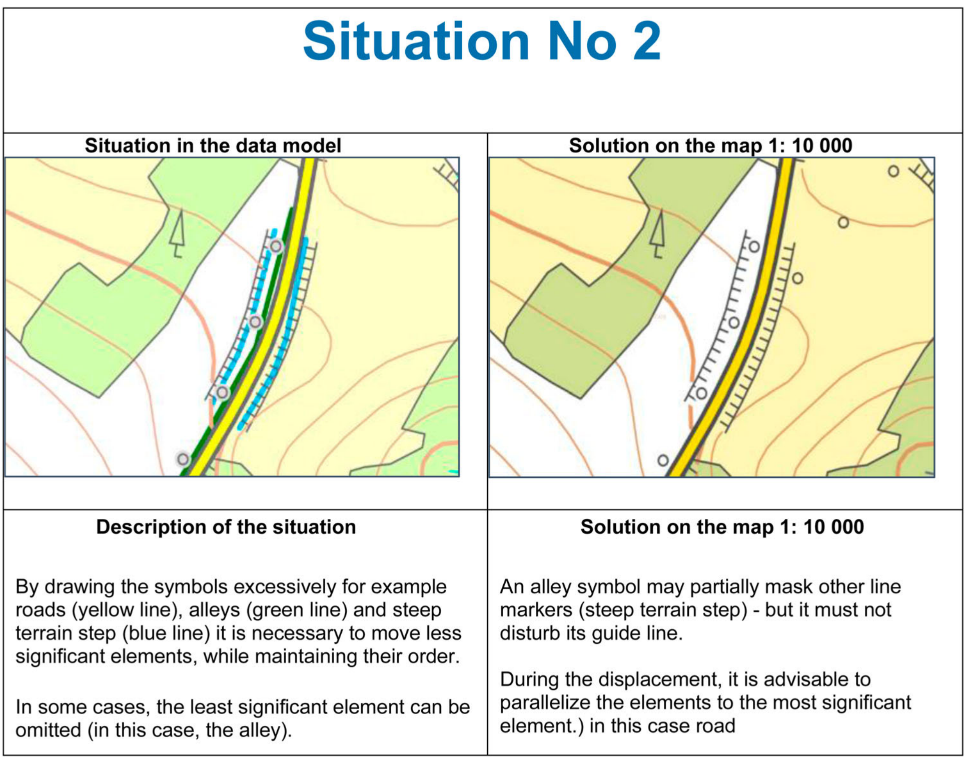

Figure 2. Example of a processed card with evaluation of cartographic rules.

General cartographic rules

The general cartographic rules are mainly rules intended to improve the readability and clarity of the filled map parts, to express the characteristic map elements and to solve conflicts between individual elements (map symbols or their footprints overlaps). The general cartographic rules apply mainly to the creation of cartographic models from source databases. According to them, cartographic models are generated in such a way as to allow, as far as reasonably possible, their seamless visualization in the chosen map style. Based on the consideration that maps of the same type, especially topographic and geographic maps, use similar map styles (shapes and sizes of map features, definition of their minimum dimensions, definition of their minimum spacing, etc.), it is possible to create a set of general cartographic rules for a given map type and a given scale, or a given scale range.

Depending on the nature of the cartographic situation, different cartographic generalization procedures are used, which are usually divided into six basic groups: *elimination, typification, amalgamation, enhancement, enlargement,* and *displacement* (Forester et al., 2009).

Table 1. Example of part of the initial arrangement of part of the conflict's rules.

Point × point conflict	Element with a lower weight is subject to modification	Point movement	Lower-weight element is moved so that the symbols do not overlap Base on the colour, the marks should be moved to keep set of thresholds If the point element is located inside of the area, it must not be moved outside this area
		Replacement with a combined symbol	Tower elements and geodetic points are replaced by combined symbol at the position of the geodetic point
		Point detection	Point element with a lower weight is deleted
		Shape edits of symbol	For some elements, their symbols can be graphically modified
Point × line or area border conflicts	Reference point of symbol overlaps with the footprint of the line symbol. Point element or an element with a lower weight is subject to modification	Moving a point from the line	Point element is moved so that its reference point is located outside of line footprint or boundaries Base on the colour, the marks should be moved to keep set of thresholds If the point element is located inside of the area, it must not be moved outside this area After moving, moved point symbol must not be on the opposite side of the line
		Moving a line from the point	Line symbol is moved so that the reference point of the point symbol is outside the footprint line or boundaries
		Line detection	Line element with a lower weight is deleted
		Point detection	Point element with a lower weight is deleted
		Line masking	Point element does not conflict with the line, it masks the line
		Shape edit symbol	The shape of the point symbol or shape of line symbol are modified

The general rules for the creation of cartographic models are not comprehensively described in the professional literature; therefore, the basic activities that are or have been carried out in analogue map creation and are practically applied in computer map processing have been identified. In cartographic models for topographic maps, *conflicts of elements and selection of elements* are most often dealt with. The *shapes and sizes of the elements* and the cartographic *connections between the elements* are also dealt with. For all situations that were the subject of the research, individual cartographic rules were written and arranged in a hierarchical structure, and then the rules were stored in a knowledge base. An example of such a description is given in the table (Table 1).

The following are two examples of general rule solutions – feature conflict and relationship between features.

Feature conflict is the most common cartographic situation to be solved, when the symbol drawings of the features to be displayed overlap, or the map symbols are in the same colour too close and therefore are not sufficiently legible. Depending on the scale and spatial arrangement of the entities, several map features may conflict with each other at the same time; these conflicts are resolved according to a hierarchy of cartographic rules.

The most frequent case of map feature conflict is the situation when a map feature is portrayed by a symbol disproportionately larger than the real size of the feature in the map scale. Other cases may be caused by inaccuracy of the base or inconsistency of the source data.

The schema of cartographic rules structure (Table 2) shows the individual cases of conflicts, divided according to the type of element (point, line, area), and the operators that can be used to resolve these conflicts in the processing of ZM10 and ZM25.

Table 2. The example of cartographic rules structure – feature conflicts.

Elements conflict	Point × point conflict	Point displacement Substitution by combined symbol Point symbol deletion Shape of symbol modification
	Point × line or borderline conflict	Point displacement from line Line or part of line displacement Point symbol deletion Line symbol deletion Masking of part of line Shape of line or point modification
	Line × line or borderline conflict	Line or part of line displacement Line symbol deletion Substitution by combined symbol Lines paralleling Lines mating Masking of part of line
	Line × area conflict	Line or part of line displacement Area displacement Area deletion Line or borderline paralleling Line or borderline mating Masking of area
	Area × area conflict	Area or part of area displacement Area deletion Borderlines paralleling Borderlines mating Masking of area

In terms of meaning, it is mainly a matter of respecting the following principles:

- adjustments are usually made to a point element or an element with a lower importance,
- the element is offset so as not to overlap the drawings of other map symbols,
- map symbols of the same colour should be offset to a specified minimum distance,
- if the point feature is located within the area, it shall not be offset outside the area.

Although the solution may not always be straightforward, these are usually simple cartographic tasks. Solution problems may arise in the case of the accumulation of more overlapping features and the need to solve individual conflicts systematically.

The solution of *relation between features* consists in observing the topological relations between features in the cartographic model. Breaking of topological relations of features can be caused by 'imperfection' of input data, combination of different background materials, but also by cartographer's interventions during displacement or modification of already displayed features. This mainly concerns the adherence to the rules of symbol placement dependent on the position of other features (start and end of lines, changes in the shape of a symbol or its rotation depending on another feature, placement of symbols on lines or in areas, etc.).

This category also includes aggregation of adjacent features or features with similar characteristics where their distinction and separate display is irrelevant for the map (aggregation of different forest stands, unification of classification of road sections, etc.).

The elaborated list of feature connections is not and cannot be completely exhaustive, because some connections are defined in cartographic rules linked to specific map parts. For ZM10 and ZM25 the following rules were identified from the supplied situations (Table 3):

Next is given some examples of cartographic rules of connections between features:

- when a start and end symbol is defined for a line, the line must always start and end at this symbol (e.g. in ZM10, a power line must always start and end at a building or power line pole symbol),
- the width of the symbol is adjusted according to the width of the symbol of the guide feature, e.g. adjusting the width of the symbol of bridges and culverts according to the width of the symbol of roads or tracks,
- the symbol rotates according to the guide feature (rotation of culverts and bridges according to the angle of the watercourse).

Table 3. Connection relation between features.

Elements relation	Elements aggregation
	Element's location
	Line start-end symbol
	Shape editing of symbol
	Symbol rotation
	Area filling
	Line continuation

Cartographic rules linked to the feature symbols

The second main group of cartographic rules are rules related to the map symbols used. These are mainly the shape, size, position and colour of the individual symbols. Then the selection rules for individual features in relation to the purpose and use of the given map (density and minimum size of individual features), and finally the order of display of features and their relationships, including the properties of specific map symbols. The emphasis here is on the elaboration of specific cartographic rules for the construction of cartographic models of a particular map work and the design of the structure of the knowledge base of these rules so that they can be further used in the generalization management process.

Furthermore, in order to control the behaviour of individual features in the cartographic generalization process, properties have been assigned to each map feature (Table 4).

Formalization of cartographic rules

From the complex structure of the cartographic rules, a knowledge base was created. Mostly, this involved creating a brief notation using a few simple rules (principles) that describe the word statements of experienced cartographers when dealing with different cartographic situations. To write the rules, some form of formalized notation had to be used so that the rules could be 'machine readable.'

As an example, the verbal description of situation No. 33: *Symbol placement in the area*, which is included in the DATA10 Map symbols catalogue (CUZK, 2020b). According to this catalogue the symbol is suitably placed within the area, and in case of lack of space it can be reduced to 1/3 of its original size (original size is in the green circle, reduced size in the blue one) or the symbol is placed outside in a suitable location outside the area and an arrow indicates its belonging to the area (red circle). For small areas, if there is no space for the symbol, the symbol may be omitted in exceptional cases (purple circle). A formalized description is shown in the figure (Figure 3).

This rule is transformed into the following formalized notation:

- areas of vegetation, surface and land use should be visualized with a symbol,
- the symbol should be placed at the reference point of the area,
- if it is not possible to place the symbol at the reference point, the symbol is placed at the centre of gravity of the area (if the centre of gravity lies within the area),
- if it is not possible to place the symbol in the centre of gravity, it may be suitably placed anywhere in the area,
- the symbol should be size 1,

Table 4. Map features properties.

Element attributes	Accuracy class
	Element shape
	Minimum size of element
	Weight of element
	Element colour
	List of operators
	List of symbols

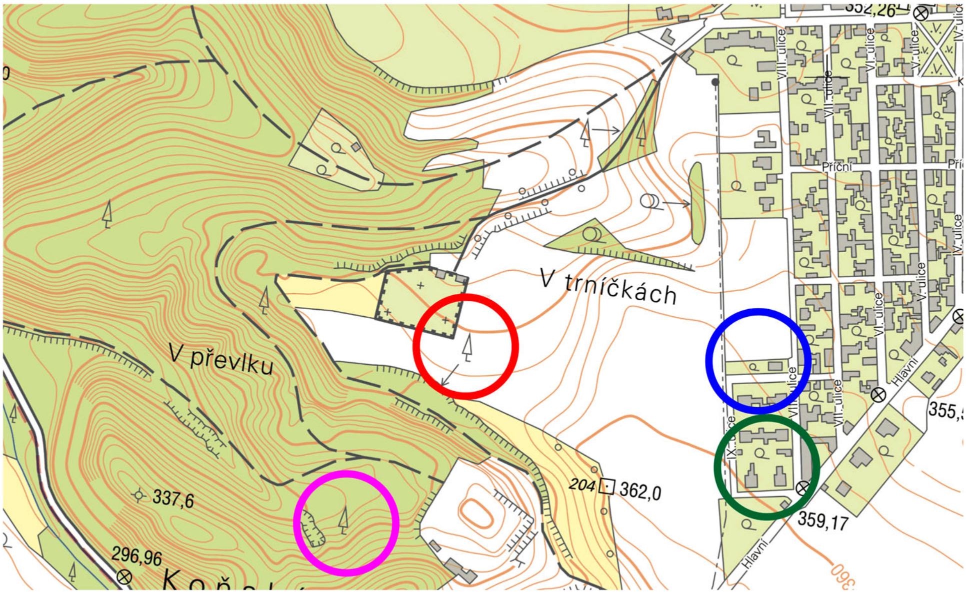

Figure 3. Example of the rule *Symbol placement in the area* – the situation No. 33.

- if there is no space for a size 1, the symbol shall be displayed at size 2,
- if there is no space for size 2, the symbol shall be displayed as size 3,
- if there is no space for size 3, the symbol is placed outside in a suitable location outside the premises and an arrow indicates its belonging to the premises,
- if there is no space for the symbol to be placed outside the area, the symbol is omitted.

These simple rules are processed into a digital form. In addition to the description of the cartographic rules, these rules are formalized into a suitable digital form – an ontological knowledge base in accordance with the recommendations of the International Cartographic Association – Commission on Generalization and Multiple Representation (Mackaness et al., 2015). These rules can be subsequently used to guide the generalization process. Their diversity is addressed by the structure of the cartographic rules database, which is described in the following section.

Cartographic rules database

Based on the frame systemization of the rules, a *knowledge database* can be created that can be used for general solutions of the entire content of the derived secondary data model or for the creation of a cartographic model of the type of map or maps generated in a given symbol key. The aim of the created database is to allow the editor who creates a given map to have access to this database throughout the process of creating a map image of a particular territory and to find in its guidelines for dealing with most situations. The database in Czech language is made available on-line at the following address (see http://euradin.vugtk.cz/TB04CUZK001/03_CartographicSituations/web/).

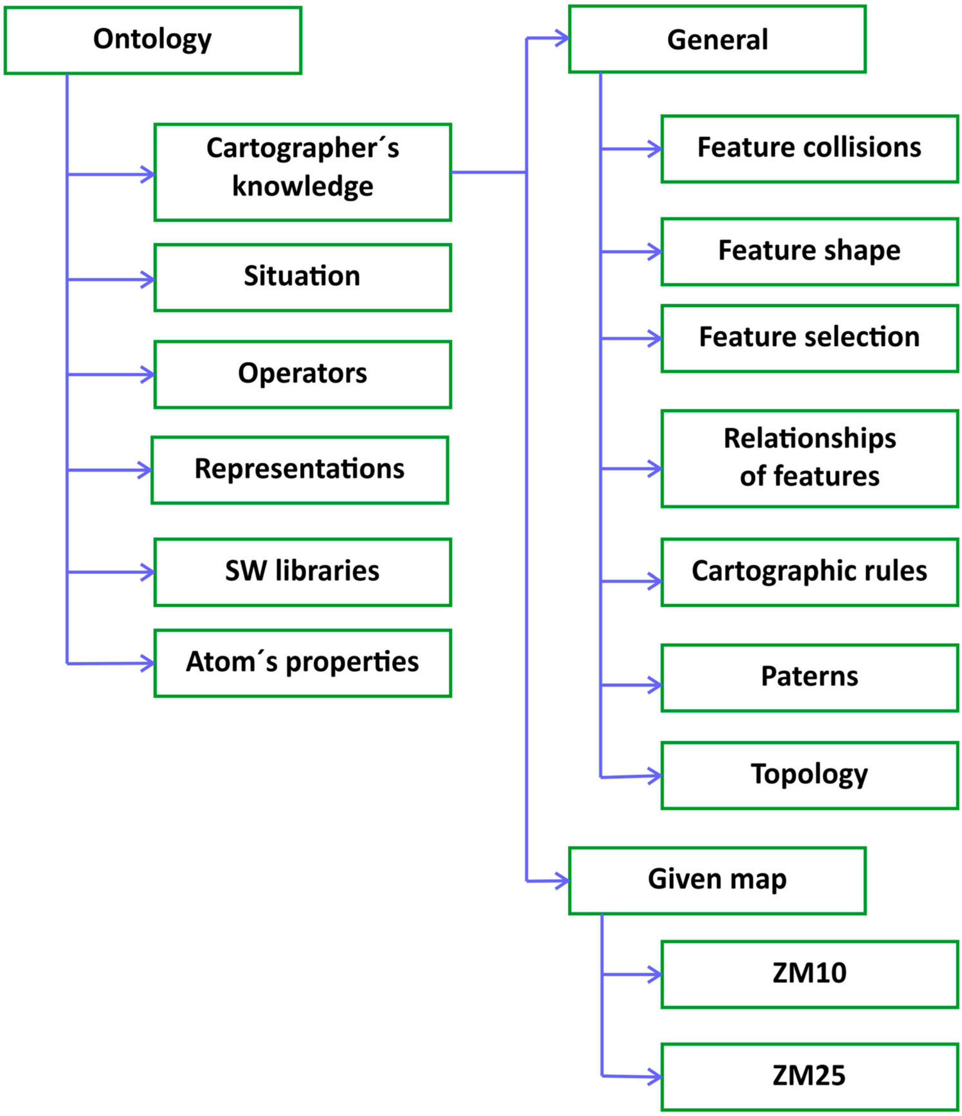

Figure 4. Database structure.

The database clearly describes cartographic rules for individual cases of map symbols conflicts. Structure of database is portrayed on next figure (Figure 4).

In the following part of the text, the use of the database is briefly demonstrated, (see right situation in the Figure 2), where multiple displacement of lines has to be solved – moving the steep terrain step and the alley from the road.

Cartographic rules (conflict line × line) are identified for the given case – line conflicts occur when lines or parts of lines run in parallel to close or when lines are crossed at an acute angle and a rule, a line with a lower weight is subject to adjustments.

Operators displacement of line, part of line displacement, line replacement, line replacement with associated mark, line parallelization, line alignment, line masking (*odsun linie,*

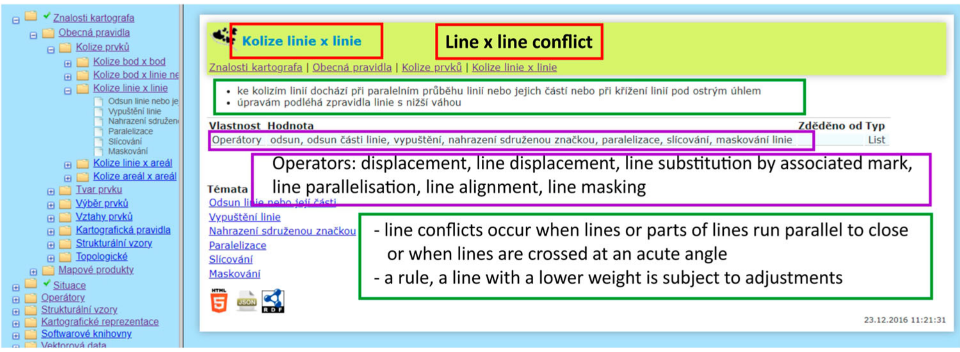

Figure 5. Example of the rule *Line × line conflict* – rule description.

odsun části linie, vypuštění linie, nahrazení linie sdruženou značkou, paralelizace linií, slícování linií, maskování linie) can be used.

Note – since the database is in Czech only, the Czech terms that correspond to the options in this database are given in brackets and some expressions are explained in boxes directly in figures (Figure 5). This is how the options will be listed in all the following figures.

The situation No 2 (in Figure 2) is solved by the sequential Line symbols displacement (Figure 6).

Additional cartographic rules are defined for line displacement:

- the line element or part of it is moved away from a more significant feature *(liniový prvek nebo jeho část je odsunuta od významnějšího prvku*);
- according to the colour, the lines should be shifted by the specified threshold (*podle barvy by značek by linie měly být odsunuty o stanovený threshold*);

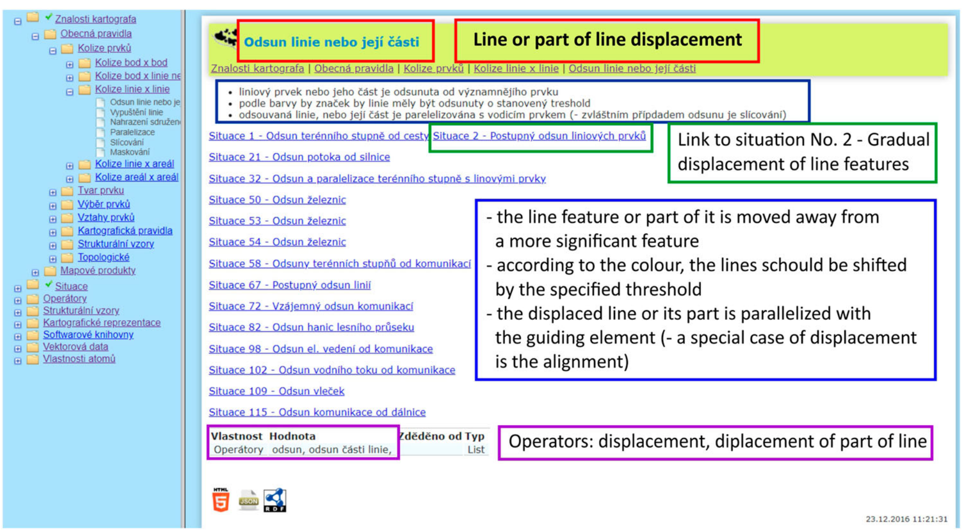

Figure 6. Example of the *Line or part of line displacement* rule description.

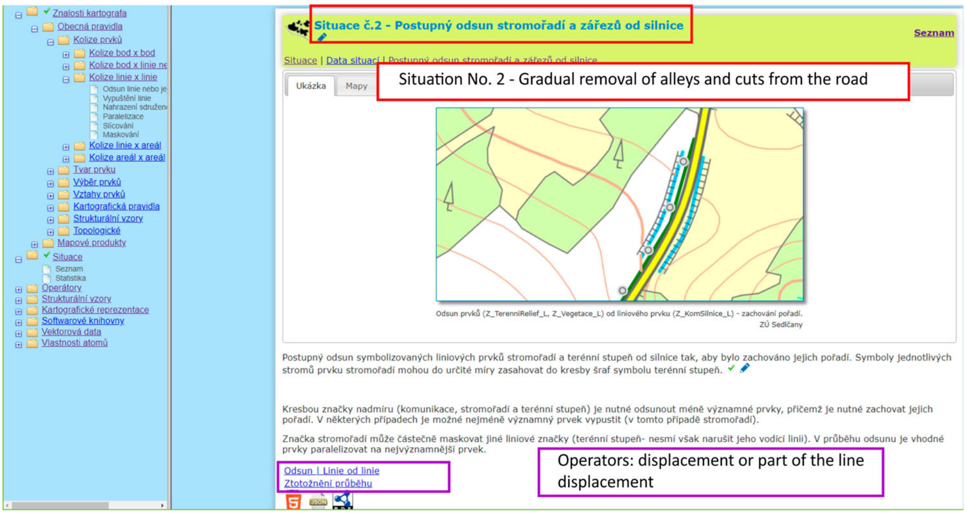

Figure 7. Description of *Line displacement* (source data) – situation No 2.

- the displaced line or its part is parallelized with the guiding element (- a special case of displacement is the alignment) (*odsouvaná linie, nebo její část je s vodicím prvkem (-zvláštním případem odsunu je slícován*)).

Operators displacement (*odsun*), displacement of part of the line (*odsun části linie*) are defined. There is list of situations with links where line displacement was identified too (Figure 7 for the source database or Figure 8 for cartographic representation of final map).

Specific rules to particular sets of map features are portrayed in database and are stored in *Specific product section* (Figure 9).

Figure 8. Description of *Line displacement* (final map product ZM10 and ZM 25) – situation.

Figure 9. Structure of elements (feature symbols) description.

This structure describes the ZM10 brand key and its rules. Each element or class (group) of elements is described by its properties:

- tag key element number(s),
- element colour (outline colour),
- element type (point/line/area),
- allowed operators,
- accuracy class,
- element weight,
- minimum element size (lines and areas only),
- each feature or feature classes can have its oven cartographic rules and/or additional properties (*Prvky nebo třídy mohou mít i další vlastnosti*).

As an example, the *alley symbol* is presented. The symbol (Figure 10) has defined additional cartographic rules, specified how it can be portrayed in map:

Figure 10. Description of alley symbol (ZM10).

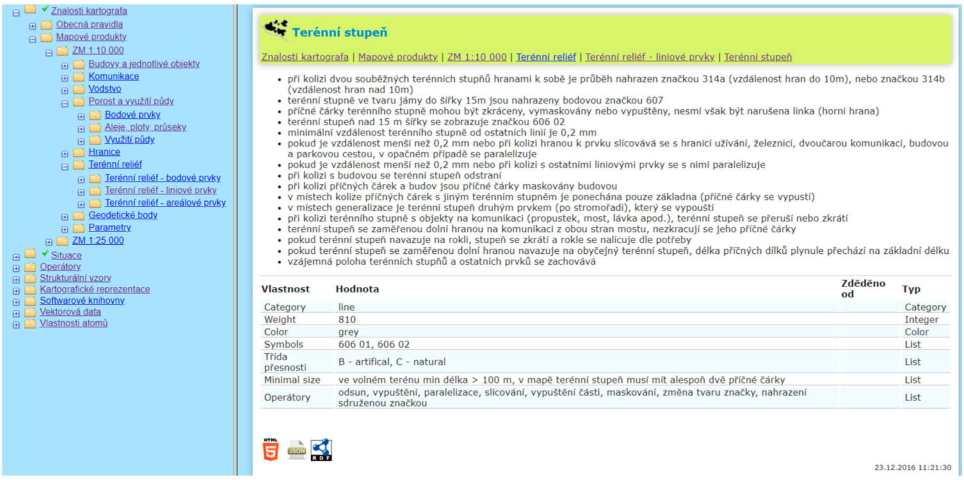

Figure 11. Description of steep terrain step symbol (ZM10).

- the alley and narrow strip of forest do not show them in forest soil, scrub, scrub and ornamental garden (*stromořadí a úzký pruh lesa je nezobrazuje v lesní půdě, křovinatém porostu, kosodřevině a v okrasné zahradě*);
- the alley masks the transverse lines of the steep terrain step (*stromořadí maskuje příčné čárky terénního stupně*);
- at least two signs must be displayed (*musí být zobrazeny alespoň dvě značky*).

And, of course, category, weight, colour, symbols, precision class minimum size and operators are defined.

Similar parameters of steep terrain step symbol are defined (Figure 11).

Cartographic rules defined for steep terrain step symbol are:

- in case of conflict of two parallel steep terrain steps with edges to each other, the course is replaced by the sign 314a (edge distance up to 10 m), or the sign 314b (edge distance over 10 m) *při kolizi dvou souběžných terénních stupňů hranami k sobě je průběh nahrazen značkou 314a (vzdálenost hran do 10 m), nebo značkou 314b (vzdálenost hran nad 10 m*);
- steep terrain steps in the shape of a pit up to a width of 15 m are replaced by point sign 607 (*terénní stupně ve tvaru jámy do šířky 15 m jsou nahrazeny bodovou značkou 607*);
- the crosslines of the steep terrain step may be shortened, masked or omitted, but the line (upper edge) must not be disturbed (*příčné čárky terénního stupně mohou být zkráceny, vymaskovány nebo vypuštěny, nesmí však být narušena linka (horní hrana)*);
- steep terrain level above 15 m width is shown by the sign 606 02 (*terénní stupeň nad 15 m šířky se zobrazuje značkou 606 02*);
- the minimum distance of the steep terrain step from other lines is 0,2 mm (*minimální vzdálenost terénního stupně od ostatních linií je 0,2 mm*);
- if the distance is less than 0.2 mm or in the event of a conflict with an edge to the element, it aligns with the boundary of use, railway, two-line road, building and park

road, otherwise it parallelizes (*pokud je vzdálenost menší než 0,2 mm nebo při kolizi hranou k prvku slícovává se s hranicí užívání, železnicí, dvoučarou komunikací, budovou a parkovou cestou, v opačném případě se paralelizuje*);

- when the distance is less than 0.2 mm or parallels with other line members (*pokud je vzdálenost menší než 0.2 mm nebo při kolizi s ostatními liniovými prvky se s nim paralelizuje*);
- in the event of a conflict with a building, the steep terrain level is removed (*při kolizi s budovou se terénní stupeň odstraní*);
- when cross lines conflicts with buildings, the cross lines are masked by the building (*při kolizi příčných čárek a budov jsou příčné čárky maskovány budovou*);
- in places of conflict of cross lines with another steep terrain level, only the base is left (transverse lines are omitted) *v místech kolize příčných čárek s jiným terénním stupněm je ponechána pouze základna (příčné čárky se vypustí*);
- in places of generalization, the steep terrain level is the second element (after the alley) to be omitted (*v místech generalizace je terénní stupeň druhým prvkem (po stromořadí), který se vypouští*);
- in the event of a conflict of steep terrain level with objects on the road (culvert, bridge, footbridge, etc.), the steep terrain level is interrupted or shortened (*při kolizi terénního stupně s objekty na komunikaci (propustek, most, lávka apod.), terénní stupeň se přeruší nebo zkrátí*);
- steep terrain level with a focused lower edge on communication from both sides of the bridge, its transverse lines are not shortened (*terénní stupeň se zaměřenou dolní hranou na komunikaci z obou stran mostu, nezkracují se jeho příčné čárky*);
- if the steep terrain level follows the ravine, the level is shortened and the gorge is faced as needed (*pokud terénní stupeň navazuje na rokli, stupeň se zkrátí a rokle se nalícuje dle potřeby*);
- if the steep terrain level with the focused lower edge follows the ordinary steep terrain step, the length of the transverse segments smoothly passes to the basic length (*pokud terénní stupeň se zaměřenou dolní hranou navazuje na obyčejný terénní stupeň, délka příčných dílků plynule přechází na základní délku*);
- the mutual position of the steep terrain steps and other elements must be maintained *(vzájemná poloha terénních stupňů a ostatních prvků se zachovává*).

All cartographic operators are stored in separate part of database (Figure 12).

Operators are divided according main cartographic tasks – classification and symbolization (*klasifikace a symbolizace*), Collapse (*kolaps*), Displacement (*odsun*), Deleting (*vypuštění*), Highlighting (*zvýraznění*), Enhancement (*vylepšení*), Simpification (*zjednodušení*), Aggregation (*agregace*) and Typification (*typizace*). Every group is described and typical situations are portrayed (Figure 13).

An example of line displacement used on situation No 2 is on figure (Figure 14). There is list of situations where line x line displacement is used. The same was created for all operators.

All parts of database are mutually linked so user can go thru all stored knowledge. All items of database are stored as separate xml part and it is easy to create and link new item (knowledge, rule, operator, map symbol and/or situation). All database parts are ready to by computer reading.

Figure 12. Operators in database.

The database of rules for map compilation and generalization was one of the key components of the generalization management. Its creation and pilot implementation were also one of the results of the project called *Research and development of methods for*

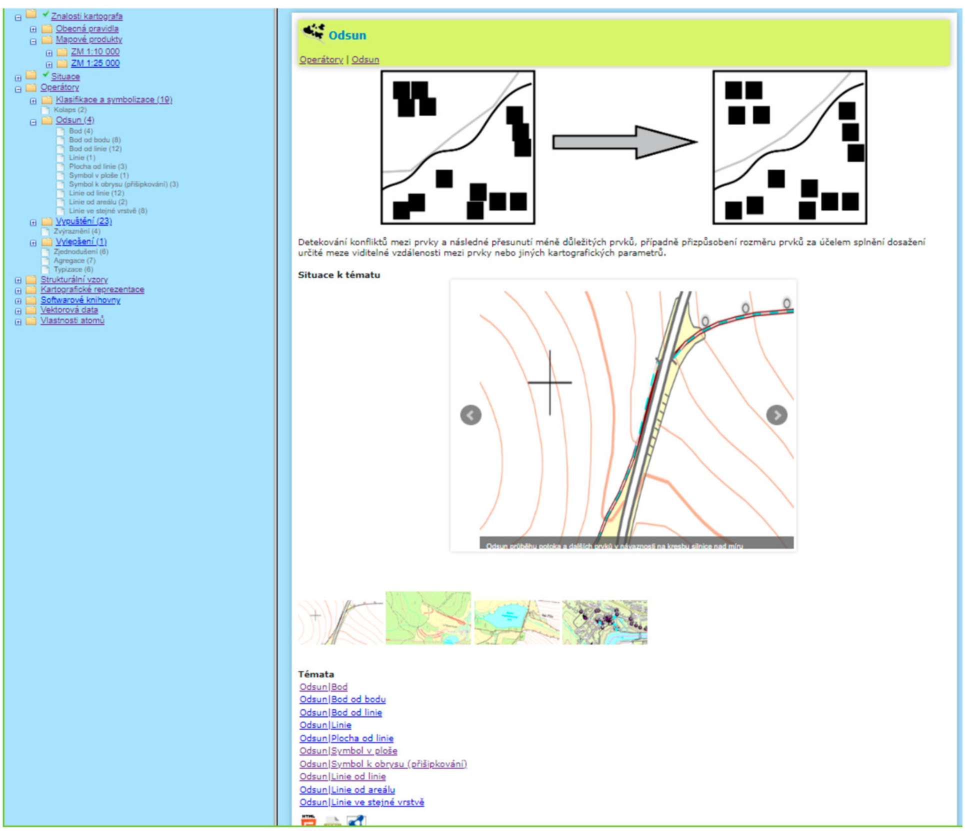

Figure 13. Example of displacement in database.

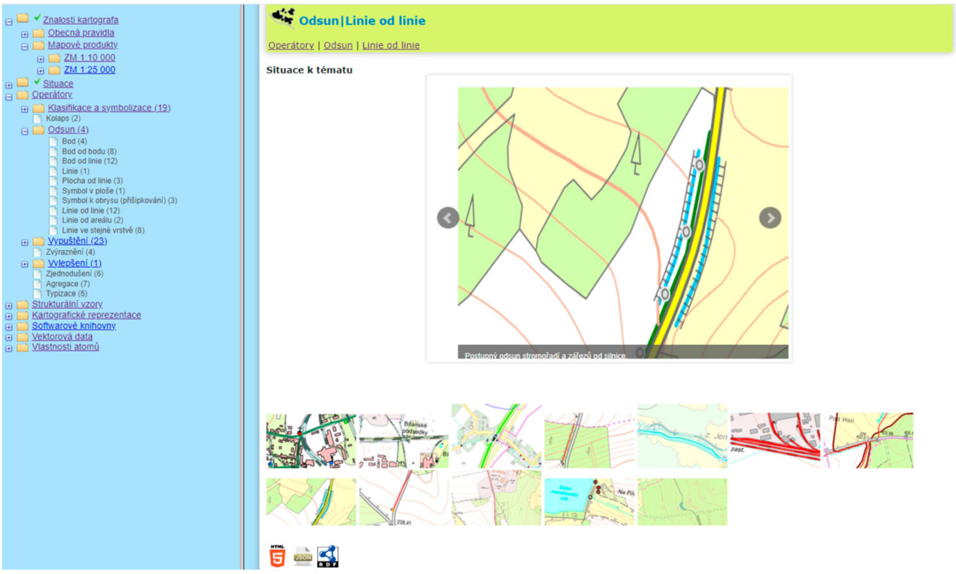

Figure 14. Example of operator *displacement line × line* (for situation No 2).

cartographic generalization of medium-scale state maps (project code TB04CUZK001) (Drozda & Augustýn, 2016).

Discussion of the results achieved

In the required length of the article, it was not possible to describe all the details that were addressed in the scope of the mentioned project. However, one of the possibilities has been presented how to systematize the cartographic rules used in current digital mapping technologies. The whole system of rules that govern not only the cartographic creation itself, but also the definition of the source data model features and their implementation was described.

In addition, a method of formalizing the notation of cartographic rules was presented so that they can be entered into an ontological knowledge base as a source of information on how to resolve, in particular, conflict situations during the actual map creation. The ontological database was created as an open database with the possibility of additions and is ready for dynamic processing of various, especially conflict situations.

The proposed solution was primarily intended for the creation of topographic maps in the Czech State Administration of Land Surveying and Cadastre (ČÚZK). However, this solution is universal and applicable to basically all map works. With minor modifications for topographic maps created from other source databases and in other map symbols keys, for example for Defence Topographic Maps created within the NATO alliance. Then, with major modifications, for geographic maps.

Since the database was created within the framework of the project for the ČÚZK, it was created only in the Czech language and with regard to the state map work of the Czech Republic. As the solution of the project was completed and its further funding was not ensured, the further development of the ontological database of cartographic rules was temporarily terminated.

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