THE TIME CARTOGRAM APPROACH AS ALTERNATIVE VISUAL REPRESENTATION OF SPACE TIME PATHS

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February, 2011

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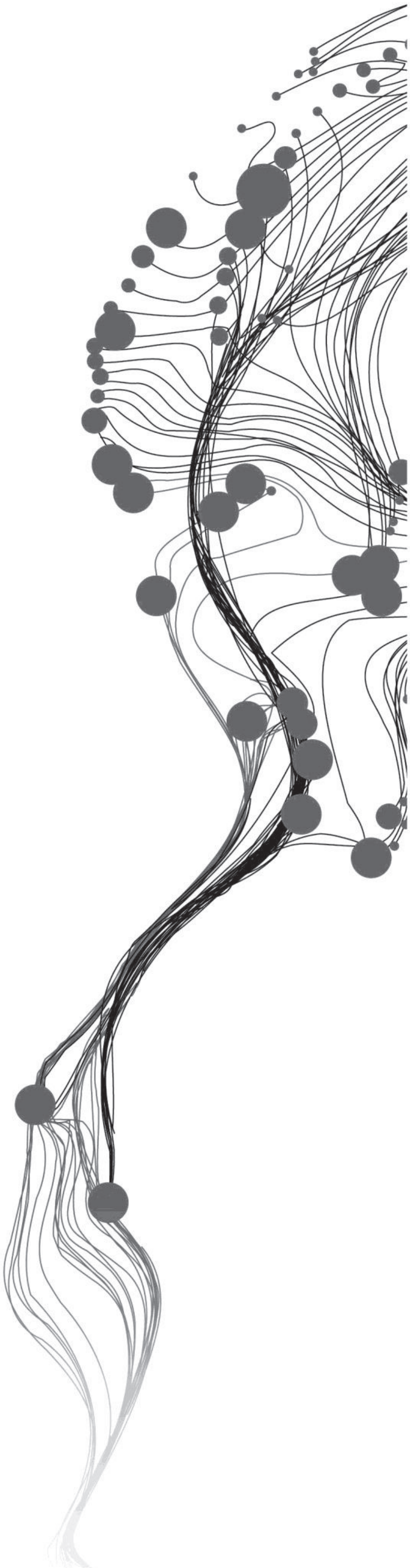

THE TIME CARTOGRAM APPROACH AS ALTERNATIVE VISUAL REPRESENTATION OF SPACE TIME PATHS

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Specialization: Geoinformatics

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ABSTRACT

Cartographic visualization always played a significant role in human being's activities. New development of computer technologies makes it possible to use alternative visualization methods. Nowadays it is possible to display space-time data using different types of mapping methods such as the cartographic animation and the Space Time Cube (STC). These methods have the capability to represent relationships between objects and actions in space and time.

On the other hand, the time cartogram is a mapping method that makes it possible to use time as a distance unit. The time cartogram demonstrates distortion of geographic space based on time since the Euclidean distance is replaced by time distance. Generally, a time cartogram is used to visualize transportation systems where movement of objects along the network follows fixed paths.

As mentioned above there are mapping methods and tools such as the STC and the animation that have capabilities to represent space-time data. This research focused on the examination of a time cartogram approach in order to display space-time data and see if it is useful for displaying such data by comparison with alternative mapping methods such as a traditional geographically correct map (map), the STC and the animation.

To estimate if this mapping method is appropriate and suitable for displaying space-time data a usability research test was conducted (in three sessions): comparing the time cartogram with the map, with STC and animation. Effectiveness, efficiency and satisfaction for the time cartogram in comparison with the map, the STC and the animation were determined with respect to spatial and temporal aspects.

The overall result shows that the time cartogram is a more usable method than the other mapping methods concerning the temporal aspects. The tests persons could examine the time cartogram easily and executed the tasks correctly that were related to temporal aspects, but the test persons had problems with examining the time cartogram on spatial aspects and they performed the tasks related to this aspects incorrectly.

Key words: (time) cartogram, the STC, cartographic animation, Space Time Path (STP), usability evaluation.

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1. INTRODUCTION

1.1. Motivation and problem statement

For long time people have tried to illustrate space-time data. In order to visualize movement data people used different graphical symbolization such as various types of arrows, a text and etc. Nowadays there are some modern methods and techniques that could be used to display space-time data. Examples are Space Time Cube (STC) and cartographic Animation. Both have capabilities to represent relationship between objects and actions in space and time.

The idea of STC has been introduced by Hägerstrand. He developed a three-dimensional diagram with Z axis to display time (Hägerstrand, 1970). The STC has possibilities to present the relation between time, space and additional variables (Kraak, 2003). The STC has been applied to investigate many applications, among them archaeological events (Huisman, et al., 2009). It has been used as an alternative graphics to enhance the understanding of data for instance Napoleon's march into Russia (Kraak, 2003).

According to Slocum (2009) the earliest cartographic animation was produced in the 1930s. They can be divided into temporal and non-temporal animation (Kraak, et al., 2010). Nowadays numerous examples of animation are accessible. "The temporal animation is used to display world time in a temporal sequence, specially to display and explore the increasing varieties of spatio-temporal data sets becoming available" (Kraak, et al., 1997). Cartographic animation with a temporal legend has capabilities to view temporal information of data and it is widely applied in different disciplines. Several researchers, including Acevedo and Masouka have developed animations of urban growth (Acevedo, et al., 1997).

As mentioned above there are time mapping methods such as STC and animation that have capabilities to represent space-time data. As alternative for the animation and the STC this thesis will investigate how cartograms can be used to display time-data. "A Cartogram is a technique in which spatial geometry is distorted to reflect a theme; for example, sizes of countries might be made proportional to the population of each country" (Slocum, 2009). According to Tyner (1992) there are several types of cartogram used in cartography: linear or distance cartogram, areal cartogram and abstract maps (timetable cartogram). Linear or distance cartogram are used to visualize transportation networks (Monmonier, 1996). Distance time cartograms are normally used to represent time-space maps that graphically illustrate time-distances between two points. These types of cartograms have possibilities to represent time based on the time required to travel real-world distance. The main goal of this research is to illustrate space-time data and substitute travel time for distance. To achieve the goal of this research there a time cartogram approach will be developed.

In 1869 Charles Joseph Minard published a flow maps about the French invasion of Russia in 1812. Minard's map is considered to be one of the best map designed ever (Tufte, 1983). This famous two–dimensional time map uses several variables: location, direction, dates, size of the army, temperature and also showing where the units split off and rejoined. According to the historical data of Napoleon's army was consisted of several corps. These corps had movements in space over time which can be considered as space time paths (STP). It is possible to distinguish between a single STP and multiple STPs. A single STP displays a movement of only one corps, while multiple STPs present a movement of several corpses.

These STPs can be considered as free flowing path(s). Since Minard's data is complex it is motivated to see how it can be used the time cartogram approach. In addition it seemed useful to compare this approach with an animation and the STC of the same data. A usability research has been set up to test this.

1.2. Research identification

The research project is defined by research objectives and research questions:

1.2.1. Research objectives

Main objective:

Develop a mapping method to visualize Space Time Paths (STP) based on the time cartogram approach and see how this compares to a map, animation, and the Space Time Cube (STC)

Sub-objectives:

1. Investigate if (when and how) a time cartogram approach can be applied to STP.
2. See how the different mapping method can applied to STP.
3. Evaluate the visualization of STP based on time cartogram approach in comparison with map, STC and animation.

1.2.2. Research questions

1. What is a (time) cartogram?
2. What are the characteristics of STP?
3. How can the STP be represented by the time cartogram?
4. What are the implications of the path characteristics for the time cartogram approach?
5. What are the existing time mapping methods?
6. How to design and develop the time cartogram using Minard's data?
7. How to design the map, the STC and the animation using Minard's data
8. How to evaluate the visualization of STPs based on time cartogram approach in comparison with map, STC and animation?

1.3. Methodology

The following methodologies have been proposed to meet the objectives of the research and to answer the research questions:

1.3.1. Literature Review:

Literature on - cartogram, STP, existing time mapping methods and usability research methods will be reviewed. The research questions 1, 2, 5 will be answered by a literature review. The question 8 will be partially answered by literature review as well.

1.3.2. Develop conceptual design

Design concept will be formulated for visualization of STP by a time cartogram. The research questions 3, 4 will be answered by this method.

1.3.3. Design of different mapping methods:

In order to answer the research question 6, 7 different implementations (the time cartogram, the map, the STC and the animation) will be developed and those will be realized by using different appropriate software.

1.3.4. Evaluation

For the evaluation of the prototype it is executed a usability research. Usability testing should give a clear picture how efficient and effective a time cartogram will be for display of a STP in comparison with a map, STC and animation. In order to carry out the evaluation process efficiently, it is important to select a correct and an appropriate usability method(s). In this research a think aloud method in combination with screen logging and questionnaire are used. The questions and all technical equipments which are necessary to conduct a usability testing will be prepared. The Participants (students) could be selected from ITC's different departments. This method will be applied to answer the research question 8.

1.4. Thesis structure

This thesis is composed of seven chapters. Chapter 1 presents the motivation, the problem statement and the research identification. Chapter 2 describes the concept of cartogram. It presents different types of cartogram and it discusses the principles and techniques of creation of time scaled map. Chapter 3 is addressed to give theoretical background of STP and its major characteristics. Additionally the time mapping methods such as the STC and cartographic animation are presented. Chapter 4 refers different methods and algorithms that were examined in the previous studies in order to illustrate time distance and to create time cartogram. It introduces the conceptual and design approaches of the time cartogram. Additionally it discusses the problems that are related to the selection of the time scale and the initial point. Chapter 5 includes explanation about design and implementation to visualize free flowing movements based on the time cartogram, the traditional geographically correct map, the animation and the STC approaches. Chapter 6 is about measuring usability of designed time cartogram. It begins with determination the usability research goals, with introduction different types of usability research methods and with selection of the appropriate methods for this thesis. Finally the usability test result and analyzes are summarized. Chapter 7 presents conclusion of the thesis and introduces some recommendations for the further research.

2. CARTOGRAMS

2.1. Introduction

This chapter presents a general overview of the concepts, principles and techniques of cartograms. Different types of cartograms (area cartogram, linear cartogram and central point cartogram) will be introduced and described. The principles of time and cartograms will be discussed in order to prepare for the creation of a time cartogram.

2.2. Different types of cartogram

A cartogram is a map where the geographic features are distorted based on some variable in order to express this variable (which has no geographic characteristics) effectively. According to Raisz (1948) a cartogram demonstrates a single idea in a diagrammatic way and it is useful tools of modern geography. The term of cartogram is derived from French language and there are various ways of using it, for example: “Anamorphose”- France, “Verzerrte Karte”-Germany, Post Soviet Union -“Varivalent” (Tobler, 2004). According to Dent (1999) the history of cartogram begun in 1868 ; French educator Émile Levasseur introduced cartogram (see Figure 2.1) in his textbooks in (1868 -1875) and which was used by Funkhouser in his paper (1937). Later Tobler (2004) mentioned about this cartogram and demonstrates the principle. It represents European countries by a square; the size of square is proportional to the area of the country.

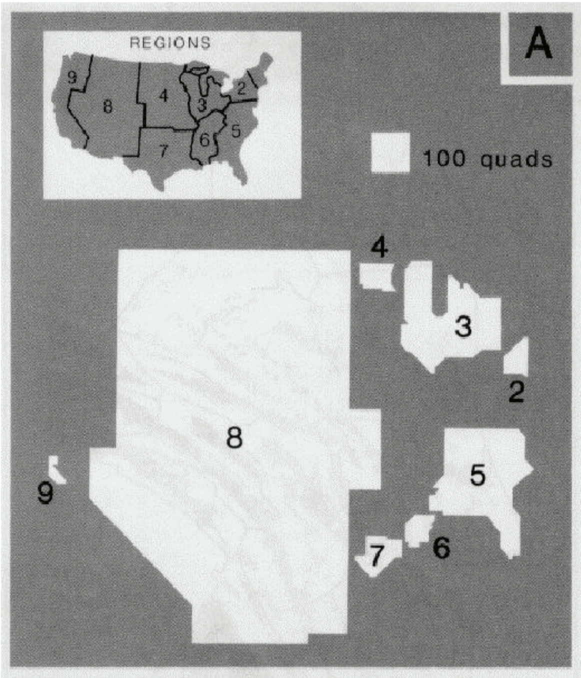
Figure 2.1: Levasseur’s cartogram in 1870 (Funkhouser, 1937)

A cartogram is a suitable tool to visualize statistical data about countries, states or counties in a way that size of an area in a cartogram corresponds to a particular variable (van Kreveld, et al., 2007). This variable could be election results (House, et al., 1998), spread of disease (Barford , et al., 2007), population size (Tobler, 1976) or Gross National Product (Dorling, 1995). A cartogram is also suitable to visualize transportation system where often a time scale is used instead of a distance scale and routes are simplified. Traditionally there are three types of cartograms: Area (value-by-area) cartogram, linear cartogram and central point cartogram.

2.2.1. Area cartogram

A value-by-area cartogram is a cartogram on which the size of the different areas is proportional to some variable such as population or economic indices (Tyner, 1992). Raisiz (1948) states that "Value-area cartograms helps a great deal in our geographic thinking". The Value-by-area cartograms can be applied for any statistical distribution successfully, and it can make socio-economic problems more clear and understandable (Raisz, 1962).

Two basic forms of the value-by-area cartogram can be distinguished: noncontiguous and contiguous (see Figure 2.2).



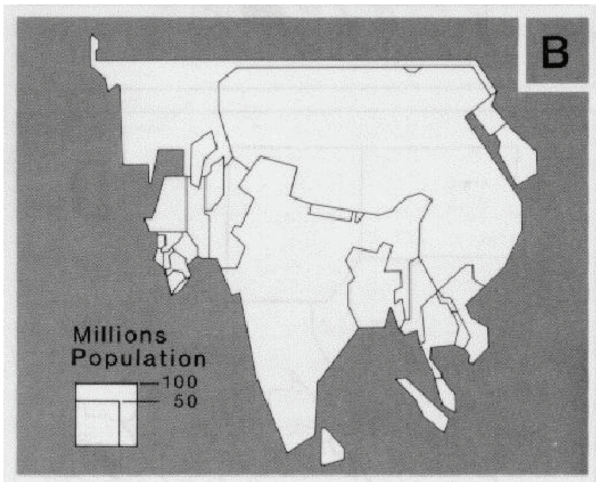


Figure 2.2: Value-by-area cartograms(URL10)

Part A, the noncontiguous cartogram, showing energy resources in US economic regions; Part B, the contiguous-area type, showing world population numbers, taken from Goode's World Atlas, 15th edn.

A noncontiguous cartogram shows the shapes of every enumeration area correctly, but adjoining areas do not touch and they are separated by empty spaces. The gap between objects gives to object possibilities to change their size growing or shrinking. They do not convey the continuous nature of geographic space, but shape of each unites is preserved and it is easy to scale and construct (Dent, et al., 2009). Although there is usually noncontiguous cartogram where the projected borders were traced, keeping objects centered on their original centers (see Figure 2.3). Since only sizes of enumeration area change and not their shapes, recognition of the units represented is relatively easy for a user (Olson, 1976).

Contiguous cartogram represents enumeration area without gaps and it conveys the continuous nature of geographic space. The enumeration area is represented by an appropriate size based on the attribute value. In this case it is very important to preserve the shape of the object, as best as possible, because great distortion of shapes may make recognition of the unites difficult and almost impossible (Dent, 1999).

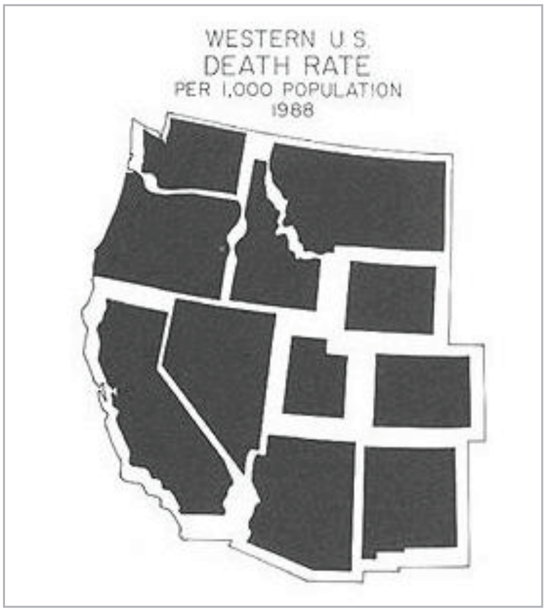


Figure 2.3: Non-contiguous cartogram, Western U.S.1988 (Tyner, 1992)

In 1996 Daniel Dorling developed a different variation of the cartograms where enumeration areas are represented with a uniform shape such as a circle. These kinds of cartograms are known as Dorling or circle cartogram where each circle is scaled proportionally to the attribute value replace the enumeration area (see Figure 2.4).

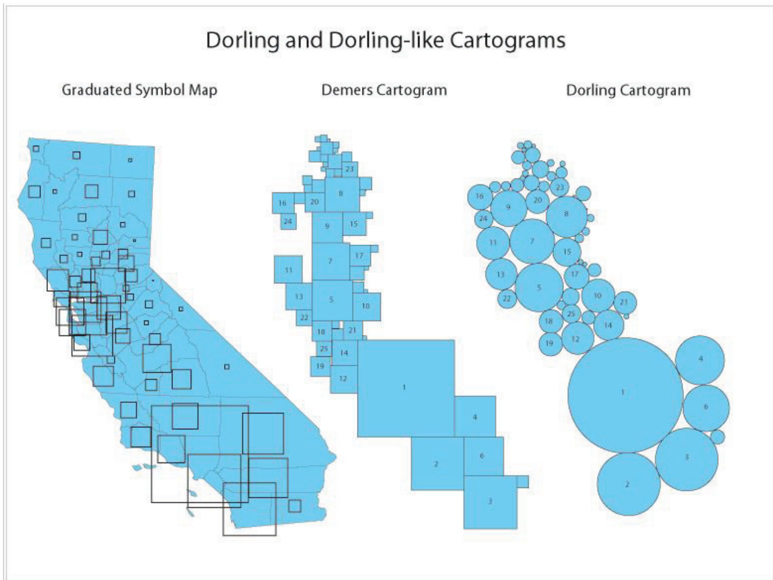


Figure 2.4: Dorling and Dorling-like cartograms(URL4); Population of California counties

To avoid overlap between objects the circles are moved away from their correct location hence the full area of every shape can be seen. Castner et al.(2004) considers Dorling cartogram as noncontiguous, because there are gaps between circles and they touch each other at only one point. But some cartographers consider Dorling cartogram as a variation of the contiguous cartogram, since the uniform shapes are touching (Dent, et al., 2009). Some other forms of cartogram, exist one of them is a pseudo-cartogram (or false cartograms) which was developed by Tobler (1986), where the author moves the object's connections to a reference grid such as latitude or longitude, in order to give the same implementation (see Figure 2.5). Another form of cartogram is Dorling-like cartogram (square-based cartogram) known as Demers Cartogram. Demers Cartogram uses squares instead of circles. It leaves fewer gaps between the squares and sacrifices distance to maintain continuity between figures and certain visual cues (URL4).

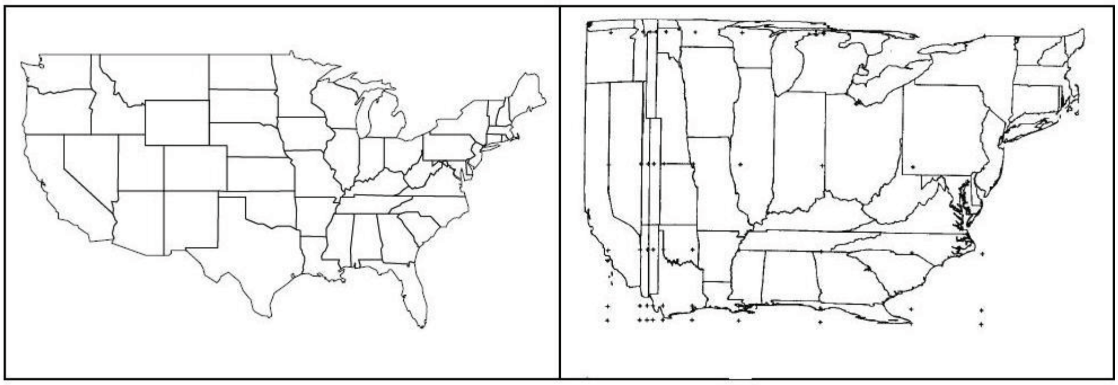


Figure 2.5: Pseudo-cartogram population density approximation of the U.S by Tobler (1986)

As we mentioned above there are different forms of area cartogram which traditionally can be produced in two ways: manual and using computer techniques. "Manual techniques for the construction of value-by-area maps are relatively simple, and they provide a viable alternative to those wanting more design control in their cartograms than is afforded in the automated methods. While the mathematics behind the algorithmic solutions is not always intuitive, studying the manual approach can be quite illustrative of the basic premise" (Dent, et al., 2009). On the other hand manual methods are useful when only a few areas are being presented and computer algorithms have to be used to design area cartograms of many places (Dorling, 1996). In order to create area cartogram the first computer algorithm was developed by Waldo Tobler (Tobler, 1973). Nowadays several algorithms have been formulated for designing of area cartogram; According to (Dent, et al., 2009) there are two of the most widely used algorithms: the (Dougenik, et al., 1985) algorithm and (Gastner, et al., 2004) diffusion algorithm.

2.2.2. Linear cartogram

Generally linear cartograms show network in such a way that the length of a connection is related to some feature of the connection, while in common maps such length is correlated to the length of the connection in the real world (Justo, 1977). In a linear cartogram a length can be the travel time for each link, the amount of traffic on each link or cost of travel on each link.

According to Tyner (1992) linear cartograms have also been called distance-by-time cartograms, is not new idea; Early time people created their maps according to a time scale, rather a distance scale, as they were more interested in length of time needed to travel between two points than actual geographic distance.

Shimizu et al. (2009) presented an application of distance cartogram which visualizes the changes of railway transportation service in Japan over years. The distance cartogram shows difference in region and changes in time of the transportation level of service (see Figure 2.6). These maps show that the shapes of transportation network are distorted in different times. Most of the connections between regions are getting shorter and there is an impression that the size of network is getting smaller; this means that the quality of transportation service is improved.

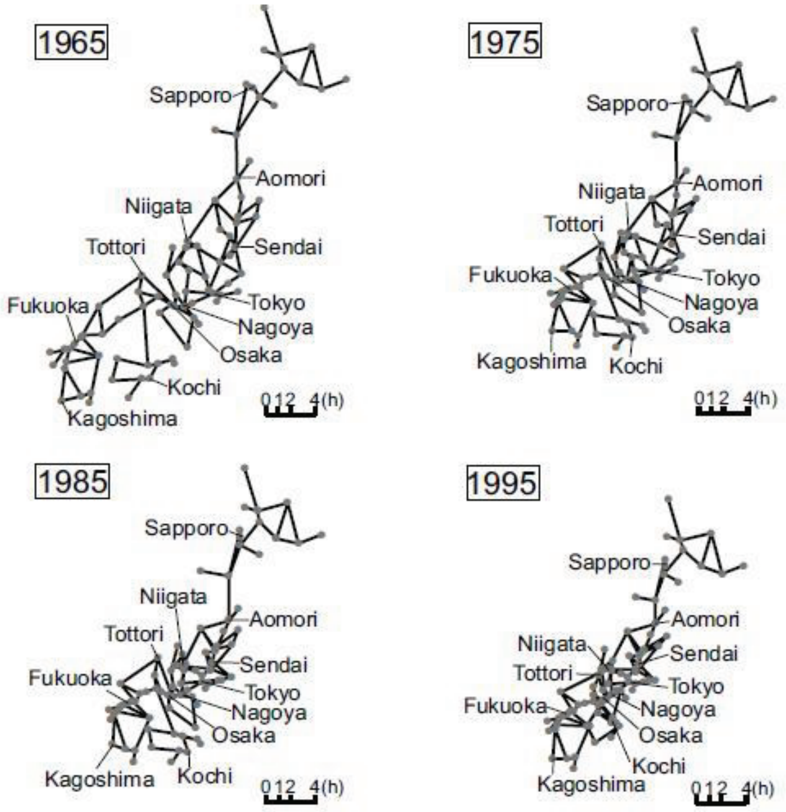


Figure 2.6: Railway service in Japan over years by Shimizu et al. (2009)

Monmonier (1996) considered schematic maps as linear cartograms; He and Dorling (1996) categorize underground route maps as linear cartograms, while some authors, like Aveler (2002) examines underground maps as schematic map, because distortions in the map are not in proportion to a measurable feature. The Figure 2.7 shows contemporary version of well- known London underground schematic map, which was first designed in 1931 by Henry Beck. In this map links between different routes are simplified in order to help passengers get the right connection (Avelar, et al., 2006). Tyner (1992) states that "often such kind of cartograms are created by graphic artists, not professional cartographers, but they serve many of the same functions. They attract attention and communicate information in a clear, uncluttered manner". Such kind of map does not preserves scale and the main importance of them is to show routes and stations, where routes are typically delineated in light colours and each colour illustrates a different route and station.

However it can be said that a linear cartogram is a map where network is distorted in distance, sometimes in form, which is related to some value. The value can be the time needed to travel the real-world distance or cost of travel. Linear cartogram gives opportunity to movements easily indicates through complex systems; choose the shortest path according to travel time and destinations without difficulty founded at a quick look.

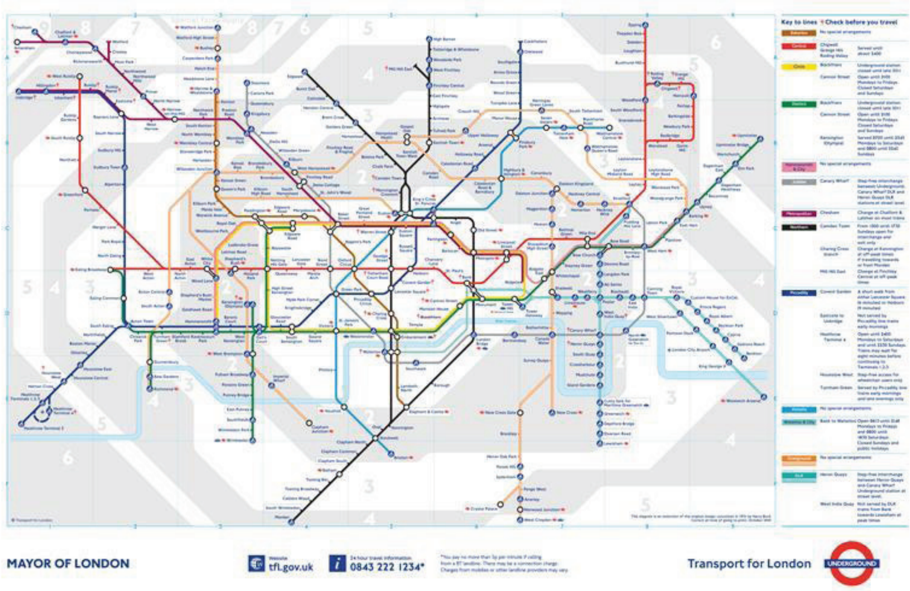


Figure 2.7: London underground map (URL11)

2.2.3. Point cartogram

The central point cartogram displays time which is needed for traveling from a center point to the other points. In this map direction is significant since time cannot be fixed between any other points of the map, because all points are related to the center. Concentric circle, which is got from equal time isochrone line, distorts the geographic base by removing some locations from the center and moving the others closer (Tyner, 1992).

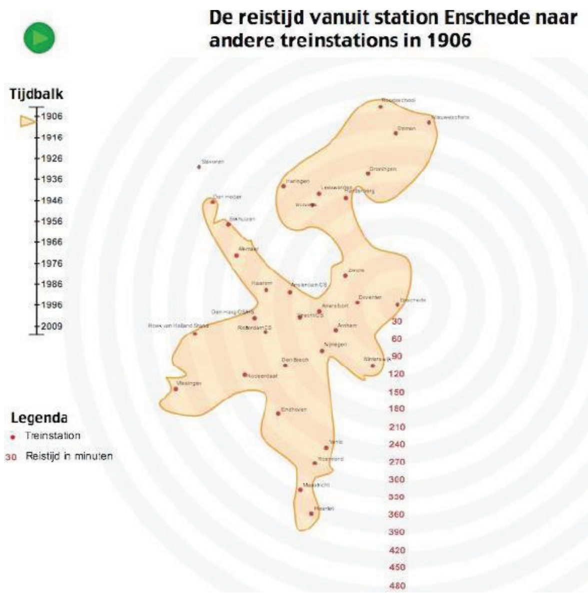
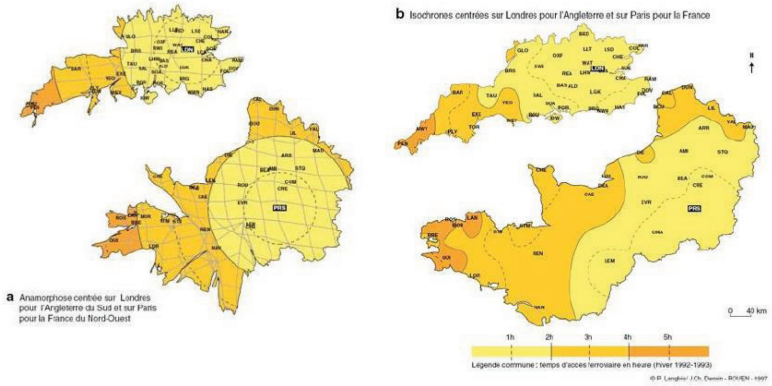


Figure 2.8: Travelling from Enschede 1906-2009

(Source: the lecture handout of Kraak (2010) in ITC)

The Figure 2.8 is a good example of central point cartogram. This map illustrates railway travel time from Enschede over years and like railway transportation service in Japan it makes the achievement in transportation service understandable.

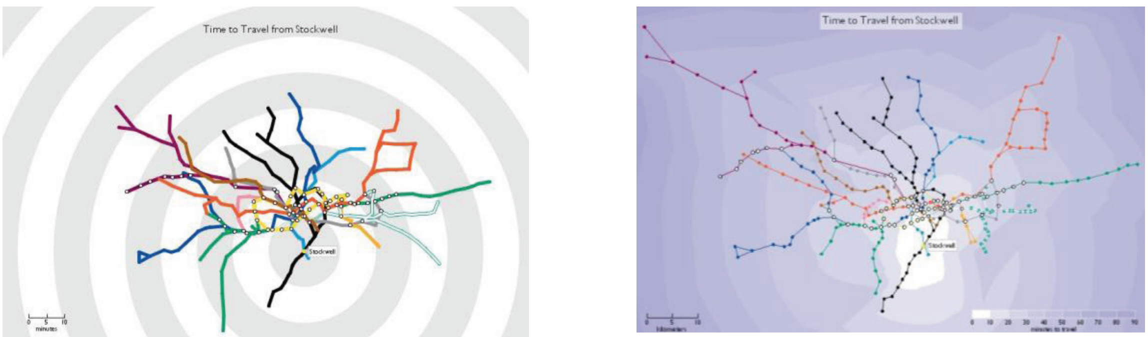
Street (2006) compares two different approaches such as central point cartogram and isochrones map (see Figure 2.9) and he states that isochrone approach is a little more effective, because it is easier to recognize the shape of France and Southern Britain. However both of them present clear picture about travel times around London and Paris. He also states that: "The maps' clarity is based on the combined use of the visualisation technique and choice of colour. The different blocks of colour make the isolines stand out from one another, and provide an easy referencing system against time. The use of a sequential scale of colours is important here – we quickly learn that a darker colour indicates an increased journey time allowing us to make relative judgements without having to refer back to a key or read numbers".



Anamorphosis map centred on London (top) and Paris (bottom)   Isochrone map centred on London (top) and Paris (bottom)

Figure 2.9: A comparison of central point time cartogram and isochronic maps (Street, 2006)

In 2005 Carden presented a project about transportation network (URL1). He produced interactive Travel Time Tube Map of London Underground (see Figure 2.10.A) which was motivated by Oskar Karolin's studies.



A. London underground Central point cartogram   B. London underground isochrone map

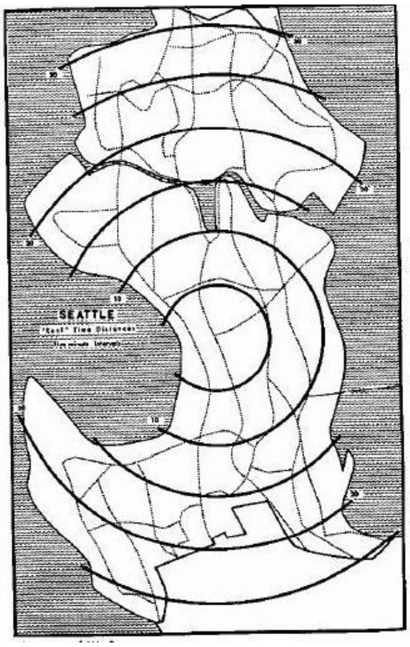
Figure 2.10: London underground travel time cartogram and isochrone map (URL1) (URL2)

This interactive London subway cartogram illustrates shortest paths from one station to the other station. The concentric circles are at 10 minute intervals and there radius are proportional to travel, and their angles are corrected for as the crow flies direction on a map. London underground central point time cartogram is more user-friendly and effective than interactive isochrone map which is also implemented by Carden one year later (see Figure 2.10.B). This map demonstrates isochrones also 10 minute interval and indicates travel time from the selected station. However according to Street (2006) this prototype implementation are successful but it has some disadvantage, for example, the unfamiliar unlabelled layout makes it difficult to relate to the underground.

2.3. Time and cartogram

In order to analyze events, to show future scenarios geographers illustrate time information in different forms on maps. Sometimes using time as a distance measure between two geographic phenomena makes geographic space more understandable. People are often more interested in length of time needed to travel from one location to other than actual geographic distance. In this case to use time scaled maps is very useful because it gives opportunity to analyze events that are contacted with movement in space in way of expressing distances in terms of time. Nowadays the nature of the roads, amount of traffic, presence or absence of traffic lights and nature of the terrain are sometimes the reasons to take different time to achieve exactly the same number of kilometres (Tyner, 1992). It is obvious that to use time scaled maps gives clearer picture for travelling than just typical distance scale maps.

Cartographers always tried to create time scaled maps; a cartogram is one of such a map where it is possible to use time as a scale. Cartograms demonstrates time based on distortion geographic space and the Euclidean distance is replaced by travel-time distance, in order to illustrate time which is required to travel between two points or gives clear picture how quality of transportation service could be improved overtime. As it was mentioned earlier there are different types of cartogram. One of this cartogram is central-point Cartogram and as it was discussed above it has a long history in geography and it has widely used to illustrate time distance. According to Tobler (1961) Bunge presents maps where distances were measured in minutes from the center of the city (only) to all the other locations. Later Campbell (2000) illustrates this map as central-point Cartogram (see Figure 2.11). Nowadays there are several interesting examples where travel-time distance is illustrated by using central point cartogram and addition it is embedding animation or dynamic approach.



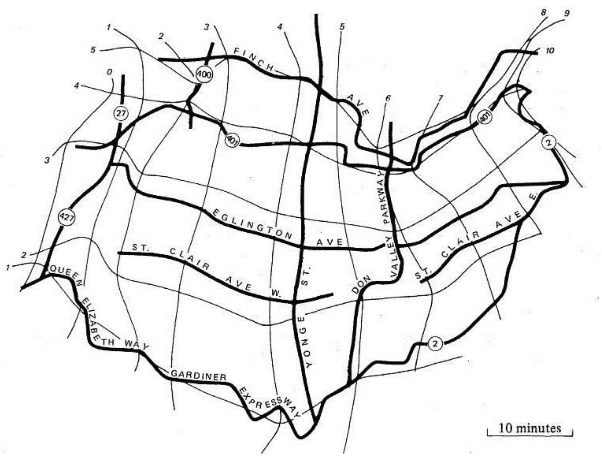


Figure 2.11: Central point Cartogram (Campbell, 2000)

Figure 2.12: Toronto in time-space based on displacement vectors (Ewing, et al.,1977)

Some authors like Ewing et al.(1977) solved time-scaled problem by using area cartogram approach which displays travel-time distance by shrinking and stretching of geographic space. They developed method which is capable of showing regular grid squares distortion in time space and also the distortion of road network or any surface feature (see Figure 2.12). Later several works have been done for construction such kind of cartogram and generally all of this work was based on MDS algorithm (see Chapter 4). Spiekermann et al. (1994) employed MDS algorithm in their research and implemented railway travel time-scaled map of Europe (see Figure 2.13). Axhausen et al. (2006) constructed road travel and public transport travel time-scaled maps using weighted least squares estimation on MDS and demonstrate how much the shape of Switzerland has shrunk based on travel time in over years (see Figure 2.14). Linear cartogram approach is also very practical and straightforward to illustrate time on a map. In linear cartogram time-distance is represented as line between geographic places and users can read maps easily. As it was mentioned earlier Shimizu et al. (2009) presented an application of linear cartogram which visualizes the changes of railway transportation service in Japan over years. This work illustrated success of cartogram as a tool to show differences in the level of transportation service over years.

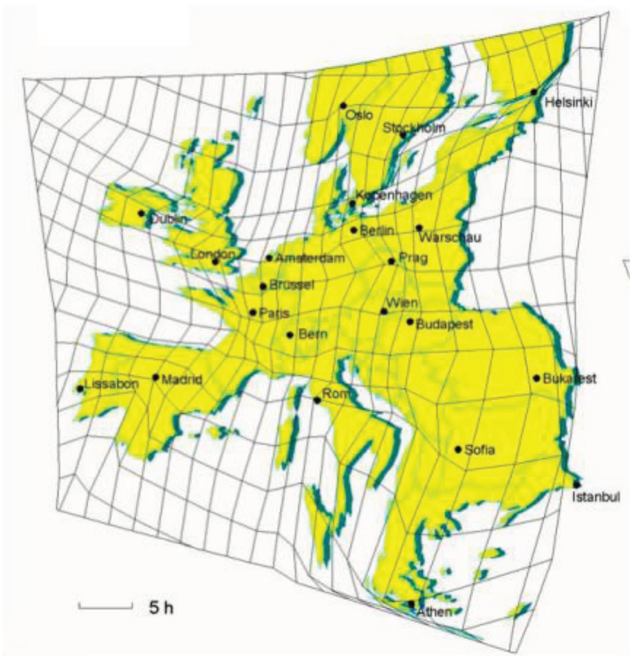
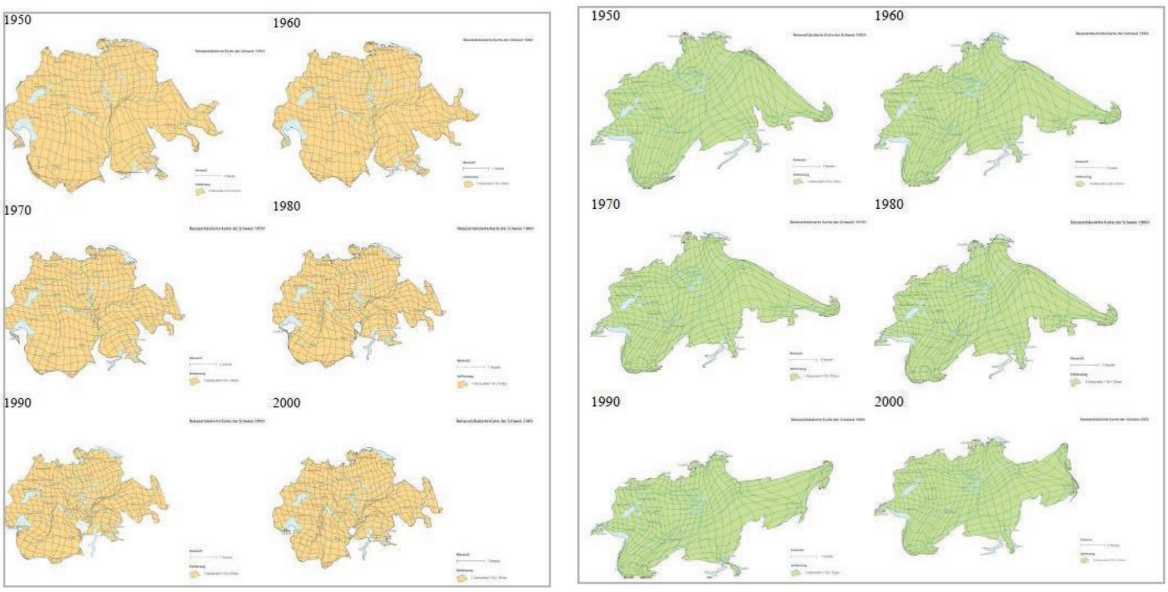


Figure 2.13: Railway travel time-scaled map of Europe, 1993 (Spiekermann, et al., 1994)



A. Road travel time-scaled maps B. Public transport travel time-scaled maps

Figure 2.14: Switzerland (Axhausen, et al.,2006)

2.4. Summary

In the present chapter the cartogram concept has been discussed. Different types of cartogram were presented and described. Since this research is focused on the time cartogram approach as alternative visual representation of STPs, the principles and techniques of the creation of time cartogram were introduced.

3. STP, THE STC AND THE ANIMATION

3.1. Introduction

In this chapter the concept of STP will be presented. It is addressed to give a theoretical background of STP and its major characteristics. Additionally this chapter refers to the visual representation of STP using different time mapping methods such as the STC and the animation.

3.2. STP

In geographic geography is a powerful concept to study human behaviour in space and time. Time geography deals with the investigation of temporal factor on spatial human activities with constraints like authority, capability and coupling (Hägerstrand, 1970). Swedish geographer Hägerstrand was one of first who was studying human activities and movement in space and time. He developed concept of a STP to illustrate how a person navigates his or her way through the spatio-temporal environment.

3.2.1. Single STP

A single STP can be considered as a movement of single geographic object. STP is just a line (trajectory) on a map, which can visualize in a different way. Figure 3.1 is a good illustration of Single STP in a STC. It can easily identify object's location at the certain time or identify the time period when the object is in the certain place. Z axis displays the time which gives opportunity to illustrate an individual visit or multiple visits to the same location, while it is difficult to display multiple visits to the same location on a traditional map. The STP in the STC illustrates the characteristics of a movement, the slope of a path indicates movement velocity and if there is no-movement the path appears vertically.

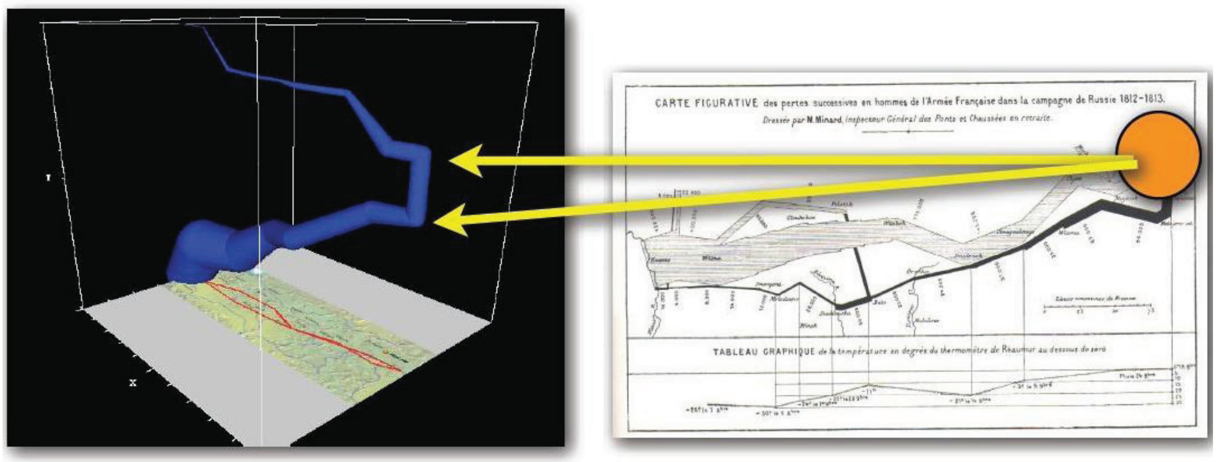


Figure 3.1: Single STP in STC

(Source: the lecture handout of Kraak (2010) in ITC)

3.2.2. Multiple STP

Movements of several geographic objects in space and time can be displayed as multiple STPs. Figure 3.2 illustrates multiple STPs in a STC. Kristensson et al. (2007) in their research formulate a formal empirical experiment comparing space time cube against a baseline 2D. In order to illustrate the result they used error rates and response time. The result supports the claim that users benefit more from the STC than from 2D displays when analyzing complex spatiotemporal patterns. However other authors like Andrienko et al. (2007) state that the complexity of the geometry of the trajectories, increasing number of moving objects or the length of the time period make difficult extracting information

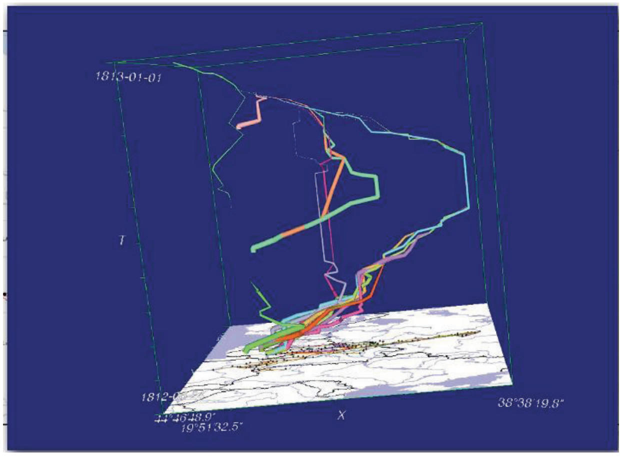


Figure 3.2: Multiple STPs in STC

(Source: the lecture handout of Kraak (2010) in ITC)

3.3. Visual representation of STP, the time mapping methods

3.3.1. STC

As it was mentioned to study individuals in their day-to-day activities a space-time model has been introduced by Hagerstrand in 1960. People's physical mobility network can be represented by this model and it is based on STC (Kraak, 2008).

STC is capable to represent the complex trajectory of individual movements in space-time with many interacting dimensions that include the location, time, duration and sequence (Andrienko, et al., 2003; Kraak, et al., 2009). STC has the ability to visualize time information. It can be considered as the most prominent element in Hagerstrand's approach where the cube has on its base a representation of the geography (along the x- and –y-axis), the cube's height represents time (z-axis) (Kraak, 2003). There are several traditional and non-traditional STC applications that have capabilities a better exploration and understanding of time information (Kraak, 2008). Generally STP is represented in 3-D space (Z axis displays the time and X,Y the geographic surface) and it has possibility to illustrate an object location at the certain time, to find out when the object is in the certain place or to give information that who is in the certain place at the certain time. Kraak (2003) used STP in STC in order to display the author's travels on an average Thursday in Enschede, the Netherland (see Figure 3.3.I). There are three types of constraints in this representation: capability constraints (for instance mode of transport and need for sleep), coupling constraints (for instance being at work or at the sports club) and authority constraints (for instance accessibility of buildings or parks in space and time) (Kraak, 2003). STP can be projected on a map, resulting in the path's foot print (see Figure 3.3.II). It is interesting also to considered Space-Time-Prism as the alternative representation of space-time data (see Figure 3.3.III).

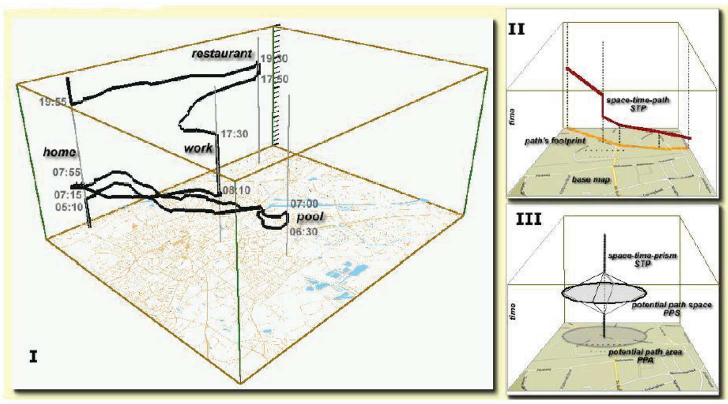


Figure 3.3: I. The STC; II. The STP and its footprint; III. The Space-Time-Prism (Kraak, 2003)

Miller et al. (2009) illustrate a STP between three activity locations (see Figure 3.1) : the path is vertical (when the individual is stationary in space); differs from vertical (when the person is moving in space with respect to time), and its slope (a shallower slope indicates less time per unit of space). They illustrate also analytical definition where S_{ij} (t) is a simple linear interpolation based on the temporally adjacent control points c_i (t_i), c_j (t_j) and the relative elapsed time within the unobserved interval $t \in (t_i, t_j)$.

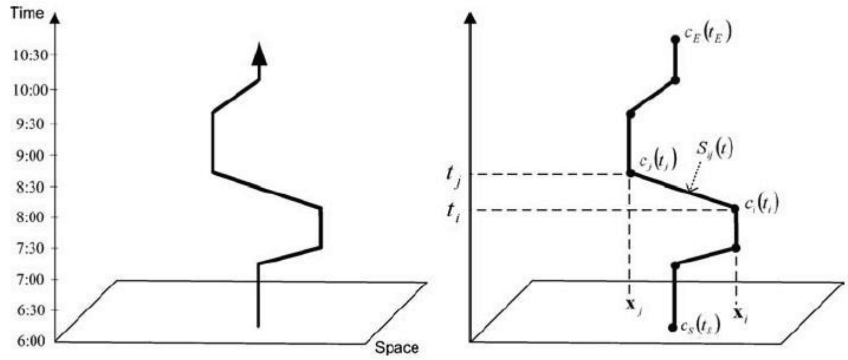


Figure 3.4: STP (Miller, et al., 2009)

3.3.2. Cartographic animation

Animation can be considered as a visualization method which is widely used in cartography (Monmonier, 1991, Kraak, et al., 1994 , Edsall, et al., 1997). Since the 1960s using of animated maps in cartography has become popular. According to Kraak et al. (1996) animation is the process of design and production of images that suggest movement. Monmonier (1991) defines animations as "a scale model in both space and time". Animation can play a significant role in order to display patterns, trends or spatial relations. The animated map is a series of individual maps that shown in a quick succession for the purpose of depicting some type of trend or change (Peterson, 1994).

Map animation can be very useful to visualize space-time data sets. In the cartographic animation can be distinguished temporal and non-temporal animation (Kraak, et al., 1997):

- **Non-temporal animation** is used to show spatial relations or to specify geometrical or attribute characteristics of spatial phenomena by presenting individual map images in a logical sequence.
- **Temporal animation** is used to show world time (the moment an event takes place in the real world) in a temporal sequence. The varieties of spatio-temporal data sets can be explored and visualized using temporal animation. The user can interact with the animated maps (i.e. play with the time line: forward, backward, pause and etc.)

As mentioned above animated map can deal with space-time data. Free flowing path can be considered as one form of space-time data and it could be visualized by using animation. The animated map displays the route of the object from the starting point of the movement and it represents movement of the object. When the object ends its movement (at the end of the route) the whole route is visible. In order to visualize free following path by animated map there is a need to use the dynamic graphic variables of animation such as: size, position, shape, speed, viewpoint, distance, scene, texture, pattern, shading and colour (Peterson, 1994). The main advantages of animated map are that it can display temporal information and dynamic graphic variables can be used to represent changes.

3.4. Summary

In the present chapter the main characteristics of STP were discussed and the visual representation of STP was described in detail. Time mapping methods such as the STC and cartographic animation were presented.

4. THE TIME CARTOGRAM: CONCEPTUAL APPROACH

4.1. Introduction

This chapter will introduce different methods and algorithms that were examined in the previous studies in order to illustrate time distance and to create time cartograms. For example, the key features of the multi-dimensional scaling (MDS) method and algorithm, the network time-space method will be discussed. This is followed by conceptual design approach of the time cartogram. Problems will be discussed that are related to the selection of the time scale and the initial point.

4.2. Methods and algorithms for time-distance cartogram construction

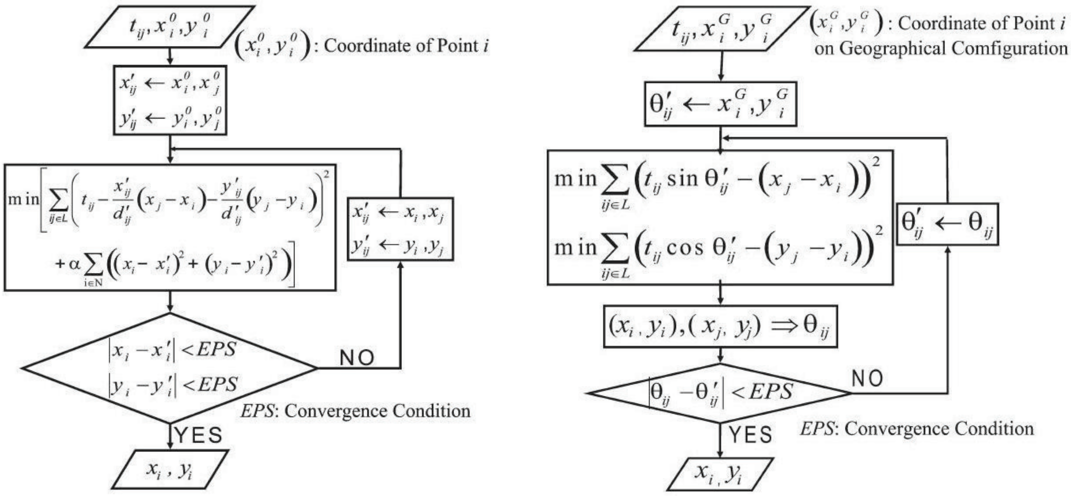
In order to illustrate time distance and create distance cartogram several researches have been done (Ahmed, et al., 2007; Angel, et al., 1972; Dorling, 1991; Ewing, 1974; Muller, 1978). All these researches examine different methods and algorithms. Dorling (1991) and Angel (1972) proposed method, which focused on illustrating time-distance in a three-dimensional space. On the other hand to illustrate time-distance in two-dimensional space all work was based on MDS algorithm.

4.2.1. Multi-dimensional scaling

The first MDS method was proposed by Torgerson (1986). Multi-dimension scaling is a method which takes a set of distances among points and based on them creates a 'map' of the points, dependent on the number of dimensions required, except still retaining the order of distances (Golledge, et al.,1972). According to Parkes et al. (1980) using MDS method it is possible to display how spaces are warped by use of measures other than Euclidean distance. The aim of MDS method is to find positions $x_i \in R^d$ in d-dimensional space, where δ_{ij} represent metric dissimilarities or distances between all i, j ∈ {1, . . . , n}. The solution is a vector X = {x_1, . . . , x_n} for a given δ_{ij}, such that $\delta_{ij} \approx x_i - x_j$ (Brandes, et al.,2007). According to Shimizu et al. (2009) MDS method is mathematically straightforward but increasing number of plotted points reduce the precision of the proximity representation in some point pairs. The Authors Ewing (1974), Muller (1978) and Ahmed et al (2007) used MDS method to display time distance. In general there are several approaches that have been made to design distance cartogram and reduce the deformation, for instance Spiekermann et al. (1994) employed stepwise MDS method which they extended to cope with boundary effects. On the other hand Axhausen et al (2006) employed weighted least squares estimation on MDS method. It is significant also to mention that Kaiser et al. (2010) proposed user-centric transforms which is modifications and extensions to classic MDS in their work. User-centric algorithm for time-distance map transformation presents geographical space of conventional road maps into a spatial temporal hybrid map where locations of network points are adjusted to show the time it takes to travel between them. They provide two approaches for represented user-oriented time-distance map: the first approach provides a user-centric visualization in which map features are positioned relatively to their travel time from the user and second approach focuses on representation the temporal proximity relatively to a specified route of path along the road network.

4.2.2. The algorithm which includes the key features of MDS and network time-space mapping method

Shimizu et al. (2009) developed new generalized solution in order to create a linear cartogram. To achieve this solution first they formulate linear cartogram construction as a nonlinear least squares problem and propose a generalized solution using the Levenberg-Marquardt method (see Figure 4.1.A). Because of Levenberg-Marquardt solution has some difficulties to create linear cartogram and these difficulties arise with selection of initial values, they formulate another approach to normalize linear cartogram construction and propose a new generalized solution (see Figure 4.1.B).



A. Algorithm of Levenberg-Marquardt method. B. Algorithm of proposed solution for distance cartogram

Figure 4.1: Levenberg-Marquardt method, algorithm for distance cartogram(Shimizu, et al., 2009)

The advantage of this algorithm compared to the other existing methods is that relevant calculations require short time; it is possible to automate the setting of the primary data and it is user-friendly (Shimizu, et al., 2009).

4.3. Visualization of STP using time cartogram approach

In some situations expressing distance between geographic phenomena in time is more clarifying than in Euclidean distance. The time cartogram is a graphic representation that makes it possible to use time as a distance unit. The time cartograms demonstrate distortion of geographic space based on time because the Euclidean distance is replaced by time distance. According to the literature review (see Chapter 2) various researches on time cartograms have been done. Generally, a time cartogram is used to visualize transportation systems, such as a road network or a railway network. Movement of objects along the network follow fixed path. The network consists of nodes and segments. In a cartogram, nodes are moved in such a way that the segment length reflects the time needed to travel between the nodes. The most important step for the creation of time cartograms is the introduction of time-distances between the nodes of the network. In most cases, time-distances are provided dynamically from some other data sources, such as time tables of traffic services. Also, travel times can be estimated from the network itself based on, for example, speed limits for the road categories.

The algorithms discussed in 4.2 do not work when movement is not following a fixed network. The difficulty with regard to the visualization of a free flowing path (which consists of points as nodes in a transportation network) is that path can crosses itself, an object can return to the same location, and a moving object can use the same path several times (see Figure 4.2).

Figure 4.2: The free flowing path

4.4. Conceptual design of a time cartogram

As it was mentioned before a free flowing path consists of points and segments. Points of path can be considered as nodes in the network and the most important stage for the creation of a time cartogram is to create a new configuration of points that represents time distance instead of Euclidean distance. The following formula is used to convert coordinates of points in such a way that segments between converted points represent time distance. This formula preserves orientation between neighbour segments as formed in original map data; it calculates new coordinates for points based on a time scale.

$$X_d = (X_i - X_{i-1}) / \delta_{xy} * t_i * S_d$$
$$Y_d = (Y_i - Y_{i-1}) / \delta_{xy} * t_i * S_d; \quad i \in \{1, \ldots, N\} \quad (1)$$

Where X_d , Y_d represent new coordinates and X_i, Y_i -geographic coordinates

δ_{xy} is the Euclidean distance between geographic coordinates $\delta_{xy} = \sqrt{((X_i - X_{i-1})^2 - (Y_i - Y_{i-1})^2)}$

t_i is a time that is need to cover the distance (δ_{xy}),
S_d is an average of the distance that is covered by an object during basic time unites.

This average length was chosen as a time scale $S_d = \sum_i S_i / \sum_i t_i$, where S_i is a distance that is covered by an object during t_i time interval.

Based on formula (1) the following formula could be used to calculate time distance:

$$\delta_{X_d Y_d} = \sqrt{((X_{d_i} - X_{d_{i-1}})^2 - (Y_{d_i} - Y_{d_{i-1}})^2)}$$

The angles between the segments of path would be preserved as there were between geographic segments which give opportunity to preserve the orientation between neighbour segments as formed in original map data.

4.5. Discussing implementation

As test dataset the movement of one of Napoleon's army corpses that participated in his Russian campaign was used. The corps movement in space over time can be considered as a free flowing movement. The test data represent daily information about Napoleon's IV corps movement which started on the 30th of June 1812 from Pilony and they reached Moscow on the 15th of September. On the 17th of October they started returning back and finished their trip on the 12th of December in Kowno. Since the original data (see Figure 4.3) include the locations of the corps for each day it is possible to select one day as the basic time unit to map the day; the drawing length of basic time unit is chosen based on the average daily distance of movement that was covered by corps during the campaign. But the complexity is that the existing data includes also information about where this corps stopped for some days and based on this it is possible to calculate two types of average daily distance.

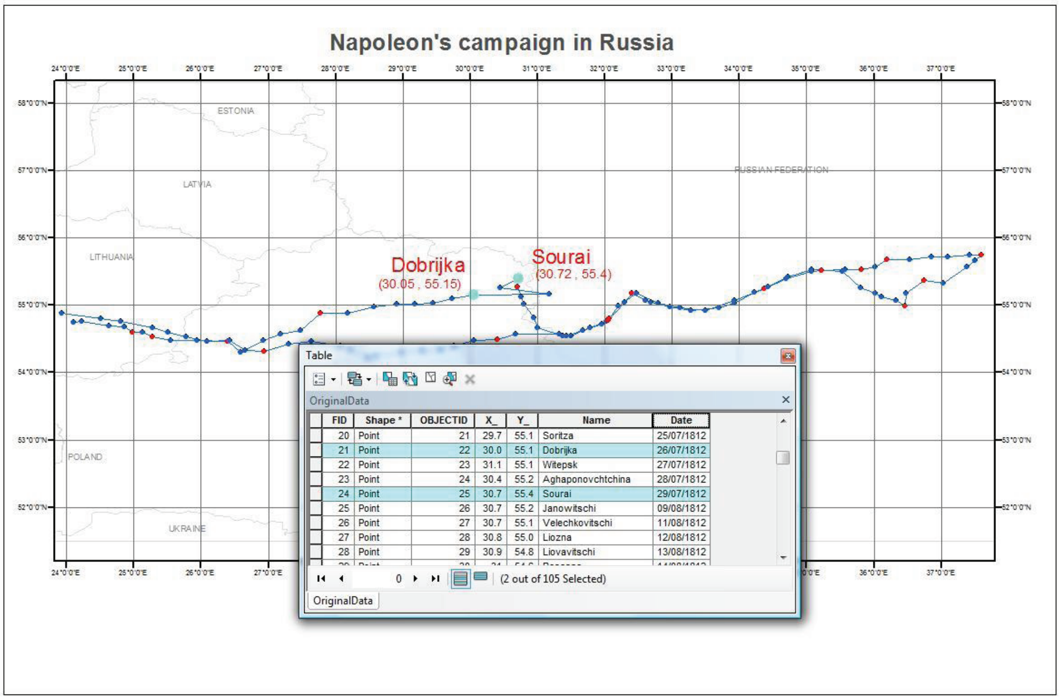
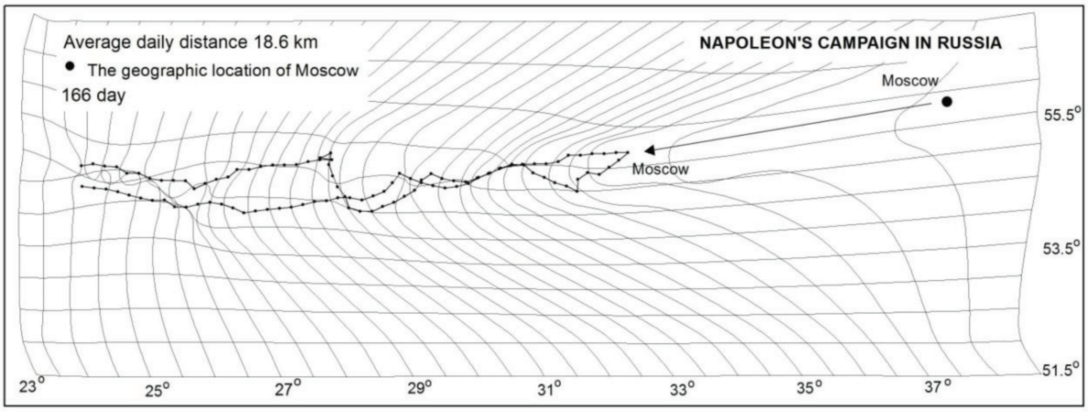


Figure 4.3: The original data

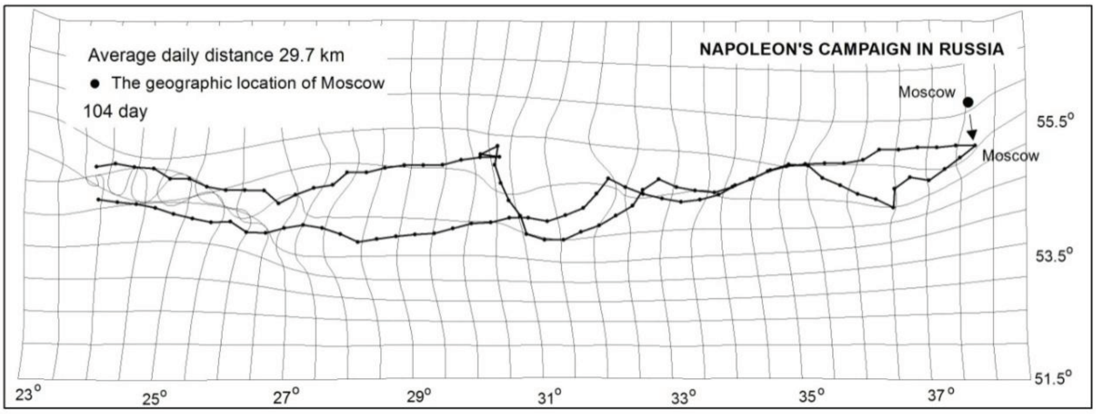
The first average daily distance calculation is based on all numbers of days there are between the 30th of June and the 12th December, and the second one is based only on the number of days the corps actually moved, which does not include the number of days when they were staying at the same location. After those calculations two pairs of new coordinates were created for each location (node), based on the different average daily distance. According to these new coordinates the corps' movement is represented differently (see Figure 5.2)

Generally, in MapAnalyst (URL8) software which is used for the analysis of the geometric properties of old maps, it is possible to perform efficient identification and management of control points on a historical map and on a corresponding reference map as well. This software application has capabilities to visualize and study the planimetric accuracy of map, "visualization of planimetric accuracy illustrate how rotation, shearing, shrinkage, and stretching vary locally on the map" (Jenny, et al., 2007). In order to estimate which average daily distance is more accurate in terms of a scale distortion MapAnalyst software was used.

The Figure 4.4 illustrates the new coordinates created for each location, which uses average distance as a time scale that represents the constant distance between points (places) since the corps covered different distances in one day and a time scale represents average daily distance. It means that the geography of this movement is distorted based on time scale. The average daily distance, which was calculated, based on the sum of movement days in terms of a scale distortion, come more closer to geographical scale than the average daily distance that is based only on the number of days the corps was on the way (see Figure 4.4.A.B). Formula (1) which changes a geographical distance into new physical distance (that presents time) preserves the orientations between the segments of the path as it was in case of geographical segments.



A. Average daily distance 18.6 km



B. Average daily distance 29.7 km

Figure 4.4: Different average daily distance

However the calculations showed that new coordinates (that were obtained using above mentioned formula (1) preserve a correct orientation between segments only when an object moves in to one direction. Problems occur when the object comes back and moves along approximately the same segments and passing by the same geographical locations. The result is the geographical displacement of the new points. The above mentioned problem has become obvious by using MapAnalyst. Figure 4.5 shows a selected area that a high level of geographical displacement. The reason of the grid distortion of this area is the movement of the points from the north to the south (their coordinates are changed).

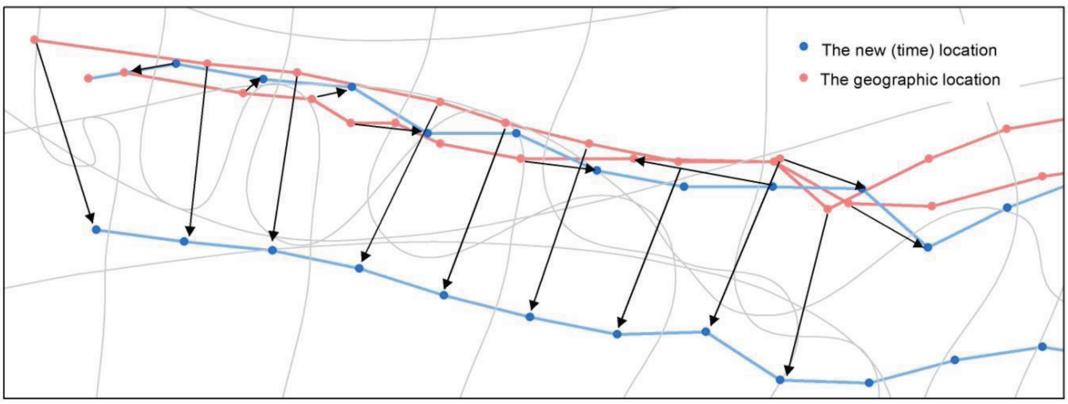
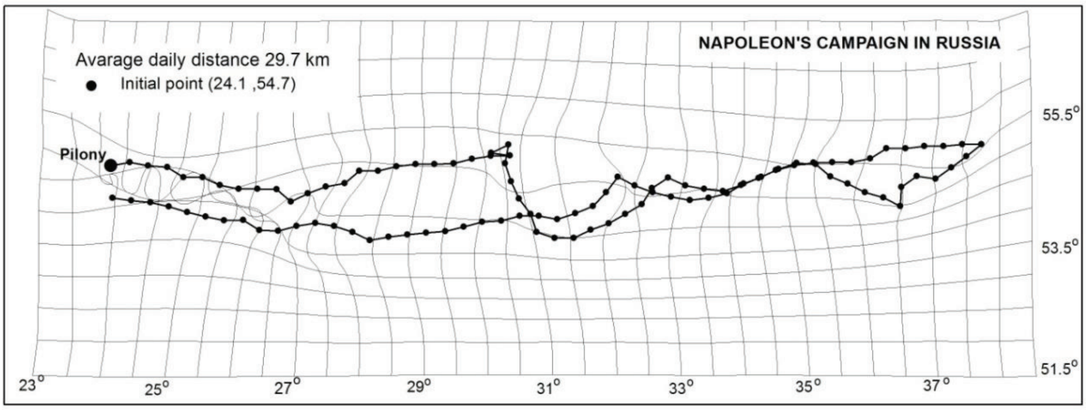
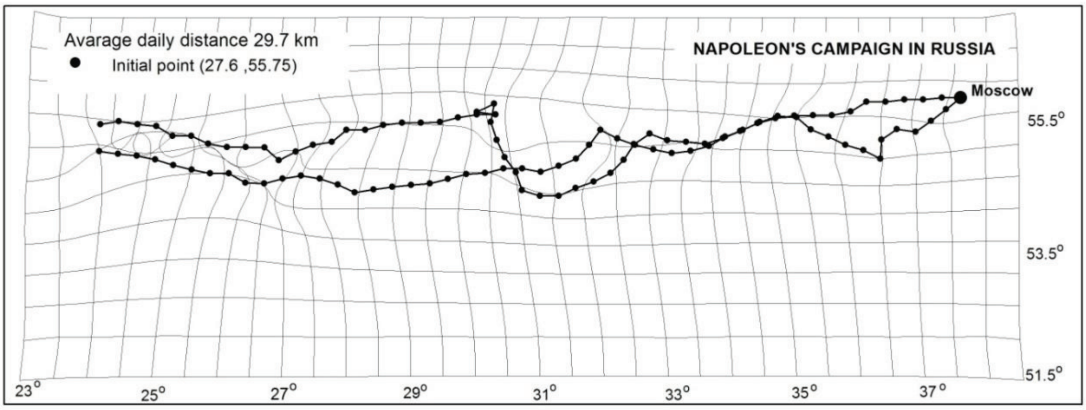


Figure 4.5: Geographical displacement

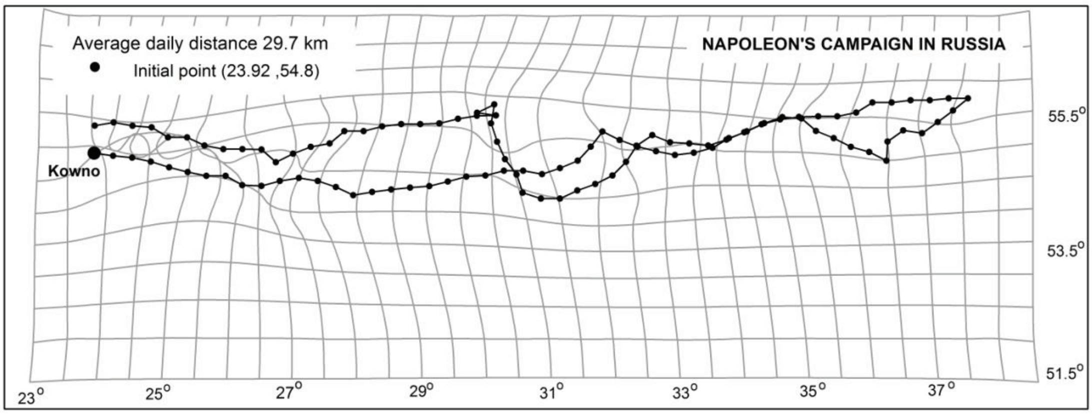
As was mentioned above, in order to use the formula (1) it is necessary to fix the initial point. Any node of a geographical segment can be considered as the first point of the path. Experiments were executed with choosing the coordinates of the point from where an object has started its movement (the start (west) point), or the extreme point in east of an object's movement (the end (east) point), or the end point of an object's movement (the end (west) point). By selection of these three points it was possible to calculate three different coordinates for each geographical point in such a way that the distance between points (with new coordinates) displays time distance instead of geographical distance. Based on these three different initial coordinates it is possible to get three types of geographical grid distortion by using MapAnalyst. Figure 4.6 shows that the selection of the initial point does not influence the distortion of the geographical grid.



A. The start (west) point of an object's movement



B. The end (east) point of an object's movement



C. The end (west) point of an object's movement

Figure 4.6: Different initial points

4.6. Summary

In order to illustrate time distance and to create a time cartogram different methods, such as multi-dimensional scaling (MDS), and a new algorithm, including the key features of MDS and the network time-space method were discussed in this chapter. The conceptual design approach of the time cartogram was presented as well. The time scale and the initial point were selected. Formula (1) was used in order to convert the coordinates of points in such a way that segments between converted points represent time distance. A time scale was chosen as the average daily distance (calculated based only on the number of days the corps was on the way). The start point of an object's movement was selected as the initial point.

5. DESIGN AND IMPLEMENTATION OF STP

5.1. Introduction

Since the main goal of this research is to develop a mapping method to visualize free flowing movements based on the time cartogram approach and to see how this compares with alternative mapping methods such as the traditional geographically correct map (map), animation and the STC it is essential to introduce and explain the design and implementation of these mapping approaches.

5.2. Map design

Maps present geospatial information. Map design plays a significant role in a mapping process. There are several approaches and definitions of map design. According to Moor (1981) design is more than simply drawing something; it is the invention and disposition of the forms, parts, or details of something according to a plan. A cartographic design can be considered as communication between map author and user; cartographic knowledge can be transformed by cartographic design. The map design process is a complex activity that includes both intellectual and visual aspects (Dent, 1993). DeLucia (1974) states that design is the most fundamental, challenging, and creative aspect of the cartographic process. According to (Wood, et al., 1996) in order to have an appropriate cartographic design it is important to have good understanding of what design is; the purpose of graphic design; the process of graphic design; to work within limitations imposed on design by technology, the media, and operational logistics. All the design elements, like all the components of a map, are interdependent (Robinson, 1966). Considering Robinson's view about map design DeLucia (1974) defined design as "a systematic thought process which yields solutions to a wide range of human problems. The process is logically independent of the specific nature of the systems or products required to solve those problems". According to Dent (1993) the first stage of the design process is the symbolization of the map information, the next step is the definition of the map's purpose (why the map author wants a map and what he expects to achieve), the last step of the map design process is implementation, when the final map production begins.

5.3. Design of different mapping methods

In the last few years maps are designed and widely used for an on-screen environment, which requires a different design approach compared to paper maps. Digital maps can store much more data behind the map. Besides graphic representation maps can give the user the analytical power of Geo-Information Systems (GIS), the ability of understanding and answering the questions quickly (Aveler, 2002). For the mapping process it is important to determine which information should be kept and what information can be ignored. There are some special cases when the geometric accuracy in the map is less important than other relationships between features on the map. In order to show relations that are more important to the users the map's geography is distorted (Muehrcke, et al., 1997). As described before in this research a cartogram can be considered one of such special cases. Cartograms are created for different purposes. This research is focused on the time cartogram which illustrates time distance instead of Euclidian distance.

5.3.1. Time cartogram

In order to visualize temporal information on the cartogram different graphic variables may be used. Generally, line symbols can be used to show the temporal and spatial extent of an event's continuance (Vasiliev, 1997). To display the complete information about the IV corps movement (date and time period when the corps didn't move) there was a need to create the time cartogram with different design. Considering the fact that the segment on the time cartogram presents time (each segment presents one day) instead of geographical distance, there were some problems to display time period when the corps didn't move. It would be logical to display the number of days when the corps didn't move by the same number of segments since one segment presents one day on the time cartogram (see Figure5.1. A) This presentation could not be considered as correct one because in this case it is not possible to identify the direction of the segments, the corps didn't move to any direction and accordingly not possible to determine its orientation.

Another design approach for creation of the time cartogram was to use different colours for points (stop one day, stop for some period of time) (see Figure 5.1.B), but also this approach doesn't give the ability to get the whole information about time, for example, it is not possible to get information about dates and the number of days when the corps didn't move. In order to solve these problems the time cartogram with different design approaches were created (see Figure 5.1(C, D, E, F)). Finally nominal line symbols, proportional point symbols and time labels are added to the time cartogram in order to visualize the free flowing path of Napoleon's IV corps movement completely.

Nominal line symbols are used to indicate time distance (months); proportional point symbols are used to show different amounts of days that on which the IV corps stopped, time label at point symbols is used to depict the dates (see Figure 5.2).

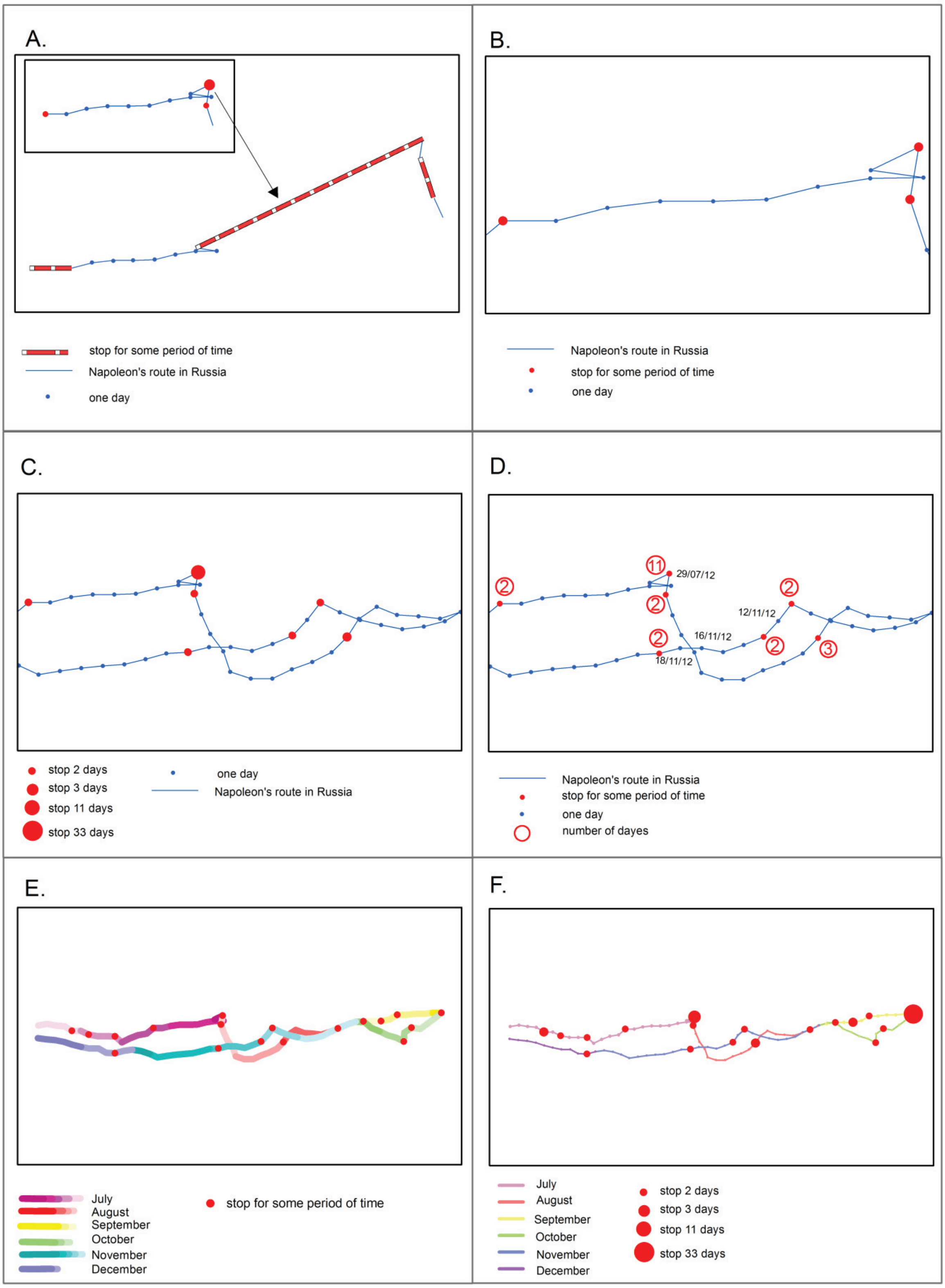


Figure 5.1: Different design for the time cartogram

A. Same number of segments. B. Points by different colours .C. Proportional point symbols D. Time label.
E. Nominal line symbols (weeks) F. Nominal line symbols (month)

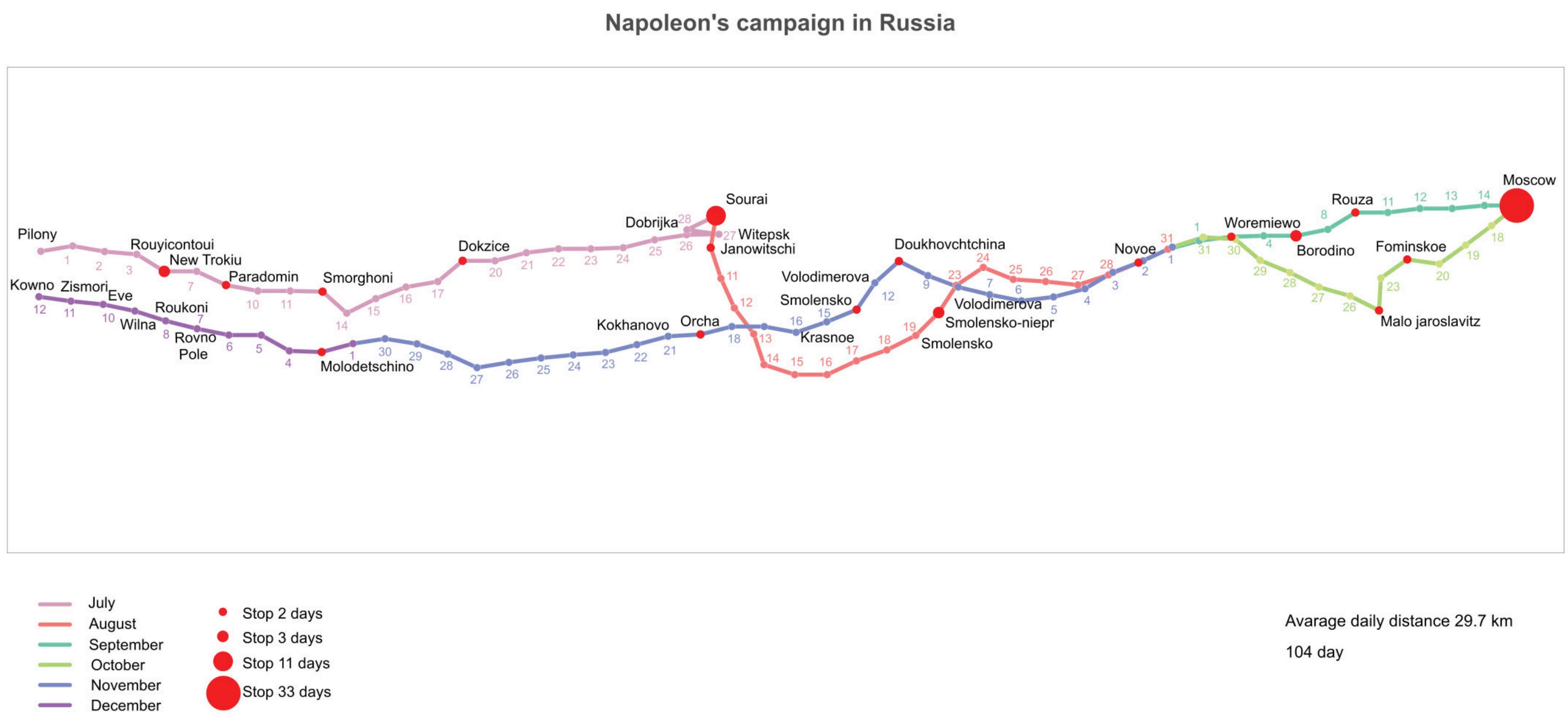


Figure 5.2: The time cartogram

5.3.2. Traditional geographically correct map (map)

Since a comparison between different mapping approaches will be performed the same map design approach was selected for those alternatives as the one that was used for the time cartogram. The difference between the two is that on traditionally geographically correct map the line segments present geographical distance while on time cartogram the line segments show time distance (see Figure 5.3).

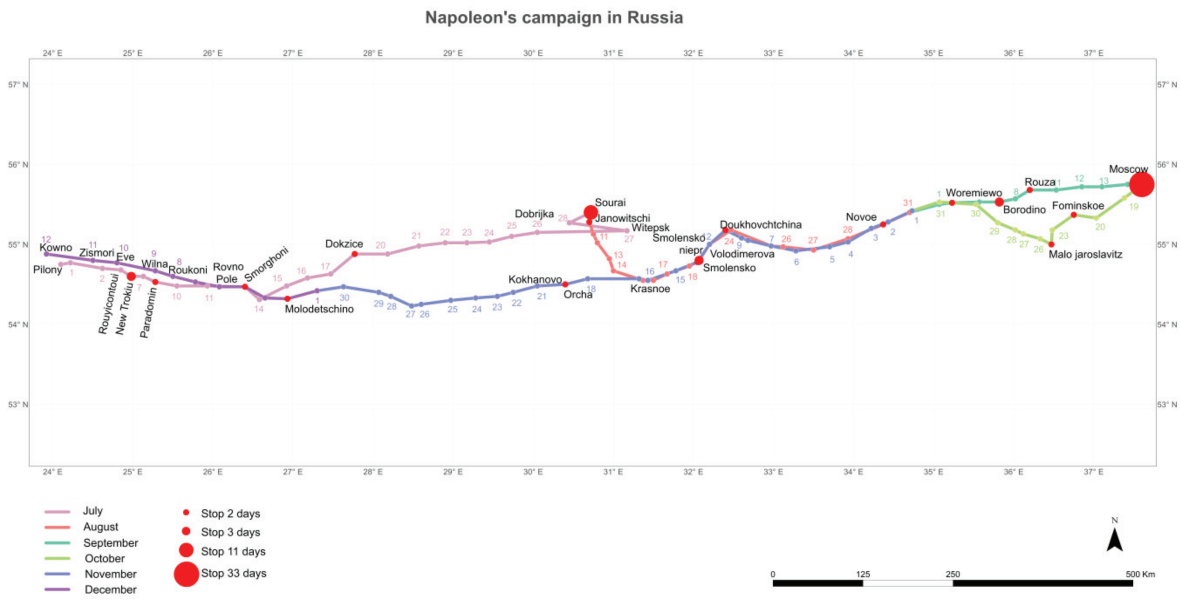


Figure 5.3: Traditional geographically correct map

5.3.3. STC

In a space time cube time is displayed by vertical axis (T) and the spatial coverage of the base map is shown on the (X,Y) axis. The space time path (STP) indicates corps movement in space and time. The STP (represented by the thick blue line in the STC) is vertical when the corps didn't move. The STP differs from vertical when the corps is moving. Information about time (date) is represented on the vertical axis. Time interval on vertical axis is one day and by moving the base map on the time axis vertically the time change can be identified. The trajectory in space is shown by a foot print on the map. It is possible to move a foot print (which includes the names of the geographic location) vertically along the time axis (see Figure 5.4).

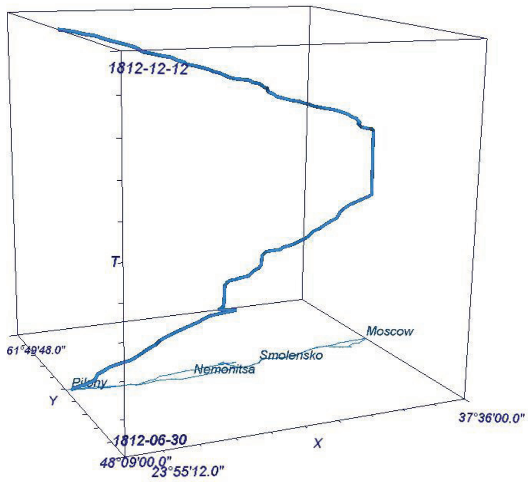


Figure 5.4: STC

5.3.4. Animation

The animation is designed in such a way that the line shows the path of the movement and the point indicates location where the corps was passing (see Figure 5.5). It gives the user time information using:

- point symbols (highlighted by colour) that indicate the corps' stops
- temporal animation interactive functions: play- begins the animation; stop-stops the animation; time slider- for dragging animation forward or backward in time; display date/time- shows date/time

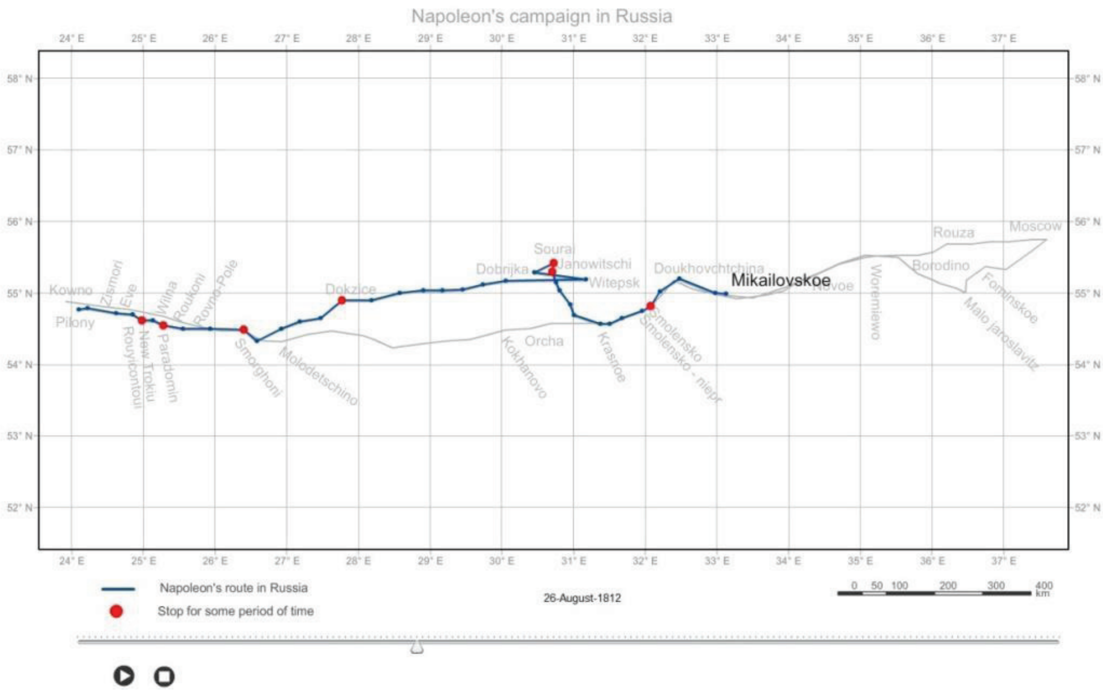


Figure 5.5: Animation

By dragging the time slider it is possible to identify when the corps did not move (the time line is moving but nothing happens).

5.4. Implementation of different mapping methods

5.4.1. Selection of appropriate software

In order to create the cartogram and create traditionally geographically correct map ArcGis software was used. ArcGis is the Geographic Information System provider which have capacity for building own application, to create data set, to design map, to analyze and manipulate spatial data. ArcGis is installed on both the Unix and networked Personal Computer services and has different applications-Arcmap, ArcCatalog, ArcToolbox, ArcGlobe and ArcScene. Only ArcMap and Arc Catalog are used in this research for handling of spatial data, for design and creation of maps.

The STC is a plugin in the UDig open source GIS. The STC represents a 3D cube where the vertical axis is time (T) and horizontal axes represent space (X, Y).

In this research Adobe Flash CS5 is used to add interactive functions to the animated map. Adobe Flash software has functionality for animated frame by frame images. The map designed in ArcGIS has been imported into Adobe Flash CS5 where interactive functions were added on the map (see Appendix 2). Adobe Flash is powerful software with embedding ActionScript which is the programming language of the Adobe Flash Platform.

5.4.2. Data

In order to create the time cartogram it was necessary to convert coordinates of points in such a way that the segments between converted points represent time distance. For this transformation there was a need to select time scale (average daily distance) and the initial point that was performed using MapAnalyst by entering the information as a text file. After selection of the time scale and the initial point new points with new coordinates have been calculated and segments between those points present time distance instead of geographical distance (see Appendix 1). The new dataset includes information about time and geographical names.

For building the animation a series of segments and points was created directly from the original point and line data. This data contains information about time, location and name of geographical entities. For the animation a time-slider was created by using ActionScript (see Appendix 2).

The original data with time information and geographical names was entered in to STC.

5.5. Summary

The aim of this chapter was to discuss the design and implementation of the time cartogram to visualize free flowing path movement. Since the main goal of this research is to compare the time cartogram approach with alternative mapping methods such as the traditional map, the animation and the STC, these mapping methods have also been used to visualize spatio-temporal information. Considering the fact that a comparison between these different mapping approaches would be performed the same map design approach was selected as the one that has been used for the time cartogram. For the implementation of mapping methods the appropriate software was selected and used.

6. USABILITY TESTING

6.1. Introduction

In the previous chapter the design and implementation of different mapping methods for the representation of free flowing movement was described. Usability research is now required because the main objective of this research is to develop a mapping method to visualize free flowing path based on the time cartogram approach and to see how this method compares to the traditional map, animations and the STC.

Usability research is also required to evaluate the "ease-of-use" for specific aims.

6.2. Objective of usability testing

According to Nielsen (2003) "usability is a quality attribute that assesses how easy user interfaces are to use". It is a measurable trait of a product user interface that is present to a greater or lesser degree (Deborah, 1999). The International Organization for Standardization, ISO (241-11) defines usability as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (URL5).

Three main aspects of usability can be defined (URL6):

Effectiveness – the accuracy and completeness with which users achieve specified goals
Efficiency – the accuracy and completeness of goals achieved in relation to resources
Satisfaction – freedom from discomfort, and positive attitudes towards the use of the system

Based on these three characteristics of usability research, the purpose of this usability evaluation is:

- To examine the capability of the time cartogram to display free flowing paths
- To examine when the time cartogram is more informative and where it has difficulties in terms of displaying the paths
- To examine how users perceive free flowing paths with different mapping methods

In order to achieve the main objective of this research a usability test will be conducted in three sessions:

- Comparing the time cartogram with the traditional map
- Comparing the time cartogram with the STC
- Comparing the time cartogram with the animation

The specific usability research questions can be defined as follows

1. What capability has the time cartogram in comparison with a traditional map, an animation and the STC for giving the most correct and complete answer to specific tasks? (Effectiveness)
2. Can the test person easily understand the time cartogram with regard to displaying the path? (Effectiveness)
3. Can the test person complete the specific tasks using the time cartogram approach quickly and correctly? (Efficiency)
4. Does the time cartogram satisfy the user's needs in comparison with a map, animation and the STC? (Satisfaction)

6.3. Methods of usability testing

The aim of this usability research is to conduct qualitative research in which the main usability problems of the time cartogram method in comparison with other mapping methods will be found. The results may be used for an improved design of a prototype which may later be tested in a quantitative way.

Several methods and techniques of doing this type of user research are available. In order to conduct usability research it is important to select an appropriate evaluation method. In this research the think aloud method in combination with screen logging during the execution of tasks and questionnaires will be used. The questionnaire method is selected to obtain information about the characteristics of the test persons and about the user satisfaction with the mapping methods tested. It is relatively easy to summarize data gathered and; it is less time-consuming than other methods (Swanson, 2007). But this method also has disadvantages, for example, people may misread items. To deal with such difficulties the presence of a moderator who asks a test person to complete the questionnaire is useful. Since it will not be possible to derive meaningful conclusions about the usability of the mapping methods themselves in using the questionnaire method only, the think aloud method in combination with screen logging is adopted as well.

The think aloud method in combination with screen logging is selected since is allows to express the thoughts that come into the mind of the users without rationalizing or interpreting them first. It helps the moderator to understand how the test person observes the usability of the object. Also, the moderator can easily identify the user's misconceptions about the object (Nielsen, 1993). Nielsen (1993) states that the method excels in avoiding later rationalizations of the data gathered from the test by showing explicitly what the users are doing and why they are doing it. According to Van Elzakker (1999) the data gathered with the think aloud method are purely original user's actions and comments, which come as non-rationalized, unexplained and original (without interpretation) spoken thoughts. The researcher can analyze the recorded data extracting the true meaning of the comments made by the test persons in combination with their physical actions. It means that this method gives a close approximation of the actual feeling of the test persons (Madzudzo, 2007) and the main usability problems can be discovered. A disadvantage of the think aloud method is that it is not very relevant for gathering most types of usability performance measurements (Nielsen, 1993). Van Elzakker (1999) lists the following disadvantages of the think aloud method: very time consuming; subjects sometimes have difficulty translating their thoughts into words and this may, result in incomplete gathered data. But after analyzing data gathered with the think aloud method (in combination with screen logging) the researcher can discover why the test person made mistakes with performing the tasks (or not).
Data gathered during the usability testing sessions gives ability to evaluate the usability of a time cartogram to visualize free flowing movement in comparison with the other mapping methods.

6.3.1. Think aloud method

According to van Someren (1994) the think aloud method has its roots in psychological research and currently this method is accepted as a useful method by scientific community in psychology and also has its place in range of many knowledge engineers. The think aloud method is widely applied in disciplines such as education science, psychology research, knowledge engineering, in geo-information science and cartography it also has been applied already (van Elzakker, 1999).
The purpose of the think aloud method is to make explicit what is implicitly present in subjects who are able to perform a specific task. In the think aloud method the test persons are saying their thoughts as they follow certain tasks and this is recorded with audio and/or video techniques. The think aloud method

has the capability to collect valid and the most complete data on cognitive processes (van Elzakker, 1999). These are the main advantages and disadvantages of this method.

Advantages:

- Test persons do not have to memorize their remarks to say them later on and they also make their remarks without interpretation
- Test persons are concentrating more on the task because during the test session they are asked to say what they are looking at, thinking, doing and feeling

Disadvantages:

- It is a time consuming method. It takes time to collect the data as well as to analyze them
- There is an unnatural environment of a test session which sometimes leads to stressed test persons

6.3.2. Recording screen activity

According to (URL9) to record test person's screen activity (mouse moving, pages scrolling clicking links, typing in the search terms, and so on) is a crucial aspect of usability testing. There are three ways of recording screen activity (URL9):

- **Camcorder**-this is the simplest way of recording screen activities. Camcorder can be put on a tripod, point it at the screen and record. Although simple, the resulting video will be a bit fuzzy and hard to read. It's useful for getting an idea of what the test person did, but sometimes it can be difficult to read small text.
- **VCR**-if a video card has a TV-out option it can probably connected it to a VCR and record directly to tape. The result should be an improvement on the camcorder method, but because the resolution and sharpness of a television is lower than a computer screen the result will still be fuzzy and downgraded from the original image.
- **Software**-in the software solution a program runs in the background, capturing everything that appears on the screen and saving it to a video file. The result is a perfect recording with no loss of detail. Each frame of the resulting video could serve as a screenshot.

6.3.3. Questionnaires

Root et al. (1983) state that "questionnaires have long been used to evaluate user interfaces." This method is useful for studying how users can use the products and their preferred features. In a questionnaire method test persons are asked to write down the answers to a list of questions about product. Several researches have been done on the questionnaire method. Different authors distinguished various forms of questionnaires that could be used; also they have different points of view regarding the advantages and disadvantages of this method. Some of them are described and discussed below.

According to Nielsen (1993) the questionnaire method ensures the possibility of investigating the specific needs of small groups of users. The questions should be created carefully since they can be too long or, not understandable and because of these reasons they can get a low response rate. There is a need to do a pilot test in order to refine and redesign the questions before the actual test will be started. Nielsen (1993) states that questionnaires should rely on closed questions where users can go through a checklist, or state their opinion on a rating scale.

According to (URL7) there are three main types of questions:

- **Factual-type questionnaires**: Such questions ask about public, observable information that would be tedious or inconvenient to get in any other way

- **Opinion-type questions**: There is no right or wrong answer in this type of questions; the users can express their feelings (i.e. do they like it or not, or which do they prefer?).
- **Attitude questions**: focus the respondent's attention to inside themselves, to their internal response to events and situations in their lives.

The following advantages and disadvantages of using questionnaires in usability research are distinguished in (URL7):

Advantages:

- A usability questionnaire gives you feedback from the point of view of the user. If the questionnaire is reliable, and it is used according to the instructions, then the feedback is unfailing.
- The measures gained from a questionnaire are to a large extent, independent of the system, users, or tasks to which the questionnaire was applied.
- The questionnaires are usually quick and therefore cost effective and questionnaire data can be used as a reliable basis for comparison or for demonstrating that quantitative targets in usability have been met.

Disadvantages:

- A questionnaire describes only the user's reaction as the user perceives the situation. Thus some kinds of questions (e.g. those that have to do with time measurement or frequency of event occurrence) are not usually reliably answered in questionnaires. On the whole it is useful to distinguish between subjective measures (which is what questionnaires are good for) and performance measures (which are publicly-observable facts and are more reliably gathered using direct event and time recording techniques).
- A questionnaire is usually designed to fit a number of different situations (because of the costs involved). As a result a questionnaire cannot describe in detail what is going right or wrong with the application that is tested. But a well-designed questionnaire can get the researcher near to the issues, and an open-ended questionnaire can be designed to deliver specific information if properly worded.
- If the aim of the investigation is to analyze the overall usability of a piece of software, then the subjective data must be enhanced with performance, mental effort, and effectiveness data. In addition, one should also ask, *why?* This means talking to the test participants and observing them.

6.4. Test execution

The usability research was performed in as three different test sessions:

- Comparing the time cartogram with the traditional map
- Comparing the time cartogram with the STC
- Comparing the time cartogram with the animation

The following materials were prepared for each session: two representations of different mapping methods (see Figures 5.1; 5.2; 5.3; 5.4), and instructions (for each session considering different mapping methods) for the test persons on how they are expected to work through the tasks (thinking aloud) (see Appendix 5); There were a questionnaire on the background and experience of the test persons (see Appendix 4); and a questionnaire with the tasks to be performed (see Appendix 6). The time cartogram and the static map were represented as pdf document, the animation in swf format and the STC in the

Udig environment. All these were presented to the test persons on the computer screen. The questions formulated as tasks should be performed by users and are directed towards temporal and spatial aspects:

Temporal aspects:

1. Where was the IV corps on 3 July, 1812?
2. When did the IV corps arrive in Dokzice?
3. When did the IV corps arrive in Moscow and how long did they stay there?
4. How long did it take to go from Krasnoe to Kochanovo?
5. When and where did the IV corps go from Sourai ?
6. At which place did the IV corps stop for the longest period and how many days did they stop?

Spatial aspects:

7. Which day did the IV corps cover the greatest distance?
8. In which 3 days period did the IV corps cover the greatest distance?
9. Did the path between Pilony and Dokzice (to Moscow) and the path between Molodetschino and Kowno (from Moscow) overlap?
10. Did the IV corps follow almost the same path from Smolensko to Volodimerova and back?
11. Is Pilony located South of Kowno or not?
12. What was about the distance between Smolensko and Volodimerova on the path to Moscow and back (from Moscow)? :

    1.Almost the same   2. Not the same

6.4.1. Test environment

The usability evaluation was carried out from 1st February to 3rd February 2011. At ITC there is a usability research laboratory, that is well-equipped with the materials needed for conducting the usability research test and, therefore, it was used for this evaluation. There are facilities in the laboratory for thinking aloud research and for video recording the test person's interaction with the visualization environment. In this usability research two laptops were used and one Digital Video Camera recorder (Sony Handycam DCR-SR100/E). The video camera was used to record the comments made by the test person as he/she performed the tasks, together with his/her actions on the computer screen. Laptop one (HP EliteBook 8530) was used during the test session to present the mapping methods to the test persons. The second laptop (HP Compaq nc8430) was used to import recordings from the digital camera and for this Picture Motion Browser, Version-4.3.02 was installed which is compatible with Windows 7. Figure 6.1 shows the usability test environment.

Figure 6.1: The test environment

6.4.2. Test persons

The usability test was conducted by one test person at a time. Three groups of test person participated in the usability test, with four participants in each group (twelve participants in total).

The test persons were ITC students. 9 of them were the students from GFM course and 3 of them from Land administration; Applied Earth Sciences; Governance and Spatial Information Management courses.

The test persons were divided into three groups based on their background (3 test persons from GFM course and one test person from the other course in each group). Information about test person background and experience was collected by questionnaire (see Appendix 4).

6.4.3. Test set-up

As mentioned above the evaluation process was performed as three different test sessions therefore three groups were participated in the usability test:

- Group one- compared the time cartogram with the static map
- Group two-compared the time cartogram with animation
- Group three-compared the time cartogram with STC

This usability test was conducted in three phases:

- **briefing phase:**

  Introduction to the test (see Appendix 3)
  This session was for about 5 minutes.
  Questionnaire
  The test person was asked to answer the questions on his/her background and experience and to practice the think aloud method while completing the questionnaire (see Appendix 4).

- **familiarization phase**:

  The test person was asked to get familiar with the software to be used (for each group an appropriate instruction) (see Appendix 5).

  This session was for about 10-15 minutes.

- **think aloud phase**:

  The test person was given the tasks and was asked to complete them whilst thinking aloud (see Appendix 6).

The first test person of each group started to conduct the usability test by examining the time cartogram (executing the tasks that were given). Thereafter, the test persons performed the same tasks with one of the alternative mapping methods. The next test person started to examine the alternative mapping method and then worked with the time cartogram.

Such a structure of the usability prevents a learning bias and takes into account that the test persons may feel uncomfortable at the beginning of the usability test or may be tired at the end of the session. After completing the tasks the test persons were asked to answer one additional question: did they feel comfortable to perform the tasks with the time cartogram than with the other mapping method?

6.5. Analysis of the usability test results

The test persons were asked to perform tasks related to temporal and spatial aspects. The results of each test session (comparing the time cartogram with the map, comparing the time cartogram with the STC, comparing the time cartogram with the animation) can be evaluated in terms of temporal map reading (the first 6 tasks) and spatial map reading (the last 6 tasks).

Effectiveness, efficiency and satisfaction of the four mapping methods are measured based on the success of the task execution (correct answers), the task completion time and the test persons' reactions during and after the test session.

6.5.1. Data arrangement

In order to organize the data gathered from the usability test, tables were designed for test session. This table includes information about success of executed tasks; time, comments and reaction (see Appendix 7). Table 6.1 illustrates information about background and experience of the test persons.

Test person	Current field of studies	Work with spatio-temporal data	Map	Animation	STC
TP1 (group 1)	Land administration	Rarely	High	Little	No
TP1 (group 1)	Geoinformatics	Rarely	High	Moderate	Moderate
TP1 (group 1)	Geoinformatics	Rarely	Moderate	Little	Little
TP1 (group 1)	Geoinformatics	Rarely	High	Moderate	Little
TP1 (group 2)	Geoinformatics	Rarely	High	Moderate	Moderate
TP2 (group 2)	Geoinformatics	Every day	Very high	Very much	Very much
TP3 (group 2)	Geoinformatics	Rarely	High	Little	Little
TP4 (group 2)	Applied Earth Sciences	Rarely	High	Little	Little
TP1 (group 3)	Governance and Spatial Information Management	Never	Moderate	Little	Little
TP2 (group 3)	Geoinformatics	Every day	Very high	Moderate	Much
TP3 (group 3)	Geoinformatics	Every day	Very high	Much	Much
TP4 (group 3)	Geoinformatics	Rarely	High	Much	Much

Table:- 6.1 Information about the test persons' background and experience

6.5.2. Results

As mentioned above, in order to measure the effectiveness, efficiency and satisfaction, the result for each test sessions (group1, group 2, and group 3) were evaluated based on temporal and spatial aspects.

6.5.2.1. Effectiveness

In order to measure the effectiveness of the time cartogram in comparison with other mapping methods the average percentage of success (correctness) of the executed tasks on temporal and spatial aspects was calculated (see Appendix 8). Also, the success of each task for each mapping methods was calculated by percentage (see Tables 6.2; 6.3; 6.4).

Group1	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
Test person 1												
Cartogram												
Map												
Test person 2												
Map												
Cartogram												
Test person3												
Cartogram												
Map												
Test person 4												
Map												
Cartogram												
Cartogram	100%	75%	75%	50%	25%	100%	0%	0%	0%	25%	25%	0%
Map	75%	50%	25%	25%	0%	100%	100%	25%	75%	100%	100%	100%

Table:- 6.2 The success of each task for the time cartogram and for the map

Group2	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
Test person 1												
Cartogram												
STC												
Test person 2												
STC												
Cartogram												
Test person 3												
Cartogram												
STC												
Test person 4												
STC												
Cartogram												
Cartogram	75%	75%	75%	75%	0%	100%	0%	0%	0%	25%	0%	0%
STC	75%	75%	0%	50%	50%	75%	50%	25%	50%	100%	75%	50%

Table:- 6.3 The success of each task for the time cartogram and for the STC

Group3	Task1	Task2	Task3	Task4	Task5	Task6	Task7	Task8	Task9	Task10	Task11	Task12
Test person 1												
Cartogram												
Animation												
Test person 2												
Animation												
Cartogram												
Test person 3												
Cartogram												
Animation												
Test person 4												
Animation												
Cartogram												
Cartogram	100%	100%	75%	100%	25%	75%	0%	0%	0%	50%	25%	25%
Animation	100%	75%	25%	75%	50%	25%	50%	25%	75%	25%	75%	0%

Table:- 6.4 The success of each task for the time cartogram and for the animation

Effectiveness in the comparison of the time cartogram with the (traditional) map

Figure 6.2 shows the success of each of the tasks in the comparison of the time cartogram with the map (Group 1) on spatio-temporal aspects (all 12 tasks). Figure 6.3 shows the average percentage of success of executed tasks on temporal aspects (first 6 tasks) and on spatial aspects (last 6 tasks).

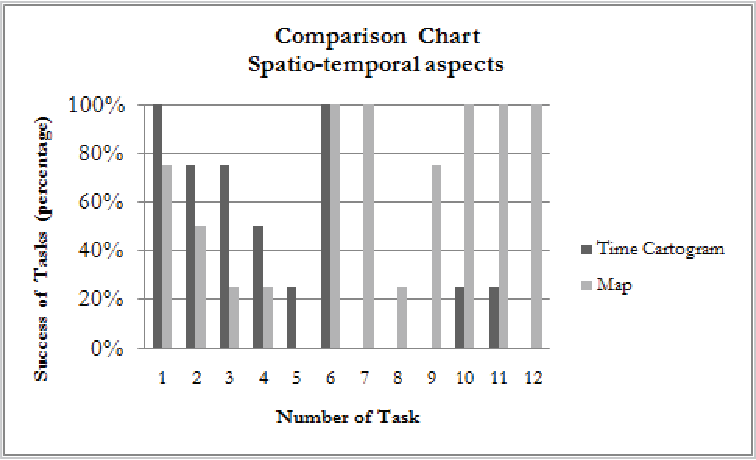
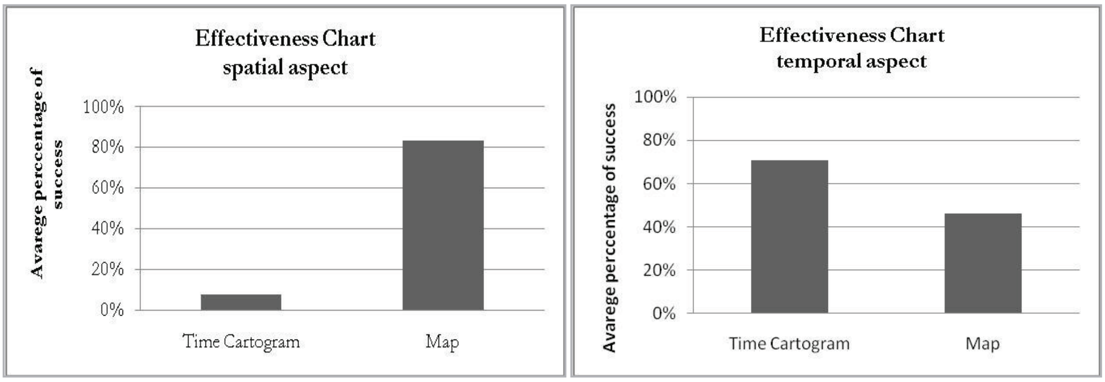


Figure 6.2: Comparison chart for all tasks for the time cartogram and the map



A. B.

Figure 6.3: Effectiveness chart for the time cartogram and the map

Figure 6.2 illustrates that questions 7, 8, 9 and 12 have 0% success for the time cartogram; these questions are related to the spatial aspects. As figure 6.3.B shows the effectiveness of the time cartogram on temporal aspects (71%) is higher than the effectiveness of the map, while the effectiveness of the map on spatial aspects is higher than the effectiveness of time cartogram (see Figure 6.3.A).

Effectiveness in the comparison of the time cartogram with the STC

Figure 6.4 shows the success of each task in the comparison of the time cartogram with the STC (Group 2) on spatio-temporal aspects (all 12 tasks). Figure 6.5 shows shows the average percentage of success of executed tasks on temporal aspects (first 6 tasks) and on spatial aspects (last 6 tasks).

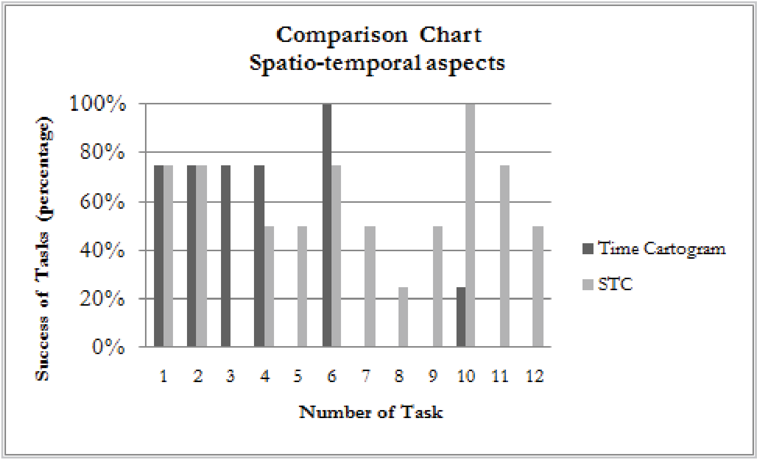
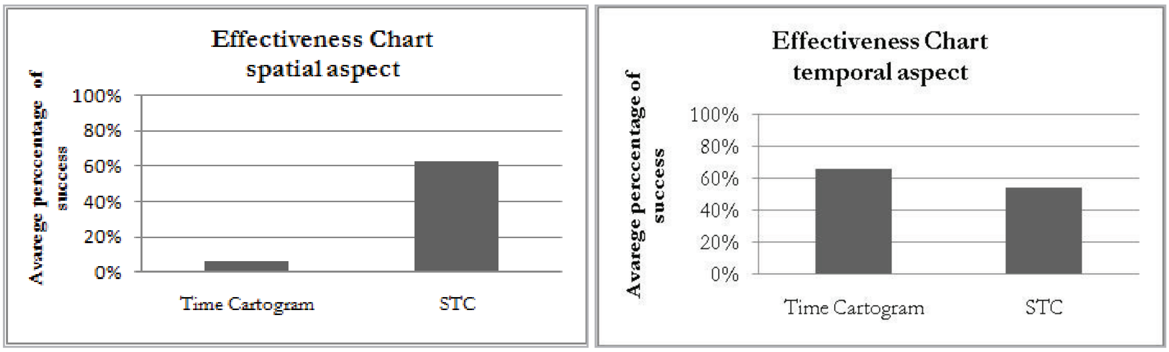


Figure 6.4: Comparison chart for all tasks for the time cartogram and the STC



A. B.

Figure 6.5: Effectiveness chart for the time cartogram and the STC

Figure 6.4 illustrates that questions 7, 8, 9, 11 and 12 have 0% success for the time cartogram; these questions are related to the spatial aspects. Figure 6.5.B shows that effectiveness of the time cartogram (66%) on temporal aspects is higher than the STC. But effectiveness of the time cartogram on spatial aspects is lower than the STC (see Figure 6.5.A).

Effectiveness in the comparison of the time cartogram with the animation

Figure 6.6 shows the success of each task in the comparison of the time cartogram with the animation (Group 3) on spatio-temporal aspects (all 12 tasks). Figure 6.7 shows the average percentage of success of executed tasks on temporal aspects (first 6 tasks) and on spatial aspects (last 6 tasks).

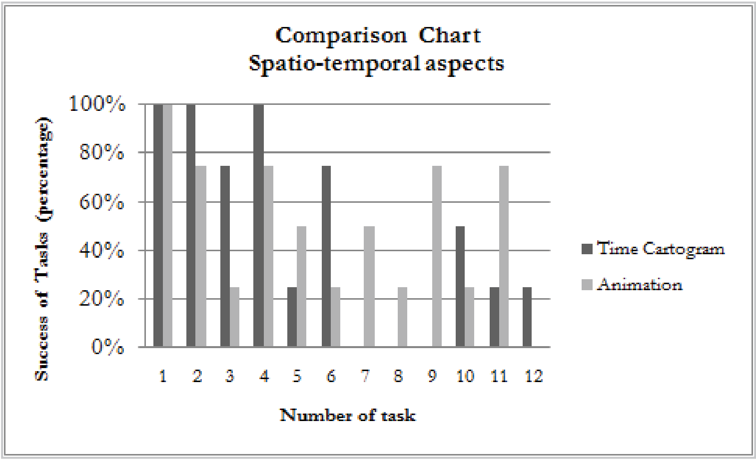
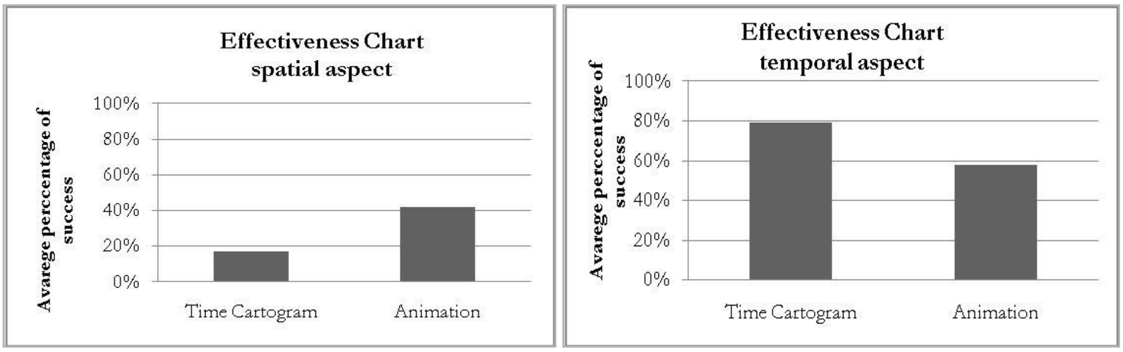


Figure 6.6: Comparison chart for all tasks for the time cartogram and the animation



A. B.

Figure 6.7: Effectiveness chart for the time cartogram and the animation

Figure 6.6 illustrates that questions 7, 8, 9 and 12 have 0% success for the time cartogram; these questions are related to the spatial aspects. Figure 6.7.B shows that effectiveness of the time cartogram (79%) on temporal aspects is higher than the animation. But effectiveness of the time cartogram on spatial aspects is lower than the animation (see Figure 6.7.A).

6.5.2.2. Efficiency

In order to measure the efficiency of the time cartogram in comparison with the other mapping methods, the average time of executing the tasks on temporal and spatial aspects was calculated. Also the average time that was needed to complete the whole assigned task was calculated (for each mapping method) (see Appendix 9).

Efficiency in the comparison of the time cartogram with the map

Figure 6.8 shows the average time that was needed to complete the assigned task for the time cartogram and the map. The average total task execution time for the time cartogram and the map on temporal and spatial aspects is shown in figure (see Figure 6.9).

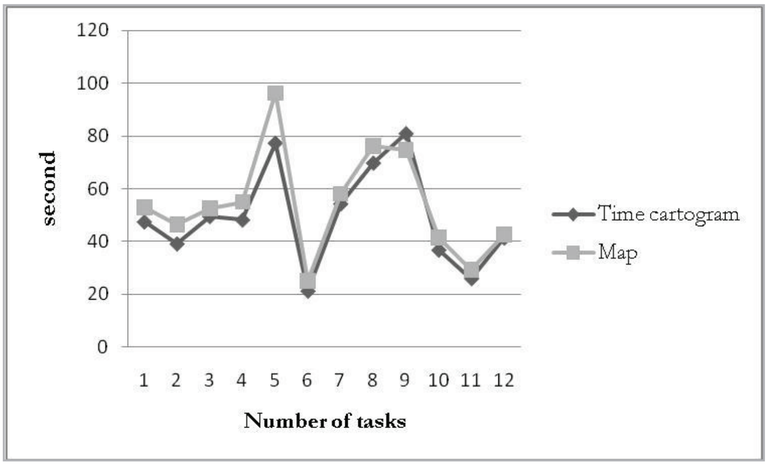
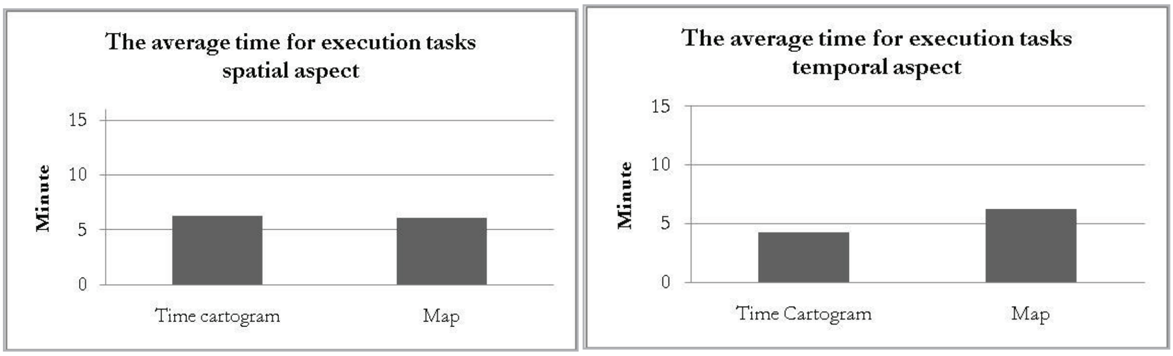


Figure 6.8: The average time for the execution of each task of the time cartogram and the map



A. B.

Figure 6.9: The average time for total task execution with the time cartogram and the map

Figure 6.8 illustrates that, questions 5, 7, 8, 9 are more time consuming to perform the tasks using the time cartogram than the other questions. Figure 6.9.B shows that the test person is able to perform the assigned tasks (on the temporal aspects) faster using the time cartogram (4.28 minutes) than the map (6.25 minutes). While to execute the time cartogram by performing tasks related to spatial aspects takes more time than the map (see Figure 6.9.A).

Efficiency in the comparison of the time cartogram with the STC

Figure 6.10 shows the average time that was needed to complete the assigned tasks with the time cartogram and the STC. The average total task execution time for the time cartogram and the STC on temporal and spatial aspects is shown in figure 6.11.

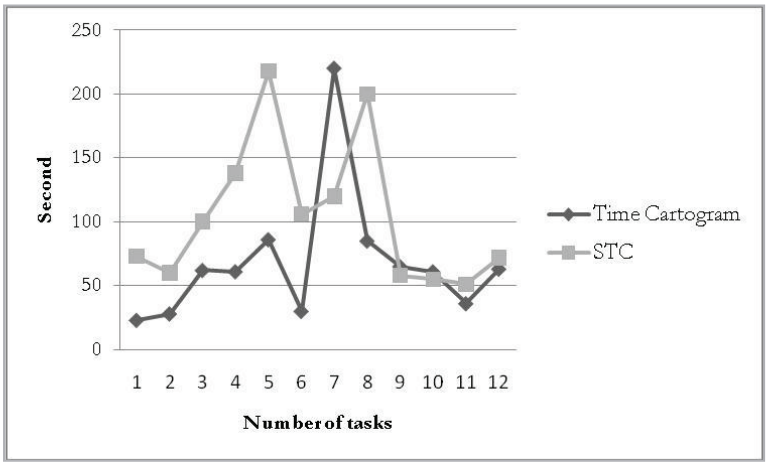
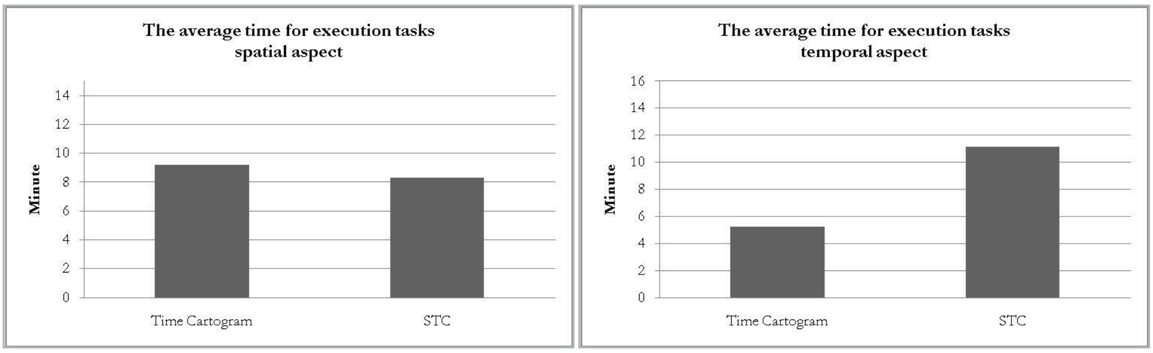


Figure 6.10: The average time for the execution of each task for the time cartogram and the STC



A. B.

Figure 6.11: The average time for total task execution with the time cartogram and the STC

Figure 6.10 illustrates that the question 7 is more time consuming to perform the task using the time cartogram than the other questions. Figure 6.11.B shows that the test person is able to perform the assigned tasks (on temporal aspects) faster using the time cartogram (5.27 minutes) than the STC (11.13 minutes). While to execute the time cartogram by performing tasks related to spatial aspects takes more time than the STC (see Figure 6.11.A).

Efficiency in the comparison of the time cartogram with the animation

Figure 6.12 shows the average time that was needed to complete the assigned tasks with the time cartogram and the animation. The average total task execution time for the time cartogram and the animation on temporal and spatial aspects is shown in figure 6.13.

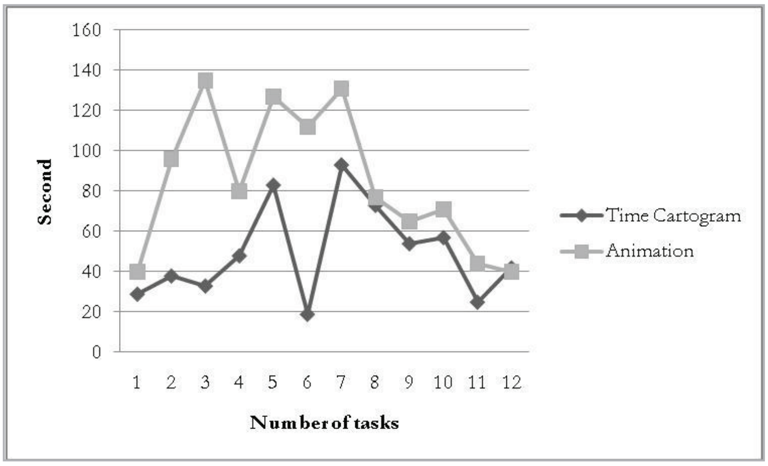
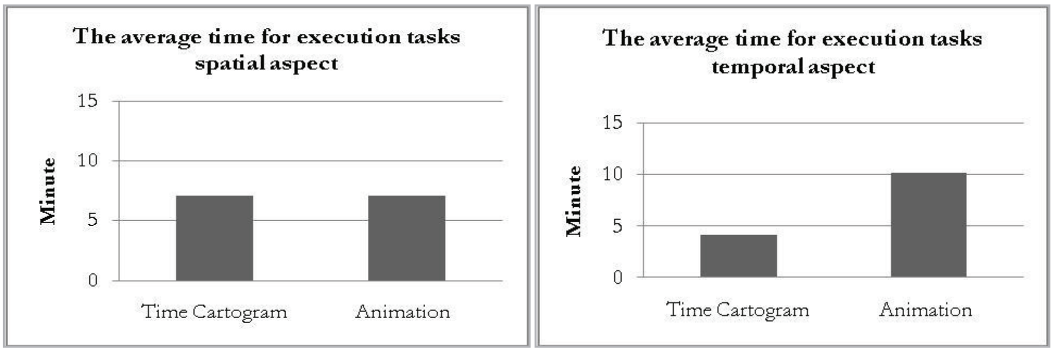


Figure 6.12: The average time for the execution of each task for the time cartogram and the animation



A. B.

Figure 6.13: The average time for total task execution the time cartogram and the animation

Figure 6.14 shows that the test persons are able to perform the assigned tasks (on temporal and spatial aspects) faster using the time cartogram than the animation.

6.5.2.3. Satisfaction

In order to measure satisfaction with the time cartogram in comparison with other mapping methods, the test persons' reactions and opinions about the tasks to be performed (temporal and spatial aspects) were analyzed. On the basis of the test persons' reactions and opinions it was established whether they were said if they are satisfied or not after the usability test session. The test person can be considered satisfied after the test session if he/she felt comfortable (or more comfortable) during the test session, the tasks to be performed were clear, and the test person answered the questions confidently. Not satisfied means that the test person felt not comfortable during the test session, he/she was confused with regard to performing the tasks and to answering some questions.

Satisfaction in the comparison of the time cartogram with the map

The test persons felt more comfortable and answered the question more confidently on temporal aspects using the time cartogram than using the map. While the test persons were not satisfied with the time cartogram on spatial aspects; the test persons confused and could not answer questiotions 7, 8,9 and 12 and because of this they felt not confortabele.

Satisfaction in the comparison of the time cartogram with the STC

The satisfaction with the time cartogram and the STC considering temporal and spatial aspects were analyzed. The test persons were not satisfied with the time cartogram (on spatial aspects) than with the STC (on spatial aspects) because the test persons could not perform the tasks related to the spatial aspects, for example, estimation of geographical distance. The test persons felt more comfortable to perform the assigned tasks using the time cartogram than using the STC (on temporal aspects).

Satisfaction in the comparison of the time cartogram with the animation

The satisfaction of the time cartogram and the animation considering temporal and spatial aspects were analyzed. The test persons were not satisfied with the time cartogram on spatial aspects. The test persons confused and could not answer the questiotions 7, 8 ,9 using the time cartogram and they felt not confortabele during performing these tasks. While the test persons felt more comfortable to perform the assigned tasks using the time cartogram than using the animation (on temporal aspects).

6.5.2.4. Summary of the results

The usability of the time cartogram in comparison with the other mapping methods will be summarized considering spatial and temporal aspects.

Spatial aspects

The usability of the time cartogram in comparison with the map, the STC and the animation measured considering the spatial aspects is shown in the table 6.5.

	Effectiveness success of task (percentage)	**Efficiency** time diuration (minute)	**Satisfaction**
Map	83.33%	6.08	Satisfied (more comfortable)
Time Cartogram	8%	6.25	Not satisfied
STC	62%	8.29	Satisfied (more comfortable)
Time Cartogram	6%	9.22	Not satisfied
Animation	42%	7.12	Satisfied (more comfortable)
Time Cartogram	17%	7.11	Not satisfied

Table:- 6.5 Usability summary (spatial aspects)

Table 6.5 shows that the time cartogram is not usable methods regarding spatial aspects because the test persons cannot execute the tasks related to spatial aspects. On the other hand it could be concluded that the time cartogram is not more time consuming than the other mapping methods since the test persons could examine the time cartogram easily.

Temporal aspects

The usability of the time cartogram in comparison with the map, the STC and the animation measured considering temporal aspects is shown in the table 6.3.

	Effectiveness success of task (percentage)	**Efficiency** time diuration (minute)	**Satisfaction**
Map	46%	6.25	Satisfied (comfortable)
Time Cartogram	71%	4.28	Satisfied (more comfortable)
STC	54%	11.13	Satisfied (comfortable)
Time Cartogram	66%	5.27	Satisfied (more comfortable)
Animation	58%	10.22	Satisfied (comfortable)
Time Cartogram	79%	4.13	Satisfied (more comfortable)

Table:- 6.6 Usability summary (temporal aspects)

Table 6.6 shows that the time cartogram is usable methods than the other mapping methods regarding temporal aspects because the test persons were able to execute the tasks related to temporal aspects easily. It could be also concluded that the time cartogram is not time consuming method than the other mapping methods since the test persons could examine the time cartogram without any difficulties. Also the test persons felt more comfortable to perform the tasks (on temporal aspects) related to the time cartogram than to the other mapping methods.

6.6. Discussion

The problems related to each mapping methods analysed based on the test persons' reactions, opinions and comments during and after the test session, also considering the difficulties they faced during performing the tasks.

The main problem the test person faced during working with the time cartogram was related to spatial aspects. The test persons could not estimate geographical distance. One test person had difficulties with reading colours on the time cartogram and suggested using more distinct colours to display months on the time cartogram. Another test person advised to use arrows in order to show the movement of the corps.

Since the traditional map is created using the same map design approach as the time cartogram (the only difference between those two representations is that on traditional geographically correct map the line segments present geographical distance while on time cartogram the line segments show time distance) the test person could get the spatial information and also the temporal information using traditional geographically correct map. There were difficulties when the path overlapped and the test persons could not identify two different colours anymore.

One test person had some difficulties to use interactive functions on working with STC. These problems were mainly related to estimate of intersection of foot print and STP in order to find the name of the locations of the corps. Another test person had difficulties to calculate the exact number of days when the corps had no movement. They suggested adding some interactive functions in order to identify an intersection of foot print and STP or to improve the design of foot print to find the locations easily.

Two test persons had problems with working on animation that was related to control of animation speed since they considered that animation speed was fast and didn't use the stop button in order to control the speed of animation. The test person tried to get more information about each location by clicking on the location, he concluded that there was a lack of interactive functions and suggested to add the interactive functions in order to get additional information about the location and the corps movements and stops. Also there were problems with calculation of exact numbers of days when the corps didn't move, also were difficulties when the path overlapped and in such cases the test persons had to play the animation several times.

6.7. Summary

The present chapter is about the usability test. First of all the usability research goals were determined.
This chapter introduces different types of usability research methods. For this research the appropriate usability research methods (think aloud method in combination with screen logging and questionnaire) were selected. After selection the appropriate usability research methods the usability test was conducted. The next step was data (gathered from the test sessions) analysis. Effectiveness, efficiency and satisfaction for the time cartogram in comparison with the map, the STC and the animation were calculated regarding spatial and temporal aspects.

The overall result shows that the time cartogram is a more usable method than the other mapping methods regarding temporal aspects.
The test persons could examine the time cartogram easily and executed the tasks correctly that were related to temporal aspects, but the test persons had problems with examine did the time cartogram on spatial aspects and they performed the tasks related to this aspect incorrectly.

7. CONCLUSIONS AND RECOMMENDATION

7.1. Introduction

This chapter presents conclusion that aims to conclude how the research questions have been answered, on what this research is mainly focused. Also in this chapter will be introduced some recommendations for the further research.

7.2. Conclusions

What is a (time) cartogram?

The cartogram is a map where the geographic features are distorted based on some variable in order to express this variable (which has no geographic characteristics) effectively. This variable can be travel time, travel cost, human population and any statistical information. Traditionally there are three types of cartograms: Area (value-by-area) cartogram, linear cartogram and central point cartogram. The area (value-by-area) cartogram on which the size of the different areas is proportional to some variable typically used to illustrate any statistical distribution successfully also it can make socio-economic problems more clear and understandable. Generally linear cartograms and central point cartograms are used to illustrate transportation networks, where network is distorted in distance, sometimes in form, which is related to some value. The value can be the time needed to travel the real-world distance or cost of travel.

What are the characteristics of STP?

The characteristics of STP are introduced in the chapter 3. It illustrates an object's location at the certain time or identifies the time period when the object is in the certain place. The STP can be considered as free flowing movement of the object. The single STP and multiple STP(s) can be distinguished. Single STP can be considered as a movement of single geographic object. While the movements of several geographic objects (in space and time) can be displayed using multiple STP (s).

How can the STP be represented by the time cartogram?

In order to illustrate STP (free flowing path) conceptual design of a time cartogram was set up, which is represented in the chapter 4. The most important stage for the creation of a time cartogram is to create a new configuration of points that represents time distance instead of Euclidean distance. In order to convert coordinates of points in such a way that segments between converted points represent time distance the formula (1) was used. This formula preserves orientation between neighbor segments as formed in original map data; it calculates new coordinates for points based on a time scale.

What are the implications of the path characteristics for the time cartogram approach?

The path information includes information about the objects' movement and their stops for some time period. In order to display all time information (the dates of each moving day; also stops in the same location) there was a need to add some graphic variables such as size and colour.

What are the existing time mapping methods?

About the existing time mapping methods such as the STC and the animation have been discussed in the chapter 4. The STC is a 3D cube where the vertical axis represents time (T) and the horizontal axes represent space (X, Y). The STC has the ability to visualize time information and relation between time, space and additional variables. The idea of the STC has been introduced by Hägerstrand. He developed a three-dimensional diagram with Z axis as graphic displaying the time. A cartographic animation is widely used to visualize spatio-temporal data sets. It is divided into temporal and non-temporal animation. A cartographic animation with a temporal legend has capabilities to view temporal information of data and it is widely applied in different disciplines.

How to design and develop the time cartogram using Minard's data?

Because of the complexity of data used for this research (it includes daily information of corps' movement and their stops for some time period) there were some difficulties to illustrate all temporal information. Series of different map designs were prepared and most suitable illustration was chosen. Nominal line symbols, proportional point symbols and time labels are added to the cartogram in order to visualize Minard's data. Nominal line symbols are used to indicate time distance (months); proportional point symbols are used to show different amounts of days that on which the IV corps stopped, time label at point symbols is used to depict the dates.

How to design the map, the animation and the STC using Minard's data?

Since a comparison between different mapping approaches was performed it was used the same map design approach for the map and as the time cartogram. Nominal line symbols are used to indicate time distance (months); proportional point symbols are used to show different amounts of days (the IV corps stops), time label at point symbols is used to depict the dates.

In the STC time is displayed by vertical axis (T) and the spatial coverage of the base map is shown on the (X,Y) axis. The STP indicates the corps' movement in space and time. The STP is vertical when the corps didn't move. The STP differs from vertical when the corps is moving. Information about time (date) is represented on the vertical axis. It is possible to move a base map (which includes the names of the geographic location) vertically along the time axis.

The animation is designed in such a way that the line shows the path of the movement and the point indicates location where the corps was passing. It gives time information using: point symbols (highlighted by colour) that indicate the corps' stops; time slider-by dragging the time line forward or backward in time it shows date.

How to evaluate the visualization of STP based on the time cartogram approach in comparison with the map, the STC and the animation?

In order to achieve the main objective of this research the usability test was conducted in three sessions: comparing the time cartogram with the map, the STC and the animation. The usability test was task oriented. Each usability session was conducted in three phases: briefing, familiarization and think aloud phases. In the briefing phase the test person was given the introduction about the test to be conducted. Then the test person was asked to answer the questions on his/her background and experience and to practice the think aloud method. In familiarization phase the test person was asked to get familiar with software to be used, he/she worked through the tasks based on the instructions, considering different mapping methods and the questionnaire with the tasks to be performed. In think aloud phase the test person was given 12 tasks (for each mapping methods) to be performed (the whole 24 tasks) by examination of the time cartogram and another mapping methods (i.e. the map or the animation or the STC).

What is the outcome?

Effectiveness, efficiency and satisfaction for the time cartogram in comparison with the map, the STC and the animation were calculated regarding spatial and temporal aspects. The overall result shows that the time cartogram is more usable method than the other mapping methods concerning temporal aspects. The test persons could examine the time cartogram easily and executed the tasks correctly that were related to temporal aspects, but the test persons had problems with examine did the time cartogram on spatial aspects and they performed the tasks related to this aspect incorrectly.

7.3. Recommendation

In this research the time cartogram approach and also the alternative mapping methods (the map, the STC, the animation) are used to display single STP (the movement of one of Napoleon's army corpses (IV corps) that participated in his Russian campaign was used as test dataset). According to the historical data, Napoleon's army was consisted of several corps. This means that the corpses' movement can be illustrated using multiple STPs. For the further research a recommendation would be given to display multiple STPs using the time cartogram approach.

In this research for comparison of different mapping methods the same design approach was selected for those alternatives as the one that was used for the time cartogram, except for the STC. For the further research it would be interesting to select the same map design approach for the base map in the STC.

In this research in order to visualize temporal information completely, nominal line symbols, proportional point symbols and time labels were added to the time cartogram. Proportional point symbols were used to show different amounts of days when the object did not move. Because the STC illustrates such information as vertical line (STP is vertical when the object did not move), for the comparison of different mapping methods it would be interesting to design a time cartogram in such a way where 3D proportional point symbols will be used instead of 2D proportional point symbols.

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Appendices

Appendix 1

To create a new configuration of points that represents time distance instead of Euclidean distance (Actual script, Microsoft Visual Basic)

Step 1. Calculate geographic distance:

```
Sub S1_lenght()
Dim i As Integer
Dim a, b As Double
i = 3
While Sheet1.Cells(i, "A") <> ""
 a = Sheet1.Cells(i, "A") - Sheet1.Cells(i - 1, "A")
 b = Sheet1.Cells(i, "B") - Sheet1.Cells(i - 1, "B")
 Sheet1.Cells(i, "j") = Sqr(a * a + b * b)
 i = i + 1
Wend
End Sub
---------------------------------------------------------
```

Step 2.Count time (day)

```
Sub S2_DayCount()
Dim i As Integer
Dim T1, T2, T3 As String
Dim DayC As Integer
Dim DayOption As Integer
DayOption = 0
i = 3
While Sheet1.Cells(i, "A") <> ""
 T1 = Sheet1.Cells(i - 1, "H")
 T2 = Sheet1.Cells(i, "H")
 If T1 <> "" And T2 <> "" And T1 <> T2 Then
  Sheet1.Cells(i, "K") = 1
  GoTo 100
 End If
 If T1 = "" Then
 DayC = DayC + DayOption
  If T2 <> "" Then
   If T3 <> T2 Then
    Sheet1.Cells(i, "K") = DayC
   End If
  End If
  GoTo 100
 End If
 If T2 = "" Then
  T3 = T1
  DayC = 1
  GoTo 100
 End If
100:
 i = i + 1
Wend
End Sub
-------------------------------------------------------------------------
```

Step 3. Route

```
Dim i, j As Integer
Dim a, b As Double
Dim T1, T2 As String
i = 3
j = 2
While Sheet1.Cells(i, "A") <> ""
 If Sheet1.Cells(i - 1, "H") <> "" Then
  T1 = Sheet1.Cells(i - 1, "H")
  a = Sheet1.Cells(i - 1, "A")
  b = Sheet1.Cells(i - 1, "B")
 End If
 T2 = Sheet1.Cells(i, "H")
 If Sheet1.Cells(i, "K") > 0 Then
  Sheet2.Cells(j, "A") = T1
  Sheet2.Cells(j, "B") = a
  Sheet2.Cells(j, "C") = b
  Sheet2.Cells(j, "D") = T2
  Sheet2.Cells(j, "E") = Sheet1.Cells(i, "A")
  Sheet2.Cells(j, "F") = Sheet1.Cells(i, "B")
  Sheet2.Cells(j, "G") = Sheet1.Cells(i, "J")
  Sheet2.Cells(j, "H") = Sheet1.Cells(i, "K")
  j = j + 1
```

```
  GoTo 100
 End If
 100:
 i = i + 1
Wend
End Sub
```

Step 4. Time scale

```
Sub S4_Summary()
Dim i As Integer
Dim SumDay As Integer
Dim SumDayTot As Integer
Dim SumLength As Double
Dim AvLength As Double
SumDayTot = 2
While Sheet1.Cells(SumDayTot, "A") <> ""
 SumDayTot = SumDayTot + 1
Wend
SumDayTot = SumDayTot - 2
i = 2
SumDay = 0
SumLength = 0
While Sheet2.Cells(i, "A") <> ""
 SumLength = SumLength + Sheet2.Cells(i, "G")
 SumDay = SumDay + Sheet2.Cells(i, "H")
 i = i + 1
Wend
Sheet2.Cells(i + 1, "G") = SumLength
Sheet2.Cells(i + 1, "H") = SumDay
Sheet2.Cells(i + 2, "H") = SumDayTot
Sheet2.Cells(i + 3, "G") = SumLength / SumDay
Sheet2.Cells(i + 4, "G") = SumLength / SumDayTot
AvLength = SumLength / SumDay
i = 2
While Sheet2.Cells(i, "A") <> ""
 Sheet2.Cells(i, "I") = Sheet2.Cells(i, "H") * AvLength
 Sheet2.Cells(i, "N") = Sheet2.Cells(i, "H") * SumLength / SumDayTot
 i = i + 1
Wend
End Sub
```

Step 5. Create the new XY

```
Sub S5_NewXY()
i = 2
While Sheet2.Cells(i, "A") <> ""
 If i = 2 Then
  Sheet2.Cells(i, "J") = Sheet2.Cells(i, "B")
  Sheet2.Cells(i, "K") = Sheet2.Cells(i, "C")
 Else
  Sheet2.Cells(i, "J") = Sheet2.Cells(i - 1, "L")
  Sheet2.Cells(i, "K") = Sheet2.Cells(i - 1, "M")
 End If
 Sheet2.Cells(i, "L") = Sheet2.Cells(i, "I") * (Sheet2.Cells(i, "E") - Sheet2.Cells(i, "B")) / (Sheet2.Cells(i, "G")) + Sheet2.Cells(i, "J")
 Sheet2.Cells(i, "M") = Sheet2.Cells(i, "I") * (Sheet2.Cells(i, "F") - Sheet2.Cells(i, "C")) / (Sheet2.Cells(i, "G")) + Sheet2.Cells(i, "K")
 If i = 2 Then
  Sheet2.Cells(i, "O") = Sheet2.Cells(i, "B")
  Sheet2.Cells(i, "P") = Sheet2.Cells(i, "C")
 Else
  Sheet2.Cells(i, "O") = Sheet2.Cells(i - 1, "Q")
  Sheet2.Cells(i, "P") = Sheet2.Cells(i - 1, "R")
 End If
 Sheet2.Cells(i, "Q") = Sheet2.Cells(i, "N") * (Sheet2.Cells(i, "E") - Sheet2.Cells(i, "B")) / (Sheet2.Cells(i, "G")) + Sheet2.Cells(i, "O")
 Sheet2.Cells(i, "R") = Sheet2.Cells(i, "N") * (Sheet2.Cells(i, "F") - Sheet2.Cells(i, "C")) / (Sheet2.Cells(i, "G")) + Sheet2.Cells(i, "P")
 i = i + 1
Wend
```

Appendix 2

The interactive functions to the animated map

(Adobe Flash CS5, ActionScrip)

1. The time slider

```
import fl.controls.Slider;
import fl.controls.Label;
import fl.events.SliderEvent;
stop();
sldTime.addEventListener(SliderEvent.CHANGE, changeHandler);
function changeHandler(event : SliderEvent):void
{		gotoAndStop(event.value);
		timeLabel.text = getDateString(1812, 6, 29 + event.value);
}
function getDateString(year, month, day)
{
		var d = new Date(Date.UTC(year, month-1, day));
		return("" + d.getDate() + "-" + getMonthString(d.getMonth()+1) + "-" + d.getFullYear());
}
function getMonthString(month)
{		switch(month)
		{case 1:	return "January"; case 2:return "February";case 3:return "March";case 4:return "April";case 5:return "May";case 6:return
"June";case 7:		return "July";case 8:return "August";case 9:return "September";	case 10:return "October";case 11:return
"November";case 12:return "December";
				default:
				return "unknown";
		}
}
```

2. The play button

```
import flash.events.MouseEvent;
Playbtm.addEventListener(MouseEvent.CLICK, startplaying);
function startplaying(event:MouseEvent):void{
		play();
}
```

3. The stop button

```
import flash.events.MouseEvent;

Stopbtm.addEventListener(MouseEvent.CLICK, stopplaying);
function stopplaying(event:MouseEvent):void{
		stop();
}
```

Appendix 3

Introduction to the test

The main goal of this usability research project is to compare the time cartogram -a new methods for mapping spatial-temporal data which I have developed in my research- with existing mapping methods such as, in your case, the static map. The expected outcome of this research is evaluation of the capabilities of the time cartogram to represent free flowing movements. The time cartogram and the static map are represented as a pdf document on the computer screen.

As test data-set the movement of one of Napoleon's army corpses that participated in his Russian campaign was used. The test data represent daily information about the movement of Napoleon's IV (fourth) corps to and from Moscow.

This is a testing procedure where your interaction with the product will be videotaped and recorded and later analyzed. The testing will be conducted for one test person at a time. The test is task oriented. You are asked to think aloud as you work through the tasks. During the test session there will be no interaction between you and the moderator.

You will be asked to perform 12 tasks with each of the two mapping methods (the time cartogram and the static map). Before you execute these tasks, I will ask you to complete a questionnaire about your background and experience and after the test I will ask you to answer one additional question.

So, this usability test will be conducted in three sessions:

- **briefing phase:**
  introduction to the test
  This session will be for about 5 minutes.
  questionnaire –You are asked to answer the questions on your background and experience and to practice the think aloud method.

- **familiarization phase**: you are asked to get familiar with software to be used (see instruction for time cartogram and static map).
  This session will be for about 10-15 minutes

- **think aloud phase**: you will be given the tasks and are asked to complete then whilst thinking aloud. Please speak out your thoughts and feelings when completing the tasks.

Thanks a lot for your participation!

Appendix 4

***Participant No:.*……..**
***Date:.*………**
***Test Time:*…………**

Information about your background and experience:

1. Your age:

   ____

2. Your gender:

   ☐ male
   ☐ female

3. What is your nationality?

   ____

4. What is your profession?

   ____

5. What is your current field of studies?

   ____

6. Which university degrees do you already possess?

   ____

7. What do you know about Napoleon's march to Moscow?

   ____

8. Have you ever seen Minard's map? (see Figure 1.)

Yes No

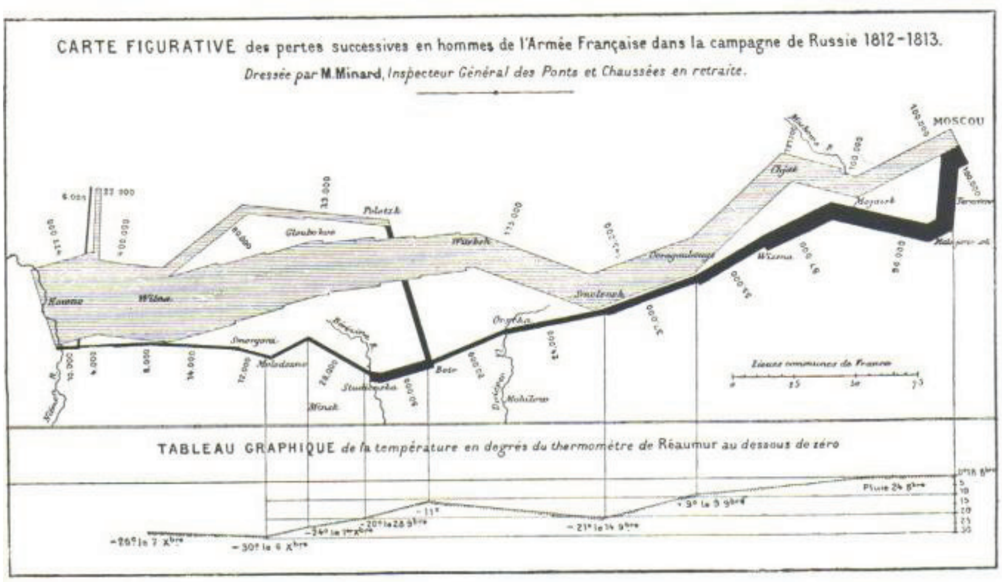


Figure1. Minard's map

9. How often do you use maps?

a) Low b) moderate c) high d) very high

10. How often do you work with spatio-temporal data (i.e. geographical data which also vary in time)?

a) Every day b) every month c) rarely d) never

11. Do you have experience with cartographic animations?

a) Little b) Moderate c) Much d) Very much

12. Do you have experience with the Space Time Cube?

a) Little b) Moderate c) Much d) Very much

Thank you!

Appendix 5

Instruction for the use the time cartogram, the map, the STC and the animation

Instructions for the use of the time cartogram:

The time cartogram (see Figure 1) is represented as a pdf document on the computer screen -Time Cartogram.

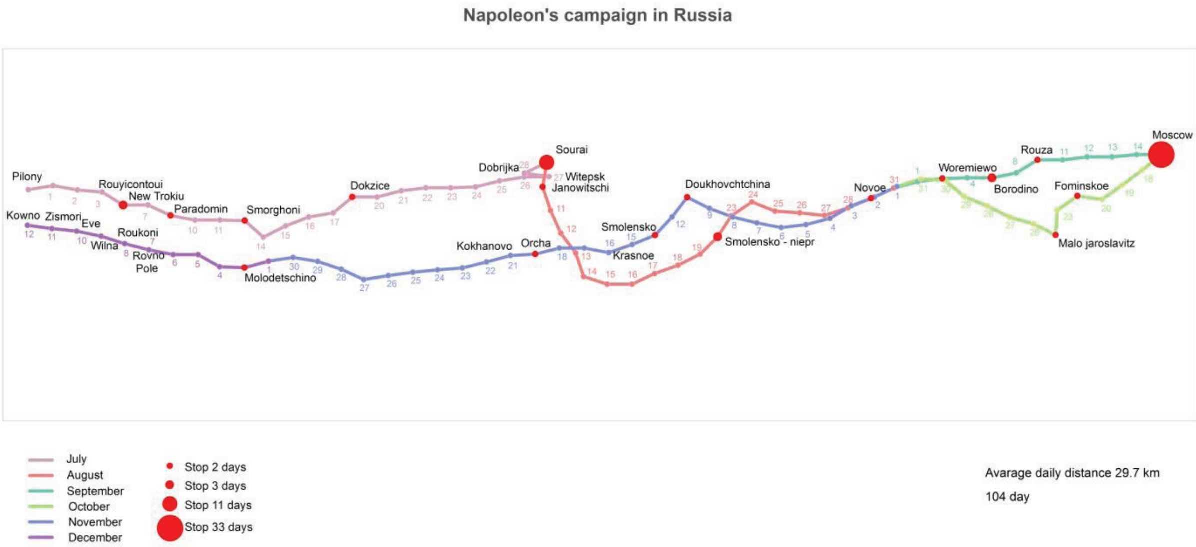


Figure 1. Time Cartogram

The Time Cartogram illustrates the daily movement of Napoleon's IV corps as line segments which present time distance instead of geographic distance (each segment presents one day). Napoleon's IV corps started movement on the 30th of June 1812 from Pilony and finished the trip on the 12th of December in Kowno.

Information about time (dates) is represented as:

- Differently colored line symbols indicate different months, which you can find in the map legend
- Proportional point symbols are used to show the stops of Napoleon's IV corps during different amounts of days (see map legend).
- Time label at point symbols is used to depict date (for example the 30th of June)

Please see the map and get familiar with it

Instructions for the use of the map:

The static map (see Figure 2) is represented as a pdf document on the computer screen - Map.

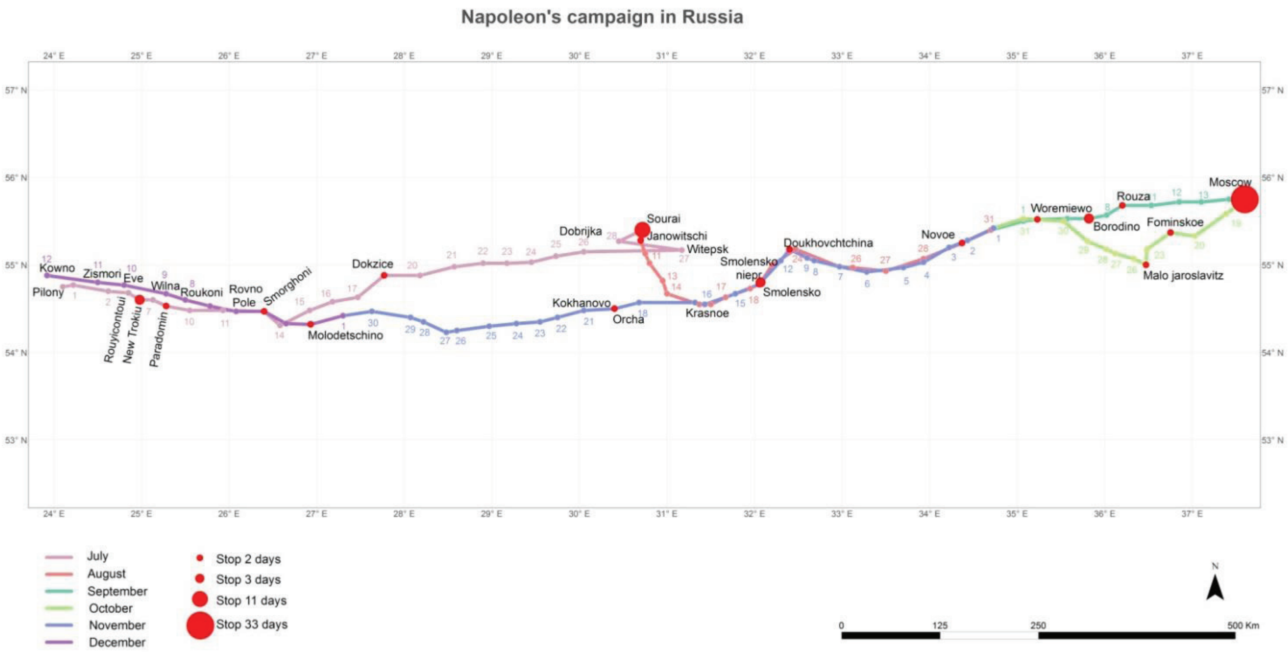


Figure2. The map

This map illustrates the daily movement of Napoleon's IV corps. The corps started movement on the 30th of June 1812 from Pilony and finished it's trip on the 12th of December in Kowno.

Line segments present the geographical distance covered by corps during one day.

Information about time (date) is represented as:

- Differently colored line symbols indicate different months (see map legend)
- Proportional point symbols are used to show the stops of Napoleon's IV corps during different amounts of days (see map legend)
- Time label at point symbols is used to depict date (for example the 30th of June)

Please, see the map and get familiar with it

Instructions for the use of the STC:

The STC (see Figure 3) is represented as shortcut on the computer screen in an Udig (software) environment. The STC is a 3D cube where the vertical axis represents time (T) and the horizontal axes represent space (X,Y)

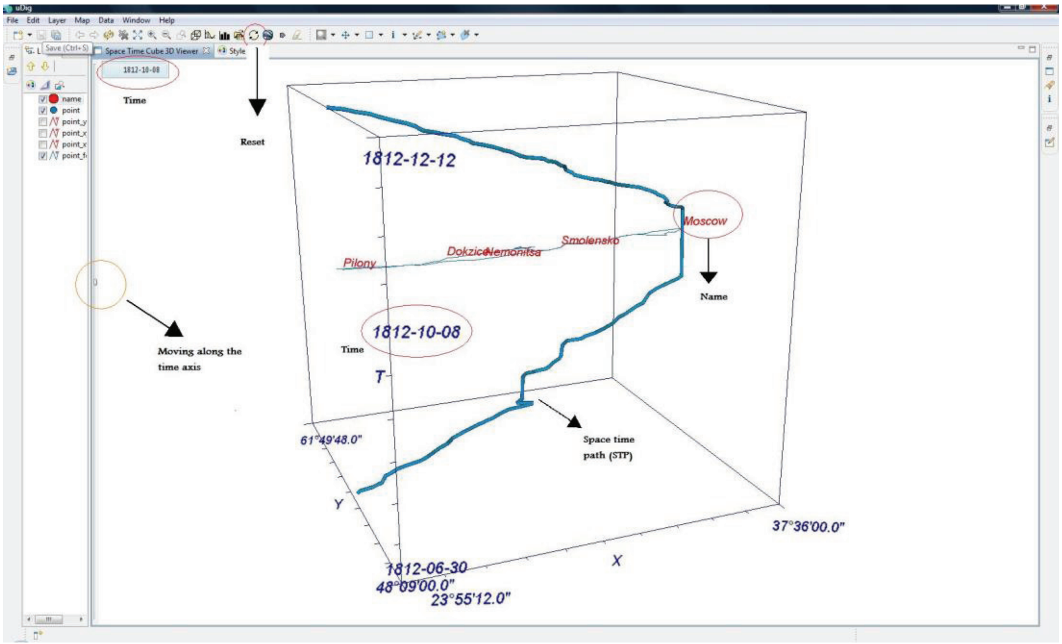


Figure 3. The STC

The STC illustrates the daily movement of the Napoleon's IV corps. The corps started movement on the 30th of June 1812 from Pilony and finished their trip on the 12th of December in Kowno.
The space time path (STP) indicates corps movement in space and time. The STP (represented by the thick blue line in the STC) is vertical when the corps didn't move. The STP differs from vertical when the corps is moving. Information about time (date) is represented on the vertical axis. It is possible to move a base map (which includes the names of the geographic location) vertically along the time axis.

During the movement of the base map, time is displayed on the time axis and in the left corner of the cube as well.

- Moving along the time axis

It is also possibale to rotate and move the cube by using the left mouse button.
In order to identify a name of geographic location you should to zoom in and zoom out cube by using the roll wheel mouse button.

- Reset the STC on its original starting position

Please go the software and get familiar with it

Instructions for the use of the animation:

The animation (see Figure 4) is represented as a swf format on the computer screen –Animation

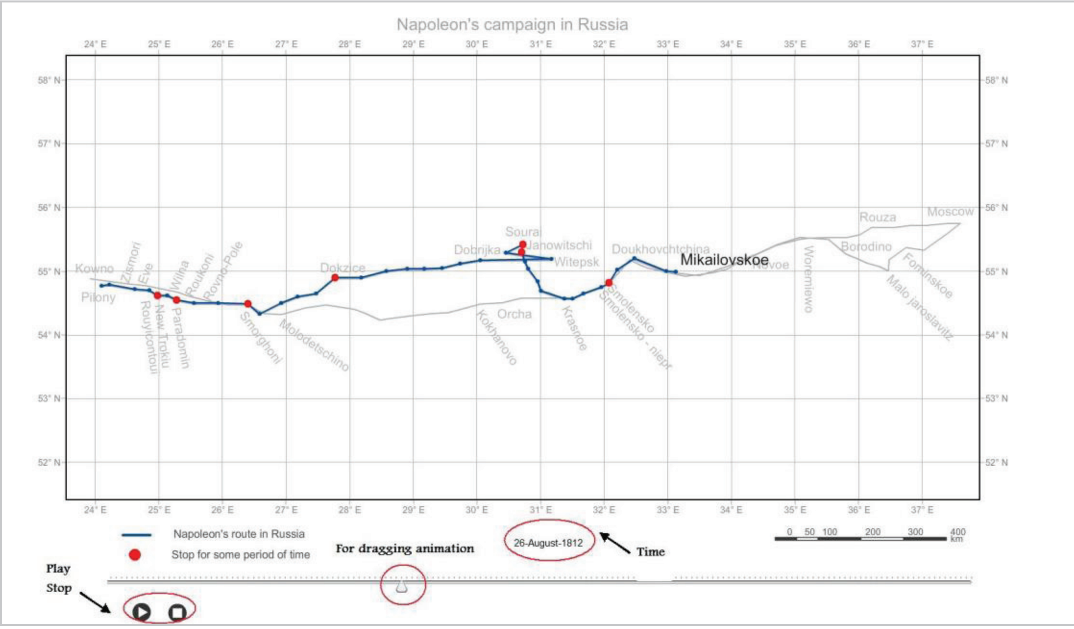


Figure 4. The animation

The animation illustrates the daily movement of Napoleon's IV corps. The corps started movement on the 30th of June 1812 from Pilony and finished it's trip on the 12th of December in Kowno. The line segments represent the geographical distance that was covered by the corps during one day.

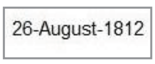
Information about time (dates) is represented as:

- point symbols (highlighted by a red color) the stops of the corps for more than one day (see the legend)
- a temporal animation with interactive functions:
  The icons:

 Play - begins the animation;

 Stop - stops the animation;

 Time slider- for dragging the animation forward or backward in time;



Display date/time- shows date/time by dragging the time slider.

Please, go the software and get familiar with it

Appendix 6

The questionnaire with the tasks

1. 1.Where was the IV corps on 3 July, 1812?
2. When did the IV corps arrive in Dokzice?
3. When did the IV corps arrive in Moscow and how long did they stay there?
4. How long did it take to go from Krasnoe to Kochanovo?
5. When and where did the IV corps go from Sourai ?
6. At which place did the IV corps stop for the longest period and how many days did they stop?
7. Which day did the IV corps cover the greatest distance?
8. In which 3 days period did the IV corps cover the greatest distance?
9. Did the path between Pilony and Dokzice (to Moscow) and the path between Molodetschino and Kowno (from Moscow) overlap?
10. Did the IV corps follow almost the same path from Smolensko to Volodimerova and back?
11. Is Pilony located South of Kowno or not?
12. What was about the distance between Smolensko and Volodimerova on the path to Moscow and back (from Moscow)? :

    1. Almost the same 2. Not the same

After completing the tasks with the different mapping methods you are asked to answer the following question:

I felt more comfortable to perform the tasks with the time cartogram than with other mapping method (please explain briefly):

Yes, because

____

____

____

No, because

____

____

____

Thanks a lot for your participation!

Appendix 7
A table for gathering data

Number of test person:			date:		
Tasks for the time cartogram	Comments	Reaction	Task for (Map or STC or animation)	Comments	Reaction
1			1		
2			2		
3			3		
4			4		
5			5		
6			6		
7			7		
8			8		
9			9		
10			10		
11			11		
12			12		
More comfortable:			More comfortable:		

Appendix 8
Correctness of tasks

Correctness of tasks temporal and spatial aspects (Group1)

Temporal Aspects (Time cartogram-Map)					
Group 1	TP1	TP2	TP3	TP4	Average
Time Cartogram	33.33%	83.33%	83.33%	83.33%	70.83%
Map	33.33%	33.33%	66.67%	50%	45.83%
Spatial Aspects (Time cartogram-Map)					
Group 2	TP1	TP2	TP3	TP4	Average
Time Cartogram	0%	0%	33.33%	0%	8%
Map	83.33%	83.33%	66.67%	100%	83.33%

Correctness of tasks temporal and spatial aspects (Group2)

Temporal Aspects (Time cartogram-STC)					
Group 2	TP1	TP2	TP3	TP4	Average
Time Cartogram	66.66%	50%	83.30%	66.66%	66.66%
STC	50.00%	83%	33.33%	50%	54.17%
Spatial Aspects (Time cartogram-STC)					
Group 2	TP1	TP2	TP3	TP4	Average
Time Cartogram	0%	0%	0%	25%	6%
STC	50%	83.30%	66.67%	50%	62%

Correctness of tasks temporal and spatial aspects (Group 3)

Temporal Aspects (Time cartogram-Animation)					
Group 3	TP1	TP2	TP3	TP4	Average
Time Cartogram	83.33%	50%	100%	83.33%	79.17%
Animation	50%	50.00%	66.67%	66.67%	58%
Spatial Aspects (Time cartogram-Animation)					
Group 3	TP1	TP2	TP3	TP4	Average
Time Cartogram	0%	0%	33%	33%	17%
Animation	50%	17%	33%	67%	42%

Appendix 9
(Calculate time for doing the tasks)

Group 1	Test person 1		Test person 2		Test person 3		Test person 4	
	Time Cartogram	Map	Map	Time Cartogram	Time Cartogram	Map	Map	Time Cartogram
Task 1	45	30	60	15	12	31	65	34
Task2	55	56	54	35	28	17	55	20
Task3	58	80	35	45	26	41	74	85
Task 4	60	110	99	47	27	28	46	40
Task 5	102	109	105	87	20	21	122	53
Task 6	27	19	31	46	20	10	31	40
Task 7	62	80	42	85	17	43	63	63
Task 8	132	150	133	44	88	51	60	68
Task 9	54	70	87	71	85	100	63	76
Task 10	70	30	67	80	43	23	46	72
Task 11	24	10	37	35	67	16	37	27
Task 12	64	17	55	30	11	38	47	38
Tasks total time	753	761	805	620	444	419	709	616
Session total time	29.06		31.46		18.4		24.41	

Group 2	Test person 1		Test person 2		Test person 3		Test person 4	
	Time Cartogram	STC	STC	Time Cartogram	Time Cartogram	STC	STC	Time Cartogram
Task 1	28	120	42	20	24	69	60	20
Task2	18	94	25	44	26	65	54	25
Task3	111	131	104	35	50	106	60	65
Task 4	50	139	163	84	40	95	156	70
Task 5	98	160	300	44	95	190	220	106
Task 6	38	68	60	45	20	50	106	16
Task 7	90	113	200	628	110	85	120	53
Task 8	23	11	270	220	80	56	200	15
Task 9	60	71	55	95	63	65	58	40
Task 10	126	55	40	40	36	20	55	40
Task 11	45	80	30	50	16	69	51	34
Task 12	70	87	140	142	30	19	40	10
Tasks total time	757	1129	1429	1447	590	889	1180	494
Session total time	37.17		55:26		29:16		32:00	

Group 3	Test person 1		Test person 2		Test person 3		Test person 4	
	Time Cartogram	Animation	Animation	Time Cartogram	Time Cartogram	Animation	Animation	Time Cartogram
Task 1	30	48	31	19	25	35	44	40
Task2	15	29	20	50	27	14	320	60
Task3	25	70	79	29	25	40	349	50
Task 4	29	47	73	43	60	44	156	60
Task 5	122	61	110	58	95	38	300	55
Task 6	20	46	36	14	20	47	320	22
Task 7	39	69	134	95	99	39	281	137
Task 8	60	90	65	27	89	39	114	117
Task 9	45	22	50	20	89	46	140	60
Task 10	53	75	47	14	97	32	130	62
Task 11	12	29	14	32	40	13	120	17
Task 12	33	40	35	26	90	31	54	18
Tasks total time	483	626	694	427	756	418	2328	698
Session total time	26:17		22:25		27:28		55:34	