THE USE OF DIFFERENT VISUAL REPRESENTATION IN THE SPACE TIME CUBE TO EXPLORE CHANGING NETWORK DATASETS

FENGFAN YANG
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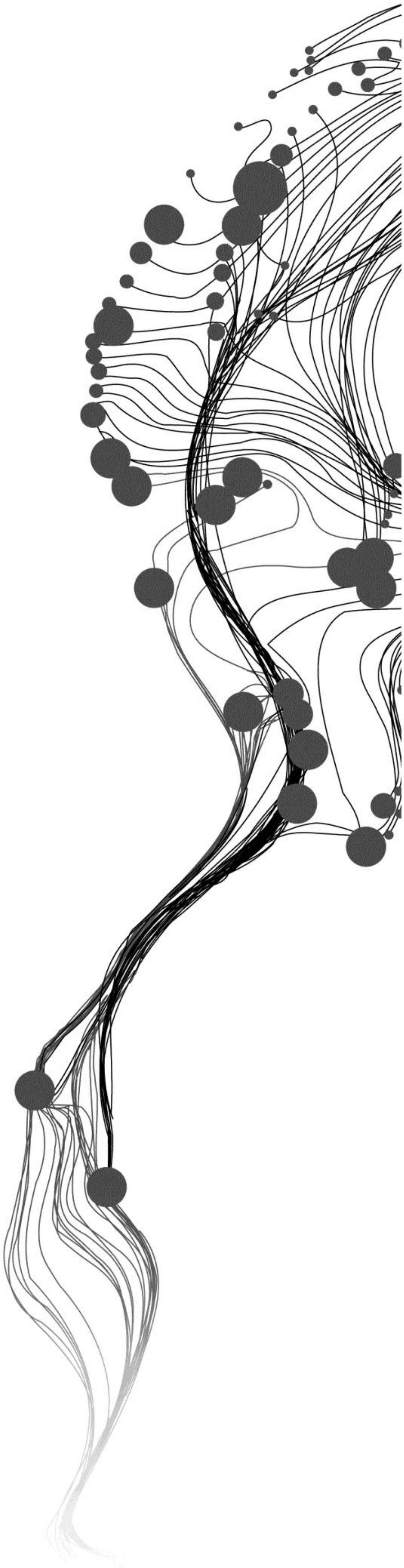

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FENGFAN YANG
Enschede, the Netherlands, Feb, 2011

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinfomatics

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...Dedicated to my dearest family...

ABSTRACT

With the increasing road network use and traffic demand, the speed of vehicles slow down, the increased vehicular queuing incurred traffic congestion. If a stream of vehicles is stopped for more time, this is leading to a traffic jam. Nowadays, transport department face great challenges to solve questions such as how to detect and manage transport congestion and accelerate the rate of transport accessibility. To answer these questions, choosing proper representation methods to represent the changing road network datasets and expose the traffic situation is essential. However, different representations may greatly influence people's understanding of the same traffic situation. It is therefore important to compare existing representation methods and judge which the suitable way to visualize road network datasets is. Moreover, appropriately use the characteristics of visual variables to create new representation methods for visualizing changing network datasets will help people better understand movement patterns.

In this research, three representations (flow map, 3D wall map and intensity map) are designed and implemented in a Space Time Cube (STC)-the potential representation method which can express location, time and attribute information for spatio-temporal network datasets in a 3D environment. Then, the research challenge exists in how effective efficiency and satisfactory when using the chosen methods to gain insight into spatio-temporal network datasets in order to facilitate transport managers to detect the traffic situation and make decisions. Based on the user centred design guidelines, usability test is executed and evaluated. 3D wall method in the STC environment is the best solution to deal with changing network datasets in this research.

ACKNOWLEDGEMENTS

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1. INTRODUCTION

1.1. Background and problem statement

1.1.1. Background

Nowadays, the capacity of acquiring and recording spatio-temporal network data is increasing. Network data have a complex structure since they can refer to the quantitative and qualitative characteristics of the network itself or of the moving object. The data can be split in elements related to location (where), time (when), objects (what) (Peuquet 1994) To give an overview of those data and to allow users to interactively browse through different portions of the data is the aim of visual exploration. This requires a high degree of interactivity, and is a key feature of visual exploration techniques (Tominski 2006). Recently, with the development of geo-technology, a large set of tools and techniques supporting geospatial network data exploration through the use of interactive visualization became available. However, the methods to represent the network data's spatial, temporal and attributes with good exploration and analysis functions are still limited. Approaches are being developed by researchers to solve the complexities of the current data problems and find ways to make analytical tools accessible and usable for potential users to support spatio-temporal thinking and contribute to solving a large range of problems (Andrienko, Andrienko et al. 2010).

Visual exploration and geovisual analytics are playing important roles to visually support the above problems. Visual exploration is the method to browse the data interactively for the purpose to get insight into the data and discover information; geovisual analytics is the science of analytical reasoning and decision-making with geospatial information, facilitated by interactive visual interfaces, computational methods, and knowledge construction, representation, and management strategies (MacEachren and Kraak 2001). All the power of computational techniques for data processing and analysis is worthless without human analysts (choosing appropriate methods depending on data characteristics, setting parameters and controlling the work of the methods, interpreting results obtained, understanding what to do next, reasoning and drawing conclusions) (Andrienko and Andrienko 2008). Visual representation of information greatly promotes human's perception and cognition. Therefore, when dealing with large amount of network data, how to well represent it and make people better understand it will be the core mission.

How to accomplish the mission? From a geo-information perspective, a comprehensive understanding of these problems requires multidisciplinary approaches and suitable tools for dealing with large amount of complex spatio-temporal data (Kraak and Huisman 2009).

Different visualization methods support different level of explorations, especially to map time change. In this research, the use of different representation to explore changing network datasets is being discussed. In order to find out the effective methods, the research needs to discover the defects of existing visualization techniques. Traditionally, there are static maps, a series of static maps and animated maps. Static maps have a limited exploratory capability which can only focus on particular map message. A series of static maps incorporate time, but its representation is limited by the number of images. It is not a proper way to deal with long time series. For animated mapping, the change is shown over time, but generally at a greatly changed scale, so users cannot compare the detail changing information between difference frames.

To solve to problem above, Space Time Cube (STC) will be studied to evaluate if it can fulfil the needs. The STC is a 3D space-time frame work, where the horizontal plane represents spatial dimension and the vertical axis represents time domain (Kraak 2003) to represent the network changes that we expect to notice and explore. The Space Time Cube conceptual model was first proposed by Hägerstrand in his paper "what about people in regional science" (Hägerstrand 1970). It could be used to investigate the constraints that affect the presence in space and time and to depict the activities in a space time context. The objective of Space Time Cube is to integrate spatial and temporal dimensions of human or nature activities into a "space time aquarium". In Space Time Cube, many elements could be represented and it is flexible to query data and change views to see the result. It is believed that STC could be a prominent visualization method to deal with these spatial-temporal network data sets.

1.1.2. Problem statement

At Present, people recognize the importance of geo-visualization to communicate geospatial information in ways that, when combined with nature changes and human understanding, allow for data exploration and decision-making processes. However, many of the tools or techniques cannot cope well with those changing network data. As mentioned above the traditional visualization methods have their limitations. Therefore, it is needed to reassess ways to analyse and explore changing network data and to meet users' need. What is more important, this research tries to create a new representation and exploration method to visualize and explore changing network data in Space Time Cube and to our knowledge the actual usefulness of different visual representation methods in a space time cube for conveying complex spatiotemporal patterns to users has not been empirically validated, so evaluating the usability of different visual representation methods in STC will be an essential issue.

1.2. Research Identification

1.2.1. Objective

The main objective of this research is to judge if the Space Time Cube is a suitable representation for changing network data to understand movement patterns; and which visual representation methods can be well used in a STC to present spatio-temporal traffic network.

1.2.2. Sub-objectives

The main objective can be reached by attaining the following sub-objectives:

1. To gain an overview of existing visualization methods for visualizing changing network data.
2. To set up a use case and design a prototype to explore the data in the Space Time Cube.
3. To investigate the capability of different visual representation in the Space Time Cube to deal with changing network data.
4. To evaluate and interpret if the suggested approach works.

1.2.3. Research questions

1. What is network data?
2. What is the traffic movement pattern?
3. Which existing representation methods are suitable to visualize this network data?
4. What are the advantages and disadvantages of the existing methods?
5. What is the role of a Space Time Cube when dealing with visualization of changing network data?

6. How to design a use case based on the Tele atlas road datasets and which visual representation methods will be used in the STC environment?
7. How to design and implement a research prototype, taking user tasks and data characteristics into account?
8. How can the changing network data be represented and explored in a Space Time Cube?
9. What are (dis)advantages for visualization of changing network data when using a Space Time Cube?
10. How to evaluate the prototype meet the users' requirements?
11. How effective the prototype works?

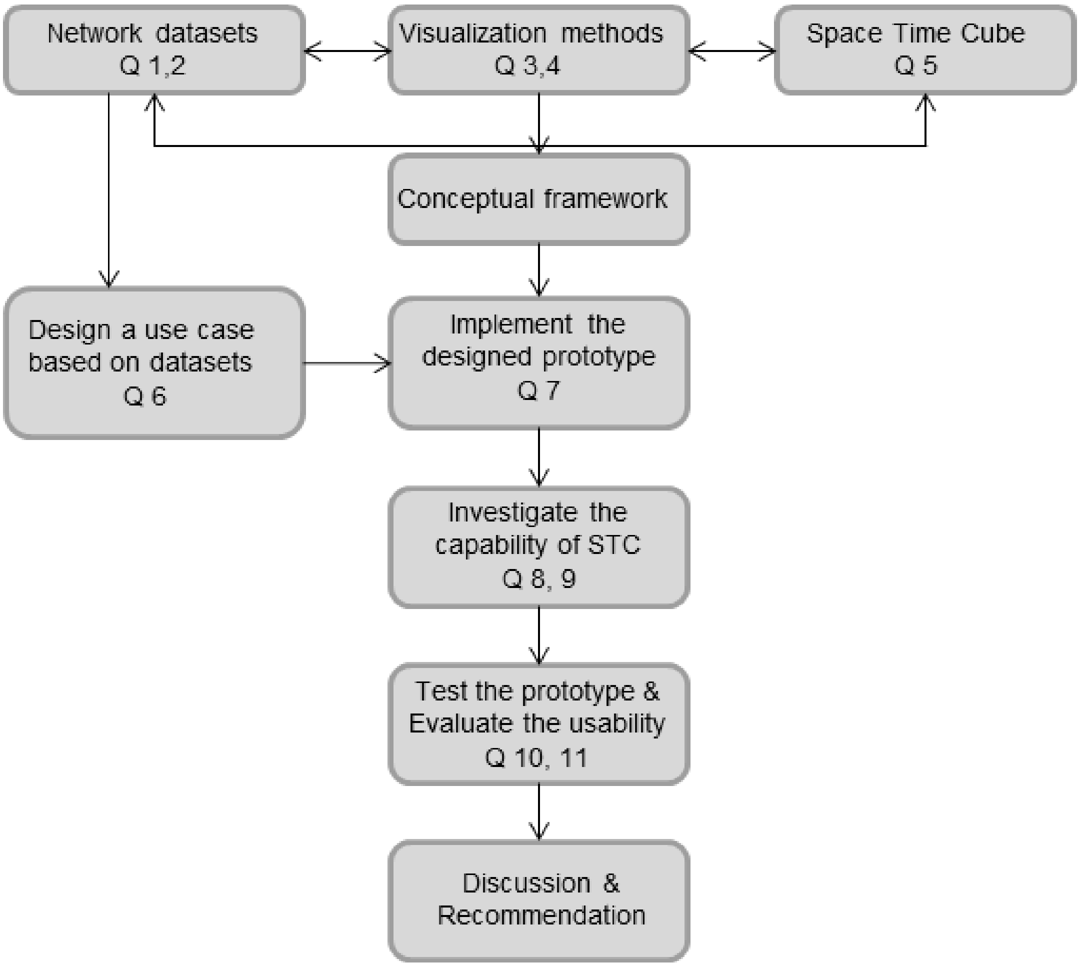


Figure 1.1 Research structure

1.2.4. Innovation

Nowadays we have many methods to visualize spatio-temporal data. However, to represent analysis and explore changing network data, many methods are not so effective. The innovation aims at using Space Time Cube to do representation and visual explore changing network data, taking user tasks and data characteristics into account. The new visual representation and exploration methods could carry out query and explore functions such as when and where congestions or free flow are, how long will it last; also it will help to research the regular traffic pattern during one day or some days.

1.2.5. Related Works

Time Geography was firstly introduced by Hägerstrand to analyze individual movement through space and time. Concepts such as space–time prisms, space–time paths, and potential path areas are proposed.

In this research, it will be introduced in Chapter 3. Typically, a two-dimensional model of space is used whilst an additional independent continuous dimension is employed to represent time. The key concept is the trajectory of each individual over 2Dspace and through time (Hägerstrand 1970). Any movement can be in a 3D visualization environment, this environment combine spatial dimension and time axis, which is defined as a Space Time Cube. Most software tools designed to support visual examination of large sets of movement data involving data aggregation. Through data aggregation we can get more information from the data. Specifically, from aggregated dataset, traffic movement patterns can be observed. There are three basic types of aggregation, spatial (S), temporal (T), and attributive (A) (Andrienko, Andrienko et al. 2008). These basic types are used in various combinations. When + where -> what: the object or sets of objects that are present at a given location or set of locations at a given time or sets of times. When + what -> where: the location or set of locations occupied by a specific object or group of objects at a given time. What + Where -> When: the time that a specific object or group of objects occupied by a specific location or set of locations (Peuquet 1994). Kwan had proposed methods to calculate space–time prisms within transportation networks using GIS (Kwan and Hong 1998). Moreover, Space Time Cube visual opportunities in different applications (Kraak 2003) are evaluated.

Cartographers Drecki and Forer have designed a visualization of aggregated movement data, and then they built a diagram consisting of six parallel planes, shown in a perspective view with a map of New Zealand depicted on each plane (Drecki and Forer. 2000). Kapler and Wright suggest ontology of movement data to support querying and search for information in the database (Kapler and Wright 2004). An interactive and flexible Space Time Cube for viewing and querying GPS data was proposed (Kraak and Ormeling 2003)

This research will based on the related work and try to represent and explore changing network data interactively in Space Time Cube to demonstrate and help people better understand traffic movement patterns.

1.3. Methodology

(1) Literature review:
The first task will be to review literature on visualization of changing network data and movement patterns, these two parts will be explained in the following chapter; traditional representation methods and Space Time Cube, Shneiderman's visual information seeking mantra, visual exploration will be introduced in the third chapter: visual representation and exploration of movement data. Literature review also will be done in every phases.

(2) Analyze the available network data sets:
Network data sets are provided by Tele atlas. The data will be cleaned to remove duplicates and errors. Some new data may be derived by doing calculation based on existing data. For example, Average time spend on each road section can be calculated by using the road length and the speed of recorded time.

(3) Develop a use case:
After that, find out which tasks are needed in exploring these changing network data. Through the use case, make sure which query functions and applications are required and could be realized, then translate tasks into views and functions.

(4) Implement the designed prototype:

Design the prototype and tools for representation network data sets in Space Time Cube: in this step, required tasks will be translated into views and functions. The changing network data will be represented and explored in Space Time Cube under three different designed visual representation environments.

(5) Test the prototype and evaluate the usability:
It is to determine the capabilities and limitations of the prototype and evaluate the usability of the prototype. The usability methods are tasks-based questionnaire and think aloud. User will evaluate the three designed visual representation methods, two cities' traffic network datasets will be implemented in the prototype.

(6) Discussion and recommendation for further research:
After achieving the five steps above, a research conclusion will be given. There will be some remarks and limitations in this research, discussion and recommendation for further research will be summarized in the last chapter.

1.4. Summary

In the first chapter, the research questions are raised; research objectives and methodology are discussed. In the following chapters, six parts will be introduced respectively:

In Chapter 2, the aspects of the characteristics of changing network data will be discussed. Literature review goes to network dataset and different movement patterns; the basic concepts are going to be identified as well.

Chapter 3 discusses the existing popular visualization methods, for example, the static map, and a series of maps, animation, their advantage and disadvantage of the visual representation methods will be analysed. The Space Time Cube will be introduced, analysed and the capability of it will be judged.

Chapter 4 is about designing a conceptual model for the representation of changing network datasets in Space Time Cube. The visual variables for visual representation will be studied. After the analysis of probability of representations methods, flow map, 3D wall map and intensity map are going to be implemented in the STC environment.

In Chapter 5 the implementation of the conceptual prototype will be shown, data processing, software operations and interactive tools will be introduced briefly, the visualization of flow map, 3D wall map and intensity map will be exhibited as well.

In Chapter 6 gives a brief introduction about usability evaluation, current usability evaluation methods and the selected methods, tasks-based questionnaire and think aloud; for this research the usability methods will be discussed shortly. Then it will goes to the procedure of evaluation, the usability result and the analysis of the result.

Chapter 7 is about the conclusion and recommendation for further research work.

2. NETWORKS AND MOVEMENT PATTERNS

2.1. Introduction

The literature review on changing network and movement patterns focuses on basic issues and concepts needed in this research, which are both the background and extension of the related knowledge. In this chapter, two topics will be discussed: changing network and movement patterns.

2.2. Changing network

2.2.1. Properties of network

The network model is a popular conceptual model to represent a network structure within a GIS environment. Network is a collection of segments with nodes. Nodes are created at the segments intersections. The model is built around two core entities: the node(a zero-dimensional entity) and the segment (a one-dimensional entity) (Fischer 2003).

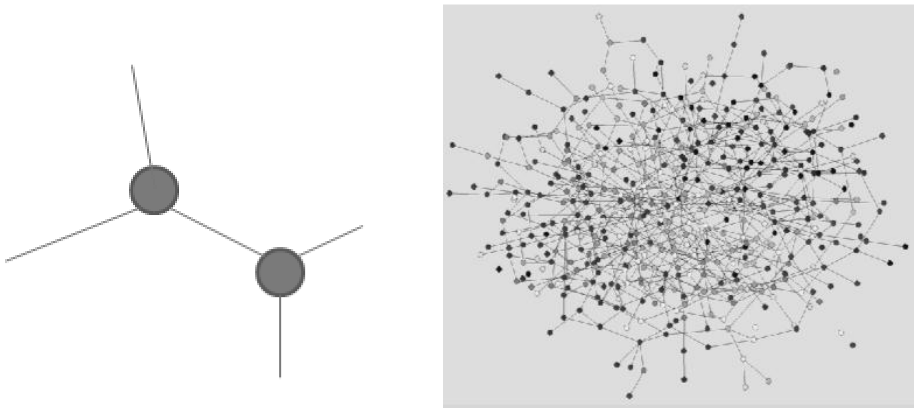


Figure 2.1 Network data structure
(Right fig URL: http://www.informatics.indiana.edu/fil/Net/)

Each of the two entities has its triad elements—space, time and attribute. When the network data structure is fixed, the node has its geographical location, at different time the point contains various attributes. Similarly, the segments represent roads in transportation application. Each road segment has geographical information, the traffic attribute is varies according to different time periods.

2.2.2. Changing network

Change can be categorized to absolute and relative; continuous and discrete. Blok (Blok 2005) classified the change into spatial and temporal domain, summarized the change in spatial domain can be defined as appearance/ disappearance, mutation and movement; in temporal domain be defined as: moment in time, pace, duration, sequence and frequency. For changing network datasets, the roads location and road network structure is not changing over a short time, while for the traffic flow is on-going changing. If people expect to visualize the changing network datasets, there should be a way to represent this phenomenon. The various visualization methods will be introduced in the following chapter.

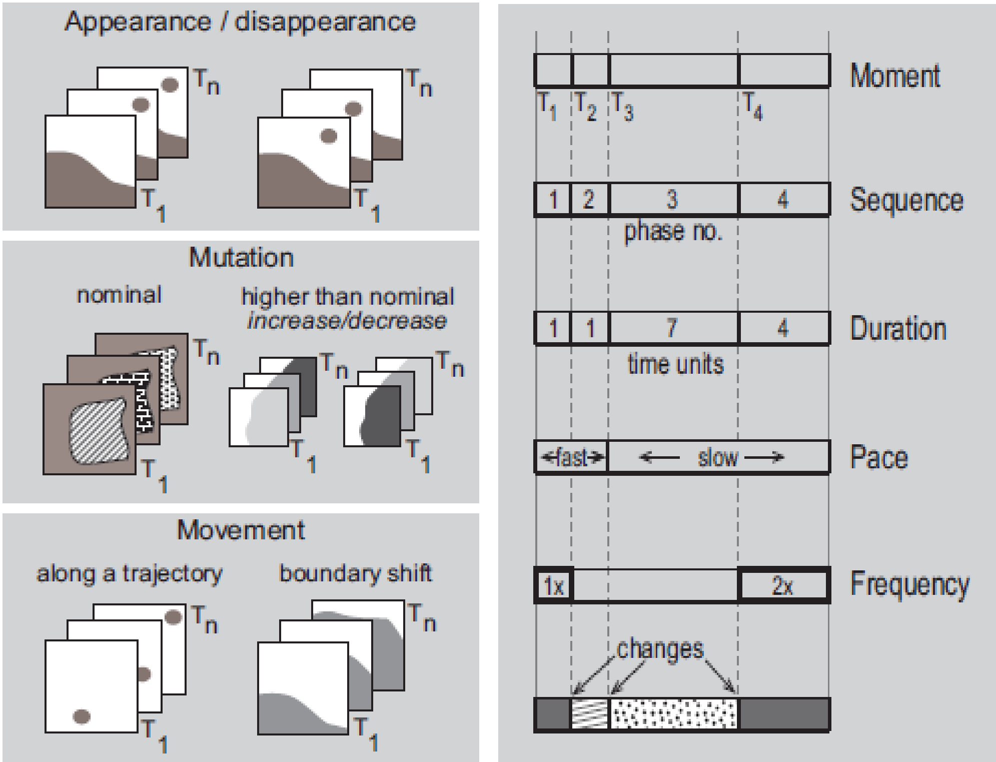


Figure 2.2 Basic characteristics of change
in the spatial domain (left) and in temporal domain (right)(Blok 2005)

With congested roadways and ever-increasing travel times, both traffic sector managers and traffic users are seeking better ways to understand whole region's traffic pattern, to travel efficiently, minimize transportation costs and find the optimal routes to their destinations by making full use of recorded spatial temporal network data, through geovisualization representation of these changing network datasets to detect the traffic congestion. Therefore, to understand changing network datasets, which contain the detail road section information and realistic average roadway speeds for different times of the day and different days of the week is an essential issue in the research.

To this research the changing network data is based on Tele atlas speed profiles, derived from aggregating and processing hundreds of billions of anonymous GPS measurements from millions of devices that reflect actual consumer driving patterns. GPS tracking data provides useful information of where and when people or vehicles are located. GPS data does not indicate the information of what and why people and vehicles are located at particular locations at certain times.

2.3. Movement patterns

Mobility is an important element of many processes and activities, so the understanding of it is becoming essential in many areas of science such as oceanography, astronomy, meteorology, biology and transportation. Hence, increasing amounts of changing movement data and other data about the dynamics of mobile objects or agents are under research. As the number of vehicle users is increasing, while the road network infrastructure is comparably developing slow and not reasonably, therefore to research on changing road network data, user's daily trajectory and the movement pattern will be beneficial for transportation department and traffic users. In most cases, moving object data sets are rather large in volume and complex in the structure of movement patterns that they record. In order to extract helpful and relevant information, a research on detecting movement patterns and exploring movement behavior visually is favorable.

Before answering the above questions about studying the movement behaviour of dynamic objects, it is important to understand what exactly the variables are that define movement, what constraints and external factors affect movement and most importantly to understand what types of movement patterns can be composed from these primitives of movement. (Dodge, Weibel et al. 2008)

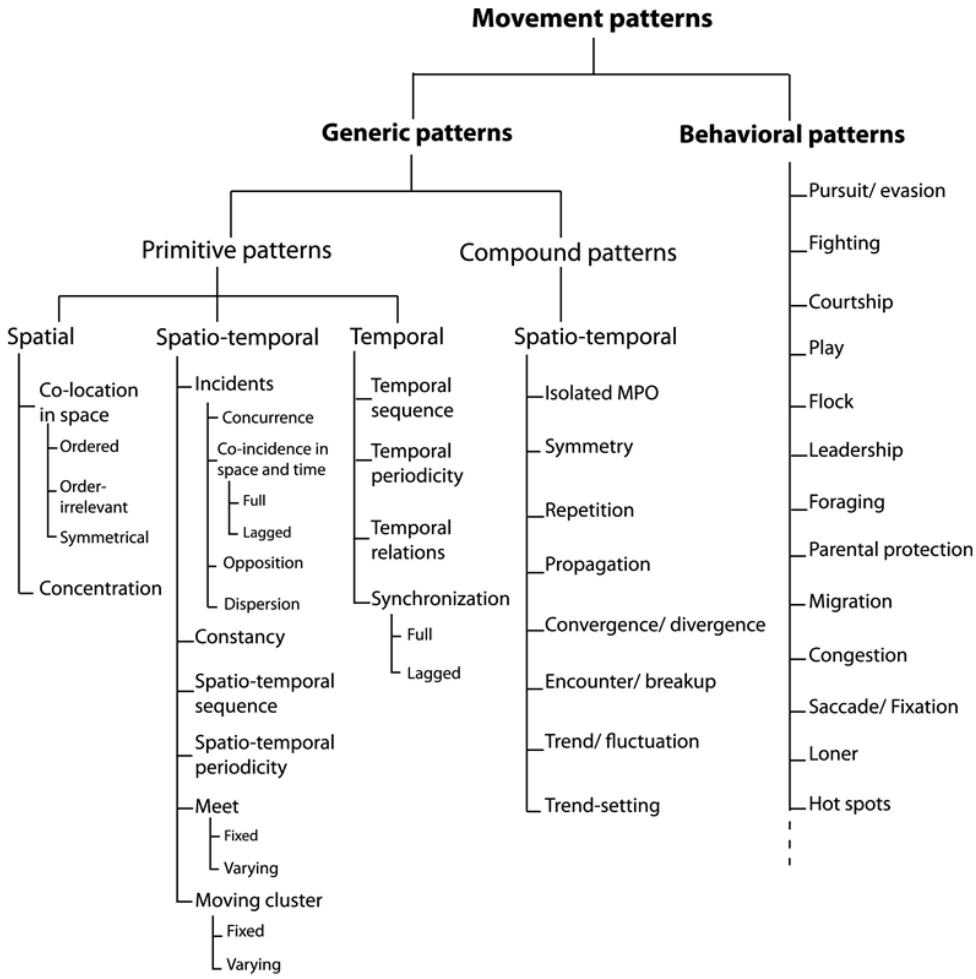


Figure 2.3 Movement patterns classification
(Dodge, Weibel et al. 2008)

In Dodge's movement patterns classification, the behavioural patterns are usually applied to animals; generic patterns are popular to describe multiple trajectories and spatio-temporal phenomena, for the changing network datasets, the representation of network datasets will mainly reflect the fixed or varying moving clusters. Normally, during workdays, the morning and afternoon rush causes the heavy traffic. Moreover, spatio-temporal sequence and spatio-temporal periodicity can be detected, such as people in workdays usually get up for morning exercise then go to work, late afternoon, back home. If we trace several trajectories, more primitive patterns, for example, spatial pattern: co-location in space can be identified. For example, people work for the same company or people live in same residential area even can be called "co-incidence in space and time" pattern.

If the research goes to a fixed area, the movement pattern in this area will follow some unknown rules; it might be affected by three factors: time, location and attribute. Movement patterns can be classified as the following three classes:

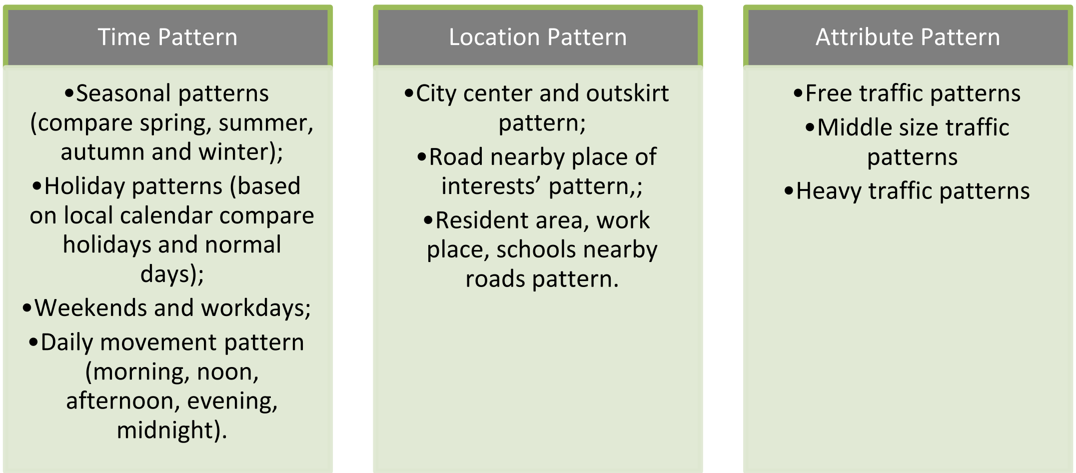


Figure 2.4 Classification of Pattern (Source: Author)

"The most effective way to support human perception, cognition, and reasoning to gain an understanding of these patterns is not purely visual methods of analysis being enhanced with interactive techniques." Now, those methods need to be combined with database operations and computational analysis techniques helping to handle large amounts of data. (Andrienko and Andrienko 2008) The visual representation is the best way and the clear, direct method for people to have an insight into the traffic movement pattern phenomena. While the better visualization is not come from the visualization itself, but originated from a meaningful and well organized datasets.

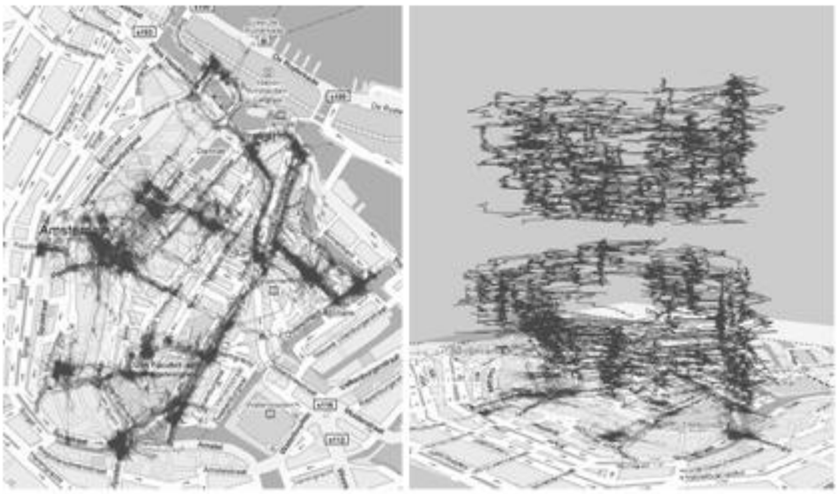


Figure 2.5 Movement pattern-GPS tracks
303 schoolchildren playing an educational game in
Amsterdam, about 57,000 points (URL: http://geoanalytics.net)

Generally, movement patterns include any recognizable spatial and temporal regularity or any interesting relationship in a set of movement data, whereas the definition depends on the application domain.

2.4. Summary

This chapter introduced the structure of network data, explained what is the changing network data, and the purpose for researching on it. Moreover, the movement pattern for network is depicted. In order to let people understand the changing network dataset, the best way is to visualize the datasets with the best representation methods. It requires the well-organized changing network datasets and the knowledge on visual representation. In the following chapter, the representation methods will be brought in.

3. VISUAL REPRESENTATION AND EXPLORATION OF MOVEMENT DATA

3.1. Introduction

Before discussing visual representations and exploration, the triad framework will be reviewed, which contains three basic components of spatial temporal data: time (when), location (where), attribute (what). The existing visualization methods which will be discussed and compared are based on these three factors in the triad framework. Then, the graphic variables, which are position, size, shape, value, color, orientation and texture, will be introduced in this chapter to give an answer to which representation method(s) are suitable for the network datasets.

3.1.1. Triad Framework

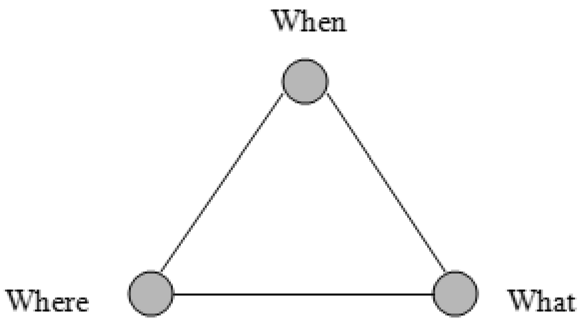


Figure 3.1 Basic Triad

Each element in network data (Figure 2.1) shares these three factors in Figure 3.1. Three questions can be raised based on the three components and the combination of these components.

1) When + where -> what: to describe the object or a set of objects in particular place at specific time. Choose time or time period, set location or locations. Then tell the traffic situation at this time or time period, at this or these locations.
2) When + what -> where: the location or set of locations occupied by a specific object or group of objects at a given time. Select the time or a span of time and movement patterns (free/busy); detect the location or some locations.
3) What + where -> when: the time that a specific object or group of objects occupied by a specific location or set of locations. Select the location(s) and movement patterns (free/busy); detect the time/ a series of time or a period/some time periods.

3.2. Existing visualization methods

Different visualization methods support certain degree of explorations. In order to find out the effective methods we need to discover the defects of existing visualization techniques. Traditionally, static maps have a limited exploratory capability which can only focus on particular map message. A series of static maps incorporate time, but representation is limited by the number of images. It is not a proper way to deal with long time series. For animated mapping, the change is shown over time; but generally at a greatly changed scale, so users cannot compare the detail changing information between difference frames.

3.2.1. Single Static

2D Maps are ordinary paper maps; on the paper the map information could be drawn.

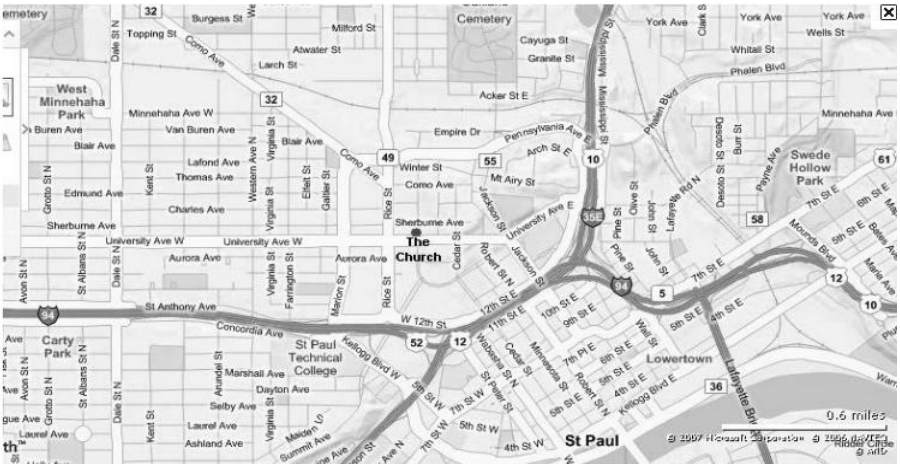


Figure 3.2 2D Google Map

At beginning no time information will be shown on this kind of map. Later on, the possibility to evolve new and possibly more effective types of visualizations to annotate time has arisen. However, to visualize the movement of a vehicle during a time period, the traditional ways to mark time are often used. From a location to another location, the start time can be noted on map, and the end time be marked as well. Moreover, we can also write down the actual time when the vehicle passed different landmarks. However, if only one trajectory, it won't be a problem for the presentation on the 2D map, if the routes are too many, then the information on 2D map will be overloaded, even lose the original map functions.

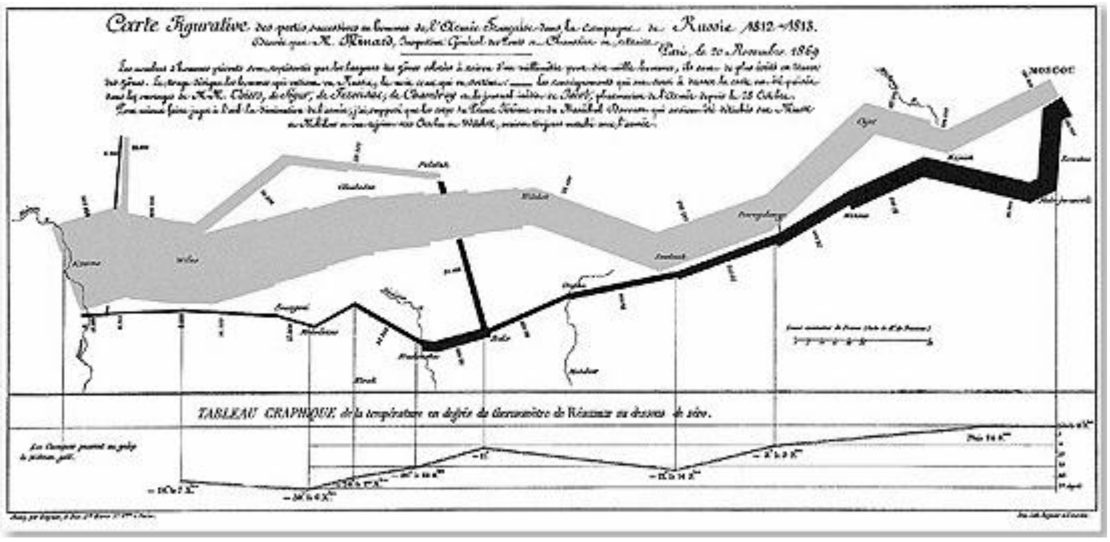


Figure 3.3 Minard's map (1869) of Napoleon's doomed campaign to Moscow (1812-13)
URL: http://cartography2.org/Chapters/page0/RepresentingTimeStatic.html

Minard's map (1869) of Napoleon's doomed campaign to Moscow (1812-13) is one of the classics. It depicts space, time and attributes both deaths and temperature all in a deceptively simple, two-colour diagram. Tufte calls this the greatest info graphic of all time. It's certainly an efficient one; it combines much information on a simple 2D static map. The temperature graph at the bottom is the explanatory variable.

Figure 3.4 Interactive map of the London Tube map Created by Tom Carden

This interactive map of the London Tube map distorts geographic space in order to create uniform travel times: The subway stations re-arrange themselves based on how far they are from each other in travel time not in geographic space. This is called cartogram, which means a map in which some thematic mapping variable, such as travel time, is substituted for distance. The purpose of using geometry distorted map is to highlight the more important information and ignoring less important ones.

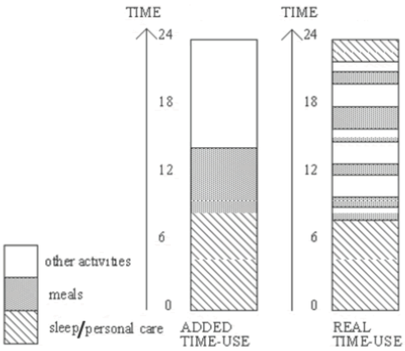
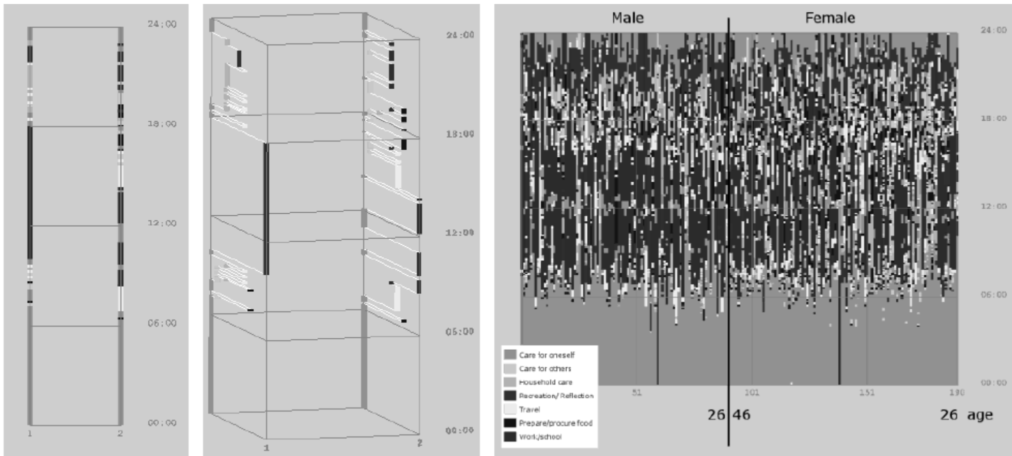


Figure 3.5 2D time-use study
(Kjellin and Pettersson 2010)

Figure3.5 is one of traditional 2D methods for people to research on time-use studies. The representations account for the accumulated time used for activities during the day, which hides information that may be important to a geographical scientist, for example where during the day an activity occurs, how many times per day and for how long.



(a) Front View Visualization (b) Rotated View Visualization (c) Front View Visualization

Figure 3.6 Visualizations of the Visual-Time Pacts

(a) Shows the activity paths viewed from the front. It is activities performed during a work day. (b) Shows a slightly rotated view of the activity paths where the 'movement' between the activities and hence the similarity to the original 'space time path' becomes clear. (c) Shows the front view visualization. Time is shown in the y-axis and the individuals are ordered along the x-axis by age and gender. Colours represent the 7 activity categories (Kjellin and Pettersson 2010).

The time of an event can be directly shown by spatial position without resorting to the use of graphical expressions such as labels, colour, line width, and so on. This means that such graphical expressions are left to be used for other important characteristics of the visualized events, and this is a fundamental difference between the space–time cube and any 2D visualization (Kjellin and Pettersson 2010).

However, these movement pattern analyses represent the attributes (free flow percentage speed in this research) and time information well, but they lost real location information. Therefore, a real geographical map should be the base map. The actual time should be recorded and also the attributes should be shown on the map. It also lack of interaction, which is a key issue in visualization.

One big advantage of static depictions of time is that they tend to be holistic and will depict all time periods at once, allowing the reader to examine and compare the moments and the spatial patterns clearly and carefully.

3.2.2. A series of maps

The map series is a succession of individual maps depicts a process of change.

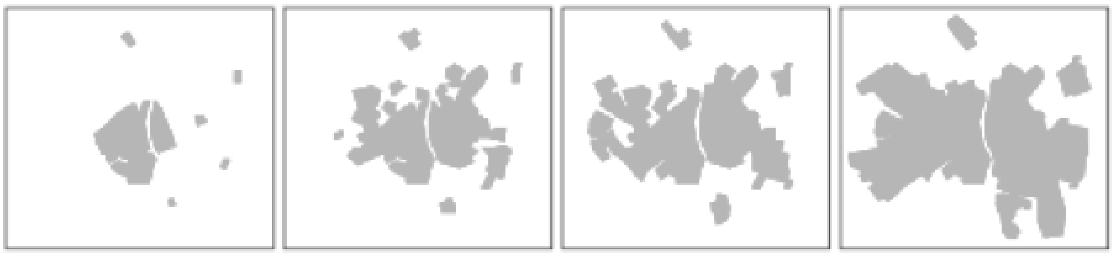


Figure 3.7 Maastricht city Urban Growth
(Principles of GIS 3rd Version; ITC)

In the figure 3.7, from left to right, it can be seen the urban area of city Maastricht is keeping growing, from a small center area to a large urban area. A general conclusion can be extracted from the map series. In this case, the information expression is limited by the number of images. No more information is provided.

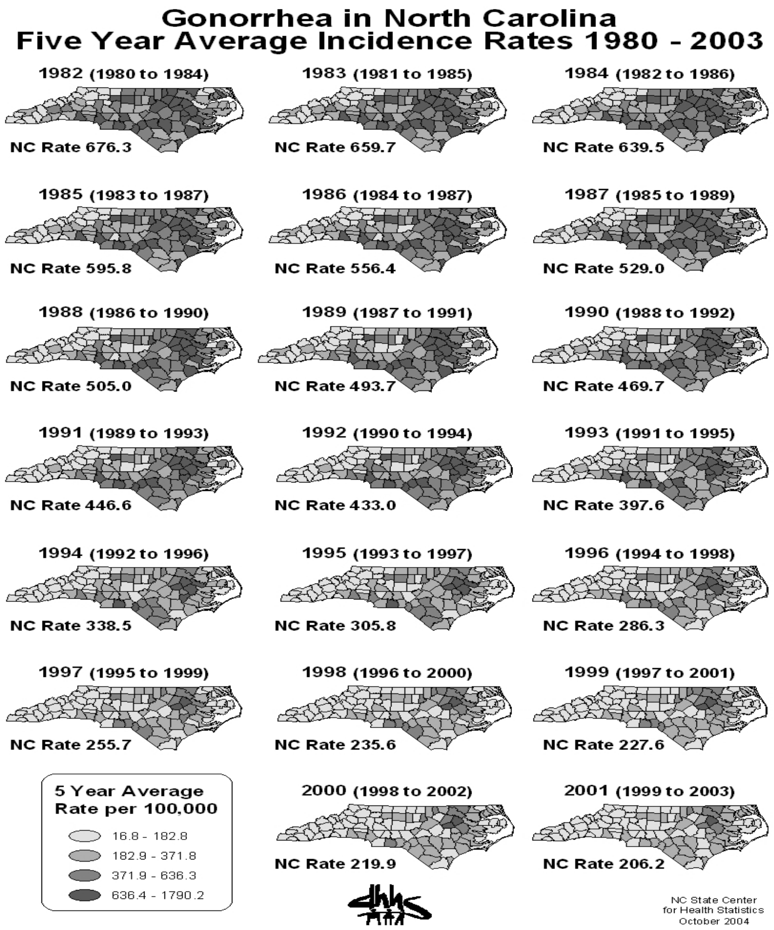


Figure 3.8 North Carolina State centre for health statistics
(URL: http://www.schs.state.nc.us/SCHS/gis/atlas/index.html)

Figure 3.8, the North Carolina Health Atlas contains maps of North Carolina that depict county level health and health-related information. The primary purpose is to provide a way to interpret visually a broad range of data and information about the health of North Carolinians. The time series sequence maps represent exact time which is good for readers to compare between them.

As 2D map shows the map of whole study area, direction and orientation are fixed, so the changing information cannot expressed by 2D map only. To observe the dynamic network, the concept of animation comes into mind, which can combine vast amounts of data into a compact package and simplify complicated concepts and convey complex inter-relationships. More advantages of animation are they can capture the user's attention and can re-create an event.

3.2.3. Animation

Another way to show a movement is to use animation; Animation is the rapid display of a sequence of frames of 2-D or 3-D images in order to create an illusion of movement. It is an optical illusion of motion due to the phenomenon of vision. The work reported by Andrienko—figure 3.9(Andrienko, Andrienko et al. 2000), where animation is used to visualize movements of individual migrating storks.

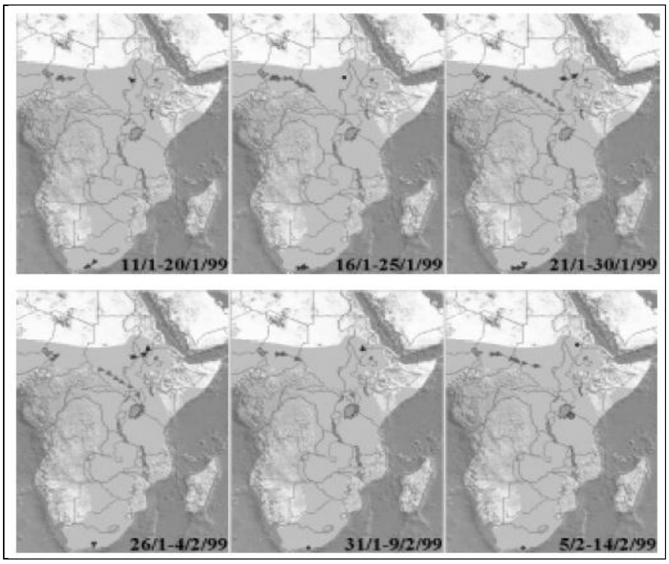


Figure 3.9 Snapshots of a dynamic presentation of the behaviour of white storks in Africa

More research is on multiple objects tracking. So far, how to evaluate of animation effectiveness and efficiency is not reach agreement. The research to investigate the optimal speed of an animation for people to follow is still going. There exists an upper limit to the number of moving objects a human observer can track with accuracy. It is suggested that five moving objects are close to that limit.

For the transportation application, animation could be a better option; it will represent the traffic situation of whole road network and the person's location dynamically. In 2D animation, a person's daily activities are recorded. For example, 6:00am get up, and then take morning exercise in a park; 9:00am begin the work, at noon, go out for lunch, afternoon shop at mall then go home. After dinner, go out for movie or sports. A moving dot could present where the person is, the road is changing network, and the characteristics of lines stand for conjunctions. Suppose the narrower lines show free flow speed, then this animation provides information with general location information and time, but the time is not continuous. Therefore no continuous time if the record data not intense and no detail information is given to explain why he is there, what he is doing at that time. For example, on the way to work, the people answered a phone call then changed the direction to train station. This virtual information cannot be depicted in an animation.

In the animation, there might be only one person's moving, if there are more people's information, and some of them share same path, some time they appear at same location same time, but how long they will stay is various. When it became more complex, 2D animation cannot come cross too many questions. At this time, STC could be a better solution.

Static 2D map, a series of maps and animated maps help users to understand the process of the dynamic phenomena and gain more insight into the spatial environment. However, the limitations of these representation methods enable people to develop new and complex methods to display and explore these spatiotemporal datasets. Generally speaking, the animation is based on 2D maps. How could it look like if the third factor is introduced? Which attribute should be the third factor? 3D can give the idea of all the dimensions and hence better designs can be created by looking at the 2D maps and the conventional maps were not that much informative compared to 3D maps. In the following section, time geography will be introduced and a representation and exploration tool -Space Time Cube - which combined time axe, going to be discussed in the following part.

3.3. The Space Time Cube

3.3.1. Basics

Time geography traces its roots back to the Swedish geographer Torsten Hägerstrand who stressed the temporal factor in spatial human activities. The time-space path, devised by Hägerstrand, shows the movement of an individual in the spatial-temporal environment with the constraints placed on the individual by these two factors. Three categories of constraints (authority, capability and coupling) were identified by Hägerstrand.(Hägerstrand 1970). In recent years, other scientists and institutes have also used this technique for example the ITC group's space–time cube visualization of Napoleon's Russian campaign.

The basic concepts related to STC:
Space time paths (STP): "lifelines", depict the trajectory of a movement.
Space time prism (STPrism): the areas one can reach in particular time period.
Potential path space (PPS): the extent radius of the STPrism.
Potential Path Area (PPA): the foot prints of PPS on the geographic base map.

STC provides a good environment to represent human movements. With GPS tracking data, time geographic concepts could be visualized at finer spatial and temporal resolution levels. The left figure of Figure 3.10, it records a trajectory, the figure contains information of location, time and attributes. The attributes can be various, for example, when the person on the way from work to shop, one of his or her friends called for a date at night; what happened from work to shop because of this distance costs a long time, maybe the car is out of order, or the person visited or stopped by some other interesting place. Using a space time path in STC environment will give answers to more realistic questions on human perception.

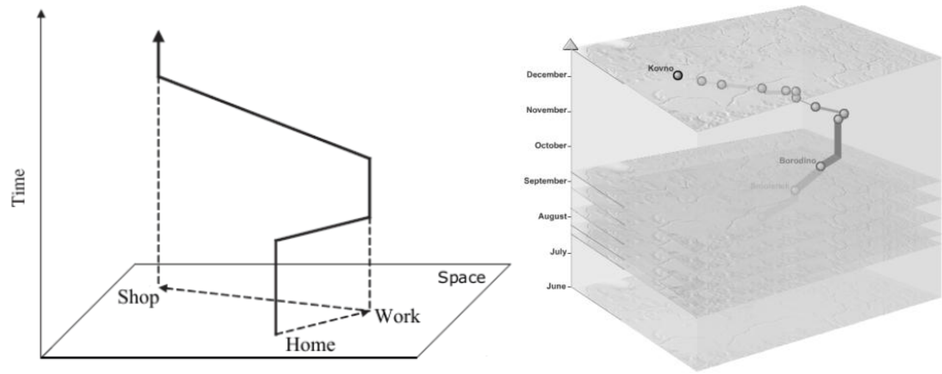


Figure 3.10 Space Time Path and Space Time Cube
A simple example of Space time path (left) Space Time Cube: Napoleon's Russian campaign (right)
(URL: http://www.itc.nl/personal/kraak/1812/minard-itc.htm)

The STC is 3D space-time frame work, where the horizontal plane represents spatial dimension and the vertical axis represents time domain (Kraak 2003) to represent the network changes that we expect to notice and explore. The Space Time Cube conceptual model was first proposed by Hägerstrand in his paper "what about people in regional science" (Hägerstrand 1970). It could be used to investigate the constraints that affect the presence in space and time and to depict the activities in a space time context. The objective of Space Time Cube is to integrate spatial and temporal dimensions of human or nature activities into a "space time aquarium". In Space Time Cube, many elements could be represented and it is flexible to query data and change views to see the result. It is believed that STC could be a prominent visualization method to deal with these spatial-temporal network data sets.

STC shows the potential of coding more data directly to form graphical representation than any 2D visualization and the large amount of information can be shown in the STC directly after data processing. This shows that human can reliably perceive all aspects of 3D structure (Kjellin and Pettersson 2010).

STC plug-in which is based on uDig prototype was developed by ITC has realized many extra functions, such as rotation, zooming, panning, highlight elements, query functions, multiple linked views, activation and deactivation of layers, footprint movement parallel to the a-axis etc. These functionalities could solve many spatiotemporal questions, however, when dealing with the large amounts of movement datasets, changing network data. The advantage of STC will not so prominent. But, using STC to present the complex traffic network at different continuous time is good to recognize the movement patterns. Thus, the questions come to what are movement patterns, and how to extract the movement patterns, there is a pressing need in appropriate visual analytics methods for movement data.

3.3.2. Justification

In STC, specific location information is recorded, also can be searched by coordinate, a person's daily route can be described with a Space Time Path. While user can control the time, the network attribute will keep changing as time goes, then where the path crosses with the traffic network layer, the point is the people's location at this specific time. Related annotations are available to add in the 3D environment to explain what is happening here at this time. If represent many people's path, to some extent, it won't be mixed up neither.

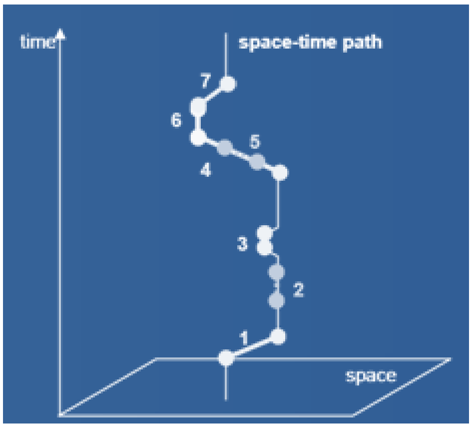


Figure 3.11 space-time path

1. Drive to work from home
2. During work time (emails, lectures, meeting etc.)
3. Lunch
4. Go for shopping
5. On the way to shopping (phone calls from friends or family members, listen to radio or chatting with people on the car.)
6. Dinner or some sports
7. Home (reading, watching DVD, house cleaning etc.)

What's more, in the Space Time Cube, by default, user used to view from one side to get a whole view of the path, then if to check at a fixed time the person meet a traffic jam or not, user should rotate the cube to look into it from the top or the bottom, which may cause the uncertainty and cost more time, so we consider using 3D symbols to show the attribute (percentage of free flow speed) instead of using 2D methods to represent. 3D symbol, such as 3D wall would give user intuitive feeling when they are dealing with questions such as at 6pm when the person finish shopping, is there a traffic jam on that road? The user can change time to 6pm, the crossing point shows where the person is and the traffic situation.

Moreover, which representation method is better for user to understand the whole movement pattern is also a task for usability test. To measure the representation methods (In chapter 4 the conceptual model for flow map, intensity and 3d wall will be brought in), questions will be set to solve reality problems, accuracy and time-consuming is a measure of the standard.

One of the advantages of STC is the dynamic environment to represent events in a temporal dimension, and hence the basic components of spatiotemporal data could provide what and where information in order to answer questions. Objects or events are related to what and where is related to locations on the base maps (X, Y coordinates) and the time is related to the Z axis, which is the time line.

Besides, the reasons why STC will be used are:

1. In most case STC are used to visualize trajectory data, which the path in the cube only stands for one moving object. While here the attempt exists in implementing integrated datasets into STC which means no simple path will be formed. Only the overall traffic situation will be able to shown due to different time. It a new utility approach for STC, it worth a test on how well it works for non-trajectory datasets.

2. 3D can give the idea of all the dimensions and hence better designs can be created by looking at the 3D maps and the conventional maps were not that much informative compared to 3D maps are. Both 2D and 3D symbols are visible in 3D environment. More graphical variables and dynamic variables can be implemented in the Cube. Users will look into a more appealing spatio-temporal environment.

3. All data can be visible at one time in a cube, user can choose the time, choose the location, choose the attributes properties or choose the combination of them to visualize the selected related datasets, which make it possible to compare various data components at the same time.

The representation methods to be realized in Space Time Cube will be introduced in next chapter.

3.4. Summary

In this chapter, the visual representation methods are introduced and compared. There are many geo-visualization methods to deal with spatiotemporal data. Each of them has their own (dis)advantages. Which option is better depend on the objective we expect to achieve; this chapter discussed on judging whether Space Time Cube is a suitable representation for changing network data to understand movement patterns. It does have great potential to represent the datasets. After analysis, it discusses the advantage of Space Time Cube in dealing with changing network datasets. It is a good visualization method for the visualization of spatial temporal data. Therefore, in the following chapters, STC will be the visualization environment. However, what would be the representation look like in a 3D environment, say the Space Time Cube? This chapter also brought in graphical variables, with the purpose to let people understand the visualization of spatial temporal datasets; it needs a design on what kinds of graphic variable are well defined and distinct in 3D environment. In the following chapter, a designed conceptual visualization will be described.

4. CONCEPTUAL DESIGN – INTERATION OF DIFFERENT VISUAL VARIABLES AND NETWORK

4.1. Introduction

Based on the previous chapters, the next step is the design and selection of appropriate graphical variables for visualizing and exploring spatiotemporal movement patterns. Hereby, the following issues should be considered:

1. A general understanding of the behaviour of movement patterns.
2. In a visual approach, the working environment includes both representation and interaction functions.(Li and Kraak 2008) therefore, it is needed to know which kinds of visual variable best represent the data representation and interaction the datasets. Testing the effectiveness of the suggested solution could be done by planning a set of tasks carried out in an appropriate working environment and with suitable data. This will be discussed in the following chapters.
3. The visualization framework will be briefly discussed.

4.2. Cartographic information analysis

New representation could offer the user opportunities to visualize explore and gain more insight into the changing network datasets to identify movement patterns.

Since nowadays information is presented by computers, the addition of motion as a new visual variable becomes to plan an important role. Changes in motion can include direction, speed, frequency, rhythm, flicker, trails, and style (Carpendale 2003).

The choice of the variable, which would be most appropriate to represent each aspect of information, depends on its characteristics.

Selective	If a mark changes in this variable and as an effect can be selected from the other marks easily the visual variable is said to be selective
Associative	Several marks can be grouped across changes in other visual variables
Quantitative	If the difference between two marks in this variable can be interpreted numerically, the visual variable is quantitative
Order	If the variable supports ordered reading it is an ordered visual variable. This means that a change could be read as more or less (e.g. in size you can order marks according to their area)

Table 4-1 Characteristics of variables

Considering the nature of two types of data: qualitative and quantitative (Bertin 1983). Qualitative data is also called nominal data. Quantitative data can be classified as interval and ratio by measurability. Data types are linked to visual variables.

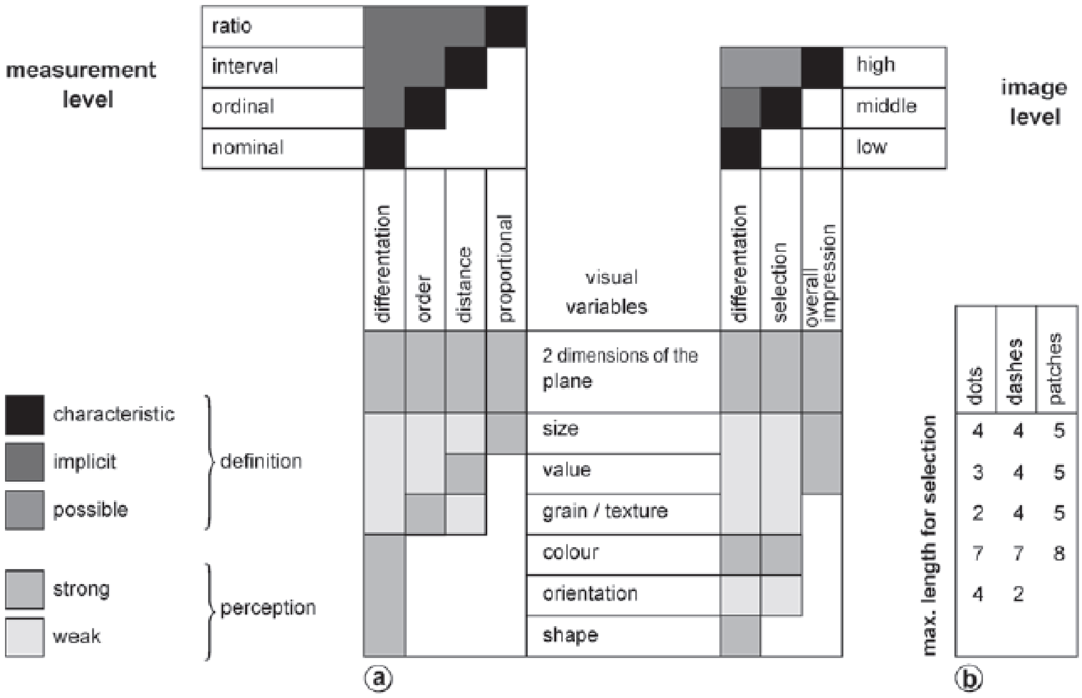


Figure 4.1 Cartographic information analysis
(Geels 1987)

Choosing different visual variables for representing different aspects of the same information can greatly influence the perception and understanding of the presented information. It is therefore important to know and use appropriate characteristics of visual variables when creating any visual data representation. For the representation methods in a Space Time Cube of changing network data, here the research will evaluate flow map (the width of road represents the traffic volume); 3D wall map (the height of road represents the traffic volume); intensity map (the different colour value represents traffic situation).

4.4. Visual variables

Visual variables are characteristics of visual symbols, are how we distinguish between them. Symbols are used to give people impressive conception to specific phenomena. Bertin (Bertin 1983) described marks as these basic units and also developed a given number of methods through which these units can be modified, including position, size, shape, or colour. These predefined modifications are called visual variables. Each of these variables can have certain characteristics. A mark is made to represent some information other than itself. It is also referred to as a sign.

Points	Dimensionless locations on the plane, represented by signs that obviously need to have some size, shape or colour for visualization
Lines	Represent information with a certain length, but no area and therefore no width. Again lines are visualized by signs of some thickness.
Areas	A length and a width and therefore a two-dimensional size.
Surfaces	Areas in a three-dimensional space, but with no thickness
Volumes	A length, a width and a depth. They are thus truly three-dimensional

Table 4-2 Classes of marks

Bertin(Bertin 1983) classified the possible variation of symbols into six different categories: size, value, grain/texture, colour, orientation and shape.

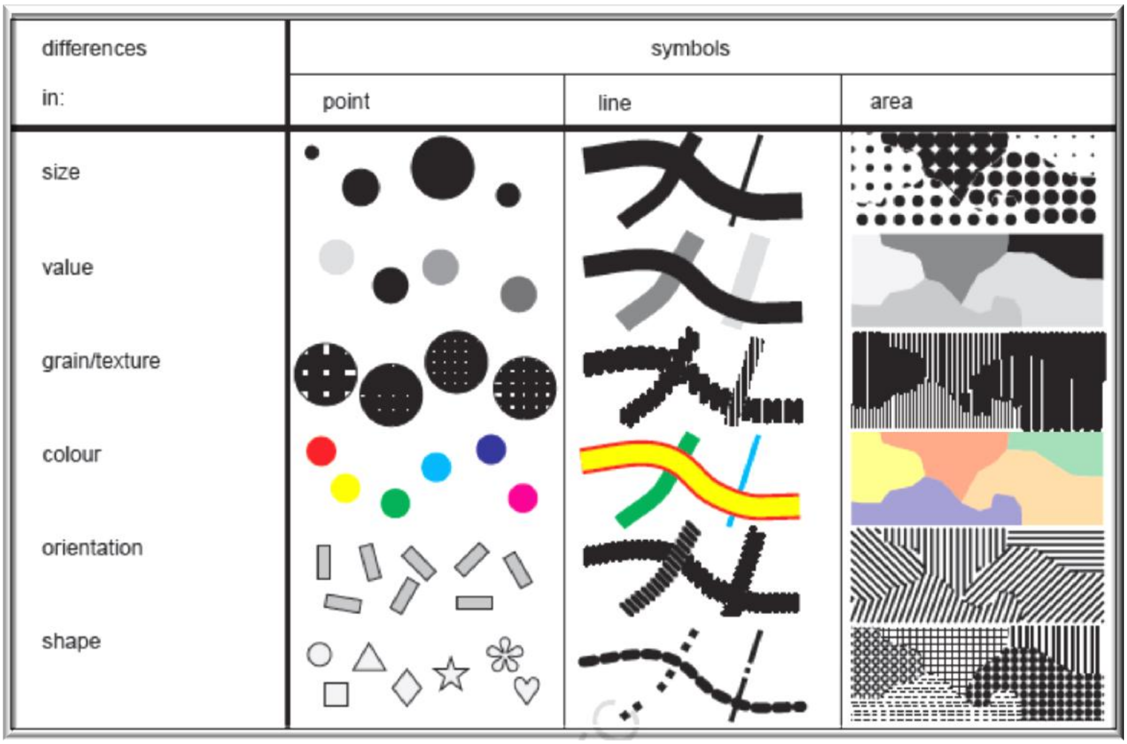


Figure 4.2 Bertin's visual variables

4.5. Graphic design options and conceptual visualization framework

In this section, the three suggested map types; flow map, intensity map and 3D wall map will be explained.

1. Flow map, Quantitative method, using the width of the roads to show free or heavy traffic, here it is called flow map.

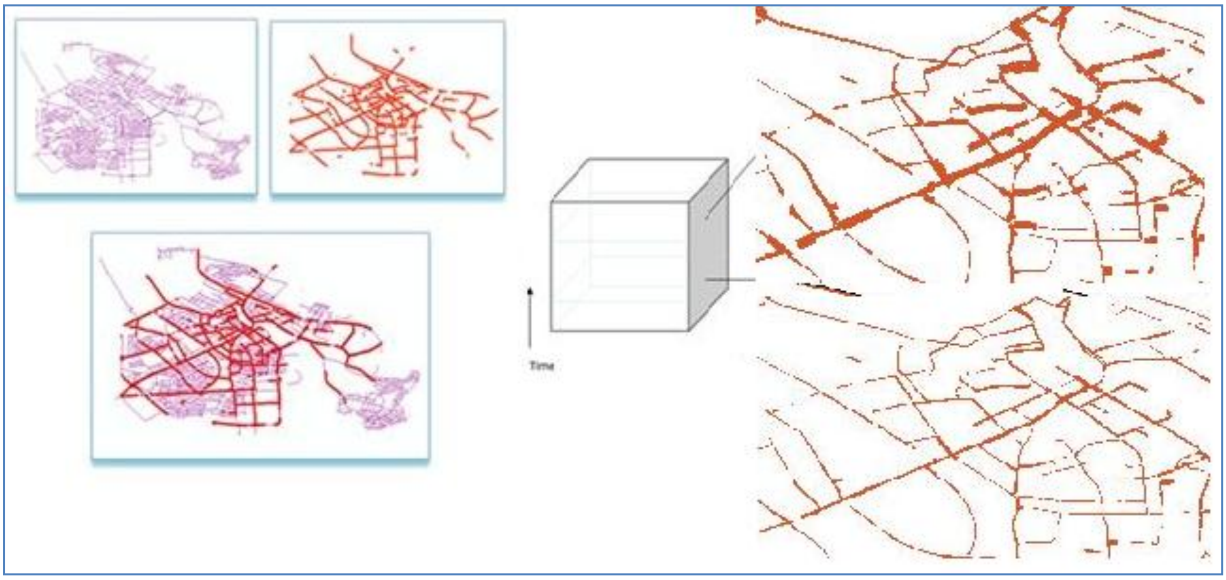


Figure 4.3 Conceptual model for flow map in a Space Time Cube

Figure 4.3 the right picture shows traffic situation, for this work the width of line represents the transportation density. Thicker lines mean the heavier traffic.

1) Advantage: Lines share the similarity of real road shape, user can have an overview of the structure of the traffic network, and the cross point on the map.
2) Disadvantage: If the road network is too crowded, the width of one road may have some common parts with neighbor roads. Then, it will not be a good representation method. It may not easy to identify small change and the angels for good view is limited, mainly look from bottom or top.

2. Intensity map, Quantitative (ordered); using lines to represent road network, using value to show free/heavy traffic (dark colour stands for heavy traffic; light colour represents free roads). Different colour values stand for various classes of percentage of free flow speed, for instance, light lines mean these roads at this time is 90%-100% of free flow. Dark lines show 80-90% of free flow.

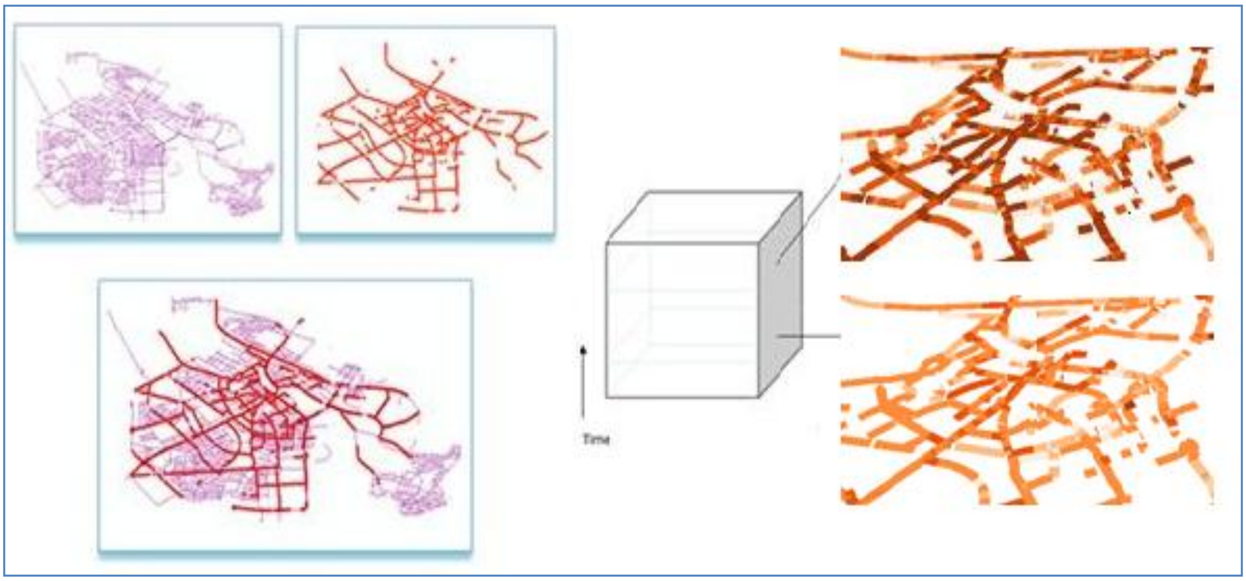


Figure 4.4 Conceptual model for intensity map in a Space Time Cube
The colour value of roads will change as time changes and the speed allowance changes.

1) Advantage: Lines share the similarity of real road shape; the width of the road won't change, so even if the traffic is very heavy, the representation of nearby roads keeps clear, one road won't integrate to another road. Moreover, color change is easier to be identified.
2) Disadvantage: the number of classification of related attribute influences the result in great deal; using color map cannot give user accuracy level of percentage of free flow speed. Besides, the angels for good view is limited, mainly look from bottom or top.

3. 3D wall map, quantitative; using 3D (wall/volume) map to show free or heavy traffic.

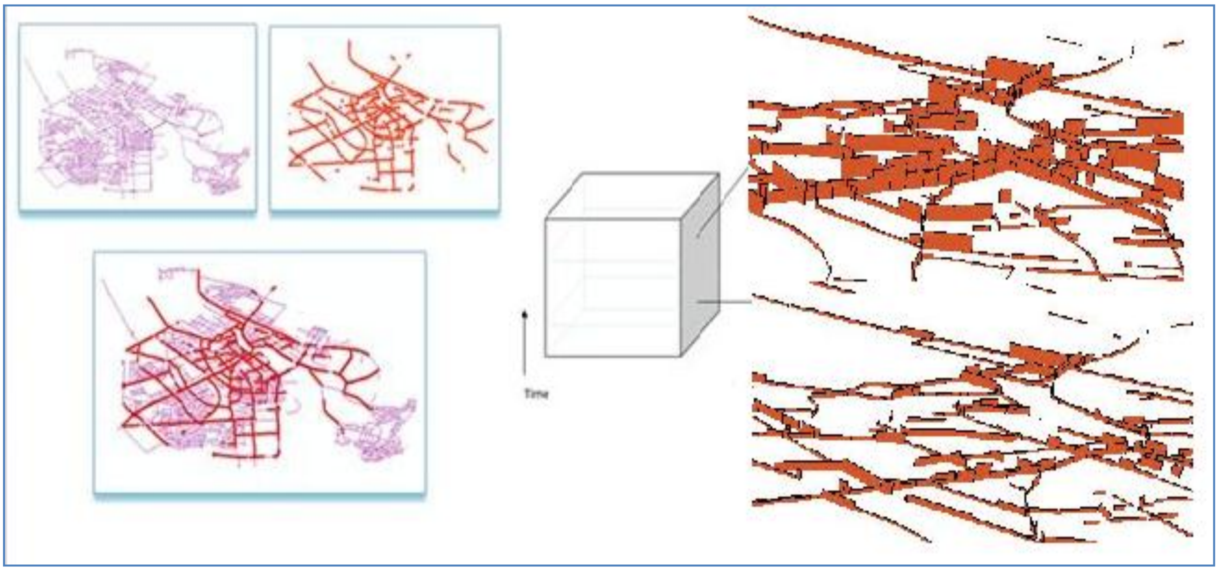


Figure 4.5 Conceptual model for 3D wall map in a Space Time Cube

3D Walls - The height of walls above each road section indicates changing traffic situation.

1) Advantages: Height change is not difficult for users to detect; users can acquire large amount of information from different angle to view; 3D wall map can present more information, it has more capability to show more attributes.
2) Disadvantages: In 3D wall representation, high walls will block lower walls at some specific angle, but this disadvantage could be solved by rotating the STC, then look at the lower walls from other direction.

Besides the options above, multivariate method can be considered, for example, using composite quantitative lines when more attributes are needed to be shown on a map. The intensity map and flow map can be combined together, using one variable to show the percentage of free flow, the other variable represent some other attributes. Similarly, using multivariate method and trying to combine 3D wall map with intensity map to represent more attributes on one map.

1) Advantages: More information is contained on one map; patterns can be generated visually.
2) Disadvantages: May not forms a good visualization if the design leads to negative side; small changes are not easy to notice.

4.6. Exploration

Function analysis should follow Shneiderman's visual information seeking mantra, firstly have an overview; then zoom and filter; finally details on demand

Simple Task for prototype	Required Views	Required Functions
Overview Zoom Query/Filtering View attributes	Base Map view (location) Temporal line view (time) Attribute view (attribute)	Zoom in/out Panning Add/ Remove items Brushing

Table 4-3 Functions for exploration

4.7. Summary

This chapter is about a general understanding of the behaviour of movement patterns; then discuss how to design a conceptual model for the representation of changing network datasets in a Space Time Cube. After the analysis of probability of the graphic variables, and three catalogues: Qualitative, Quantitative and Multivariate, three representations methods- flow map, 3D wall map and intensity map- are going to be implemented in the Space Time Cube environment in following chapter. The required functions are discussed here as well, in the next chapter; the three representation methods will be implemented.

5. PROTOTYPE: A CASE STUDY

5.1. Introduction

In Chapter 4, the conceptual graphical representation methods with STC were introduced. The question-how will they work in order to represent and explore the changing network datasets in STC environment-is going to be discussed in this chapter. Firstly, a brief introduction to preparation work, then it goes to implementation of road transportation network data.

5.2. Preparation

5.2.1. UDig and Space Time Cube plug-in

uDig is an open source desktop application framework, built with Eclipse Rich Client(RCP) technology. It can be used as a stand-alone application, can be extended with RCP "plug-ins", and can be used as a plug-in in an existing RCP application as well.

Software -Space Time Cube plug-in main interface:

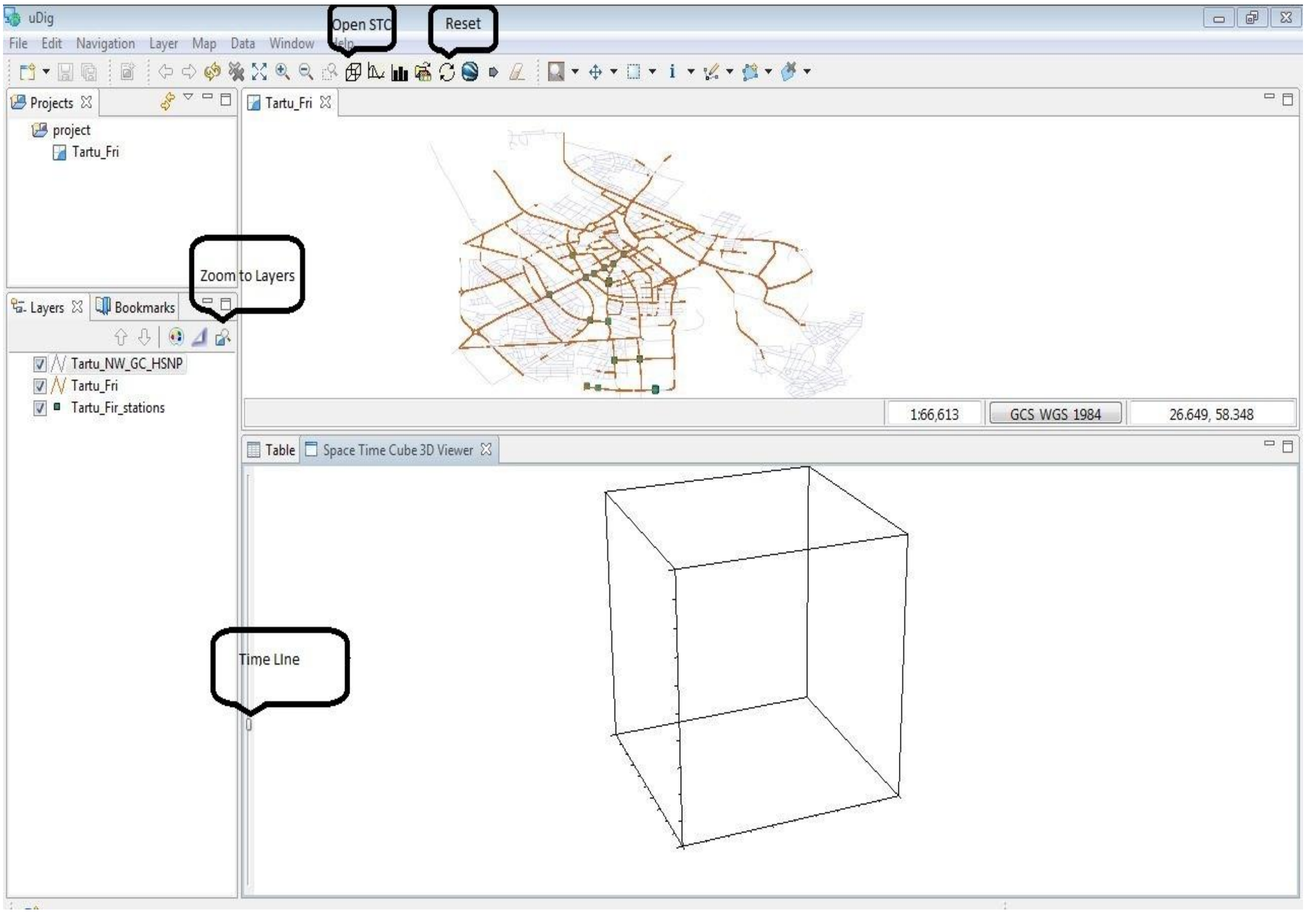


Figure 5.1 Interface of uDig- STC plug-in

5.2.2. Data processing

The Tele Atlas® Speed Profiles product contains average speed information for every five minutes of the day for each specific day of the week. User could estimate travel time on a specific route, or to determine optimal routes.

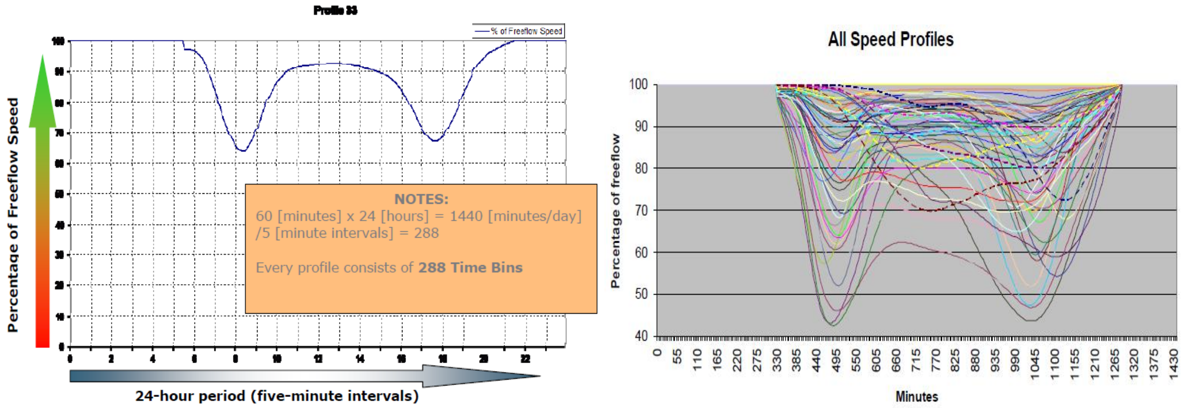


Figure 5.2 Tele Atlas® Speed Profiles

The figure 5.2 left shows a single speed profile. The value in the y-axis of the profile is a percentage value of the free flow speed; the value in the x-axis represents the change in time over a 24-hour period. Because the speed values in a profile are relative (i.e., stored as percentages), a single profile can be applied to multiple road traffic situation sharing the same traffic congestion behavior.The right figure shows a collection of distinctive speed profiles.

In the implementation, three shape files being used: Tartu_NW_GC_HSNP, Tartu_Fir and Tartu_Fir_station; the attribute of data in Tartu_NW_GC_HSNP, Tartu_Fir and Tartu_Fir_station is listed in Fig 5.3.

Tartu_NW_GC_HSNP

FID	Shape *	ID	FEATTYP	FT	F_JNCTID	F_JNCTTYP	T_JNCTID	T_JNCTTYP	PJ	METERS	FRC	NETCLASS	NETBCLASS	NET2CLASS	NAME
0	Polyline	12330000003730	4110	0	12330200054013	0	12330200005491	0	0	38.6	2	3	5	1	Ringtee
1	Polyline	12330000003780	4110	0	12330200568954	0	12330200549666	0	1	6.9	6	0	0	4	Raudtee
2	Polyline	12330000003900	4110	0	12330200004389	0	12330200055539	0	0	113.6	2	3	5	1	Ringtee
3	Polyline	12330000003902	4110	0	12330200004005	0	12330200055539	0	0	79.2	2	3	5	1	Ringtee
4	Polyline	12330000003903	4110	0	12330200004866	0	12330200004005	0	0	5.9	2	3	5	1	Ringtee
5	Polyline	12330000003925	4110	0	12330200008058	0	12330200561548	0	1	5.9	6	0	0	4	L. Puusepa
6	Polyline	12330000003928	4110	0	12330200006264	0	12330200563709	0	1	6.9	6	0	0	4	VÃ¤ike kaar
7	Polyline	12330000003930	4110	0	12330200568144	0	12330200563709	0	0	325	2	3	5	1	Riia

FID	ID	Speed	HSP	HOURS	MINS	Day
Tartu_Fri.1	1.23300000037E13	75	100.0	0	0	6
Tartu_Fri.2	1.23300000037E13	75	100.0	0	30	6
Tartu_Fri.3	1.23300000037E13	75	100.0	1	0	6

FID	Id	HOURS	MINS	Day
Tartu_Fir_stations.1	0	0.0	0.0	6.0
Tartu_Fir_stations.2	0	0.0	30.0	6.0
Tartu_Fir_stations.3	0	1.0	0.0	6.0

Figure 5.3 Attributes of datasets

The shape file Tartu_Fir records the speed of each road segment at every half an hour; HSP shows the percentage of free flow speed. Free-flow speed is the term used to describe the average speed that a motorist would travel if there were no congestion or other adverse conditions (such as bad weather). The "highest" (ideal) type of basic freeway section is one in which the free-flow speed is 70 mph or higher. HSP is the percentage of free flow speed. For example, when HSP is 100.0, it means, the speed on this road is free flow speed. No congestion or other traffic problems.

The profiles above used for this research are processed from: nw.shp, which contains network, geometry with basic attributes; gc.shp, which records information such as geocode, geometry with geocoding attributes; the hsnp.dbf is a table of Speed Profile data; hspr.dbf contains 59 "Speed Profiles". A "Speed Profile" is a curve that describes traffic behaviour for an entire day. In particular it describes the speed of the traffic. For each curve, the speed of the traffic was measured for 24 hours, at 5-minute intervals, starting at midnight. Therefore each profile has 288 samples (24 hrs = 1440 minutes = 288 x 5-minute-intervals). What is stored in the "Speed Profile" curves is not the actual speed, but a percentage: the speed of the traffic compared to the free flow-speed. It is assumed that these profiles remain valid for several years. There are only 59 "Speed Profile" curves. But each curve is to be applied at more than one location.

5.3. Implement visual representation methods in STC environment

Displaying data in the Space Time Cube requires that the data is first added as layers to an uDig Map. Then, the data is loaded into the Space Time Cube. In the Space Time Cube, the same data can be displayed in many ways, without changing the data-content.

The figure 5.4 shows the traffic network in the city Tartu

Figure 5.4 Tartu road network

The figure 5.5 is the dialog interface which will pop up when you click load layers button on Space time cube interface (figure 5.1). To have additional layers in the Space Time Cube to form a background-map (on the bottom of the Space-Time-Cube), add the layer Tartu_NW_GC_HSNP to the uDig map. Tartu_Fir_station is a Shape file which represent the location of visited places on the map, to display a Shape file with Points and a time-attribute as a Space-Time-Path in the Space Time Cube (Add the Shape file as a layer in an uDig map), when loading layers figure5.5 pops up, plot by <stp>; Tartu_Fir is a Shape file contain data information about road ID, day, hour, minute, HSP, speed etc. HSP stands for the percentage of free flow speed, which is the most important attribute in this representation. These layers are plotted as using width to represent network attribute, line size is decided by HSP, the make sure choose <regular+w>. The wider road represents heavier traffic. By dragging the time line on the left side, the width of the road is changing according to the attribute change as time goes by.

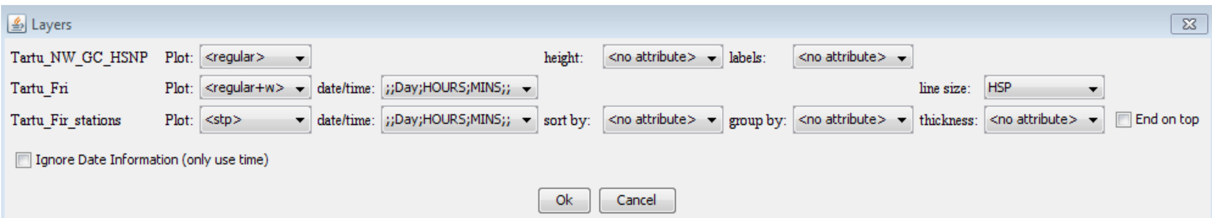


Figure 5.5 Dialog interface for loading data

The impletation in STC environment and zoom effect(the width of roads)is shown in figure 5.6; the HSP attribute is represented by the width of the road segment. The green space time path describe a person's daily movement space time path. The right figure shows the snapshot at a specific time, the width of orange roads shows the traffic situation on that road.

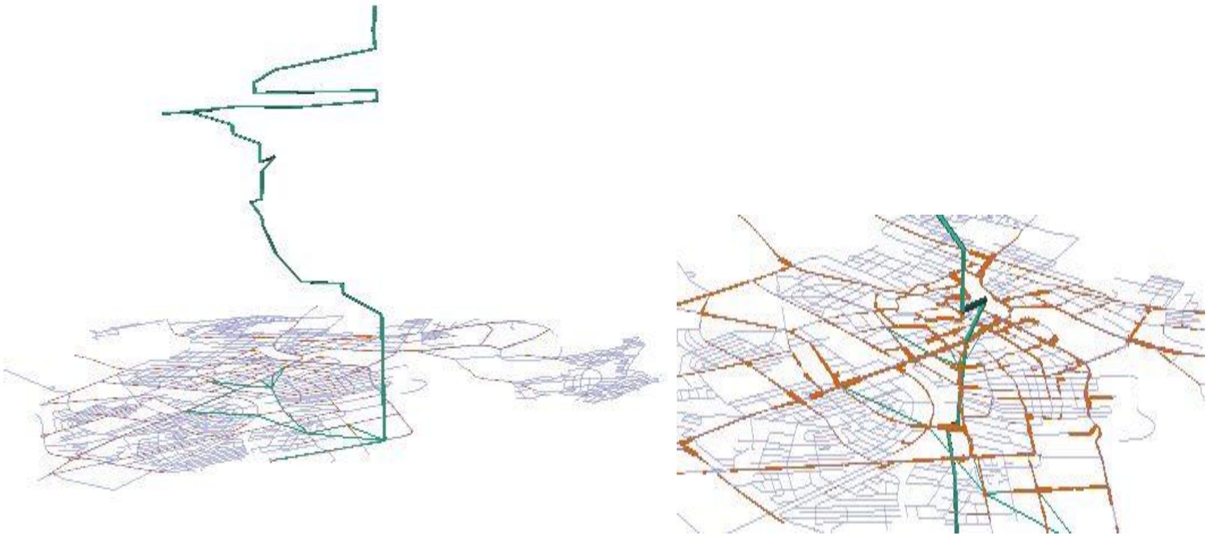


Figure 5.6 Implement flow map in STC—Overview and Zoom

To implement these layers to be plotted as 3D wall representation, the height of wall represent network attribute -- HSP. The higher wall represents heavier traffic. By changing time, the height of the road is changing according to the attribute change as time goes by. The option <regular+v> is added, that varies the size of lines vertically instead of horizontally. 3D wall implementation overview in STC environment and zoom effect (the height of roads)is shown in figure 5.7. The limitation is that user might wish to have an option to choose your own scale and offset factors. However people cannot manually scale the data yet (e.g. the HSP attribute). It is automatically done, with hardcoded factors.

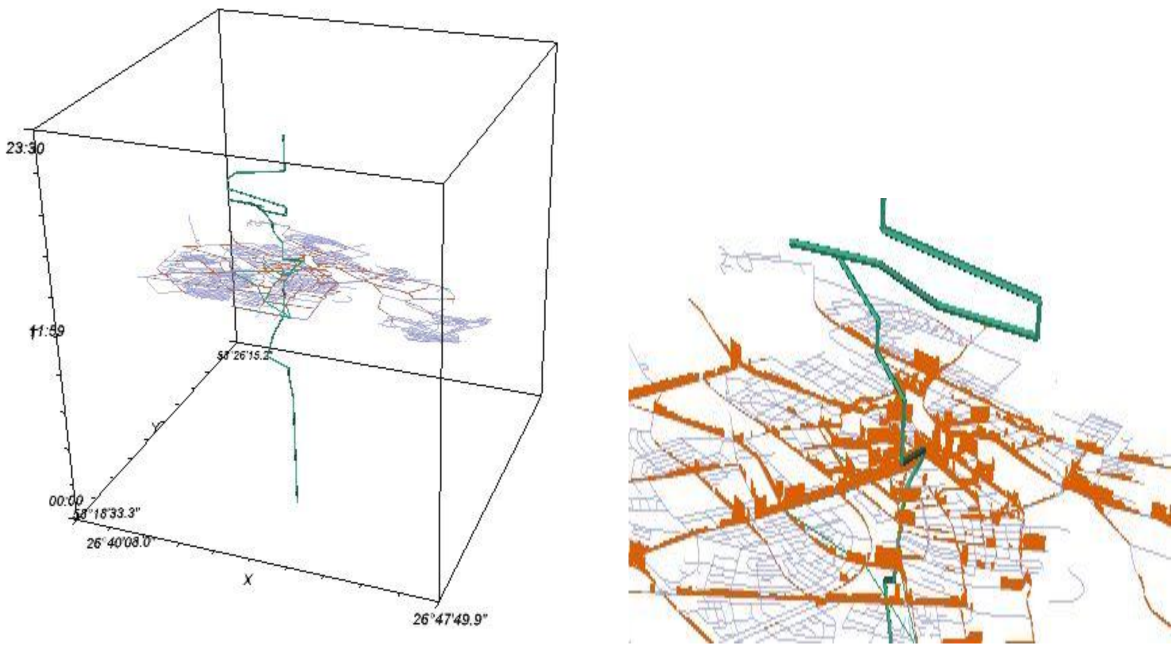


Figure 5.7 Implement 3D wall map in STC—Overview and Zoom

To implement these layers to be plotted as intensity map representation, the colour value of road segment represent network attribute -- HSP. The darker road represents heavier traffic, while the lighter road shows the traffic on that road is free. By changing time, the colour value of the road is changing according to the attribute change as time goes by. The option <regular+w> is chosen, the road width is the same for every road segments. Intensity map implementation in STC environment and zoom effect (the colour value of roads)is shown in figure 5.8. User could have an option to choose the number of colour value classes and the range of attribute factors. Moreover, in this application, people can manually change the colour value for HSP values they prefer. The limitation is that the width of the road cannot manually scale. It is automatically done, with hardcoded factors.

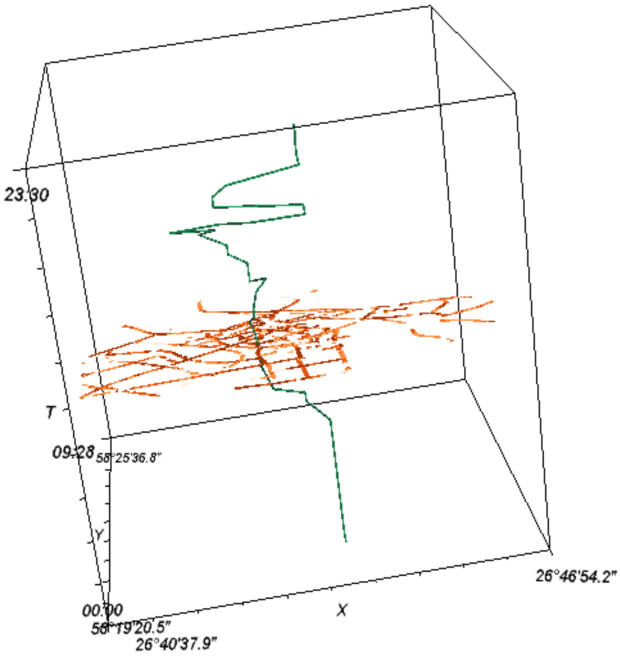


Figure 5.8 Implement intensity map in STC—Overview and Zoom

5.4. Summary

The designed prototype is implemented into a Space Time Cube in this chapter; the prototype supports visualization and exploration for changing network data. A new environment and representation method is developed in order to facilitate visually presenting the changing network datasets. The usability evaluation of the prototype will be discussed in the following chapter.

6. PROTOTYPE EVALUATION

6.1. Introduction

After finishing the conceptual design and the designed prototype implementation, in this chapter usability methods will be used to check if the system performs the function required by the users to achieve their goals? How do users utilize the system to achieve their goals with effectiveness (accuracy and completeness), efficiency (minimal resource expenditure) and satisfaction (positive attitudes)? When the usability test is finished, a use, user and usability analysis will be given. At last the conclusion will be drawn from the test results and analyses.

6.2. Usability and usability evaluation

To solve these questions, a usability test is necessary. Effectiveness, efficiency and satisfaction are three aspects of usability (ISO 9241-11)

Effectiveness: the accuracy and completeness with which specified users can achieve specified goals in particular environments.

Efficiency: the resources expended in relation to the accuracy and completeness of goals achieved.

Satisfaction: the comfort and acceptability of the work system to its users and other people affected by its use.

In choosing a method for geovisualization, the characteristics of the method, the (dis)advantage, the validation method etc. must be considered. There are many user research methods and techniques (See Figure 6.1). In this research, questionnaires and think aloud will be used to evaluate which visual representation method work better in the space time cube to explore changing network datasets.

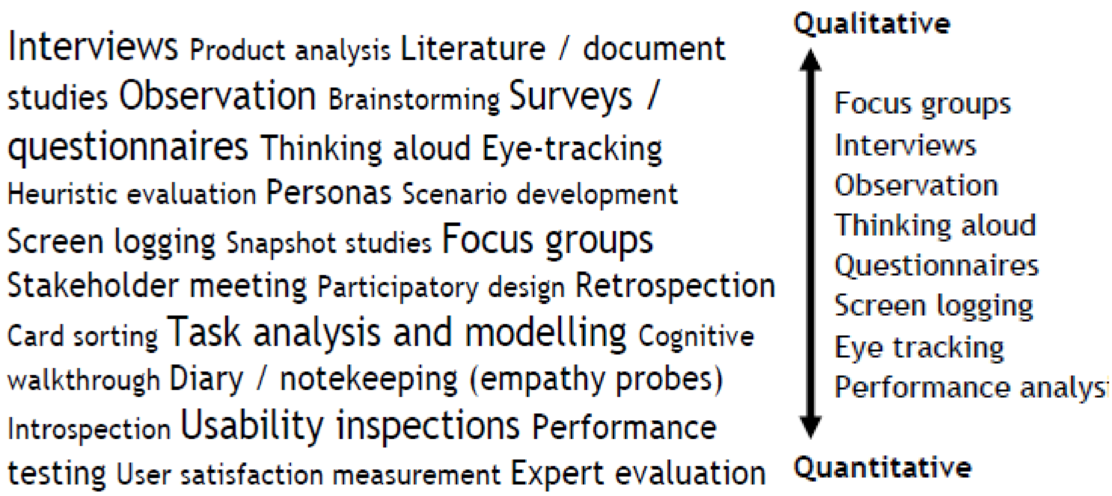


Figure 6.1 Research methods & techniques
(Van Elzakker module 13 lecture slides)

6.3. Evaluation methods

6.3.1. Questionnaires

Questionnaires have no standard format; every researcher designs them depending on the purpose and the context of use. Questions are structured, preferably in logical sequence of content and difficulty. The design allows easy tabulation during analysis and validation. The most important issue is to have clear and objective questions for research data collection, have clear definition of terms and phrases, uncluttered and easy to fill, attractive appearance in structure. Pay attention to avoids loaded questions, sensitive questions should come last in the questionnaire. What is more important, an unreasonable questionnaire will collect wrong information, which will lead to invaluable test results.

Using questionnaire share some advantages, cost effective when compared to face to face interviews. Questionnaires are familiar to large number of people and normally don't apprehend the respondents. There is no bias because questions are presented in the same way to all respondents. The researcher does not have personal influence on the responses. They are less intrusive than telephone or face to face surveys because the respondent has the time to complete them by themselves. Reliable questionnaire provides feedback from point of view of the user which may be trustworthy for the whole user population. Measures gained from questionnaires are to large extent independent of user, system or tasks which enable to capture the perceived usability and ease of use.

However, disadvantages of using questionnaire are low response rate and at times incomplete questionnaires may affect the quality of analysis. Most questionnaires are rigid in structure without room for probing the respondent or allowing the respondent to qualify their answers. Large proportion of communication is visual in terms of gestures and visual cues which lack in questionnaires may affect questions on sensitive issues or attitude which require probing. Questionnaires are not suitable for illiterate people because of poor reading skills. In the usability context, a questionnaire only tells the users' reaction as they perceive the situation and not performance which is observable. Questionnaires are designed to fit a number of situations to reduce the cost of research. Researchers may generalize questions instead of focusing on certain details which may be considered minor for global studies, but which could be useful for local studies. Responses may not be coherent especially if they are investigative because respondents may scan the questions before answering. Questions may be misunderstood by the respondents. Web questionnaires require internet connection and sometimes installation of add-ons which respondents may be unwilling to install.

Questionnaire validity is the degree to which the questionnaire collects the desired information necessary for achieving the objective at hand. It can be done by repeating the tests using the same set of question on different respondents. The results can then be analysed by content analysis or statistically by coding and tabulation. The results of questionnaire test can be validated using results of verbal protocols that can be collected in laboratory. Reliability can be studied by checking good internal consistency of results through correlation.

6.3.2. Think aloud

The think aloud method is one of the use and user research methods, developed by Ericson and Simon. Its roots in psychological research, it was developed from the older introspection method. " Introspection is based on the idea that one can observe events that take place in consciousness, more or less as one can observe events in the outside world"(Someren, Barnard et al. 1994). The method is contained with video recording to have better understanding in which avoids interpretation by the subject and only assumes a very simple verbalization process to know the way of how the test person is thinking, doing and feeling (Jaspers, Steen et al. 2004). From the usability test, 'think aloud' could be concluded as a method proved to be a useful usability testing tool to improve the design of the prototype as well as determining the satisfaction, efficiency and effectiveness of the prototype. The feedback from user is helpful for further development of the prototype.

Test person follow certain tasks and is asked to speak out what they are looking at, thinking, doing, and feeling. The purpose of think aloud method is to make explicit what is implicitly present in subjects who are able to perform a specific task. Think aloud allows first hand insight into the thought processes associated with different tasks. With the 'think aloud' method, participants are able to capture preference and performance information simultaneously, rather than having to remember to ask questions about preferences later. The thoughts which are expressed immediately could be caught.

Results are close to what is experienced by users, it leads to valid and the most complete data on cognitive processes and provides rich qualitative data. Moreover, it is a unique source of direct and in-depth qualitative information.

6.4. Usability evaluation

The objective of this user task is to test which is the best visual representation method in a Space Time Cube environment when dealing with the changing network datasets. In this usability test the datasets are TeleAtlas network data of the city of Tartu, Estonia and the city of Enschede, The Netherlands.

The representation methods are: 3D wall map, flow map and intensity map. The number of users is 12, users will perform the tasks on one computer one by one at ITC usability lab, the total time for each user is 1 hour, 10-15 minutes to familiar with basic operation of the software, 30 minutes for finishing tasks, the left time for user's after tasks suggestions and preparation for next user. The time spend on each task will be recorded by video, when user executes tasks, they should speak out what they are thinking while doing such task. Each user will do comparable tasks in three representation environments (3D wall map, flow map and intensity map), in order to avoid the learning effect, here the order for each use to operate in these three environments is different.

	1	2	3	4	5	6	7	8	9	10	11	12
3D wall	A	C	A	C	B	B	A	C	A	C	B	B
Flow map	B	B	C	A	A	C	B	B	C	A	A	C
Intensity map	C	A	B	B	C	A	C	A	B	B	C	A

Table 6-1 Task sequence

(1-12 is the number of 12 persons, A-B-C show the sequence of each person when they doing the tasks.)

Test person 1-6 will complete tasks based on Tartu network datasets in uDig a STC environment; while test person 7-12 will perform tasks on Enschede network datasets in uDig a STC environment. Using two cities' road network is going to avoid of possible variety in the case of the prototype only work well on one kind of network data.

Effectiveness: the accuracy and completeness with which specified users can achieve specified goals in particular environments (to be evaluated by the accuracy of the answer of the tasks).
Efficiency: the resources expended in relation to the accuracy and completeness of goals achieved (to be calculated by the time the user spends on each task).
Satisfaction: the comfort and acceptability of the work system to its users and other people affected by its use (to be assessed by the Likert scale after performing tasks).

6.4.1. Tasks

The whole tasks questionnaire is concluded in appendix. In this section, the tasks will be introduced one by one. Task (1) (2) (3) will be executed in 3D wall representation, flow map representation and intensity map representation respectively.

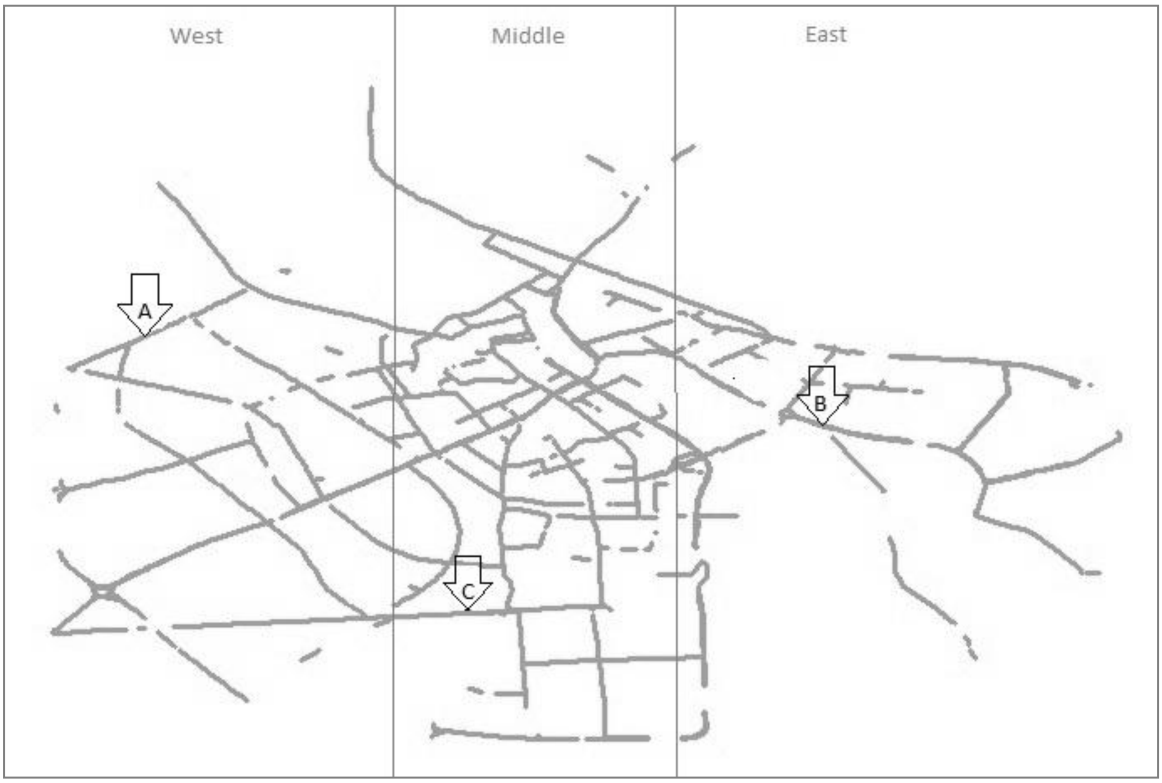
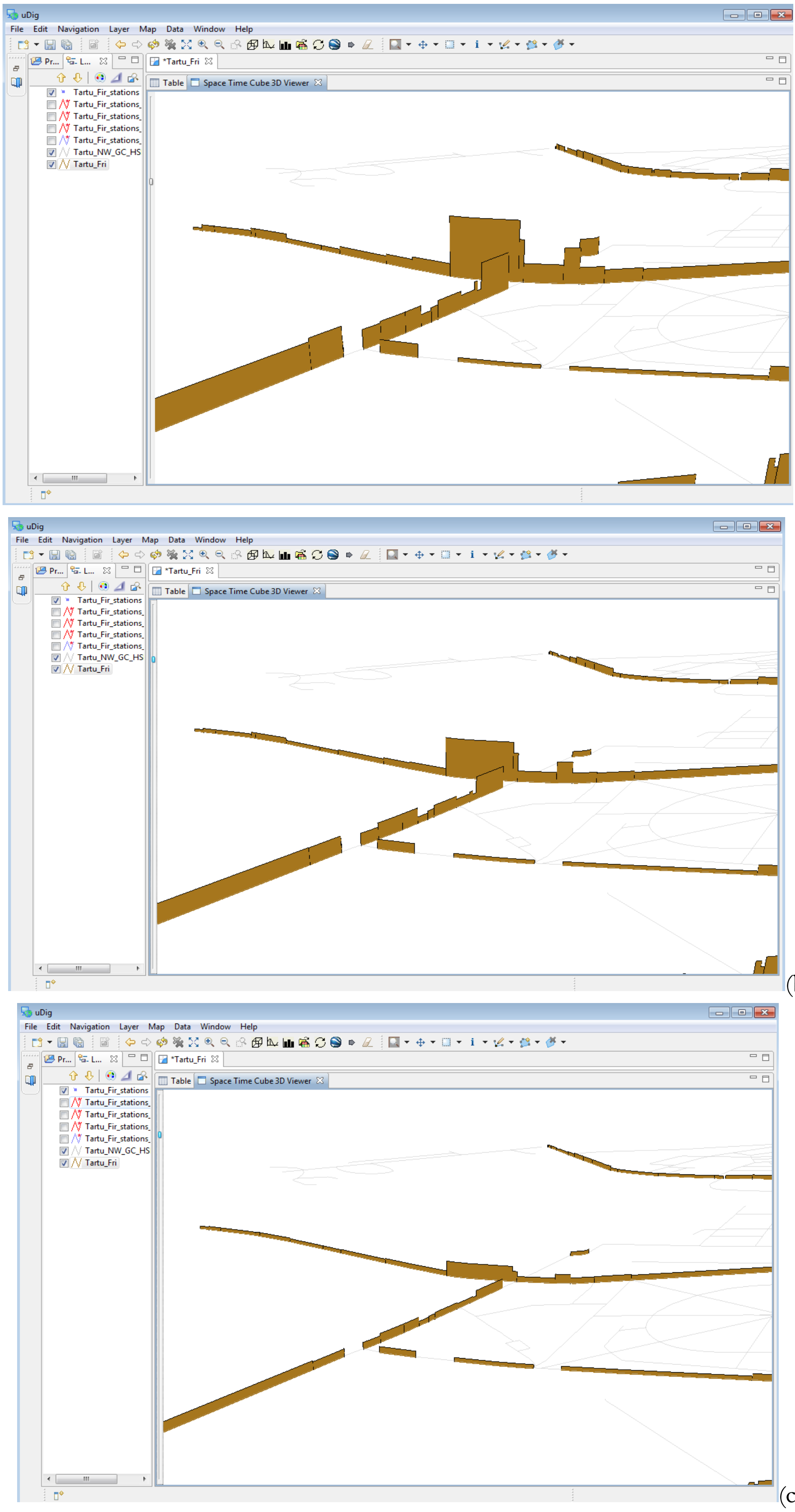


Figure 6.2 Tartu traffic network map

Using the 3D wall representation:

Task (1): Look at the Tartu traffic network map Figure 6.2. A road is marked with letter A; work with this road in STC by dragging the time line in STC environment.
Question: which is the busiest time period for this marked road?
(a) 18:00-19:00 (b) 19:00-20:00 (c) 20:00-21:00

The following pictures are snapshot of at 18:00-19:00, 19:00-20:00, and 20:00-21:00 time periods. When users deal with this task, they will have a view of dynamic pictures rather than these series of pictures. Then compare which time period the traffic is heavier.



(a)

(b)

(c)

Figure 6.3 3D wall implementation in STC

(a), (b), (c) are traffic networks at time periods

Task (2): Using the person's movement path, at what road is this person at 17:00. Focus on this road. Question: Which is the possible busiest time period for this road?

To finish task (2), user should first make sure, at 17:00, on which road the person travel, when the road is fixed, drag the time line to see which time period is the busiest. In this case, if only drag the time line, the network will also move and change with time line's up and down, which will cause confusion easily. Considering this phenomenon, it is suggested that user should use Shift plus mouse drag, in this way, the location of network traffic map in STC will not move, the STC itself will move up and down instead of the movement of layers in STC, while the height of the 3D wall will changing as time change and the attribute change.

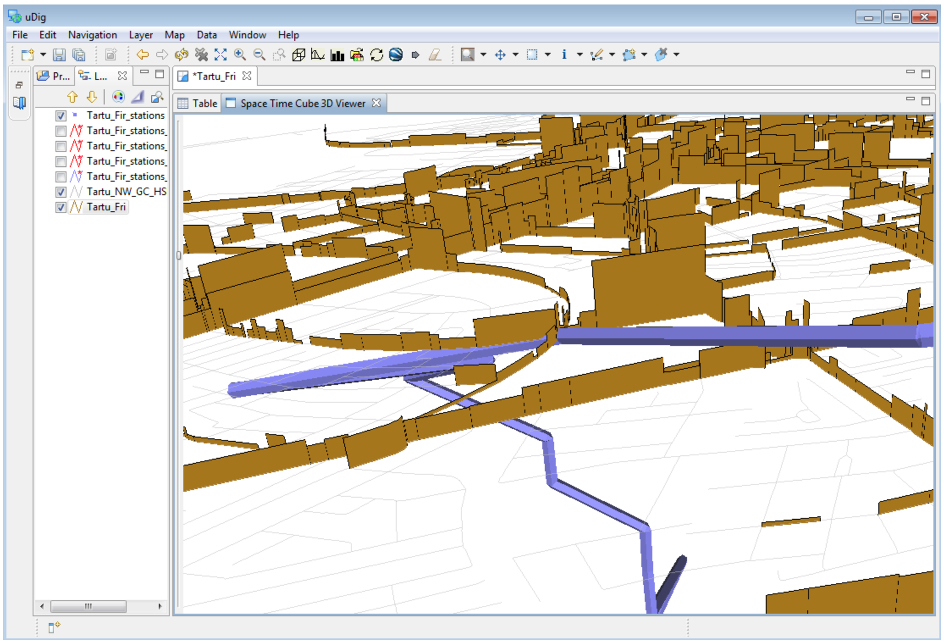


Figure 6.4 3D wall map & Space time path

Task (3): Considering the overall traffic pattern, during the whole day, which road in the eastern part of the city has the possible busiest traffic?

To achieve task (3), focus on the traffic pattern of large area, drag time line, to view the whole day's dynamic traffic situation to compare and find out the possible busiest road segment. Also user can detect the possible busiest time periods.

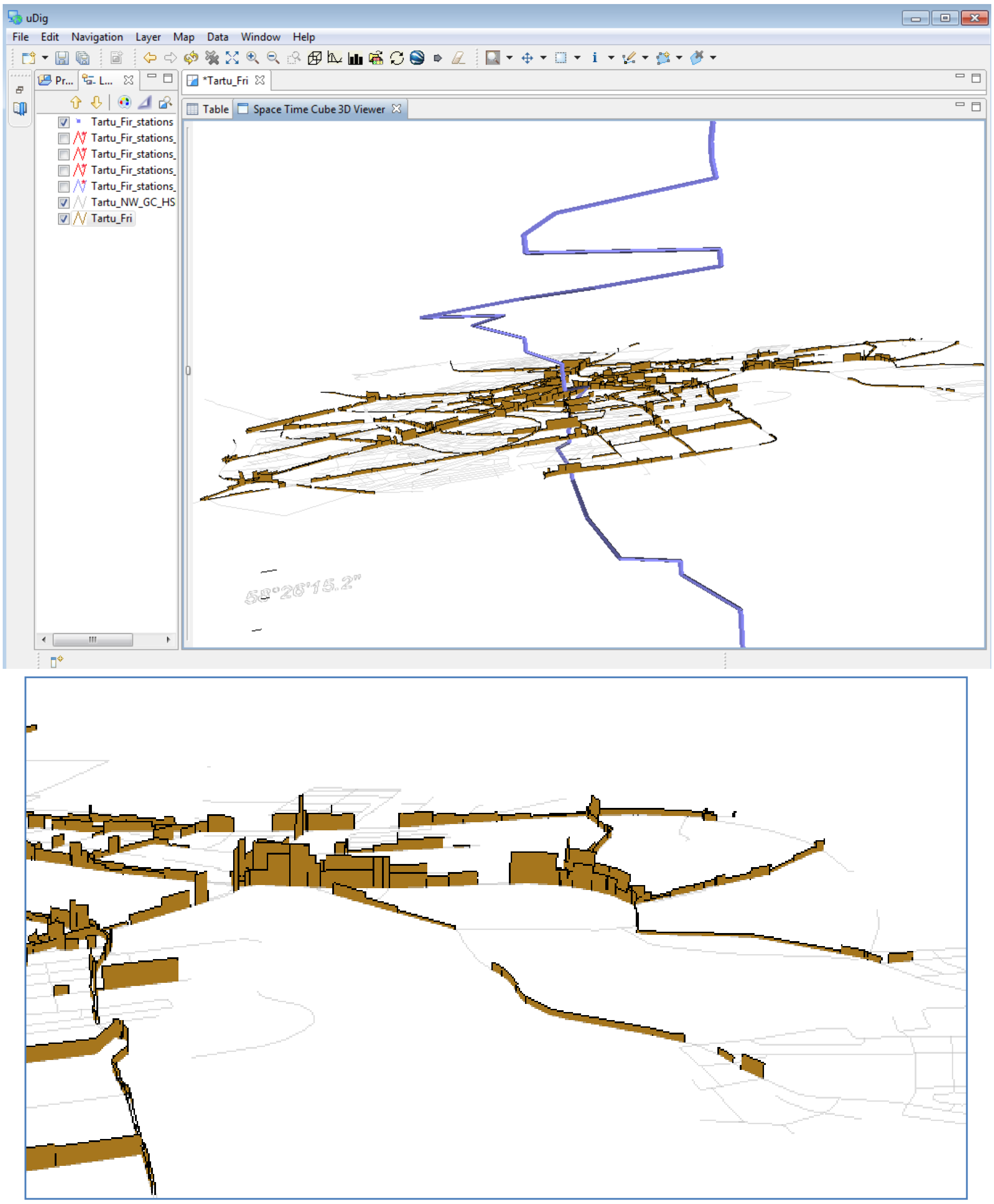
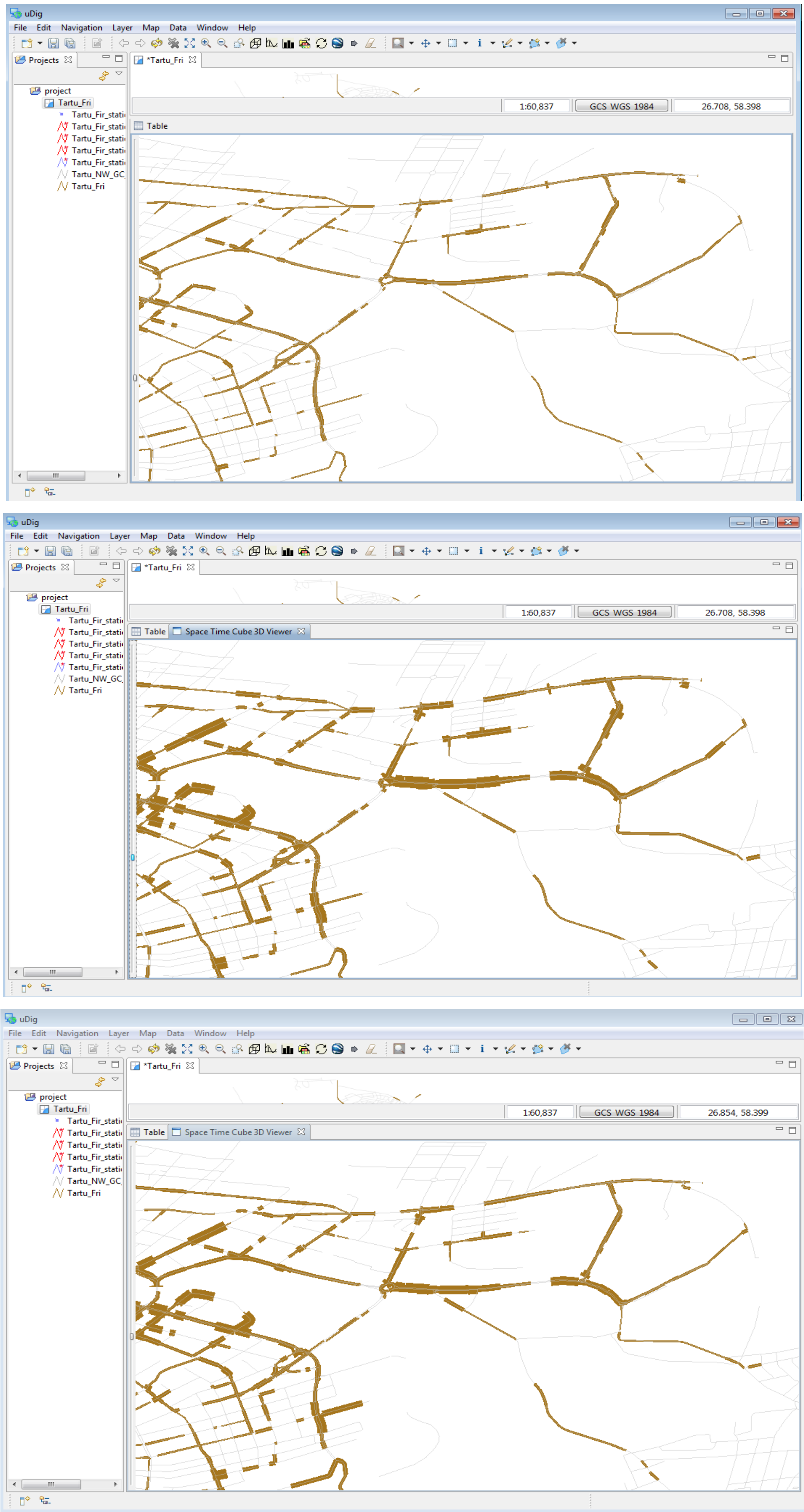


Figure 6.5 Tartu traffic situation in eastern area

Using flow map representation:

Task (1): Look at the Tartu traffic network map Figure 6.2, a road is marked with letter B; work with this road in STC, by dragging the time line in STC environment.
Question: which is the busiest time period for this marked road?
(a) 7:00-8:00 (b) 8:00-9:00 (c) 9:00-10:00

When users deal with this task, they will have a view of dynamic pictures rather than these series of pictures. Then compare which time period the traffic is heavier.



(a)

(b)

(c)

Figure 6.6 Flow map implementation in STC

(a), (b), (c) are snapshot of different time periods.

Task (2): Using the person's movement path, at what road is this person at 15:00. Focus on this road by dragging the time line. Which is the possible busiest time period for this road?

To finish task (2), user should first make sure, at 15:00, on which road the person is, when the road is fixed, drag the time line to see which time period is the busiest. In this case, if only drag the time line, the network will also move with time line, which will cause confusion easily. Considering this phenomenon, it is suggested user use Shift plus mouse drag, in this way, the location of network traffic map in STC will be static, while the width of road segments will changing as time change and the attribute change.

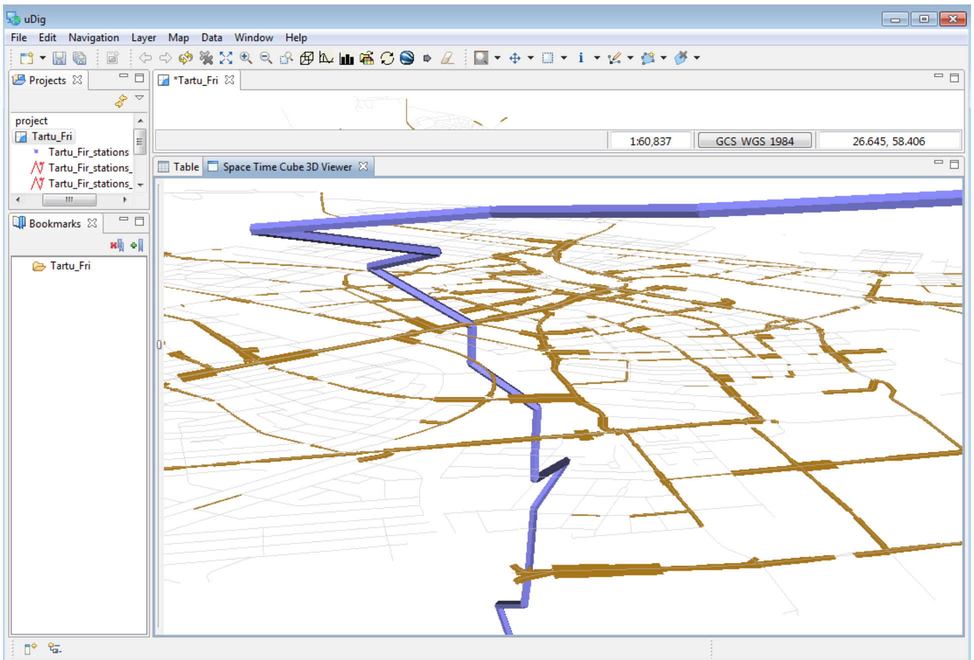


Figure 6.7 Zoom to find intersection

Task (3): Considering the overall traffic pattern, during the whole day, which road in the eastern part of the city has the possible busiest traffic?

To achieve task (3), focus on the traffic pattern of large area, drag time line, to view the whole day's dynamic traffic situation to compare and find out the possible busiest road segment. Also user can detect the possible busiest time periods.

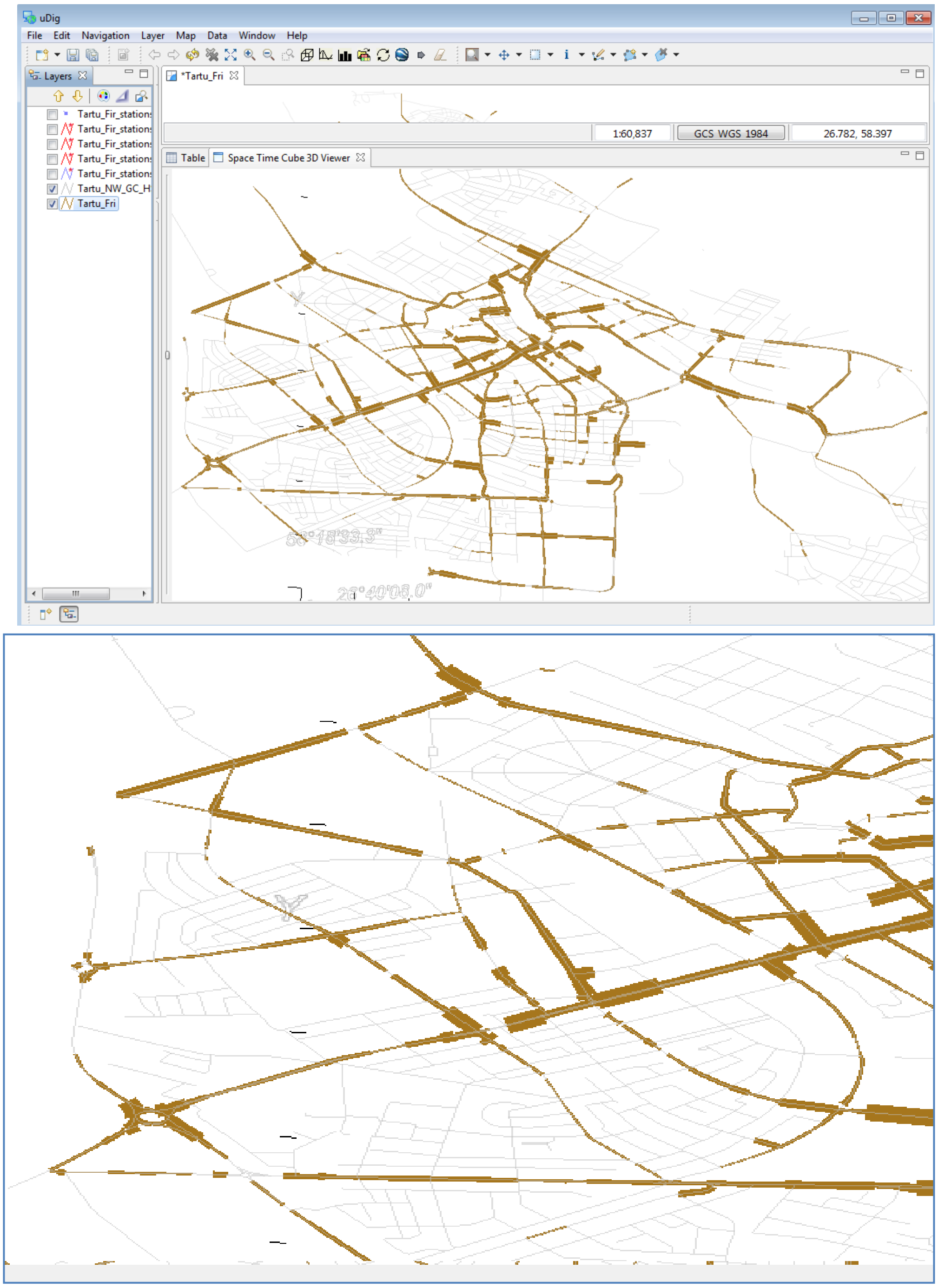


Figure 6.8 Tartu traffic situation in western area

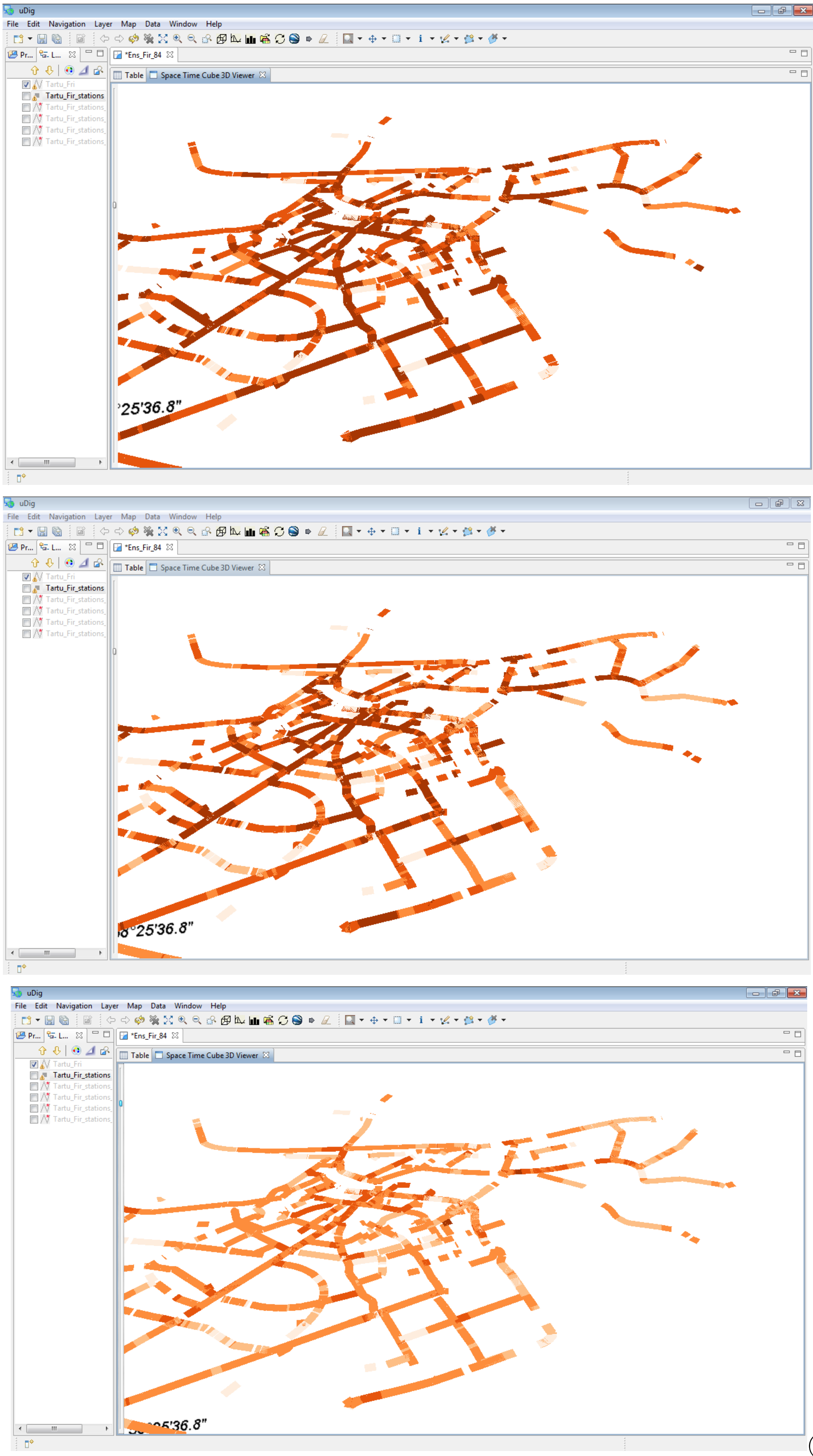
Using Intensity map representation:

Task (1): Look at the Tartu traffic network map Figure 6.2, a road is marked with letter C; work with this road in STC, by dragging the time line in STC environment.

Question: which is the busiest time period for this marked road?

(a) 7:00-8:00 (b)11:00-12:00 (c) 15:00-16:00

During user's performance, they will have a view of dynamic pictures rather than these series of pictures. Then compare which time period the traffic is heavier.



(a)

(b)

(c)

Figure 6.9 Intensity map implementation in STC

(a), (b), (c) are snapshot of different time periods

Task (2): Using the person's movement path, at what road is this person at 13:00. Focus on this road by dragging the time line.
Question: Which is the possible busiest time period for this road?

To finish task (2), user should first make sure, at 13:00, on which road the person travel, when the road is fixed, drag the time line to see which time period is the busiest. In this case, if only drag the time line, the network will also move and change with time line's up and down, which will cause confusion easily. Considering this phenomenon, it is suggested that user should use Shift plus mouse drag, in this way, the location of network traffic map in STC will not move, the STC itself will move up and down instead of the movement of layers in STC, while the intensity of the colour value will changing as time change and the attribute change.

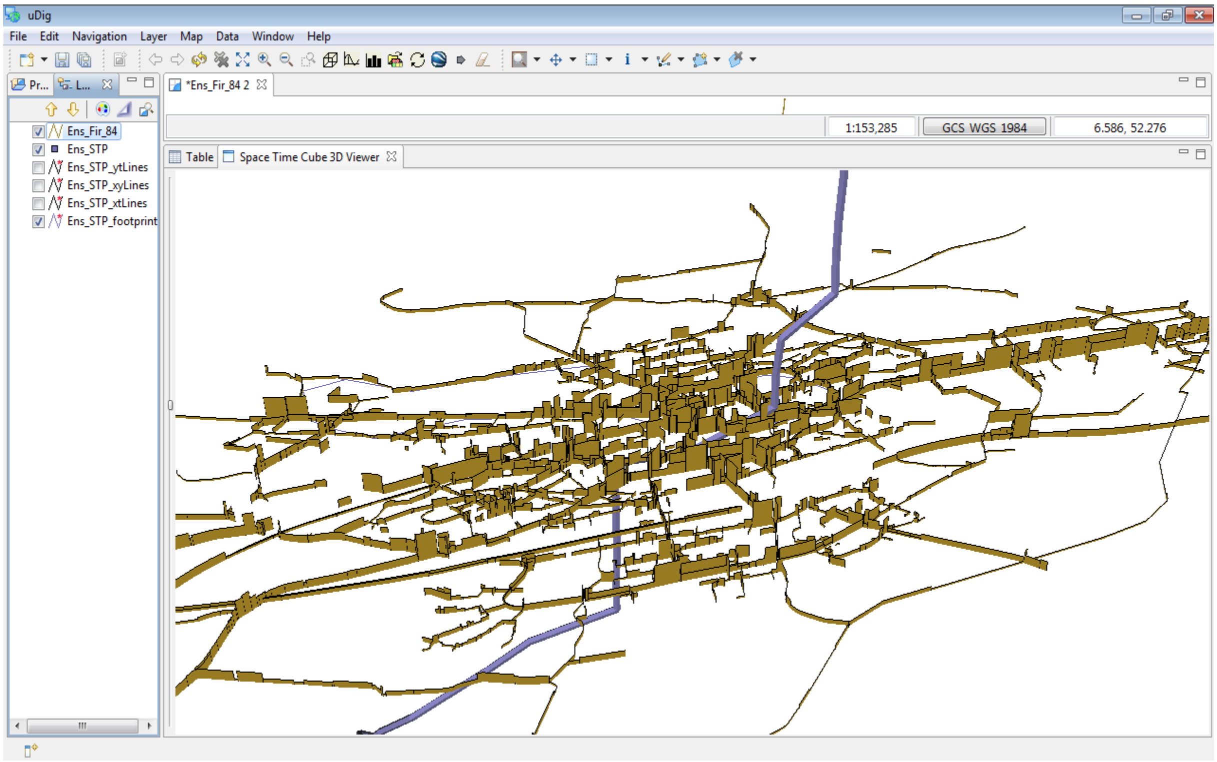
Figure 6.10 STP intersection on intensity map

Task (3): Considering the overall traffic pattern, during the whole day, which road in the eastern part of the city has the possible busiest traffic?

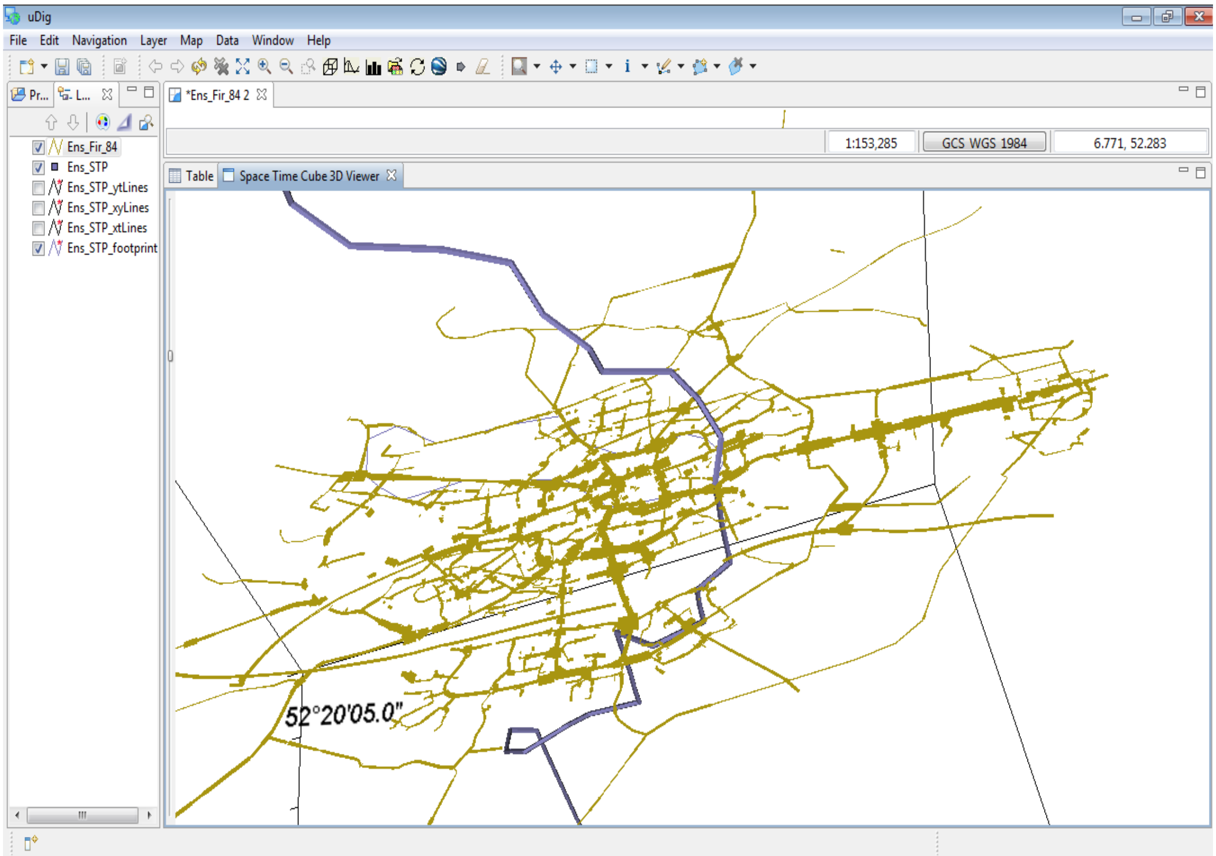
To achieve task (3), focus on the traffic pattern of large area, drag time line, to view the whole day's dynamic traffic situation to compare and find out the possible busiest road segment. Also user can detect the possible busiest time periods.

Figure 6.11 Tartu traffic situation in middle area

For Enschede network dataset, the representations of these three visualization methods are snapshots 3D wall in a STC:



Flow map in a STC:



Intensity map in a STC

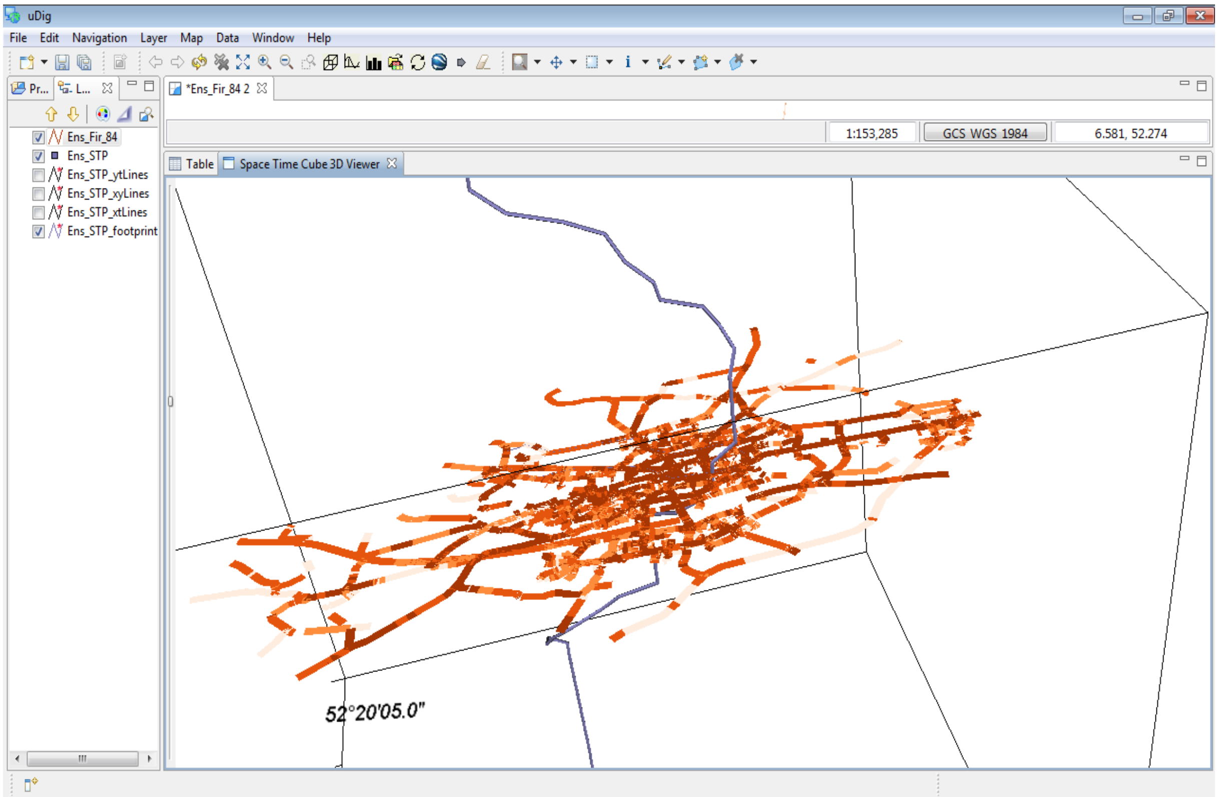


Figure 6.12 Enschede road network in STC

The six test persons who executed tasks-based questionnaire with Enschede network datasets handle the similar and comparable tasks as the other six test persons did.

6.4.2. Results analysis

The test group is 12. The distribution of text persons' preference is shown in the table 6-1.

Dep.	TP total	3D wall map	Flow map	Intensity map	N/A
GFM(senior)	4	3	0	0	1
GFM(fresh)	4	3	1	0	0
UPM(senior)	2	1	0	1	0
UPM(fresh)	2	1	1	0	0
Total	12	8	2	1	1

Table 6-2 Distribution of test person's preference to various visual representations

According to the usability test result, obviously, 3D wall representation has the most advantage among these three representation methods, 8/12 user like this representation method. Besides 3D wall representation, user prefers to use flow map, 2/12 choose it. 1/12 user chose intensity map in this usability test.

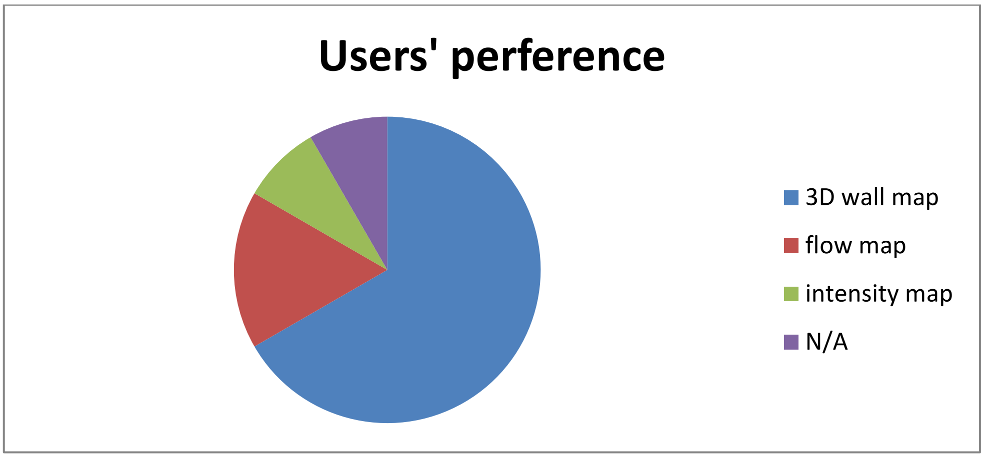


Figure 6.13 User preference pie chart

The flow map is not popular here because user reflected that firstly, this method turn roads to non-continues, which gave a not good visualization for user; secondly, it could be represented in 2D, making it in a 3D environment, no obvious advantages, and no develop space for this kind of method. However, when deal with whole pattern task to give general impression it has some advantage, but not for detail phenomenon. The main problem for intensity map is there are colour value classes; the number of classes influences the whole visualization greatly. If only a few classes, user can not notice the detail change, which means that the attribute change some but these changes still fall in the same class range. So user cannot observe the change in the cube. If classify more classes, user may not identify the colour value by nature.

Users have good comments on 3D wall representation in STC. It may has some problems such as, if the height is higher, the roads behind it may obscured, but it can be solved to rotate the cube, to get the view from other side or view angel. Besides this only short coming, it has a lot of advantages. It is easy to notice the detail change on each road segment. The change which expressed by the road height has clear visualization. If user compare the traffic situation among several road segments, the difference is easy to recognizable as well. Moreover, for the expression of the traffic pattern for the whole area, this representation method makes the dynamic phenomenon also apparent.

TP No.	Dep.	Year	Flow map				3D Wall map				Intensity map				Total time
			Q1	Q2	Q3	Total	Q1	Q2	Q3	Total	Q1	Q2	Q3	Total	
TP1	GFM	S	4	5	3	12	6	5	3	14	4	3	3	10	36
TP2	GFM	S	4	3	3	10	4	4	4	12	5	4	4	13	35
TP3	GFM	F	3	4	3	10	3	4	3	10	4	2	3	9	29
TP4	GFM	F	5	3	3	11	4	2	4	10	2	3	2	7	28
TP5	UPM	F	3	4	2	9	5	3	3	11	4	4	4	12	32
TP6	UPM	S	5	5	4	14	5	5	3	13	4	5	4	13	40
TP7	GFM	S	5	5	2	12	3	2	3	8	2	2	1	5	25
TP8	GFM	S	5	3	3	11	4	6	5	15	4	5	4	13	39
TP9	GFM	F	7	4	2	13	3	4	3	10	3	2	2	7	30
TP10	GFM	F	4	4	2	10	3	5	2	10	3	3	2	8	28
TP11	UPM	F	5	6	4	15	4	5	5	14	3	3	3	9	38
TP12	UPM	S	5	4	4	13	4	6	3	13	3	2	2	7	33
Total time(task)			55	50	35	140	48	51	41	140	41	38	34	112	393
Average			4.6	4.2	2.9	11.7	4	4.3	3.4	11.7	3.4	3.2	2.8	9.4	32.75

Table 6-3 Time cost table (Unit: minutes)

The time for each text person spent on each tasks were recorded in table 6-2. As described in the previous section, to avoid learning effect, the test person deals with tasks in different STC environments with different sequence. For example, TP (test person) 1 does tasks firstly in flow map environment, then does in 3D wall representation, finally should handle tasks based on intensity map environment. TP 2 does tasks firstly in intensity map then goes to 3D wall, finally in flow map etc. The number of TP group is twelve and there are six kinds of sequence for TPs. Usually, when TP firstly integrated with STC, the cost time for these tasks is longer than the tasks that going to be done later. From the table we can get general conclusion: when people do the similar tasks, in intensity map people use the least time, while in the other two representation, the time cost is almost the same. Normally for the first question the time TP spend is longer, because user need more time to familiar with the representation method. In the second task, user should find the intersection, which user reflected that it is not easy to find. To deal with the third task, user needs to have an overview of the traffic pattern of the whole city. This is the least time cost question.

Representation Methods	Tasks	Average accuracy
3D wall map	Task (1)	100%
	Task (2)	75%
	Task (3)	83.3%
Flow map	Task (1)	100%
	Task (2)	83.3%
	Task (3)	83.3%
Intensity map	Task (1)	66.7%
	Task (2)	83.3%
	Task (3)	75%

Table 6-4 Average accuracy for each task

After the analysis of the user tasks questionnaires, the accuracy of the answer to each tasks also various. The three tasks in each representation method sections are comparable ones. The first question is to let user compare the traffic situation in different time period on a road. To identify which time period is the busiest. The second task is use an assistant space time path to deal with more realist question, firstly find the person's location at a given time, and then try to detect which is the possible busiest time for this road in a whole day; the answer maybe has two periods in morning and afternoon. The third task is to get an overall sense of the traffic situation in large area in one day.

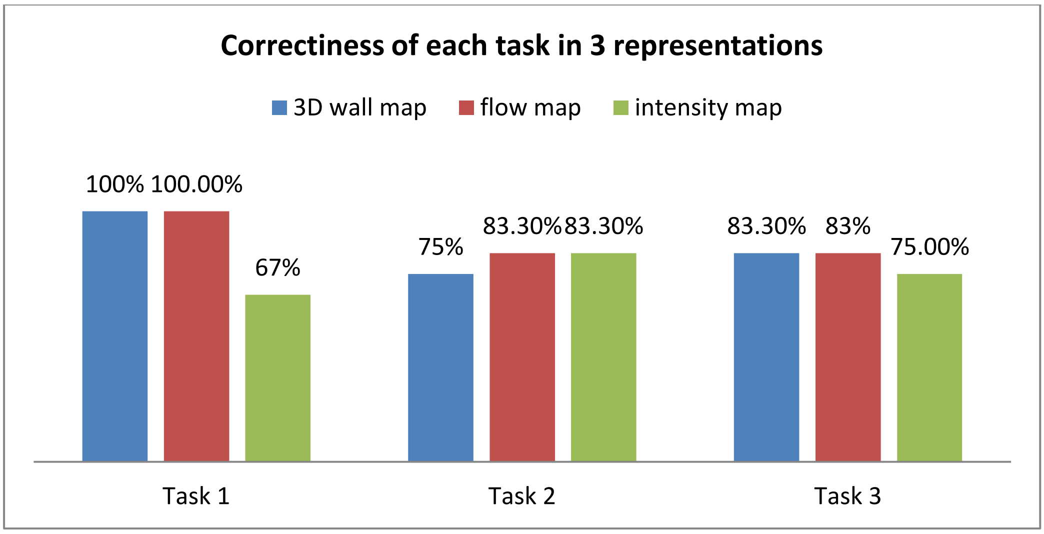


Figure 6.14 Correctness of each task in the three visual representation STC environments

Generally speaking, the accuracy of the answer to these tasks is various when doing these tasks in these three environments. In 3D wall representation the accuracy is the highest, and the answer is clear. In flow map, the answer is also certain but some of the answer is not correct. The worst outcome happened in intensity map representation, because some of the change cannot be detected and the answer is not exact and not specific.

The liker scale analysis for Tartu datasets questionnaire:

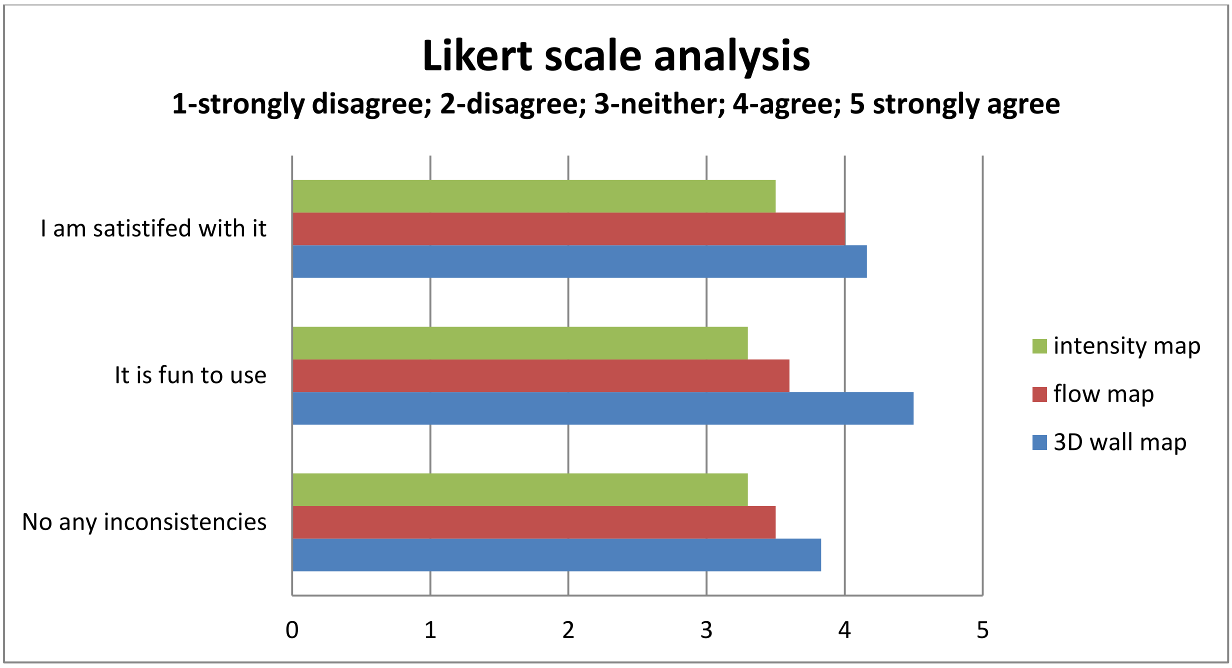


Figure 6.15 Likert scale analysis (Tartu)

The liker scale analysis for Enschede datasets questionnaire:

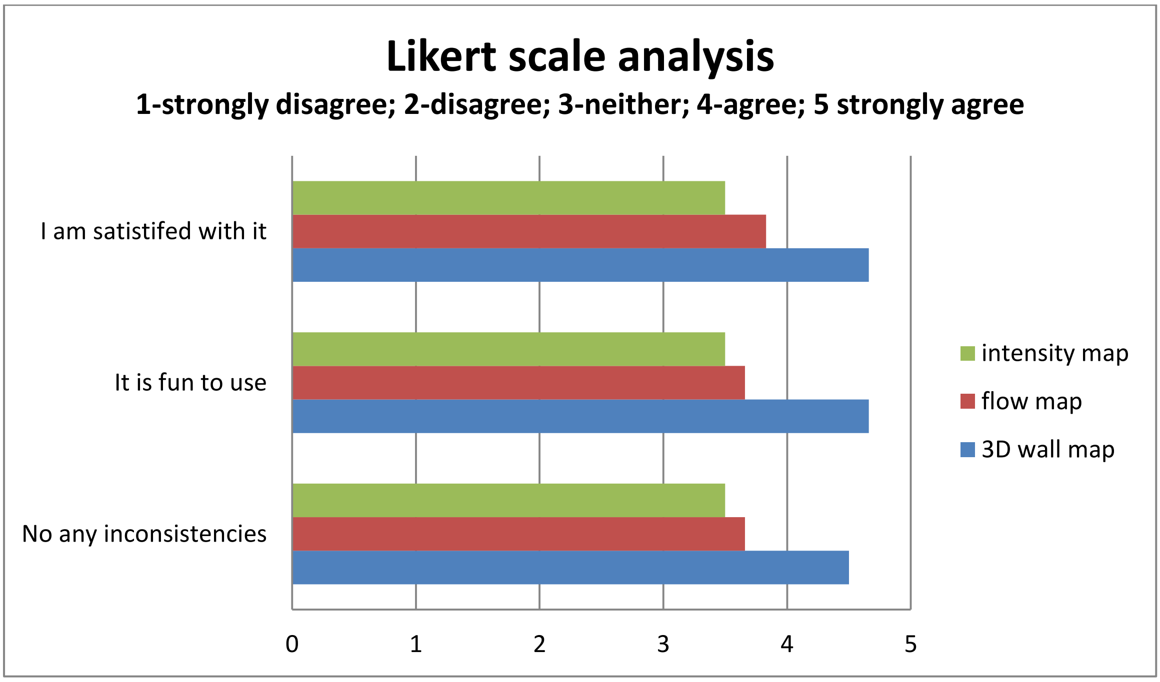


Figure 6.16 Liker scale analysis (Enschede)

Effectiveness is evaluated by the accuracy of the answer of the tasks; Efficiency is calculated by the time the user spends on tasks; Satisfaction is assessed by the likert scale after performing tasks

6.5. Summary

Usability testing is to assess the new representation's ability for helping users to deal with various tasks and to meet users' satisfaction, based on a number of users' response to tasks. Using think aloud method, the scene of user performing on tasks based questionnaire is recorded by a video camera, and the users' voice also be recorded which reflect what are the user thinking when contacting with such questions. In this usability test, 3D wall representation work better than intensity map and flow map in a Space Time Cube; especially to detect slight change, it could be one of the best representation with the most potential in a 3D environment.

The designed three types of tasks, first task is tried to find out in the three given time periods, which time period is the busiest for a fixed road. This is a detail questions, user should first find the fixed road, and pay attention to the change on this road segment. To solve this question, 3D wall and flow map work much better than the intensity map. The difference of road traffic is quite evident for the first two methods, but for the color map, the color ranges various. So somehow, it doesn't work well to detect the detail difference.

In the second task, a space time path is brought in, this is a remarkable method to represent trajectory in a 3D environment. Tracing the trajectory, user can make sure the person's movement path, then can identify where the person is at specific time or time periods. To find the intersection point where path come cross the road network layer, normally user choose use clip time, for 3D wall method, the height of wall in some case will block the possible viewing area, so when dealing with space time path, this is the one thing not so convenience.

The third task is to manage overall pattern, to detect general traffic pattern, user should have an observation on whole area's network data. For this task, each of the three representation methods work well, however, most user prefer to use 3D wall or flow map. The intensity map does give good impression in particular, but not accuracy when the color classes are limited.

There are also some limitations in usability testing.

- User individual talented variety, considering choose same target group people, test same questions on them at different time, it is suggested 2-3 months between two tests.
- The sequence problem, if user contact one representation first, later when s/he do the other representation, it will be easier to get familiar with the second one, which could lead solve tasks easily.
- In this usability test, user executes the tasks one by one. The result may different if all user perform tasks in a same room at a same period of time.

According to this usability test, 3D wall representation has obvious advantage on flow map and intensity map; 3D wall is easy to detect the busiest road segment, it is evident to notice the highest wall in a 3D environment, besides, because it has one more dimension to present more attribute, it could be the most potential method for further development. It can adapt to more complex application.

Based on this research, we cannot directly say flow map and intensity map is not good for representation in a Space Time Cube, for the flow map, some users reflect it is not look like real road, because for one road segment, the actual road with similar width. However, in this flow map representation, especially suppose some road is extremely busy, the width of the road may too wider to influence neighbor roads, which will cause bad visualization in the road network map. Some other users expose the flow map in 2D is good enough, when introduce into a 3D environment, it cannot exhibit much improvement. Also some user suggest combine intensity and flow map together, use the width of road to represent one attribute and intensity could represent other attribute. In similar situation, the intensity map is not a so bad representation method for visualizing road network data; in this case, the intensity is catalogued into five classes due to the attribute value. And the road segment is very tiny in some road section, so the intensity map may not good looking in this case. It is suggested to improve the data structure and to better design the color chosen in this use, then the result may more critical.

7. CONCLUSION AND RECOMMANDATION

7.1. Conclusions

In the previous chapter the usability test was discussed. In this chapter a conclusive remark will be given based on the whole research work. Moreover, the future research suggestions will be conducted.

The objective of the research is to judge which visual representation methods implemented in the space time cube is a suitable representation for changing network data to understand movement patterns. The whole research objective is combined by the four sub-objectives. To meet the objective, the eleven research questions which are raised in chapter 1 have been answered in the previous chapters.

Network data is composed by two parts: the linear segments and the intersection where the segments meet with each other. Network structure can be well represented on paper-based map or web-based 2D map; it can show the geographical information, and it reflects realistic road structure. As the properties of dynamic traffic, the different traffic patterns will also be detected among network datasets. The new traffic pattern will create a much better traffic flow during rush periods during the day. More characteristics of network data and movement patterns are introduced in the Chapter 2, research question 1and 2 (What is network data and what is traffic movement pattern) being solved in this chapter.

In transportation study, road network is usually represented by network structure. The traffic is not constant, then how to represent the on-going changes in traffic flow becomes an essential issue in this research. There are many visual representation methods to help people to understand the changing traffic phenomenon. With the purpose to find out how to represent the changing network dataset, so in chapter 3, static map, a series of static map, animation are introduced and compared. Generally speaking, the static map contains limited information, a series of static maps and animation cannot trace person's trajectory, animation cannot express information on more dimension, it goes to judge if a Space Time Cube is a better solution to deal with changing network datasets. Space Time Cube shows the potential of visualizing large amount of complex spatio-temporal datasets, can perceive all aspects of 3D structure. Chapter 3 describes the above issue and provides the answers to research question 3, 4 and 5 (the existing representation methods and their (dis)advantage, the role of STC when exploring changing network data).

In chapter 4, the research is on designing a conceptual model for the representation of changing network datasets in STC. After the analysis of visual variables in cartography and investigate probability of representations methods, flow map, 3D wall map and intensity map are chosen to be implemented in the STC. The required functions are discussed here briefly as well. Research question 6, 7 are answered in this chapter.

In chapter 5, the implementation is carried out in uDig, STC-plug-in environment. The representation and exploration in a STC is discussed and the comparison among these three representation methods is analysed, which answer to research questions 8 and 9 (How can the changing network datasets be represented and explored in a STC and the (dis)advantages). The data was cleaned to remove duplicates and errors. 1: N tables were joined in Arcgis for later being processed in uDig. New data was derived by doing calculation based on existing data.

To evaluate the implementation based on these three representation methods, a task based questionnaire is performed, usability method is "think aloud". After usability testing the conclusion is made. The effectiveness (measured by the accuracy of user's answer to each task), efficiency (time consuming on each task) and satisfaction (likert scale analysis and summarised from think aloud video recording) are measured after usability test. Research questions 10 and 11 (How to evaluate the prototype and how effective the prototype works) are solved in chapter 6. 3D wall map representation in Space Time Cube environment is the suitable method to explore changing network datasets.

Concluding remarks:
1. Through the study of comparison among different variable symbols to design the conceptual representation before the implementation is effective.

2. In usability test, selecting users from different department to analysis how different background group deal with same questions. It makes sense for the improvement of the prototype for different user.

3. The task questions are comparable and clear, so the deduction, which gets from usability, is more reliable. The usability test methods are tasks-based questionnaires and think aloud. Both the result and the process can be studied.

4. There is two cities' traffic network datasets, all the tasks are performed using these two networks respectively. Comparing with flow map and intensity map, 3D wall representation method in a STC environment has significant advantages when working with both datasets. More datasets is suggested to be used to test the capability of 3D wall representation methods in a STC environment to explore changing network datasets.

7.2. Recommendation for future research

1. The cities of Tartu (Estonia) and Enschede (The Netherlands). These two cities don't have too much traffic congestion. It is suggested to take much busier cities into this prototype. The implementation deals with more realistic and busier situations, the result may have some difference. I suspect that for the busiest cities, 3D wall has its advantage to visualize these relative data (the percentage of free flow speed); if represent absolute dataset, for example, the speed or the traffic volume, intensity map might be a good option.

2. Besides the flow map, 3D wall map and intensity map implemented in a STC environment, there might be some other representation methods better to represent some especial traffic phenomenon. More representation methods are suggested to be used.

3. The functions in STC plug-in environment, uDig still can be improved and developed, because when it deals with some larger datasets, the speed of executing commands becoming slow. Advanced computer hardware is also in need. Otherwise, developing new software platform for three dimension visualization of spatio-temporal network datasets is suggested.

4. 3D wall representation method could have more application when dealing with complex situation; it has development space in a STC environment, which needs exploration and research on it. When user plans

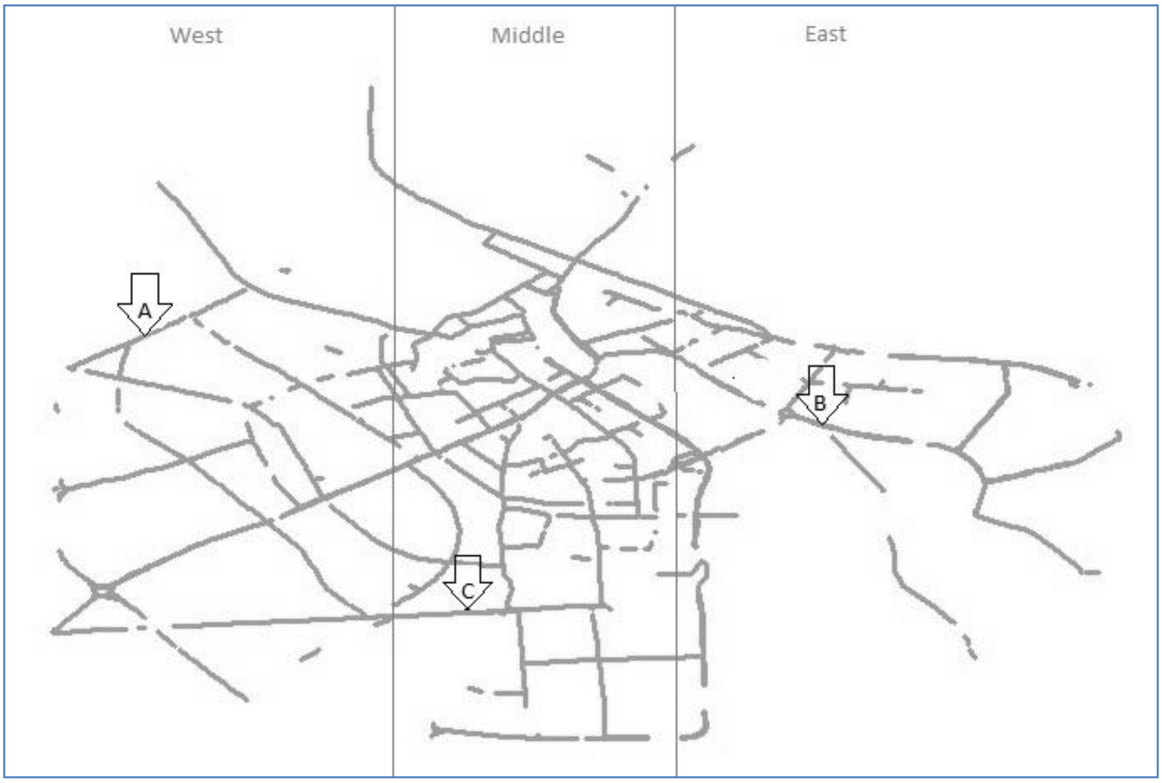
to extract more attributes, the 3D wall will be the optimal method to exhibit the various movement patterns and some other attributes. Moreover, using the methods to visualize

APPENDIX

Part1. Personal information

1) Professional background (study/work):
   - ☐ Geoinformatics(GIS/RS)
   - ☐ Urban Planning
   - ☐ Management
   - ☐ Other:______
2) Education level:
   - ☐ PhD
   - ☐ MSc
   - ☐ Bachelor
3) What is your level of knowledge about geovisualization?
   - ☐ High
   - ☐ Moderate
   - ☐ Low
4) Have you ever interacted with a Space Time Cube?
   - ☐ Yes
   - ☐ No
5) How are you familiar with uDig?
   - ☐ High
   - ☐ Moderate
   - ☐ Low

Part2. Tasks



Tartu Traffic Network

Using the 3D wall map:

1. Look at the Tartu traffic network map on previous page, a road is marked with letter A; work with this road in STC, by dragging the time line in STC environment.
   Question: which is the busiest time period for this marked road?
   (a) 18:00-19:00 (b) 19:00-20:00 (c) 20:00-21:00

2. Using the person's movement path, at what road is this person at 17:00. Focus on this road by dragging the time line. Which is the possible busiest time period for this road?

3. Considering the overall traffic pattern, during the whole day, which road in the eastern part of the city has the possible busiest traffic?

Using flow map:

1. Look at the Tartu traffic network map, a road is marked with letter B; work with this road in STC, by dragging the time line in STC environment.
   Question: which is the busiest time period for this marked road?
   (a) 7:00-8:00 (b) 8:00-9:00 (c) 9:00-10:00

2. Using the person's movement path, at what road is this person at 15:00. Focus on this road. Question: which is the possible busiest time period for this road?

3. Considering the overall traffic pattern, during the whole day, which road in the western part of the city has the possible busiest traffic?

Using Intensity map:

1. Look at the Tartu traffic network map, a road is marked with letter C; work with this road in STC, by dragging the time line in STC environment.
   Question: which is the busiest time period for this marked road?
   (a) 7:00-8:00 (b) 11:00-12:00 (c) 15:00-16:00

2. Using the person's movement path, at what road is this person at 13:00. Focus on this.
   Question: which is the possible busiest time period for this road?

3. Considering the overall traffic pattern, during the whole day, which road in the middle part of the city has the possible busiest traffic?

Questions to be answered after tasks:

Which method you prefer to answer the questions you've been dealing with?

Mark "X" in proper blanks in the following tables.

Flow map:

(1-Strongly Agree; 2-Agree; 3-Neither; 4-Disagree; 5-Strongly Disagree)

	1	2	3	4	5
I am satisfied with it					
It is fun to use					
I don't notice any inconsistencies as I use it					

3D wall map:

(1-Strongly Agree; 2-Agree; 3-Neither; 4-Disagree; 5-Strongly Disagree)

	1	2	3	4	5
I am satisfied with it					
It is fun to use					
I don't notice any inconsistencies as I use it					

Intensity map:

(1-Strongly Agree; 2-Agree; 3-Neither; 4-Disagree; 5-Strongly Disagree)

	1	2	3	4	5
I am satisfied with it					
It is fun to use					
I don't notice any inconsistencies as I use it					

Suggestions (optional)

Part1. Personal information

1) Professional background (study/work):
   - ☐ Geoinformatics(GIS/RS)
   - ☐ Urban Planning
   - ☐ Other:______

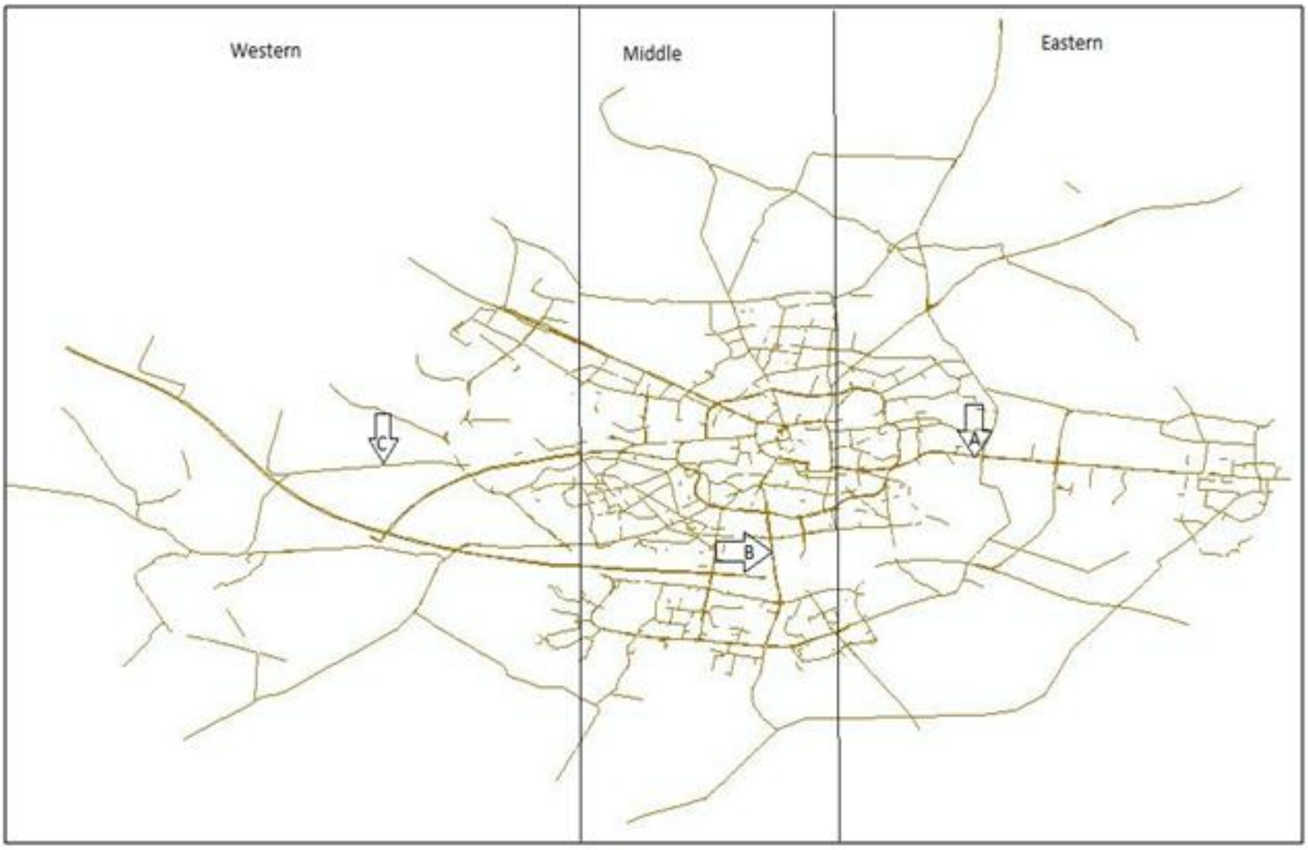
2) Education level:
   - ☐ PhD
   - ☐ MSc
   - ☐ Bachelor

3) What is your level of knowledge about geovisualization?
   - ☐ High
   - ☐ Moderate
   - ☐ Low

4) Have you ever interacted with a Space Time Cube?
   - ☐ Yes
   - ☐ No

5) How are you familiar with uDig?
   - ☐ High
   - ☐ Moderate
   - ☐ Low

Part2. Tasks



Enschede traffic network

Using the 3D wall map:

1. Look at the Enschede traffic network map on previous page, a road is marked with letter A; work with this road in STC, by dragging the time line in STC environment.
   Question: which is the busiest time period for this marked road?
   (a) 18:00-19:00 (b) 19:00-20:00 (c) 20:00-21:00

2. Using the person's movement path, at what road is this person at 17:00. Focus on this road by dragging the time line. Which is the possible busiest time period for this road?

3. Considering the overall traffic pattern, during the whole day, which road in the eastern part of the city has the possible busiest traffic?

Using Flow map:

1. Look at the Enschede traffic network map, a road is marked with letter B; work with this road in STC, by dragging the time line in STC environment.
   Question: which is the busiest time period for this marked road?
   (a) 7:00-8:00 (b) 8:00-9:00 (c) 9:00-10:00

2. Using the person's movement path, at what road is this person at 15:00. Focus on this road. Question: which is the possible busiest time period for this road?

3. Considering the overall traffic pattern, during the whole day, which road in the western part of the city has the possible busiest traffic?

Using Intensity map:

1. Look at the Enschede traffic network map, a road is marked with letter C; work with this road in STC, by dragging the time line in STC environment.
   Question: which is the busiest time period for this marked road?
   (a) 7:00-8:00 (b) 11:00-12:00 (c) 15:00-16:00

2. Using the person's movement path, at what road is this person at 13:00. Focus on this.
   Question: which is the possible busiest time period for this road?

3. Considering the overall traffic pattern, during the whole day, which road in the middle part of the city has the possible busiest traffic?

Questions to be answered after tasks:

Which method you prefer to answer the questions you've been dealing with?

Mark "X" in proper blanks in the following tables.

Flow map:
(5-Strongly Agree; 4-Agree; 3-Neither; 2-Disagree; 1-Strongly Disagree)

	1	2	3	4	5
I am satisfied with it					
It is fun to use					
I don't notice any inconsistencies as I use it					

3D wall map:
(5-Strongly Agree; 4-Agree; 3-Neither; 2-Disagree; 1-Strongly Disagree)

	1	2	3	4	5
I am satisfied with it					
It is fun to use					
I don't notice any inconsistencies as I use it					

Intensity map:
(5-Strongly Agree; 4-Agree; 3-Neither; 2-Disagree; 1-Strongly Disagree)

	1	2	3	4	5
I am satisfied with it					
It is fun to use					
I don't notice any inconsistencies as I use it					

Suggestions (optional)

Tips for the use of STC

 Open the space-time-cube plug-in

This will open the space-time-cube frame if it is not visible.

 Reset the space-time-cube

This will reset the space-time-cube to the original orientation. This is useful e.g. when the cube has moved out of the screen, and it is too difficult to find out where it went in order to bring it back.

 Load layers into the space-time-cube

This is the button providing the main functionality of the plug-in. It is described in detail below.

To display a Shape file with Points and a time-attribute as a Space-Time-Path in the Space Time Cube:

Add the Shape file as a layer in an uDig map

Click the “Load Layers” button

In the form that pops up (the “Layers” form), click OK

To reset the Space Time Cube to its original position:

Click the Reset the Space-Time-Cube button

To have additional layers in the Space Time Cube to form a background-map (on the bottom of the Space-Time-Cube):

Add the layers to the uDig map

In the “Layers” form, ensure that these layers are Plotted as <regular>, and for height, <no attribute> is used.

The SHIFT key, when used together with the mouse, slows down the cube movement (this is useful when you have zoomed in a lot on an object, and want to be more accurate).

The SHIFT key, when used together with the vertical scrollbar, will move the cube instead of the bottom-plane.

To process the data for implementation:

Firstly, select the HSP attribute not equal to zero;

Secondly, on table hsnp.dbf select by attributes, use formula Mod ("TIME_SLOT", 1800) = 0 to select data every half an hour, such as at 02:30, 15:00, 23:30 etc. There are 48 data records for each road in one day. Then export the selected records to a new file with a name: hspr_30min.dbf;

Thirdly, using tool: make query table in Arcgis to join the filtered shape file (filtered on PROFILE_1 <> 0, PROFILE_2 <> 0…PROFILE_7<>0) with hspr_30min.dbf.

The tables to be joined must be contained within the same geodatabase. In SQL Expression use Enschede_roads.PROFILE_1= hspr_30min.PROFILE_ID, .Shape should be selected if the result should be a layer. The key fields list will be used to define the dynamic objectID column. In make query table, when input tables are from a file geodatabase, tables generally join in the order listed in the Input Tables parameter. For example, if Table1 is listed before Table2, Table2 will be joined by getting a row from Table1, then getting matching rows from Table2.

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