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Evaluation of Methods and Tools for Interactively Visualizing and Exploring Traffic Data

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Arslan Muhammad Aslam

Matrikelnummer 11841675

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Betreuung
Betreuer/in: Univ. Prof. Mag. rer. nat. Dr. rer. nat. Georg Gartner
Betreuer/in: Dr. Karl Rehrl
Mitwirkung: Drs. B.J. Barend Köbben

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MASTER THESIS

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Cartography

Submitted By

Arslan Muhammad Aslam

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(Signature of Author) (Signature of Supervisor) (Signature of Supervisor)

Cartography M.Sc.

Master thesis

Evaluation of Methods and Tools for Interactively Visualizing and Exploring Traffic Data

Arslan Muhammad Aslam

Technical University of Munich

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

TECHNISCHE UNIVERSITÄT DRESDEN

UNIVERSITY OF TWENTE.

2020

Statement of Authorship

Herewith I declare that I am the sole author of the submitted Master's thesis entitled:

"Evaluation of Methods and Tools for Interactively Visualizing and Exploring Traffic Data"

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Munich, 20.10.2020 Arslan Muhammad Aslam

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Abstract

Increased traffic is becoming a growing problem in today's cities and to enable efficient traffic management, decision makers need to be supported with valuable information. This requires functional visualizations that are capable of interactively exploring large amount of spatio-temporal traffic data and support identification of traffic congestion. The thesis evaluates methods and tools to visualize line based traffic data over the road network. The evaluated visualization concepts have been implemented in a web GIS traffic visualization prototype, developed using the visualization framework deck.gl.

The dashboard based prototype incorporates a traffic attribute to measure traffic congestion (Travel Time Index), different visualization styles combining two visual variables and the ability for dynamic data exploration through data filtering, multiple temporal and spatial aggregates. These features are integrated in an interactively linked user interface allowing an overview of the data, as well as multidimensional traffic data exploration, to help in visual analytics tasks of domain experts. The developed prototype's ability to spatially and temporally explore traffic congestion is demonstrated in the thesis. Additionally, the multiple interactive features are also evaluated through a user evaluation study with traffic experts and GIS professionals. The user study yielded positive results, which has increased confidence in the developed prototype and it's capability to investigate traffic congestion. The combined use of two visual variables (color and width) for road based traffic visualization was specifically appreciated by the users.

The developed prototype is presented as an example of a powerful and functionally capable traffic data visualization, which can be applicable to other cities as well.

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1. Introduction

1.1. Motivation and Problem Statement

Transportation is one of the major aspects of human activities, over the past years the number of motorized vehicles has seen an exponential increase and this number will continue to increase rapidly. It is estimated that the global motorized vehicle fleet will increase to around 1.3 billion by the year 2030 (Picozzi et al., 2013). This can be related to not only the increasing numbers of human population, but also to the trend in migration to urban areas. Possibly 66% of the world population may be living in urban areas by the year 2050 (Andrienko & Andrienko, 2013 as cited in Andrienko et al., 2017). The urban living style, coupled with generally increasing buying power of the people ultimately results in more cars on the roads. This essentially puts more pressure on the infrastructure of an already growing city. This infrastructure mainly includes the road network and supporting facilities such as parking lots and fuel stations etc. It is approximated that 40% of the world population is on the road for 1 hour or more daily (Zhang et al., 2011 as cited in Chen et al., 2015).

“Traffic” means the movement of motorized vehicles, mostly referred to at a specific location and time. Although it may also include pedestrians, however, this study implies to only motorized vehicles when using the word “traffic”. More traffic leads to blockages on roads and highways, which results in wastage of resources in the form of time and money. It also leads to irregular journey times. Furthermore, it poses environmental hazards in the form of increased vehicle emissions and fuel consumption. In a major urban city, the traffic on the roads at rush hours can lead to increased emission of different pollutants in the range of 14.3–30.4%, as well as increased consumption of 24.3–26.8% petrol and 19.6–22.0% diesel (Wen et al., 2020). Traffic congestion is when the road becomes too saturated and its ability to allow smooth flow of vehicles diminishes. Hence the foremost cause of traffic congestion is lack of road infrastructure to cope with the growing traffic demand. However there are other causes as well, these may include construction or maintenance work on roads, delays due to accidents on roads, social events attracting multitude of traffic and also unsuitable weather conditions. The largest traffic jam was reported in China in August 2010, the traffic was at a standstill for almost 100 km and it lasted for a period of 12 days (Gorzelany, n.d.). One single journey over this congested road section took as long as 3 days. It was caused by a combination of large number of vehicles and road construction works.

In today's cities it has become vital to research on and find ways for improvement of traffic flow. This can be achieved through better traffic management practices, which would allow better efficiency from the existing road infrastructure. Since recently, the concept of Intelligent Transport System (ITS) has massively changed how traffic planners may conduct traffic data exploration and analysis. ITS utilizes Information and Communication Technologies (ICT) to generate massive amounts of data related to traffic movement within a city. This data can include in-vehicle monitoring systems, and also monitoring systems on road infrastructure. The use of ITS has brought digitalization to traffic monitoring, it has encouraged more intelligent and aware forms of transportation and is helpful towards the concept of smart cities (Andrienko et al., 2017). Examples of data collected by ITS can be sensors which count the number of vehicles passing at certain point or video surveillance cameras that monitor traffic and identify vehicles by image processing of license plates. More recently, Global Navigation Satellite System (GNSS) has enabled tracking of moving objects as well. This has allowed ITS to incorporate data from moving vehicles or mobile phone devices within vehicles. The data generated through ITS is massive and has great potential to improve the efficiency and functionality of traffic management systems (Chen et al., 2015). It should also be emphasized that these developments in generation of traffic related datasets is relatively recent as data from new technologies is being captured and made available (Andrienko et al., 2017).

Traffic data is complex, it can have a high Level of Detail (LOD) or granularity, and it also has multiple dimensions as it varies through space, and time. This essentially makes traffic data spatio-temporal in nature while also having the possibility of multiple aggregation levels. To increase the efficiency and functionality of transport networks through ITS, such a massive dataset needs to be investigated properly to extract relevant and useful information for traffic planners. Data visualization plays a very vital role in this regard, it implements visual channels to represent the data and convert it to an understandable and constructive form of information representation (Chen et al., 2015). Hence it becomes very crucial to use appropriate data visualization techniques and methods. This will ultimately lead towards better services and practices in the domain of traffic management.

The resulting visual interface achieved through information visualization mainly deals with computer intelligence, this needs to be combined with human intelligence to create an environment where the users can interact with traffic data visualizations to explore the data, understand it, and be better equipped to interpret it. This interactivity within the visualization interface plays a pivotal role to allow traffic planners and engineers to communicate with a traffic visualization system as stakeholders who would like to gain insight on spatial and/or temporal patterns within traffic data, and identify traffic congestion events. The combined functionality achieved through visual representation and interactive features moves into the domain of visual analytics, which is one of the three branches of data visualization (Chen et al., 2015). Visual analytics can be defined as "*the science of analytical reasoning facilitated by interactive visual interfaces*" (Andrienko et al., 2017). This basically refers to a type of visual representation that allows elementary forms of analysis for problem solving and aid in decision making, achieved through the communication of humans and computers i.e. by providing interactive features to users, for exploring the data.

Another major point of concern here is that although over time there has been a lot of research on visual analytics for the field of transportation, most of it has been done independent of domain experts. Hence there is a gap as visual analytics researchers are unable to establish the requirements and needs of traffic and transportation experts which limits the viability of tools they develop. On the other hand, traffic and transportation experts remain partially uninformed about advances in the field of data visualization and the possibilities of support for visual analytics tasks through advanced visualization tools (Fisher, 2005 as cited in Andrienko et al., 2017). Hence, there is a need to bridge this gap by having domain experts work closely with data visualization scientists and focus on designing powerful traffic visualization applications that enable traffic experts to explore the traffic data and identify traffic related issues e.g. congestion events.

1.2. Research Objectives

This thesis aims to evaluate visualization methods that have been historically used to represent different kinds of traffic data. Tools that allow interactive exploration will also be investigated. The next phase would involve development of a Geographic Information System (GIS) based traffic visualization application prototype, incorporating design concepts from previous related work and integration of new innovations as well. The major goals of the prototype would be to visualize traffic data using multiple visualization methods, and allow spatial and temporal exploration which would enable users to identify traffic related issues and traffic congestion events. Thus, the major user group will be traffic planners, analysts and city traffic management authorities who should be able to directly perform visual analytics tasks using the prototype. This can potentially remove the need of data scientists as intermediaries, as they have to separately perform analysis tasks on a traffic data set provided to them for investigation on traffic issues. Potential size of this user group will be 10-15 members. Figure 1 shows how the traffic visualization prototype intends to support users.

Furthermore, the prototype design will be kept user friendly and intuitive so that professionals and researchers in the domain of GIS and spatial sciences will also be able to use it. This may be used as a control user group in the evaluation study. The user groups will be asked to appraise the traffic visualization prototype through a user evaluation study. The results from this study will enable us to analyze how useful the visualization methods and tools were in investigating traffic related issues through visual analytics. These traffic issues can be: (1) spatial identification of traffic congestion at a specific time, (2) temporal identification of traffic congestion at a specific location, (3) duration of a traffic congestion event, (4) spatial extent (length) of a traffic congestion event, (5) spatial and temporal patterns of traffic congestion and (5) identification of bottle necks in traffic flow.

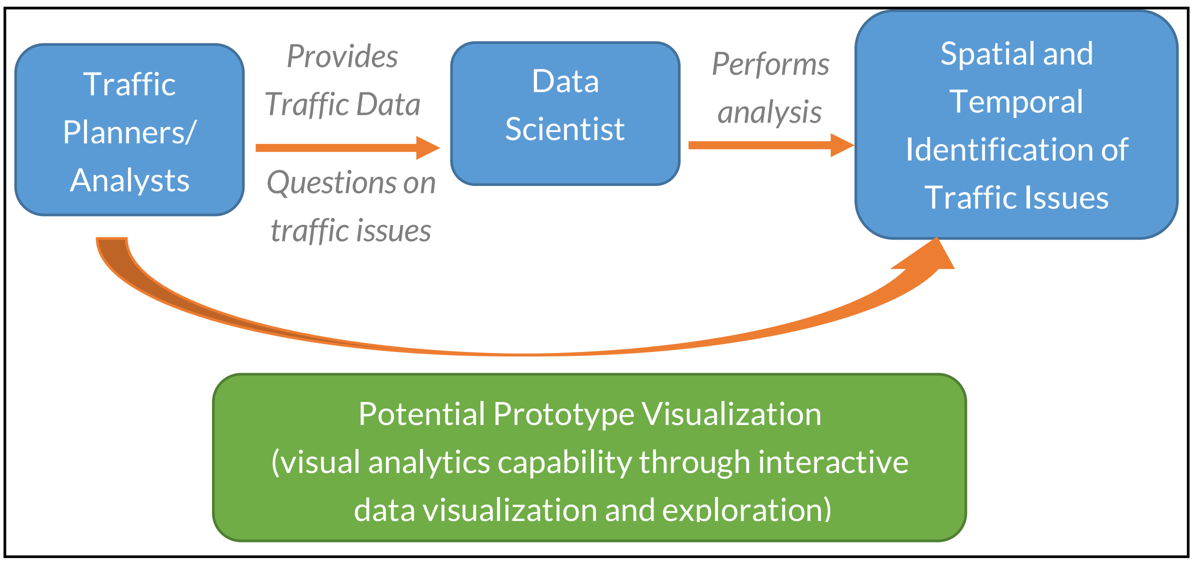


Figure 1: Aim of the prototype visualization to directly enable traffic planners to identify traffic issues.

The three main research objectives for the thesis are presented as a numbered list. Research questions to be answered within each objective are mentioned as well.

1. Evaluation of methods and tools for visualizing traffic data:
    a. Which data categories and visualization methods exist for traffic data?
    b. Which tools are used to explore and understand traffic data?
2. Development of a prototype for visualization and exploration of traffic data with focus on traffic congestion identification:

a. Which visualization concepts will be used in the prototype visualization?
b. Which spatial and temporal aggregates will be applied to traffic data?
c. Which interactive elements will assist users to explore the data?

3. Evaluation study of the developed prototype

a. Evaluation of visualization methods and interactive tools in the prototype.
b. How capable and efficient is the visualization tool for identifying and exploring traffic congestion?

1.3. Thesis Structure

The work of the thesis is arranged into seven main chapters. The current chapter has given an introduction to the thesis and presented the research objectives and questions. Chapter 2 discusses relevant literature review, while chapter 3 will present the comprehensive methodology used for answering the research questions. From here on the main work of the thesis is presented, with chapter 4 focusing on an investigation of previous traffic visualization works to answer research questions 1(a) and 1(b). Chapter 5 focuses on the traffic data, technology framework and design concepts used for the prototype development. Chapter 6 will show the results in the form of example applications of the developed prototype and the outcome of the user evaluation study. Chapter 7 will conclude the thesis work and discuss further recommendations.

2. Literature Review

This chapter will cover a review of the most relevant research done in the domain of visualization of traffic datasets. The standard practices and most frequently used visualization methods will be identified. Additionally, opportunities of further research will also be discerned. The chapter is divided into two subsections, section 2.1 deals with research studies done on surveying methods for visualizing and exploring traffic data and the related traffic datasets used. In this way an overview may be achieved of existing techniques to visualize traffic data from different perspectives. Whereas, section 2.2 will focus on previous research studies in which a specific traffic visualization application has been developed and the design tools it compromises of, and what specific purpose it served.

2.1. Traffic Visualization Survey Studies

Chen et al. (2015) surveyed the subject of traffic data visualizations from different perspectives, these include; traffic data collection and it's processing, the visualization techniques commonly used for different dimensions of traffic data, and the tasks that traffic data visualization applications can perform. The traffic data was categorized into three groups: (a) location-based, where a fixed measurement device e.g. video camera or sensor records attributes of a vehicle that passes by, these attributes can include the speed and direction at that specific location; (b) activity-based, where a specific action triggers retrieval of location and other information e.g. GSM based phone call events; (c) device-based, where a GNSS device in a moving vehicles transmits location information at specific time intervals throughout the journey. Among the data processing techniques discussed, the most important and relevant was data aggregation. Data aggregation for traffic data can be spatial, temporal, directional, or attribute related.

The different dimensions of traffic data included the temporal dimension, the spatial dimension, and a combination of both i.e. the spatio-temporal traffic data. Temporal dimension can be represented with time in a linear form, line charts and stacked charts are mostly used in these cases. The charts can be static, or dynamic i.e. which can be updated according to the time interval. On the other hand, if time has to be shown in a periodic form, radial charts are very useful for this and allow identification of periodic patterns in the data.

The spatial dimension was categorized according to the geometry of the data i.e. point, line or polygon (region) based data. Point data on a map can be used to show the location of objects at a specific time, or to represent some event or also the quantitative property of an event e.g. location of traffic accidents, or additionally, number of traffic accidents at a location. The point based data is useful to represent distribution of traffic data properties, especially if the visualization is for discrete data. However it can have visual clutter due to large amount of data, this can be solved by designing a heatmap for the data using Kernel Density Estimation (KDE). Line based data is mostly used for trajectory dataset, or to visualize traffic data properties over a road network. Visual clutter can also be a problem for line based data, an efficient method to overcome this problem is edge bundling, which will combine similar edges into groups. In addition, KDE can also be used with trajectory dataset to reduce the visual clutter, this results in density maps of trajectories. Polygon based data is mostly achieved from spatial aggregation of point or line based traffic data and then visualized in the form of regions over the map. Examples of this can include the traffic data aggregated over administrative units e.g. counties, states etc. Such data is very useful for visualizing traffic data for studying macro patterns. Some studies also visualized traffic data in spatio-temporal dimension using Space Time Cubes (STC). Traffic data and its dimensions will be further discussed with examples in chapter 4.

Study on the traffic data applications in this research wes categorized into four major categories according to visualization tools used and analytical tasks performed: (1) situation-aware exploration and prediction, for traffic visualizations in which traffic data was interactively queried to explore traffic situations; (2) visual monitoring of traffic situations, for interactive visualizations focused on observing specific traffic incidents; (3) pattern discovery and clustering, for pattern identification within traffic data through interactive visualizations; (4) route planning and recommendation, for traffic visualizations focused on support in routing.

One of the most vital parts of this research study was the proposed traffic data visualization pipeline as shown in figure 2. This includes four phases of data (that are outlined), and three intermediary steps of processing (with dotted arrows). The raw data phase was discussed with regards to above mentioned three groups of traffic data from sensors, while the processed data phase refers to the different dimensions of traffic data. The visual symbols show how the temporal, or spatial dimension of traffic data can be visualized. Lastly, the visualization phase refers to the end product for the users, with examples that can be features within a traffic visualization application.

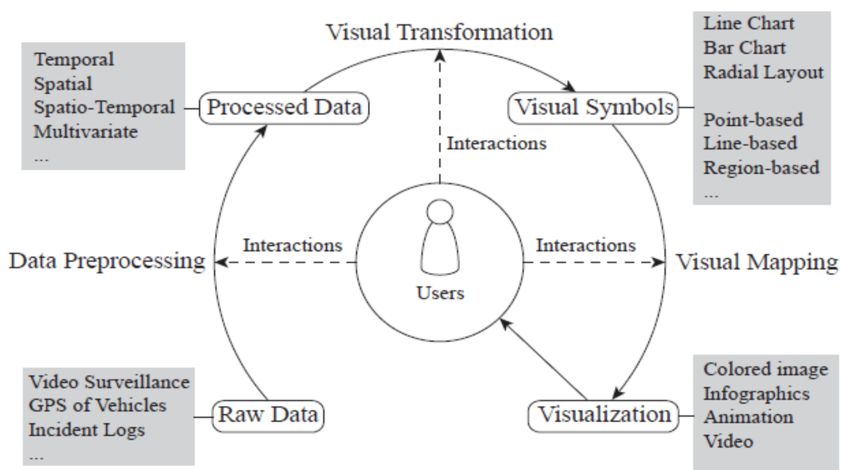


Figure 2: The traffic data visualization pipeline, with the four data phases outlined, and relevant examples listed in the grey boxes. (Chen et al., 2015)

The traffic data visualization pipeline can give vital guidance in the steps involved in the development of a traffic data visualization application.

Sobral et al. (2019) summarized research studies where urban mobility data from ITS was visualized. This was a very comprehensive study and involved evaluation of developed visualizations from two major aspects. Firstly, the visualizations were subcategorized according to their theme within the domain of urban mobility, these themes were a more detailed categorization, compared to the study by Chen et al. (2015). Secondly, the visualizations were also categorized according to the sensor data utilized in the research studies. The major three data groups presented by Chen at al. (2015) were supplemented by specific examples of ITS technology used to collect this data. Additionally, other less common traffic data collection methods were also identified, with relevant examples.

Thus, this study equips researchers with a pragmatic source on how different aspects of ITS data have been used to develop visualization applications and what analytical tasks they are able to perform. Many of these visualizations have specifically been developed to aid traffic management related stakeholders in decision making processes, some of these studies have also involved these stake holders in the development phase. Table 1 shows the subcategories these studies were categorized into and the number of studies that were researched for each. Table 2 shows the example methods of traffic data collection in the three sensor based data groups already defined, and a few other methods as well.

Table 1: Number of studies researched in each theme. Adapted from Sobral et al., 2019

Sr. No.	Theme	No. of Studies
1	Urban traffic flows and monitoring	22
2	People dynamics in urban environments	10
3	Road traffic incidents	5
4	Air pollution	5
5	Travel behavior on Public Transportation System	4
6	Level of Service on Public Transportation System	4
7	Trip patterns	4
8	Big city data	3
9	Travel demand	3
10	Public transportation ridership	2
11	Sparse trajectory data	2
12	Cyclist behavior	2
13	Temporal transportation data	2
14	Commuting efficiency	1

15	Accessibility	2
16	Urban traffic conversations	1
17	Interchange patterns	1
18	Co-occurrence	1

Table 2: The number of studies which used data from the three major sensor groups and their example data types. Some other non-sensor based examples are also listed. Adapted from Sobral et al., 2019

Sensor Group	Data Type	No. of Studies
Activity Based	Floating car data	1
	Mobile phone data	7
	Smart card data (AFC)	7
Device Based	Bicycle trajectories data	2
	Bus Automatic Vehicle Location (AVL) data	3
	Bus GNSS trajectories	1
	Vehicle sensor data	15
	Non-APC Passenger count data	2
	Taxi GNSS trajectories	13
	Subway AVL data	1
	Tram AVL data	3
	Vehicle GNSS trajectories	2
Location Based	Video Stream data (incl. ANPR)	5
Others (indirectly related to ITS)	Travel diary survey data (survey based)	4
	Car incident record data (report based)	6
	Highway traffic flow data	1
	Urban traffic flow data (model based)	5
	Road traffic air pollution (model based)	3

Among the thematic subcategories, the first four were stated as the most major ones, and this is also shown by the amount of research studies carried out related to them. Some of these studies focused on traffic data visualizations in only the temporal dimension in an abstract space. These included heatmap matrix, or circular heatmaps for pattern analysis. Others included line charts, or bar charts where time was shown linearly. However, most of these studies involved a GIS based visualization of traffic data where the focus was the spatial dimension. These studies included point based, line based and polygon based datasets. There were also some studies that focused on spatio-temporal representation of traffic data, they used the STC as a powerful visualization tool. A specific traffic attribute was represented in space using the X and Y axis, with time in the Z axis. This naturally makes it a three dimensional (3-D) visualization. These will be studied in details with examples in chapter 4.

The study also focused on what interactive elements were generally used to allow human-computer interaction. These include semantic zoom, map panning, brushing or filtering, and linking. Semantic zoom means the user can dynamically change the scale of the map, and level of detail of data represented as he or she zooms in and out. Map panning means the user can change the spatial extent of the map through mouse or keyboard interaction. Brushing and filtering allow the user to interactively select a subset of the data. Linking enables the user to view a data subset through multiple views, these multiple views generally involve different visualization techniques to represent a different aspect/ dimension of the dataset. These multiple views are mostly coordinated with each other, which ultimately develops into the concept of visualization dashboards.

A vast majority of the research works included in this study involved dashboard based visualizations. These mostly incorporated a dedicated spatial view to visualize the point, line or polygon based traffic dataset, combined with linked temporal view(s) such as line graphs, bar graphs or radial charts to solely represent the time dimension of data. Another view is usually allocated for user selections to interact with the data e.g. spatial or temporal querying and filtering. In some cases multiple attributes related to the dataset were visualized in a Parallel Coordinate Plot (PCP). Likewise, another visualization technique that was frequently used was heatmap. Heatmaps were generated over traffic data to visualize the data distribution and identify high density areas. Although they were used for all kinds of traffic data (including those focusing on only visualizing the temporal dimension), they were more common for point and line based datasets.

The study also identified that preliminary works in traffic data visualization used purely GIS based frameworks coupled with conventional, static visualizations. However with time, new visualization frameworks have been developed which feature powerful data visualization with the ability to allow user interaction as well. Additionally, they also allow integration of spatial data which makes them very useful for traffic data visualizations e.g. D3.js.

2.2. Traffic Visualization Application Development Studies

Picozzi et al. (2013) performed a thorough study into how traffic information visualization can support the decision making process of traffic control and city planning authorities. The quality of these decisions can be greatly improved if the stake holders were able to explore and identifying traffic related issues and road congestion through interactive and intuitive visualizations tools. Initially the mentioned stake holders were also interviewed to specifically identifying their requirements, and flaws in previously used system. Keeping the requirements in view, a web based interactive traffic visualization application was developed which was capable to represent the spatial and temporal dimension of traffic data utilizing multiple visualization techniques in an integrated dashboard design.

This study was focused on the city of Oulu, Finland. Interviews with traffic planners and city authorities regarding the traffic visualization they used at the time revealed that their system involved manual databases from which data selection of space, time and traffic attribute was made. This dataset was exported in a spreadsheet system and analyzed using graphs and charts. This meant that the whole process was time taking and used static methods, and lacked a distributed spatial visualization. The requirements included support in tasks such as programming of traffic light times, and also identifying locations for deployment of police vehicles to control traffic flow. Thus the study focused on a GIS based traffic visualization which would allow interactivity for the users to dynamically select the space and time, and also allow basic spatial and temporal aggregation. Temporal aggregation would be useful for users to identify patterns in historic data e.g. finding rush hour times. The data used was of traffic flow, which counted the number of vehicles passing each of the 77 traffic light intersections in the city. Each intersection was equipped with 4 to 32 lane detectors to observe the directions of vehicles as well.

The traffic visualization application that was developed had three User Interfaces (UI): (1) the map view; shown in figure 3b which was developed using the google map Application Programming Interface (API), (2) the chart view; shown in figure 3a which was developed using Highcharts API, (3) the calendar view; shown in figure 3c developed using D3.js.

Figure 3: The Interactive dashboard based traffic visualization developed for Oulu by Picozzi et al. (2013)

The map view visualized spatial distribution of traffic intersections at a specific time represented with circles (a point based dataset). The color of each intersection showed traffic volume. The chart view showed the traffic volume over time, for a specific intersection, or spatial selection of intersections. The calendar view aggregated traffic volume per day and showed them over a color scale in cells of a calendar. Interactive features involved a dashboard based overview, having synchronization between map and chart views, and balloon markers to show data details. Thus, it can be seen that visualization themes and tools identified by Sobral et al. (2019) have been used in this study as well, such as implementation of the visualization through an interactive and linked dashboard UI.

The study incorporated feedback from traffic planners and city authorities who responded to the visualization application very positively and commented that it fulfilled most of their requirements and was much better than their current framework. The author concluded that such a visualization framework can be used for any city, and play a very vital role in traffic management systems.

Petrovska & Stevanovic (2015) identified the social, financial and economic issues resulting from traffic congestion. These include delays in journeys, loss of precious human time, increase in stress levels, excessive environmental pollution, more energy and fuel usage. The solution presented was an interactive GIS based web application, which could calculate and visualize near real time traffic congestion data from Google Maps traffic layer. The target user groups were traffic managers and analysts, however it can also be used by other people that are travelling on the road network.

The application was focused on not only identifying congestion on road, but also quantifying it for the users. It was developed in Java and Hyper Text Markup Language (HTML). The application included a default map view with a Google Maps UI, the user was provided the option to firstly select spatial bounds to visualize the road network, and further select specific road segments or intersections to perform the congestion analysis on. The congestion was calculated using image processing to calculate point by point color classification of the traffic congestion scale from google maps traffic layer. This colored scale had four categories of traffic congestion; normal (N) represented in green, medium (M) represented in orange, high (H) represented in red, and severe (S) represented in grey. The result was represented as percentage of the points falling in each category from each selected road segment or intersection. Additionally the user could also select the length of time interval over which this calculation was based. Changing the time interval updated the results with a new calculation. Figure 4 shows the interface of the application.

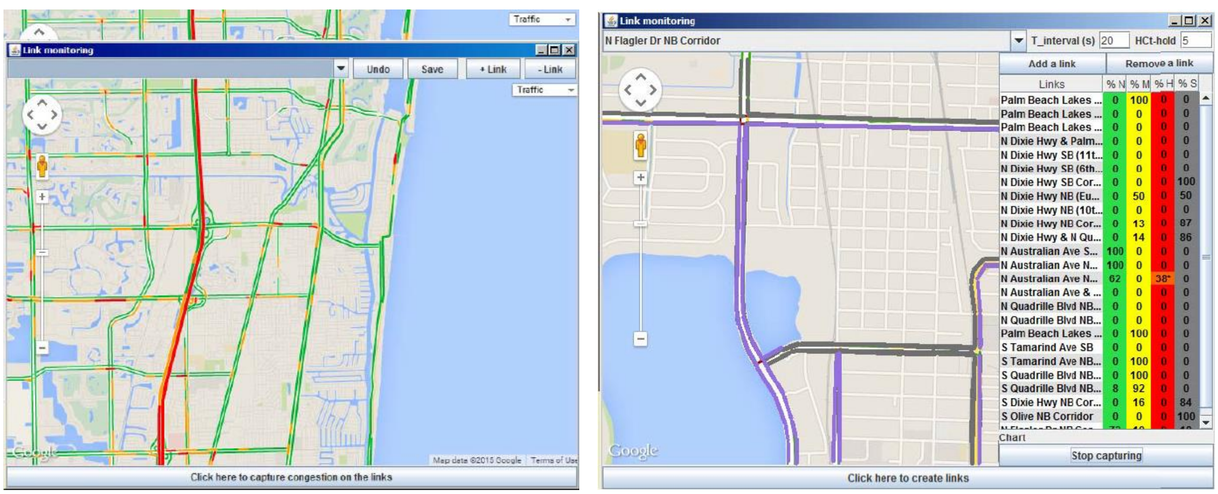


Figure 4: The traffic congestion analysis tool developed by Petrovska & Stevanovic (2015). The map view on the left allows user to select specific road segments or intersections. The view on the right shows the calculated congestion for each selected road segment or intersection.

The study was very useful as it focused solely on traffic congestion identification and exploration. It also allowed interactive methods of spatial and temporal selections. Another advantage was the use of near real time data which allowed traffic managers and analysts to have an updated measure of traffic congestion and plan to manage traffic accordingly. Additionally common motorists could also keep themselves updated regarding traffic congestions and plan their trips and routes accordingly.

3. Methodology

This chapter will define the methodology used to achieve completion of this thesis. Figure 5 presents a flow chart, followed by a brief description of all the steps involved. These steps will be further explained in the following chapters.

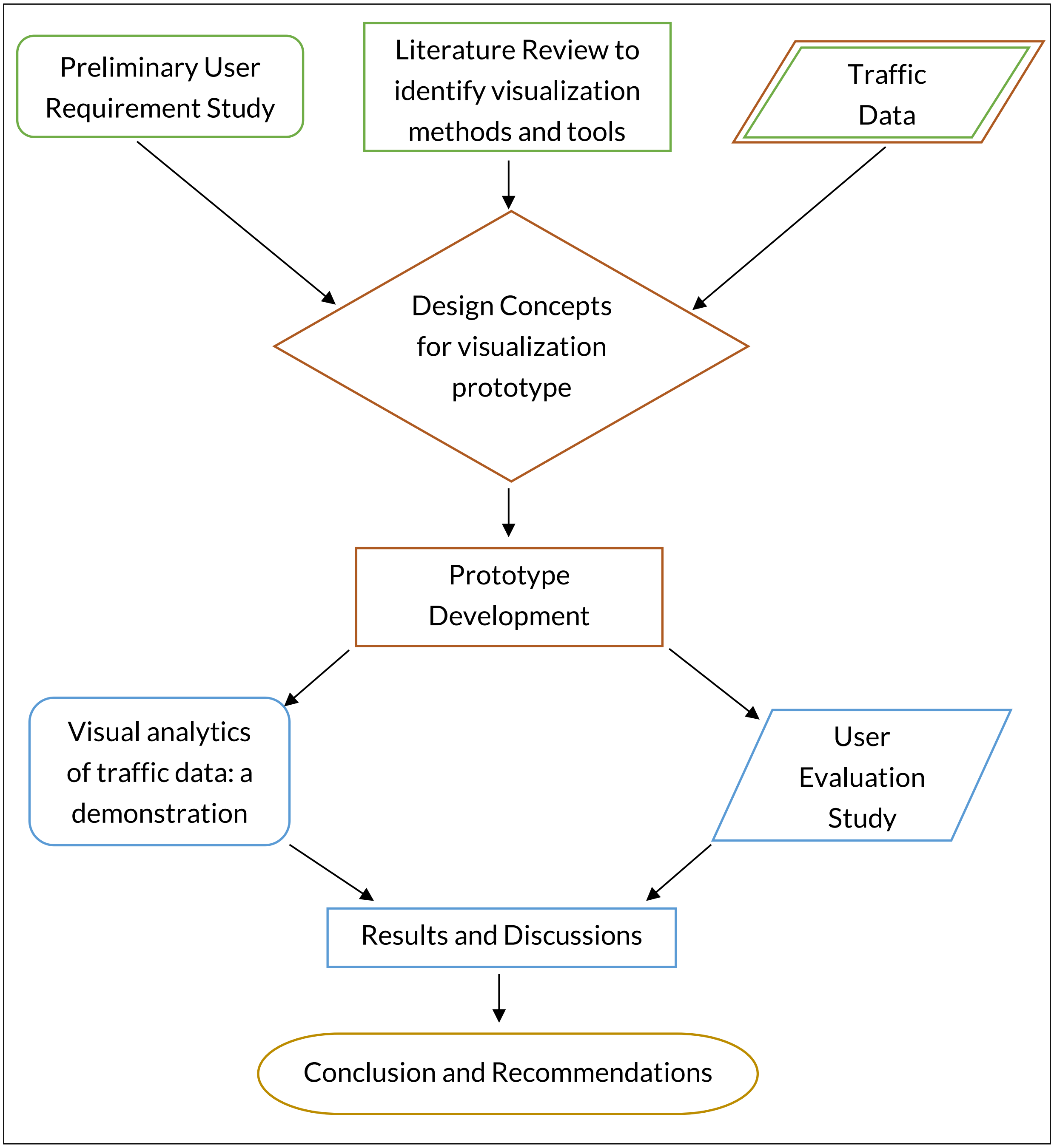


Figure 5: The methodology flow chart

This first phase of the thesis is represented in green boxes in figure 5. Chapter 4 details these steps which are related to the first research objective. Literature review will be carried out to investigate the visualization methods used for different types of traffic data and the tools used in traffic visualization applications. State of the art techniques and opportunities for new innovative visualizations will be identified. Additionally, a short preliminary user requirements study will also be conducted to gather the requirements demanded by traffic planners and analysts from an interactive visualization tool.

The traffic prototype will require traffic data, which has been provided by the Mobility and Transport Analytics (MTA) Department at 'Salzburg Research Forschungsgesellschaft mbH'. This data will be analyzed and the required post processing will be applied. The data is introduced in chapter 5.

The second phase (red boxes in figure 5) will involve decisions on design concepts and then the actual development of the traffic visualization prototype. These design concepts will be supported by findings of the first phase and the nature of the dataset. The application will be developed in a web based GIS framework called deck.gl. Deck.gl is a WebGL (Web Graphics Library) framework which uses JavaScript. The prototype user interface and its interactive features will answer research questions 2(a), 2(b) and 2(c). Chapter 5 covers the process of prototype development.

The last phase (blue boxes in figure 5) relates to the third research objective and is detailed in chapter 6. The traffic prototype will be evaluated by two methods. Firstly, demonstration of its use to perform visual analytics tasks to identify traffic congestion issues, like the examples listed in section 1.2. Secondly, a major step will be to design a user evaluation study to allow potential users to operate the prototype, give feedback on visualization methods and capability to identify traffic congestion. The results and discussions from both these methods will be presented in combination. Feedback from users and limitations of the prototype will be incorporated in the discussion as well.

Finally, a conclusion with recommendations will be presented in chapter 7.

4. Evaluation of Traffic Data Visualizations

In this chapter the methods and tools that have been used for traffic visualization will be evaluated. It will focus on research question 1a and 1b and refers to the first phase (green boxes) from the methodology flow chart n figure 5.

The two major groups of traffic data are incident data, and trajectory data. Incident data is for stationary objects e.g. data from location and activity based sensors. It represents the time and traffic attribute at a specific location. Whereas trajectory data is suited to moving objects and records spatial, temporal and traffic attribute information e.g. data from device and activity based sensors. Both of these data groups can be visualized in the dimension of time, space or spatio-temporally. Section 4.1 covers the visualization methods for traffic data that is subcategorized according to the different dimensions of visualizations, i.e. temporal visualizations, spatial visualizations and spatio-temporal visualizations. Section 4.2 investigates what tools have been used in combination with visualization methods. These tools support users for better exploration, and interpretation of the data and/or allow interactivity with the data. The merging of visualization methods and tools allows users to achieve visual analytic capabilities to solve problems and discover issues related to traffic.

4.1. Dimensional Visualization Methods for Traffic Data

4.1.1. Temporal Visualization Methods

Temporal visualizations focus on only time dimension of traffic data. They are used to show traffic attributes in an abstract space, with respect to time. Visualization methods used here can be line charts and bar charts. They can represent time in a linear form and make it easy to spot highs and lows in data values. Additionally, they make it easier to visually observe how traffic propagates or flows across time due to their linear structure e.g. flow of traffic over 24 hours of day. Figure 6a is a line chart used by Ferreira et al. (2013) to show number of taxi trips over time in different areas of Manhattan, the colors represent the different area bounds. The traffic visualization developed for Oulu by Picozzi et al. (2013) also uses a linear time chart.

However to better understand and identify patterns in traffic data, radial charts can be used to show recurring time. These can be especially useful to observe weekly patterns of traffic. Figure 6b shows time in a radial form with each day as a separate circle, and time of day along the circumference of the circle. Traffic quantity is shown by a colored scale in the cells (Pu et al., 2013). Another useful method to identify patterns can be a heatmap matrix along two temporal resolutions. Figure 6c is a heatmap matrix that represents the day, and time of the day used by Song & Miller (2012), traffic congestion is represented by a color scale (Chen et al., 2015; Andrienko et al., 2017).

However the limitation of such traffic visualizations is that they do not represent the spatial dimension at all. They can only represent time in an abstract space. Since traffic is spatio-temporal in nature, temporal visualizations can be very useful as a supporting visualization to allow users to view traffic attribute data at a specific location. They are very suitable to represent numerical information across time.

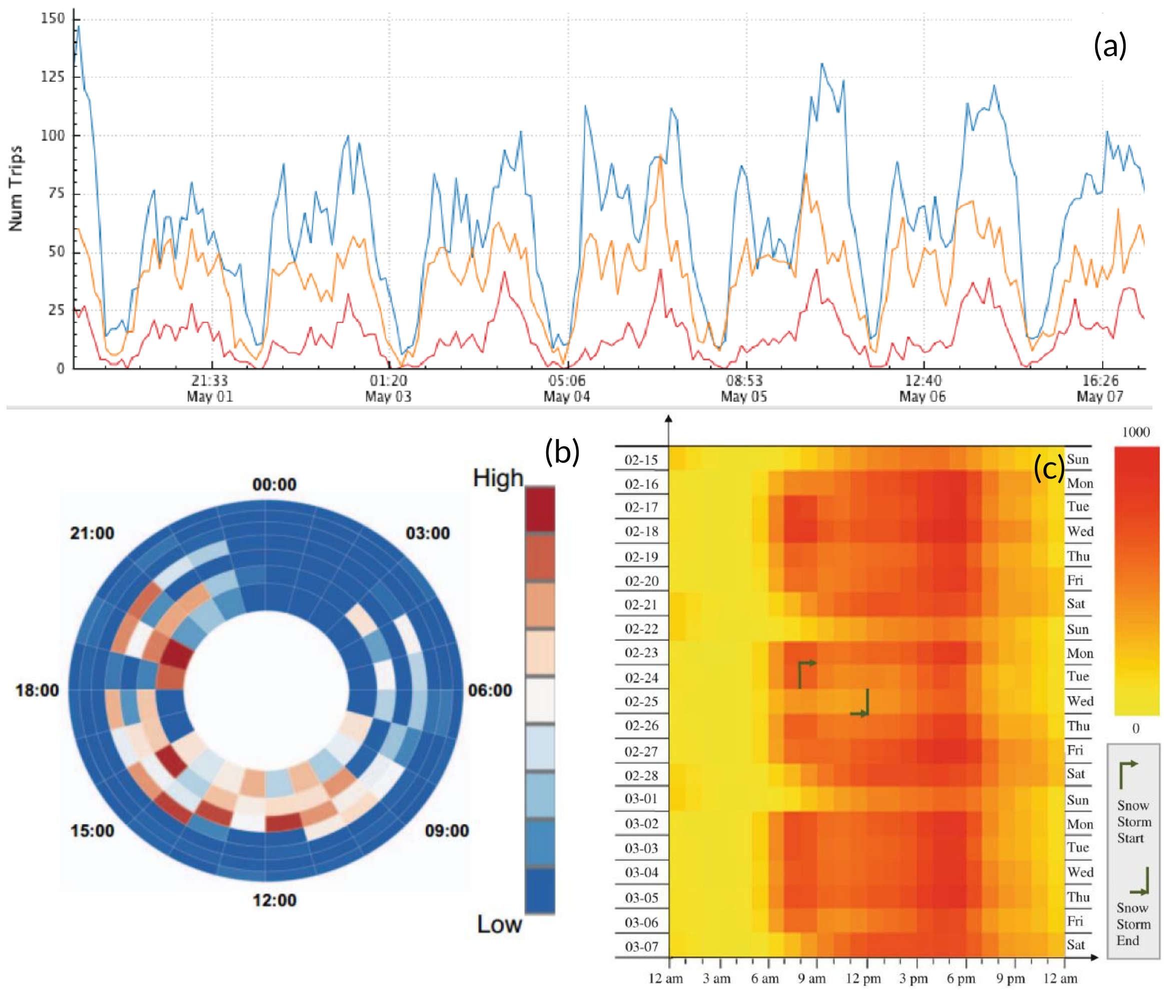


Figure 6: Examples of temporal visualizations used for traffic data.
(Pu et al., 2013; Ferreira et al., 2013; Song & Miller, 2012)

4.1.2. Spatial Visualization Methods

a) Point based visualization

Point based data can represent location of traffic attributes of moving objects at a certain time, or the traffic attributes collected from sensors at a specific location. The spatial distributions of discrete data can be efficiently visualized by point based visualizations. Typical traffic attributes can include traffic incident data, location of traffic jams, pick up or drop off locations of trips, or the intensity of any other traffic variable at a certain point e.g. traffic flow (number of vehicles) passing. Colors or sizes of point representation are most commonly used to illustrate traffic data attributes.

An advantage of point data visualizations is that it allows the state and attributes of each data element to be known. However as discussed earlier large number of data points can result in visual clutter. Heatmaps are a very useful and commonly used visualization tool to overcome this problem, they will be further discussed in section 4.2.

Figure 7a (Barry & Card, n.d. as cited in Chen et al., 2015) represents the Boston subway system where the points represent the location of a running train at the mentioned time. It shows the points over a base map, and also an abstract space, with the colors showing different attributes. Figure 7b (Ding et al., 2015 as cited in He et al., 2019) represents pickup locations (in blue) and drop off locations (in orange) for passengers using the Pudong International Airport. The visualization developed for Oulu by Picozzi et al. (2013) as shown in figure 3 and discussed in section 2.2 also uses point dataset to show traffic volume at road intersections.

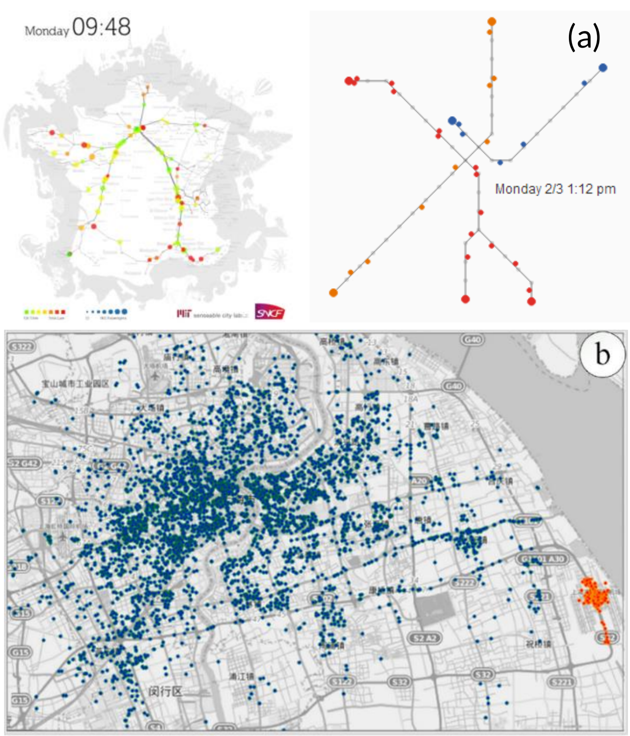


Figure 7: Color based point traffic visualizations (Chen et al., 2015; He et al., 2019)

Figure 8 (Demissie et al., 2013 as cited in Andrienko et al., 2017) shows point based traffic information based on cellular network data. Outgoing and incoming calls are simultaneously visualized and the size of the circle represents the number of calls.

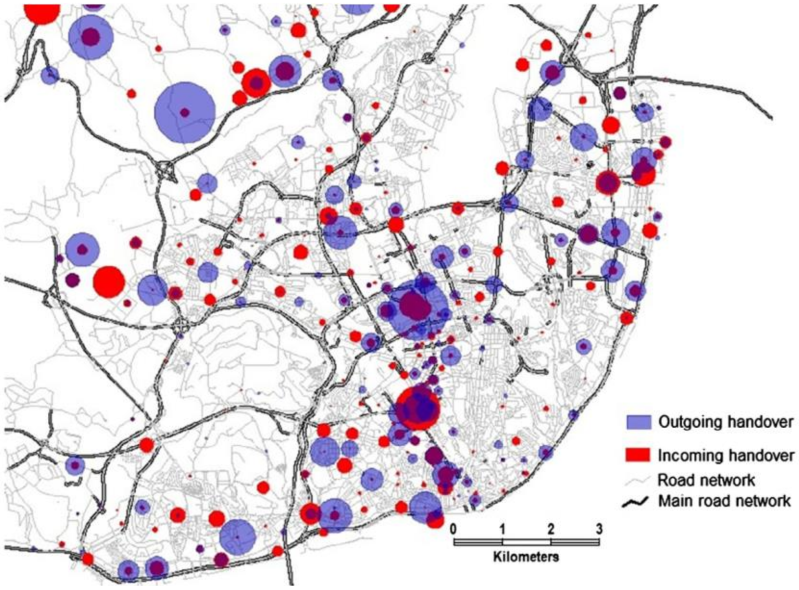


Figure 8: Size based point traffic visualization. (Andrienko et al., 2017)

b) Line based visualizations

Line based visualization are very useful to represent trajectory data or to visualize traffic attributes over the road network. Line based visualizations allow representation of continuous data in the form of lines, this can also be achieved by interpolation or aggregation of point dataset. It has been commonly used to show traffic attributes such as traffic intensity, traffic flow, traffic direction, vehicle speed, distances or time of a journey. The color visual variable is most commonly used to illustrate traffic data attributes.

Line based visualizations are also very useful to show origin-destination pair trajectories and ultimately visualize patterns in traffic flow e.g. flow maps. Flow maps are where such trajectories are simplified using clustering algorithms. Such trajectories can only visualize the traffic direction and spatial information of the start and end points which is useful to identify spatial patterns (Chen et al., 2015). However, in many cases even these clustered trajectories or raw direct trajectories result in visual clutter when plotted. Figure 9a (Demissie et al., 2013 as cited in Andrienko et al., 2017) represents a flow map showing an example of this providing visualization of direction and strength of traffic.

In contrast, line based visualizations that are represented over the spatial road network have more visual literacy, are more intuitive and easy to understand. In addition, they are very suitable to visualize traffic moving on the roads and identify areas of slow speed and traffic congestion. Figure 9b (Zuchao Wang et al., 2013) shows a traffic coverage attribute visualized over the road network. The traffic congestion tool that has been discussed in section 2.2 and shown in figure 4 also uses line based visualization for traffic congestion. In some cases heatmaps are also generated over line based visualizations however they can cause the actual road network to become hidden under the heat map visualization. This will be discussed in section 4.2 as well.

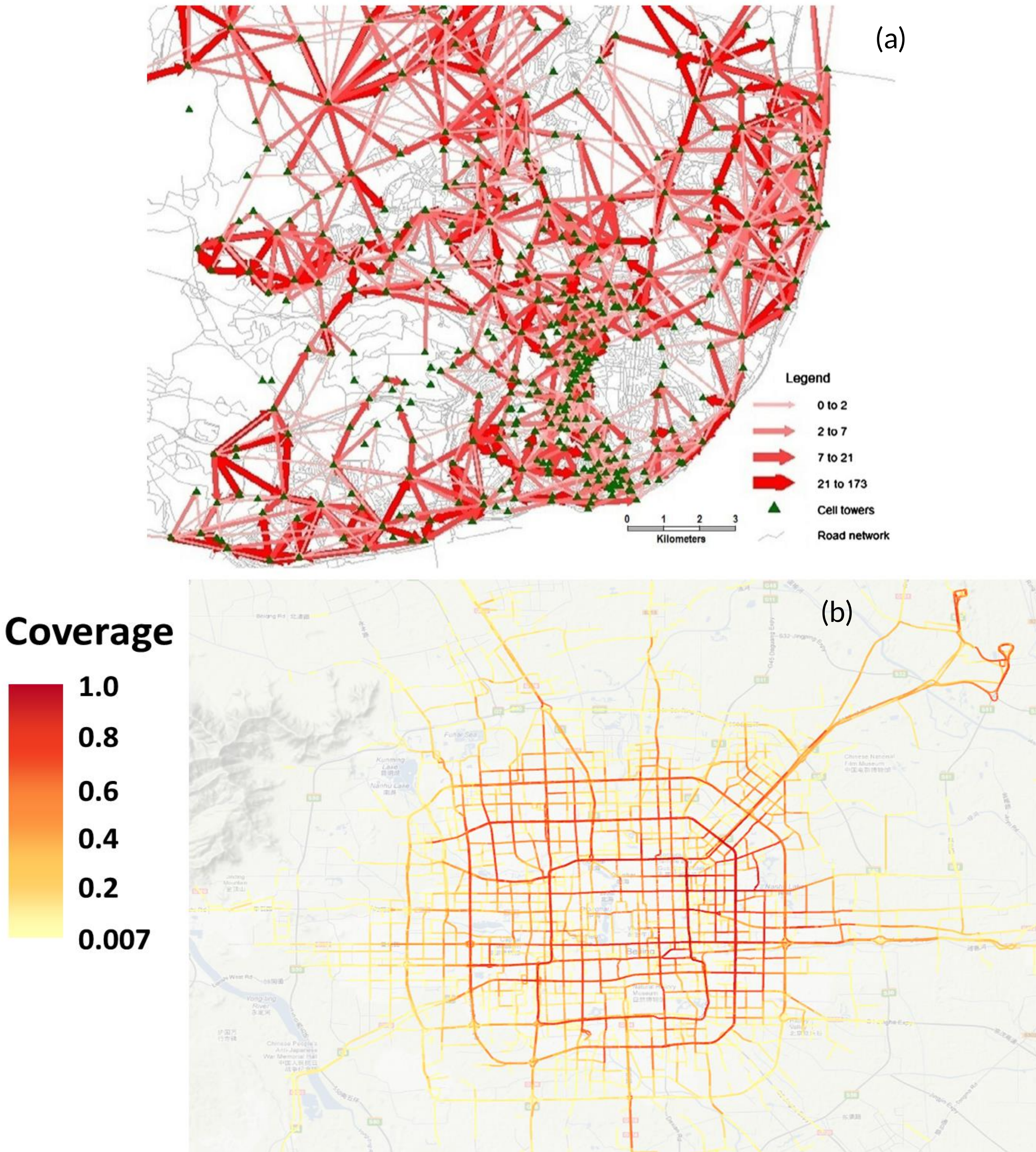


Figure 9: Line based traffic visualizations. (Andrienko et al., 2017; Zuchao Wang et al., 2013)

c) Polygon based visualizations

Polygon based visualizations normally result from point or line based traffic data aggregated over regions such as counties or other administrative boundaries. Polygon based visualizations are useful to gain an overview of the data and understand patterns that exist on a macro level. They can be used for many traffic attributes e.g. traffic flow between different regions. Figure 10 (Yin et al., 2015) visualizes accessibility indexes and travel times using choropleth and heatmap over Chicago city blocks.

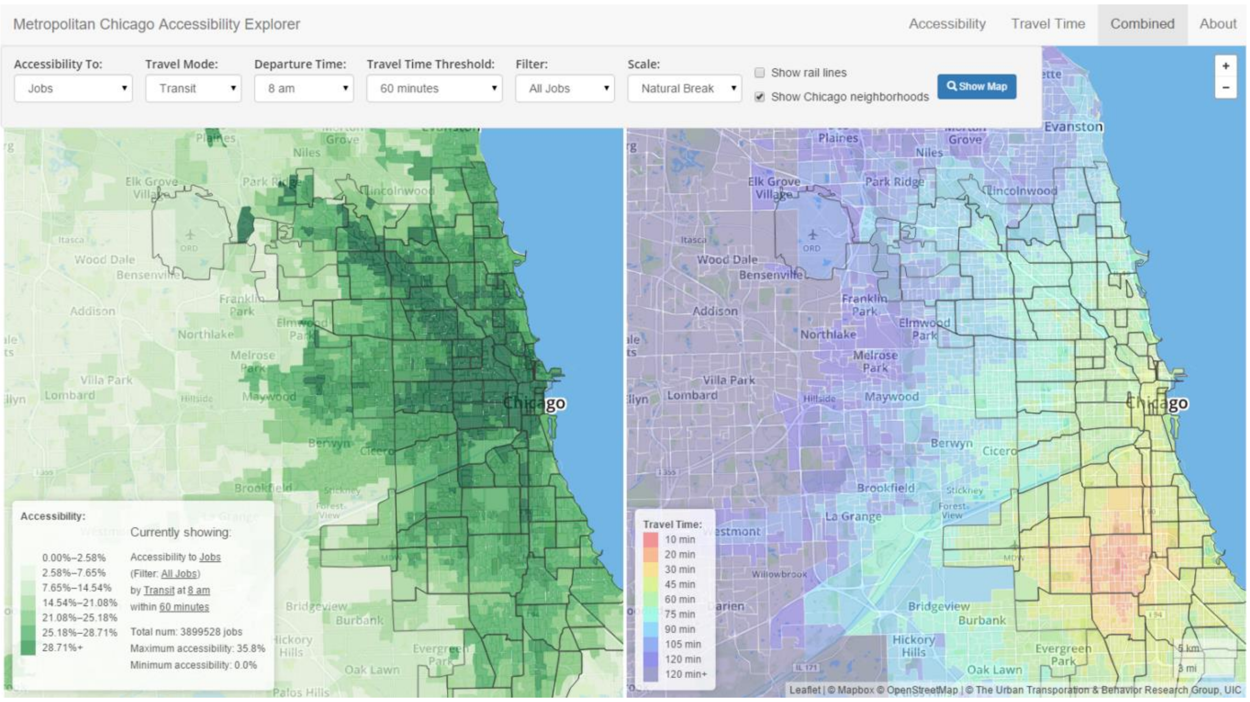


Figure 10: Region based traffic visualizations (Yin et al., 2015)

4.1.3. Spatio-Temporal visualization Methods

Spatio-temporal visualization methods have the ability to simultaneously visualize traffic attributes over time and space. STC (Space-Time-Cube) is the foremost visualization method here, it uses 3-D coordinate system where X and Y axis represent space and Z axis represents time. STC is very suitable for 3-D trajectory visualization where the path of a trajectory is visualized over time and space. Figure 11a (Kraak, 2003) shows an example of a space-time-cube where a person's journey is visualized as a 3-D trajectory. The issue with STC is that it is difficult to understand as the visualization is 3 dimensional and with a larger dataset there is a lot of visual clutter. Another method for spatio-temporal visualization is a 'map timeline' presented by Thudt et al. (2013) that shows a series of maps along a timeline (figure 11b). The concept is similar to the visualization tool called juxtaposing and requires a lot of display space. Juxtaposing will be further discussed in section 4.2.

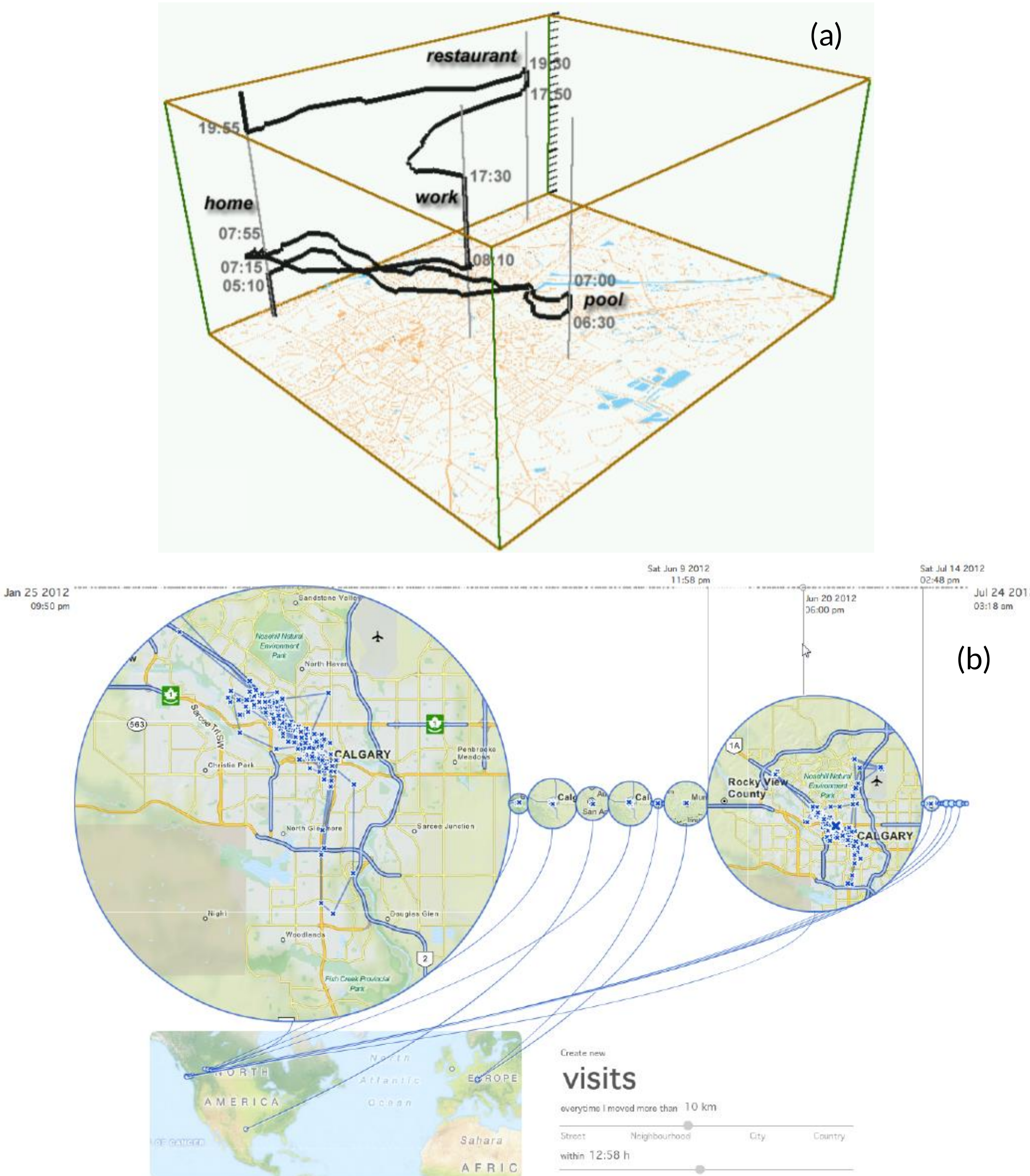


Figure 11: Spatio-temporal visualizations for traffic data (Kraak, 2003; Thudt et al. (2013)

4.2. Tools to Interpret and Explore Traffic Data

This section will discuss how visualization tools can enhance the functionality achieved from visualization methods. They support visualization methods by allowing capability for users to investigate data from different aspects and extract useful information, which ultimately supports understanding and interpretation of data. Thus, these tools assist in visual analytics tasks which increase efficiency for further in-depth analysis (Chen et al., 2015; Andrienko et al., 2017). These tools allow enhancement of visualization methods, and some of them also support communication and interaction with the user, consequently forming the link between human and computer intelligence. Commonly used visualization tools are mentioned in the next sections.

Technological frameworks and programming languages used for development of these interactive visualization tools are: Java, Javascript, HTML, C++, PostgreSQL, Open GL, ColdFusion, Flex, Processing and D3.js (Chen et al., 2015; Sobral et al., 2019).

4.2.1. Interactivity

Interaction of user with the visualization is very pivotal in information extraction and data exploration. Since traffic data has multiple dimensions, interactions can help in exploring one dimension, dynamically query data and allow the association between both dimensions i.e. space and time. In GIS based traffic visualizations interactions to control the view are state of the art e.g. zooming, panning and rotating. Additional interactions can include interactively displaying details on demand, selecting or highlighting a subset of data. Advanced interactive mechanisms for traffic data can include functions to change attribute values of the dataset, view spatial exchanges, textual labels and animations (He et al., 2019). These interactions are controlled through mouse click, hover, drag, clickables buttons etc.

Brushing, semantic zoom and linking are also common examples of interaction in traffic visualizations. Brushing is used to select a subset of data. Semantic zoom grants capability to show different level of detail or data aggregates through dynamic zooming in and out. Linking forms the association between multiple coordinated views (Sobral et al., 2019). Most of the visualization tools presented in the following sections rely heavily on interactive mechanisms as well.

4.2.2. Heatmaps

Heatmaps are frequently used to enhance traffic data visualizations. The advantage of heatmaps is that they show distribution of the dataset and allow quick and easy visual interpretation. This allows users to spatially compare different areas and identify areas with high data values (hotspots) and also areas with low data values. Heatmaps can be generated for all three forms of spatial traffic data (i.e. point, line and polygon) as already discussed in section 4.1. They generally require data processing using techniques such as KDE and edge bundling discussed in section 2.1. Figure 12a shows distribution of taxi trips over a city, mapped to a density color scale of 0 to 1 (Liu et al., 2013). Additionally they have also been used for just temporal traffic data as shown by figure 6c.

Heatmaps are very useful for a large point or line based dataset, as they greatly help to reduce visual clutter. However with respect to line based visualizations of the road network, the heatmap will conflict with visual recognition of the road network itself. If identification of precise spatial locations along the road network are necessary, heatmaps may not be a very feasible visualization tool. Figure 12b shows an example of this. Here speed of a vehicle along a route is visualized with red color showing high vehicle speeds (Silva et al., 2018). Figure 18c also shows an example of this (Andrienko et al., 2017).

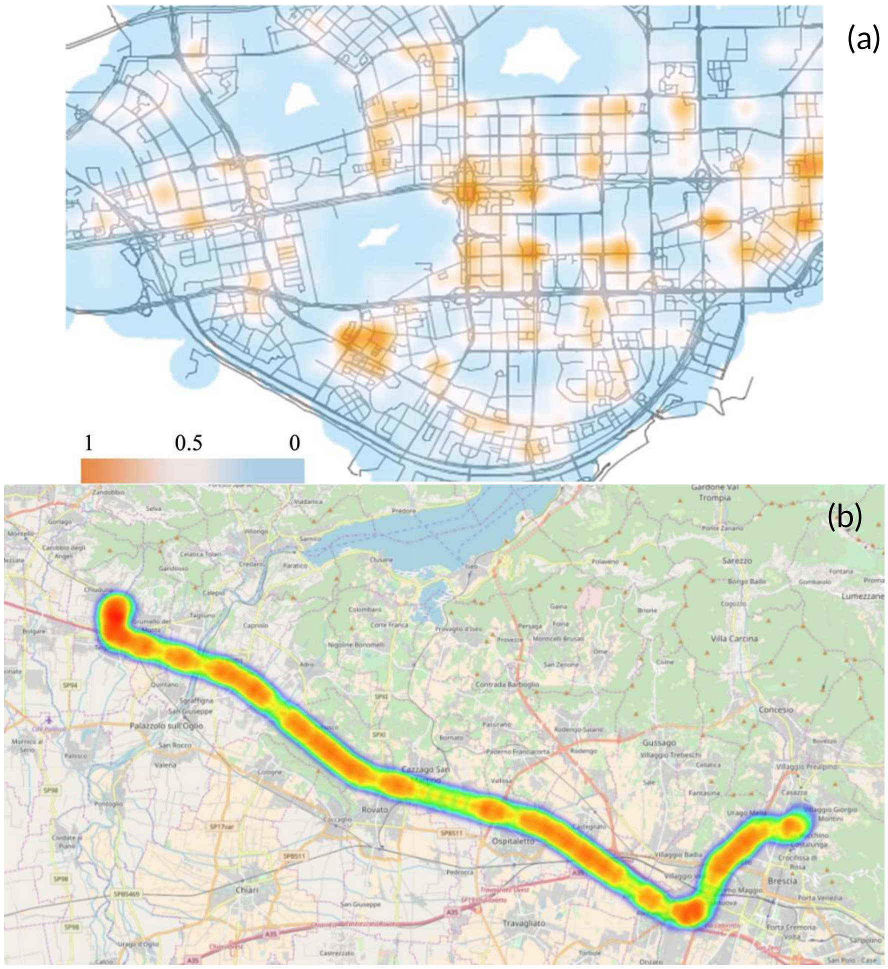


Figure 12: Heatmap visualizations for traffic data (Liu et al., 2013; Silva et al., 2018)

4.2.3. Filtering and Selection

This visualization tool refers to the interactive mechanism of brushing, which allows a user to filter the visualization using specific data selections. In the context of traffic data, these selections can be time based, or also space based e.g. filtering the traffic data set according to a specific day from the whole month, or selecting a specific spatial location within a city. This tool is specifically useful in two aspects, it allows the user to interactively subset the data that needs to be focused on and consequently it also leads to less visual clutter in cases where the data is spatially distributed. From the perspective of visual analytics, the ability to select a subset of data and visualize it is very useful. The subset data can be explored in more detail and this allows efficient information extraction especially in cases of large datasets (He et al., 2019). Figure 13 shows the taxi trip visualization by Ferreira et al. (2013) where temporal selections are possible in the selections menu A, while spatial selections on the map are allowed using the map view B and selection menu C. Hence the number of taxi trips of a specific time range and between specific regions are visualized in the graph view D.

Figure 13: Traffic visualization allowing spatial and temporal selections (Ferreira et al., 2013).

4.2.4. Aggregation and Granularity

Data aggregation and granularity are interrelated ideas and consequently determine the resolution or scale of data. Data aggregation can summarize a dataset e.g. hourly traffic over a month is averaged into daily data values. This means that the granularity of the data becomes lower. In the context of traffic data, allowing the user to dynamically change the data granularity means that data is being aggregated and updated to the visualization simultaneously. This can play a pivotal in data exploration and interpretation since users may be looking for multiscale visualizations e.g. if visual analytics tasks of a traffic analyst require visualizations of daily dataset, but with further exploration within hours of a day as well. It allows the users to be able to perform both, macro and micro analysis (He et al., 2019).

Data aggregation and granularity changes in traffic data visualizations are mostly limited to the temporal dimension. Figure 13a from taxi trip visualization by Ferreira et al. (2013) also shows a step size which the user can use to aggregate the time data by hour, or number of hours etc.

4.2.5. Juxtaposing and Superimposing

Juxtaposing and superimposing are somewhat similar visualization tools. In juxtaposing multiple visualizations which show how spatial, temporal or attribute value propagates, are placed side by side. On the other hand, superimposing is when the sequence of views are overlaid onto each other. Juxtaposing requires access to the user's short term memory to investigate how traffic changes, as the user transitions between the parallel views. It also takes up more screen space. In this aspect, superimposing is slightly better as it requires less screen space, however the transition between both views determines the quality of the visualization. Since traffic data is dynamic, stationary traffic data is changing over time, while moving traffic data is changing over time, and space. Thus, juxtaposing and superimposing are good visualization techniques in this regard and can further lead to the use of animations. Figure 14 introduces the PolyCube Mayr & Windhager (2018) and how a STC could be converted to juxtaposition, and then further onto superimposition.

Figure 14: Juxtaposition and superimposition with respect to STC (Mayr & Windhager, 2018).

4.2.6. Multiple Coordinated Views

Among other visualization tools, multiple coordinated views greatly enhances the functionality provided by a visualization. It caters to the multidimensionality of traffic data by providing a dedicated view for the spatial dimension, and supporting views for the temporal dimension in abstract space. These views are interactively linked to each other, and hence they allow the simultaneous and collaborative view of spatial locations and extents, and temporal attribute values of traffic data. The temporal view mostly represents data in line or bar charts across time, as shown in section 4.1.1. Having a dedicated view for temporal information also allows exploration of data trends over time (He et al., 2019).

Multiple coordinated views consequently leads to a dashboard framework for visualization applications. It presents the users with interactive multiple focused views i.e. spatial and temporal aspect, and additionally other attribute aspects as well. It utilizes the display space efficiently and results in high visual literacy. In the dashboard, additional attribute information may also be presented in more views. Sometimes PCP can be show in a view to visualize multiple attribute data related to the traffic data (Andrienko et al., 2017). Normally one section of the dashboard is dedicated for interactive data selection and aggregation options.

Figures 3, 10 and 13 show examples of dashboard based traffic visualizations already discussed. Figure 15 shows the interface of an interesting visualization tool developed by Wang et al. (2014). Taxi trajectory data set is used to visualize the traffic flow density distribution on the road (view e), with multiple supporting coordinated views. Figure 15a shows how the number of cars vary across time for both directions of traffic data, while figure 15b shows correlation of distance of a journey and average speed. Figure 15c and figure 15d show the saturation of a road and status of vehicle behavior on the road respectively. It is evident how spatial and temporal dimension along with other attribute information is incorporated here. Figure 16 shows a comprehensive visual analytics framework for exploring and monitoring traffic. It incorporates multiple coordinated views, data selection and filtering and other interactive features. Figure 16 a-f represent a data selection interactive menu, attribute view in a table, temporal radial graph, the spatial map view to show traffic speeds and volume, video camera feeds and real time data feeds, respectively. Figure 17 shows a visual analytics tool by Pack et al. (2009) to visualize traffic incident point based data. It supports data filtering and has multiple coordinated views in the form of a spatial map and temporal graphs.

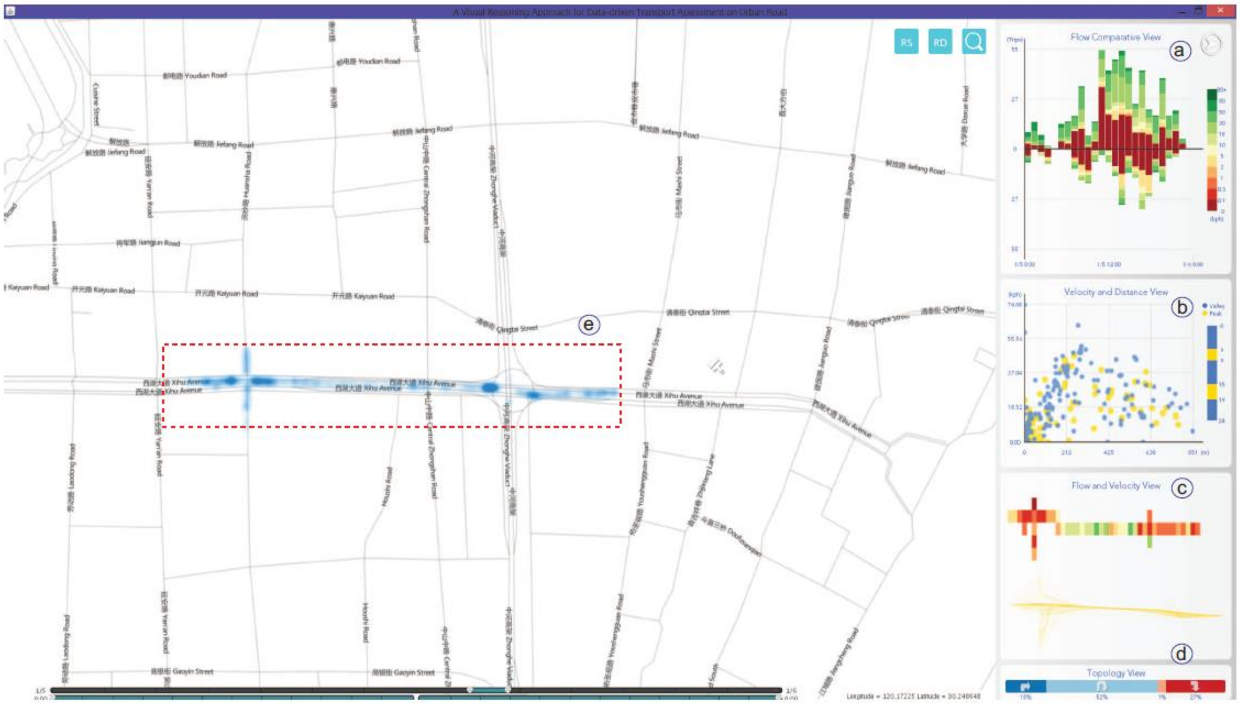


Figure 15: Traffic data visualization based on multiple coordinated views and incorporating other visualization tools and methods (Wang et al., 2014)

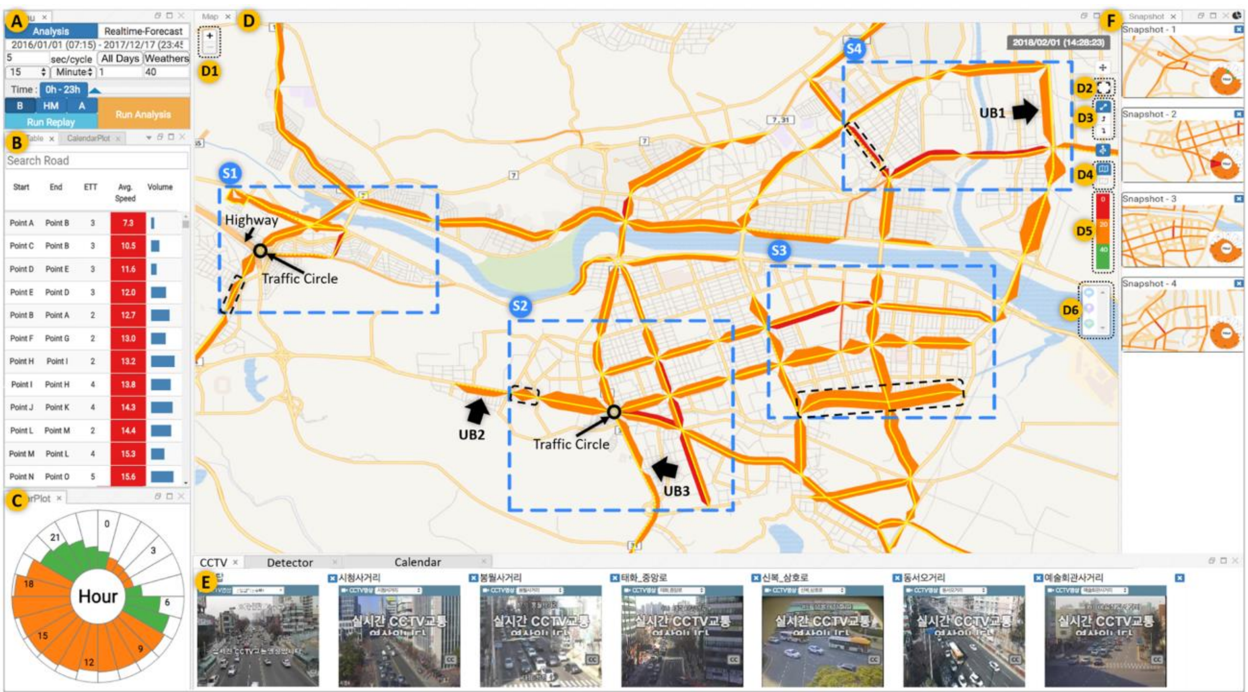


Figure 16: Traffic data visualization based on multiple coordinated views and incorporating other visualization tools and methods (Lee et al., 2020)

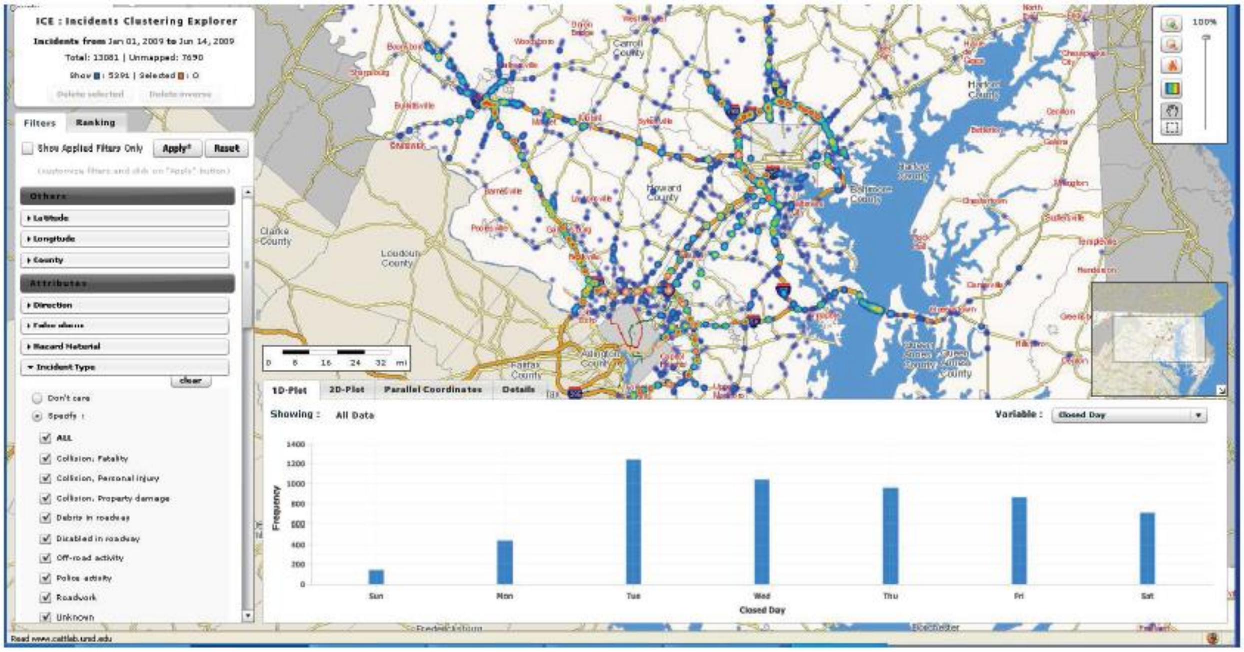


Figure 17: Traffic data visualization based on multiple coordinated views and incorporating other visualization tools and methods (Pack et al., 2009)

4.3. Requirements from Preliminary Questionnaire

A preliminary user requirements study was circulated among a small group of potential users for the traffic visualization prototype to be developed. The user requirement study questionnaire is presented in Appendix I. The aim of this user study was to gather what traffic data, and visualization frameworks are in use already. More focus was kept on questions about what kind of spatial visualization and visual analytics tasks would the users be interested in, from a potential traffic visualization prototype.

Most of the users are using travel speed data from Floating Car Data (FCD) and traffic flow data from stationary sensors. One user also mentioned mean speed data from cellular phone data is being used. Traffic data from surveys was also being used by one user.

Majority of the users are using static GIS frameworks or traffic modelling software along with supporting time based graphs and charts e.g. Quantum GIS (QGIS). The users focused on a visualization prototype that would allow dynamic visualization of time which would greatly support further analysis e.g. visualizing mean speeds for different times of the day. One user also mentioned that sometimes for traffic data analysis most recent data needs to be visualized at a higher granularity level, while historic data could be summarized and aggregated. Overall the users focused on dynamic and interactive functions from the visualization prototype, especially for the temporal dimension. Whereas for the spatial dimension, the users emphasized on a visualization that should be based on the actual road network.

In the question regarding spatial patterns of data, the users were interested in road segments with recurrent congestion issues i.e. bottlenecks within specific routes. One user mentioned the capability for spatially investigating how a traffic congestion event propagates through time. Another user mentioned the ability to investigate if specific congested road segments are dependent on their neighboring segments, or also location of traffic lights or road intersections. Users also emphasized on the ability of the visualization to cope with large datasets.

Regarding temporal patterns, users were interested in what the rush hour times are in the city and how the flow of traffic is affected over time from traffic jams and traffic incidents. Additionally temporal patterns in commuting times over weekends and holidays.

Lastly, the users were questioned on relevance of traffic issues outlined in section 1.2. These traffic issues are: (1) spatial identification of traffic congestion at a specific time, (2) temporal identification of traffic congestion at a specific location, (3) duration of a traffic congestion event, (4) spatial extent (length) of a traffic congestion event, (5) spatial and temporal patterns of traffic congestion and (5) identification of bottle necks in traffic flow. Questions 6 to 9 of the questionnaire relate to these issues, and all of the users believed that these issues were very relevant for such a traffic visualization prototype.

4.4. Traffic Attribute Overview

In section 4.1 and 4.2 an overview is provided of the traffic visualization methods, and traffic visualization tools. It has been observed how traffic changes over time and space, however actual traffic attributes that are most commonly visualized are listed in table 3 with a short description. Figure 18 shows the traffic visualizations on a traffic dataset of Milan, Italy by Andrienko et al. (2017). This work very gracefully overviews visualizations from section 4.1. It is evident that the same dataset of traffic can be used to render different kinds of visualizations. Figure 18a shows point data of car stops, 18b shows car journey trajectories as lines, 18c shows the same trajectories in STC, 18d shows traffic flow at a specific time aggregated in spatial areas and represented as sized circles, 18e and 18f show density mapping along the road network respectively, 18g and 18h show number of cars travelling between different spatial areas as arrowed or curved lines respectively and 18i represents mean car speeds in a colored scale. Note how some methods cause visual clutter e.g. 18a and 18c, while some methods hide the road network e.g. 18e and 18f.These ideas have already been discussed in section 4.1 and 4.2.

Table 3: Traffic attributes and description

Traffic Attribute	Description
Traffic Incidents	Events related to traffic e.g. accidents or traffic jams
Traffic Flow	Number of cars passing a point
Traffic (Flow) Intensity	Traffic flow per unit time
Traffic Density	Spatial distribution of traffic e.g. across lanes
Number of Trips/Journeys	Count of taxi trips over a time period
Distance	Distance covered by a moving vehicle
Travel Time	Time taken by a specific journey or road length
Average/Mean Vehicle Speed	The average speed over a certain time and space
Vehicle Emissions	Measurement of vehicle exhaust gases
Pickup/Dropoff Locations Origin-Destination Pair	Locations at origin and destination of a journey/trajectory
Crash Risk	Road safety measure
Direction	The overall direction of a trajectory
Vehicle type	Identification of size of vehicles mostly used to differentiate heavy vs light traffic e.g. trucks and cars
Free Flow Speed (FFS)	Driver's preferred speed on road segment with low traffic and no traffic controls (Abdurrahman et al., 2014). FFS is calculated mostly for highways, over a large dataset of time and vehicles.

Zhicai et al. (2004) which describes traffic congestions as "a phenomena of reduction in mean speeds (in comparison to free flow speed), an increase in travel time, increase in vehicle density, and frequent stop and go of vehicles". The study of travel times and related indices is very vital in understanding the traffic flow conditions and identification of traffic congestion. Travel Time Reliability (TTR) Measures are being used by transportation planners such as Federal Highway Administration (FWHA) of the United States Department of Transportation to investigate traffic conditions on highways (Lyman & Bertini, 2008; Chen, 2010). However, it was discovered that TTR measures have been rarely used in interactive traffic data visualizations as a method to identify traffic congestion. TTR measures explore the consistency and reliability of travel times as compared to absolute numeric travel time itself (Lyman & Bertini, 2008). Thus, they can be of more importance to traffic planners as they can identify the relative or extra time taken for vehicles to travel. Among other TTR measures, the Travel Time Index (TTI) is more focused towards measuring the congestion intensity. TTI is the ratio of actual average travel time to the free flow travel time. Thus, TTI has high potential to be used in interactive traffic data visualization and is further discussed in section 5.3.

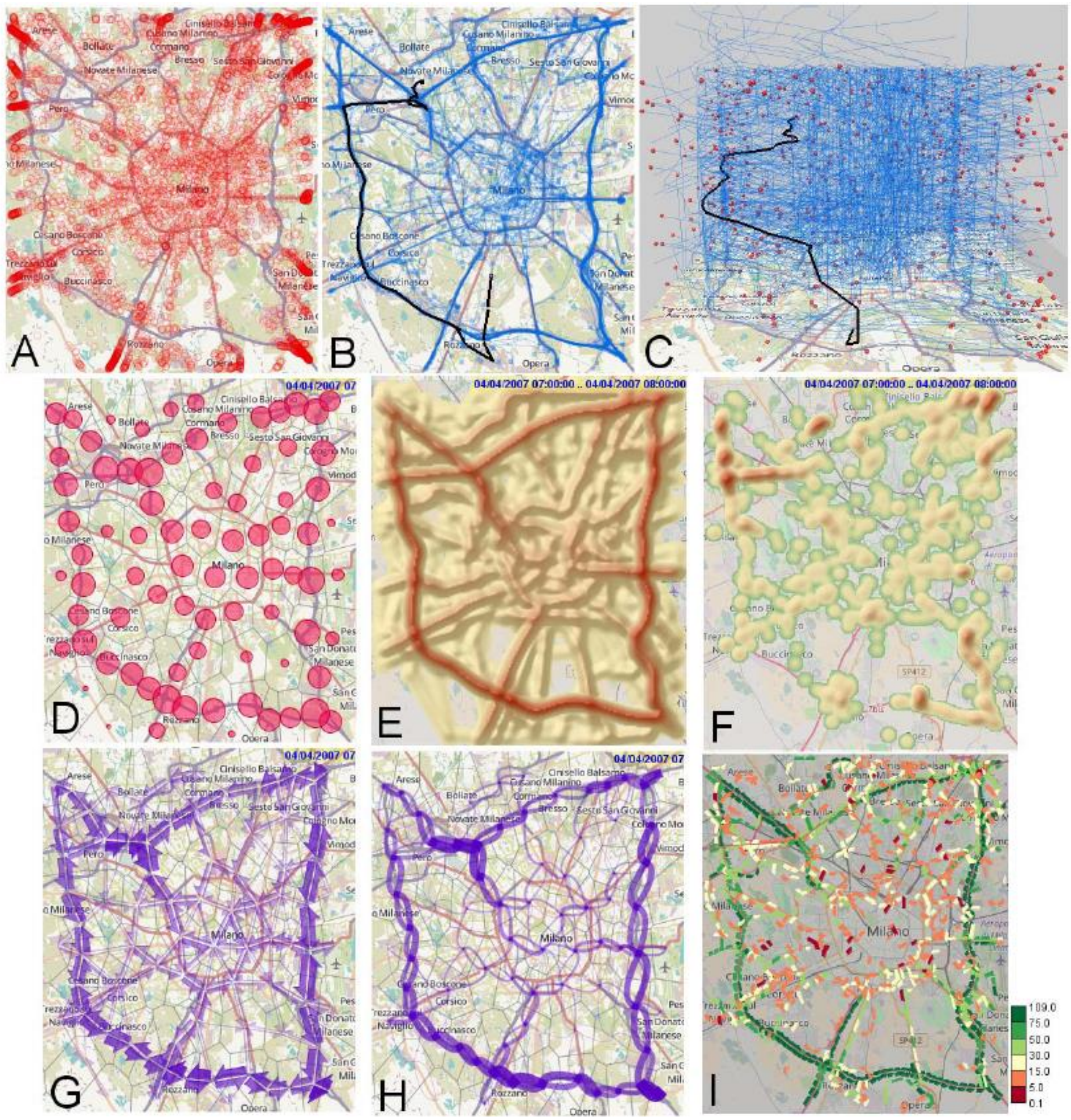


Figure 18: Combination of traffic data attributes, visualization methods and visualization tools for Milan, Italy (Andrienko et al. (2017).

5. Prototype Design and Development

This chapter will cover the main part of the thesis related to the visualization methods, visualization tools, user interface design concepts and the overall development of the prototype. It refers to research objective 2 and will answer the research questions 2a, 2b and 2c. It describes the traffic data and phase two (red boxes) in the methodology flowchart (figure 5). The visualization methods, visualization tools, traffic attributes and requirements from the preliminary user requirement study have been established in chapter 4. They will be referred to and further discussed as design concepts for the traffic visualization prototype development.

The traffic visualization prototype also follows a data driven approach and partially depends on the traffic data provided by Salzburg Research Forschungsgesellschaft mbH. FCD data is collected through GNSS measurements for vehicle trajectories and matched onto the road network of Salzburg. It shows the travel times of vehicle trajectories (Rehrl et al., 2018). This leads to line based traffic data over the road network. The dataset is further explained in section 5.1.

Thus, line based visualization methods will be used to visualize this traffic data on the road network with options for multiple visualization styles. As outlined in section 4.1.2b, traffic data visualizations over a map based road network (in comparison to origin destination trajectory data) are most useful to identify traffic attributes as they are precisely visualized over the actual roads. This leads to a high visual literacy and intuitiveness for the users and reduces visual clutter. This has also been observed as a requirement in the preliminary user requirements study. On the other hand, the temporal dimension has also been emphasized in section 4.1.1, thus, time based visualizations will be incorporated in an independent abstract space as bar and line charts, linked to the spatial map view.

Among the visualization tools discussed in section 4.2, a dashboard approach incorporating multiple coordinated views will be implemented. This will allow users to visualize the spatial component as well as the related temporal data linked through interactive views. Further enhancement and support for data exploration and interpretation will be achieved by providing users with options to change spatial and temporal granularity, as well temporal selections of specific subset of data (spatial subset maybe achieved through pan and zoom). This will considerably increase the visual analytics ability of the visualization as it allows data manipulation and filtering options to the users. The user requirements study also supports the need for dynamic and interactive visualization allowing temporal selections and aggregates. Afore mentioned visualization tools will be provided embedded interactively within the user interface, allowing users options to manipulate the view, the visualization style, data granularity and selection.

Traffic attributes used for the visualizations will be TTI and the more conventionally used mean speeds. Users will be able to interactively change between both attributes as well. These features incorporated with the above mentioned design concepts will allow a comprehensive approach to tackle tasks of traffic planners and experts such as traffic congestion identification on a temporal and spatial level. The visualization prototype will overall follow the “Visual Information Seeking Mantra” proposed by Shneiderman (Craft & Cairns, 2005). It is a guideline for visualization frameworks which states “Overview first”, then “Zoom and Filter” and lastly “Details on Demand”.

5.1. Traffic Dataset

The FCD dataset is collected from anonymous GNSS measurements of moving vehicles. The time and location of vehicles is saved and converted to vehicle trajectory data after cleaning and filtering. The vehicle trajectories are temporally ordered and further filtered and cleaned, after which they are mapped onto the road network using map matching algorithms. This determines vehicle paths over the road network, which are matched to graph based road links developed by the Austrian Institute for Traffic Data Management (Graph Integration Platform GIP, n.d.). Hence, travel duration over these road segments of known length are collected through which average speed of vehicles is determined (Rehrl et al., 2018).

Preprocessed data was provided by Salzburg Research for nine major routes for the city of Salzburg, Austria. These route start from all directions at the city outskirts and end at three major parking spaces in the city center. The data was provided for a period of two years and was for traffic incoming towards the city. The data was in its greatest spatial and temporal granularity i.e. road segments (825 in total) and 15 minute time intervals (further explained in sections 5.5 and 5.6). The data included traffic attributes of travel duration (and free flow travel duration), mean speed (and free flow speed) and TTI for each road segment, over a 15 minute time interval. From the two year dataset, one month was extracted to be used in the prototype visualization. Speed and TTI data was extracted and formatted in Comma

Separated Value (CSV) files, the column headers of the CSV file are mentioned in Appendix II (summary view of which is given in table 4).

Table 4: Format of the dataset used

Timestamp	Segment_id	TTI… (96 cols)	Average TTI	Speed… (96 cols)	Average Speed
Date (30 rows of each segment)	Identification of segment (825 segments)	TTI values in 15 min intervals over the day	TTI daily average	Speed values in 15 min intervals over the day	Speed daily average

For the extracted month (June 2019), a total of 5534190 data records were present in the data (825 segments * 30 days * 200 columns of attribute data). Due to the massive size of the dataset, the visualization prototype was limited to one month of data, while aggregated information from the 2 year dataset was incorporated as well, (further discussed in section 5.6). Spatial data is in the form of a GeoJSON (Javascript Object Notation) file. The GeoJSON file had route_id, section_id and segment_id which acted as primary key and were linked to attribute data through foreign key columns of same name in the CSV files.

5.2. Deck.gl and AmCharts

The technology framework used for the spatial traffic data visualization is deck.gl, a powerful Web Graphics Library (WebGL) developed by Uber Engineering. It allows artistic and informative spatial visualizations. There are many embedded interactive features and visualization tools in deck.gl. Additionally, this framework is capable of handling and rendering large datasets with great accuracy and computational performance. This feature alone would be very vital for the traffic data visualization prototype as we have seen in the previous section that the size of the dataset is huge. Deck.gl is very easily integrated with Mapbox.gl which is another WebGL framework suited especially for web-GIS based visualizations, incorporating basemaps (Deck.Gl, n.d.; Mapbox, n.d.).

AmCharts was used for making interactive linked temporal graphs to support the spatial data view. It is a fast and efficient JavaScript library for graph and chart visualizations, with functions allowing it to integrate with other frameworks easily (JavaScript Charts & Maps, n.d.). Other technology frameworks used were simple web application development languages; JavaScript, HTML and Cascading Style Sheet (CSS).

5.3. Traffic Attributes and Data Classes

There are majorly two traffic data variables used, the Travel Time Index (TTI) and Average Speed (km/h). TTI has already been introduced in section 4.4. TTI for a specific road segment (s) and a specific time interval (t) is the ratio of mean travel time to estimated free flow travel time (estimated using 85th percentile travel speed):

$$\mathrm{TTI}_{s,t} = \frac{\text{average travel time}_{s,t}}{\text{freeflow travel time}_{s,t}}$$

Average speed has been provided as a supporting variable since users of traffic visualization applications are conventionally more accustomed to numerical speed values. However, the users will have the option to interactively change the traffic attribute and thus perform data exploration and investigation using both variables. Users will also be able to identify and interpret traffic congestion using both traffic attributes. Use of the traffic attributes by the users will be evaluated in section 6.3.1.

Since TTI is a ratio index, its values ranged above 1. TTI value of 2 at a specific time interval would mean that a road segment which can normally be journeyed across in 20 minutes, now takes 40 minutes instead. Values of TTI mostly ranged between 1 and 2, hence the scale for TTI was designed in such a way that would allow better spread of frequency of data values over the scale categories used. A total of 6 classes were used, with an interval of 0.25 between 1 and 2, while the interval above 2 was kept at 0.5, with the largest interval covering TTI values above 2.5 (this also covered extreme traffic congestions cases where TTI values reached around 10 as well, since some road segments are extremely small, very large TTI values are still realistic in traffic jam situations). Figure 19 shows the frequency distribution and cumulative frequency of data values over these 6 data classes.

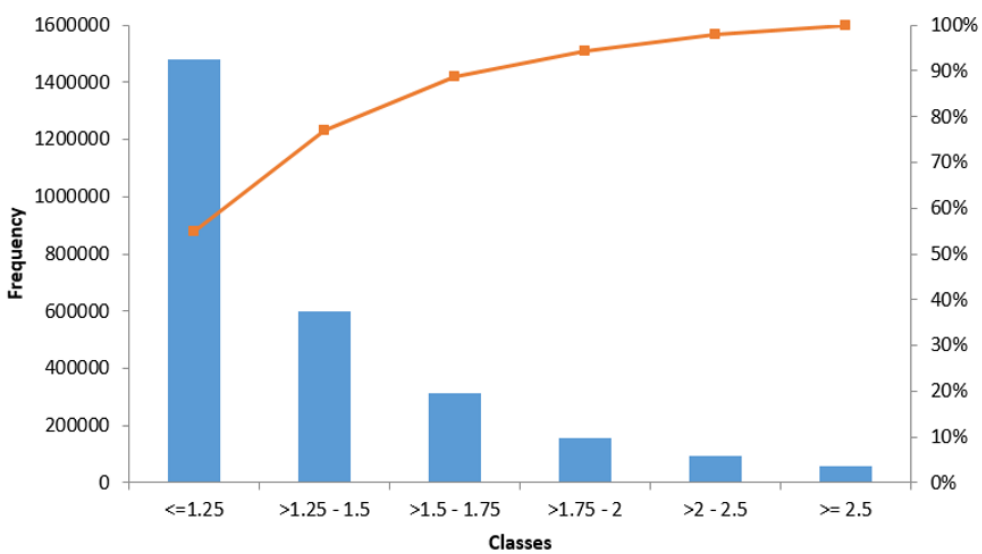


Figure 19: Frequency distribution of TTI data classes

On the other hand, mean speed values ranged from 5 km/h to 87 km/h. Since the lower speeds relate to traffic congestion issues, a data interval of 10 km/h was chosen for speeds between 0-50. In Austria, speed limits within city limits is usually 50 km/h (Chancellery, n.d.) hence the one data class for speeds above 50km/h was used which would be for cars travelling at high speeds at the city outskirts. Figure 20 shows the frequency distribution and cumulative frequency of data classes used for average speed.

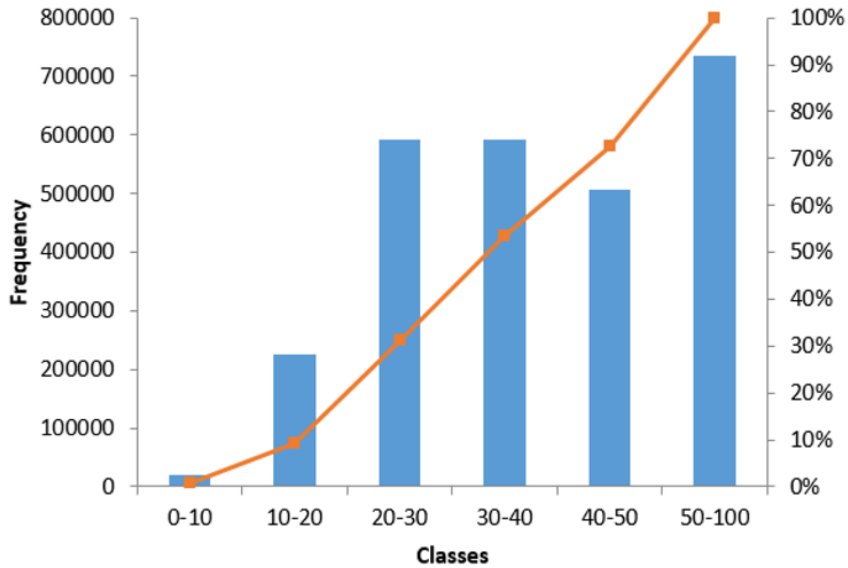


Figure 20: Frequency distribution of Speed data classes

5.4. Visualization Styles

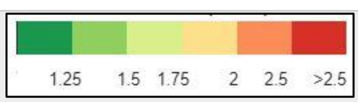
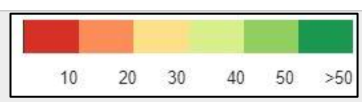
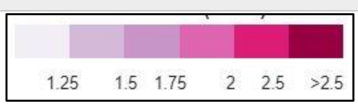
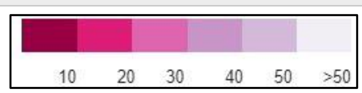
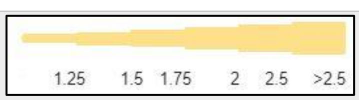
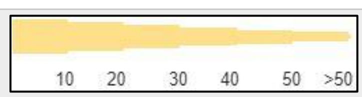
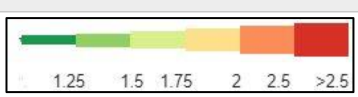
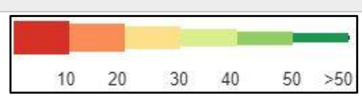
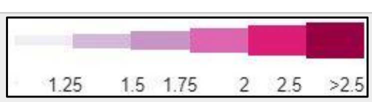
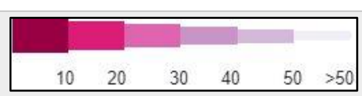
Table 5 shows the five unique visualization styles established using two visual variables. The visual variables were 'color' and 'size'. Color Brewer (ColorBrewer: Color Advice for Maps, n.d.) was used to generate two color schemes, a diverging color scheme and a sequential (multi-hued) color scheme. This meant that both color schemes changed over the three perceptual dimensions (hue, saturation, lightness) of color. The sequential color scheme is used for ordered data set over a low to high range. Color lightness is changed in a sequential multi-hued color scheme with dark colors for higher data values following the cartographic standard principle of dark color being associated with higher data values. A multi-hued color scheme was used instead of a single hue to maintain better color contrast between data classes (Harrower & Brewer, 2003). Sequential color schemes are also color blind friendly, hence it was an important design concept to incorporate one color scheme that is color blind friendly. The sequential purple colored scheme used, also contrasts well with most of the basemaps used (except lower values with the 'light' basemap). The sequential color scheme is suitable for selective, quantitative and ordered visual variable properties (Visual Variables, 2020).

The diverging color scheme is very useful when a critical data class needs to be focused (Harrower & Brewer, 2003); traffic congestion in our case. It will help to emphasize the higher data values which relate to traffic congestion on the roads. The green to red color scheme is used due to its familiarity for users, since similar diverging color scheme has been used in many traffic data visualization and users are able to correspond to green color for less traffic congestion/high speeds and red color for higher traffic congestion/low speeds (Google Maps Help, n.d.). The diverging color scheme contrasts well with all the basemaps including 'light' and 'dark', except lower values with 'satellite'. The diverging color scheme is suitable for selective and associate visual variable properties (Visual Variables, 2020).

Width visualization style changes the visual variable of 'size' which is suitable for selective, quantitative and ordered visual variable properties (Visual Variables, 2020). Use of changing line width is not very common in previous works. A specific color that contrasts well with the base maps was chosen (RGB 254,224,139). The width scale in deck.gl allows width changes in meter or pixels. The meter size was chosen as it scales according to the basemap at dynamic zooming, while pixel sizes remain unchanged on the screen. Higher width was used to refer to high TTI or low speed. Line widths were increased with an interval of 10m, starting from 10m and going up to 60m.

Visualization styles involving combination of both visual variables were also generated as an innovative approach to visualize traffic data. This approach integrated size (line width) and color (diverging scheme and sequential scheme) which is not very common in previous works. The hypothesis is that users will like these combined visualization styles, so it would be interesting to see how users evaluate them. Scales used for TTI and Speed were inverse of each other since higher TTI, whereas lower speed, relates to traffic congestion. This would allow efficient visualization when using either of the two traffic attributes.

Table 5: The five visualization styles for both traffic attributes

Visualization Style	Visual Variable	Scale for TTI	Scale for Speed
Color (Diverging)	Color		
Color (Sequential)			
Width	Size		
Color (Div) & Width	Color & Size		
Color (Seq) & Width			

Other optional visualization styles could have been achieved from changing other visual variables but there were limitations involved. For example, line opacity could be used to change the 'transparency' visual variable, but that would conflict with the basemap as lower scale values would become invisible. Similarly line patterns/ dash array could be incorporated to change the 'texture' visual variable, however since some line segments are very small it would become very difficult to differentiate it from others. Extrusion of line heights according to the TTI or speed values would make an interesting transition to a 3-D visualization. However that would have two limitations, firstly it would become difficult to gain overview of spatially distributed data since the camera view would be biased to the data closer to it and skew the data at the further end. Secondly, deck.gl limits 3-D visualization of line based dataset and allows it on polygons instead, thus posing a technological limitation.

5.5. Spatial Aggregates (Map view)

A selection menu allows users to interactively select data over three spatial aggregates. This enables dynamic level of detail visualization and allows micro and macro visual analytics tasks. Interactively changing the spatial data granularity over road network based traffic visualizations are uncommon in previous works. The three spatial aggregates are:

a) Segments

They are the smallest road segments and show highest data granularity. A new segment starts whenever any minor road leaves or joins a route. Total segments in the traffic data are 825 and they vary in length from 1.01m to 728.75m. The segments show the traffic data set in very high detail, existing between any two intersections/junctions (Rehrl et al., 2017).

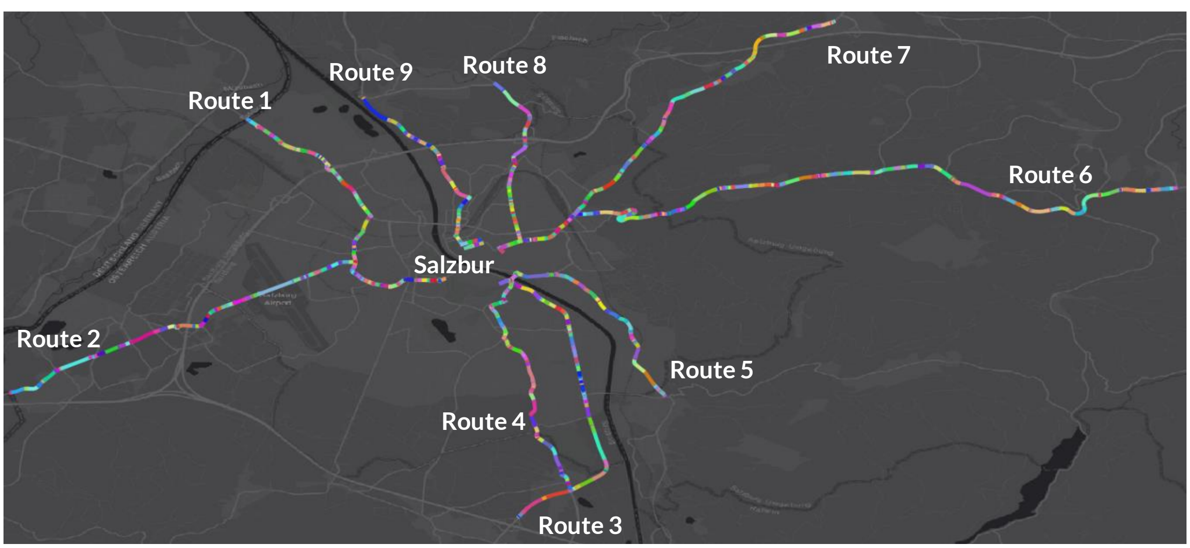


Figure 21: Randomly colored 'segments' within the traffic data set.

b) Sections

They show the middle data granularity. A new section starts when a major road leaves or joins the route. Hence sections are present between prominent intersections/junctions (Rehrl et al., 2017). There are 120 sections in total with section length minimum and maximum at 4.83m and 5980.6m, respectively. Sections are important from the aspect of traffic congestion exploration between major junctions in the city. They show less level of detail and data complexity as compared to segments which can be helpful to reduce the line based visual clutter as well. Figure 22 shows the sections in the data and figure 23 shows screenshots of segment (left) vs section (right) on the same road. Notice how a new segment starts at each street turn, while the sections start at more prominent road junctions. The data for segments was post processed to calculate aggregated values for sections in a separate CSV file.

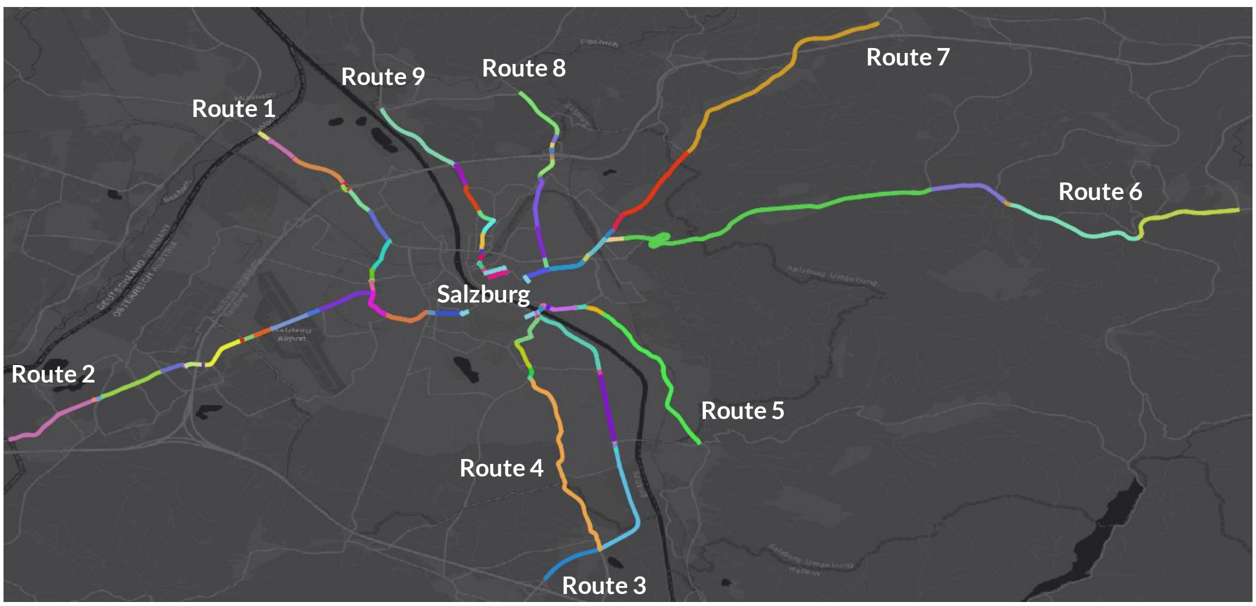


Figure 22: Randomly colored 'sections' within the traffic data set.

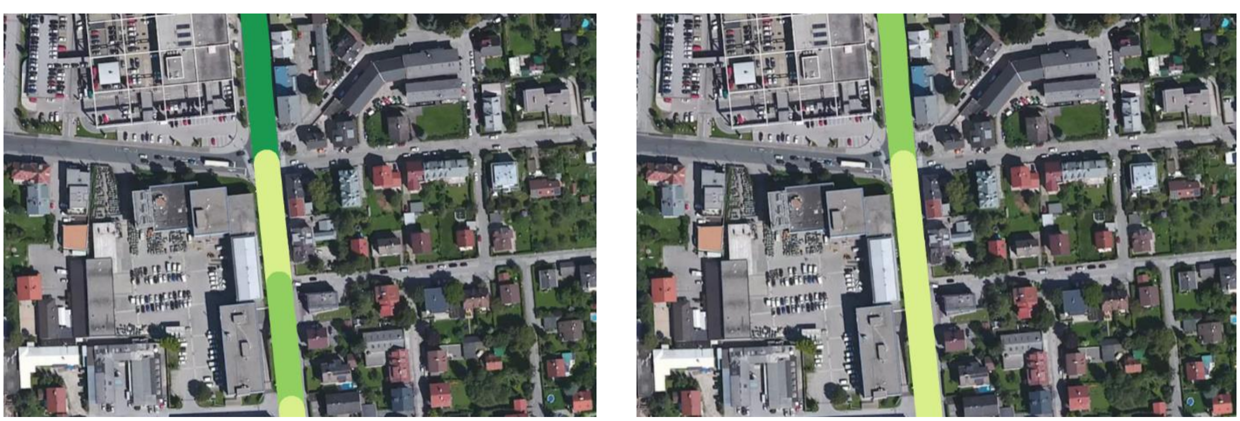


Figure 23: Segment (left) vs Section (right) on the same part of a route

c) Routes

These form the major roads or highways allowing intercity travel as well. They represent the lowest level of details and data granularity. A large number of segments merge together to make a section, which merge together to make a route. The routes represent the coarsest form of visualization, showing one traffic attribute value for the whole route over the time interval. They can be used as a starting point for macro tasks of traffic data exploration. The route length varies from 4908.19m to 13663.72m.

The data is mainly over nine routes coming into the the city of Salzburg. Route 1 starts at Freilassing (north west of Salzburg), Route 2 starts at the German-Austrian border near Piding (west of Salzburg), Route 3 starts at Neu-Anif and Grödig (south of Salzburg), Route 4 starts near Anif (south of Salzburg), Route 5 starts at Glasenbach (south east of Salzburg), Route 6 starts near Hof bei Salzburg (east of Salzburg), Route 7 starts near Eugendorf (north east of Salzburg), Route 8 starts near Lengfelden (north of Salzburg) and Route 9 starts at Bergheim (north of Salzburg). Figure 24 visualizes the routes.

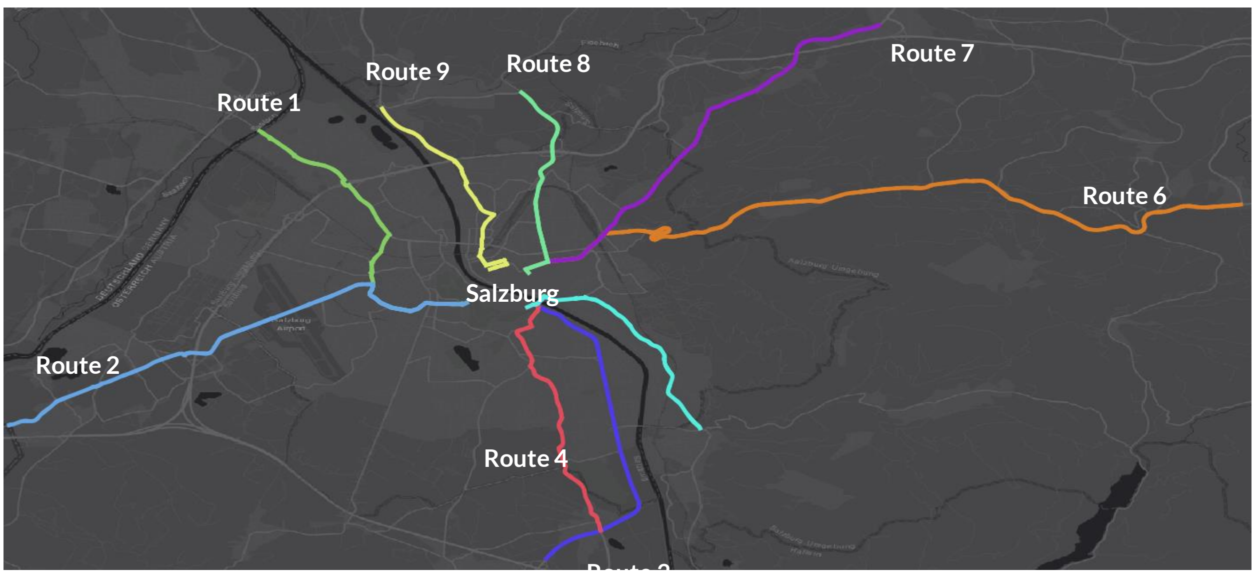


Figure 24: The 'routes' within the traffic data set.

5.6. Temporal Aggregates (Graph View)

There are five temporal aggregates in total, which are linked to all three data granularities of the spatial dataset. This means that these five temporal aggregates exist for each of the three spatial aggregates. The temporal data is arranged in linear time based charts in abstract space contained in a separate 'pop-up' window. This window is triggered by clicking on a particular segment, section or route that needs to be explored. TTI is visualized as a bar graph colored in blue with a left hand primary vertical axis, while speed is simultaneously visualized as a line graph colored in red on the right hand secondary vertical axis. This design allows visualization of both traffic attributes across time without visual clutter. The temporal graphs are most useful for getting an overview of how traffic attributes varied over a time unit. The users can employ these features to explore and investigate low and high values in a day, month or year. The user can then select a specific time through the time selectors to change the spatial view to these identified low and high values for further spatial exploration. These time aggregates are 15-min, hourly, daily, monthly and yearly. Table 6 shows a detailed description of each time interval, this includes what the chart title mentions, what the chart view shows, and how the data is fetched. Figure 25 shows all 5 temporal granularity graphs for a specific segment id.

As mentioned in section 5.1; from the dataset of 2 years, detailed data of one month chosen randomly i.e. June 2019 was incorporated on a more detailed level. The time selectors and graph view of 15 minute, hourly and daily apply to only June 2019 (as these selections are more data intensive, highlighted grey in table 6). The monthly and yearly selectors and graph views are applicable to the full dataset from October 2017 to October 2019 (as these selections are less data intensive since monthly or yearly aggregated values are visualized).

Table 6: Details of temporal dataset and graph view.

Temporal Aggregate	Data (each spatial agg.)	Chart Title mentions	Chart View shows
15 min (highest granularity)	96 values per day for TTI and speed in CSV files	Section/Segment/Route ID Current Date of June 2019 Current 15 min interval visualized in spatial view	Chart view for TTI and Speed for full day (96 intervals / day)
Hourly	24 values per day for TTI and speed calculated on the fly	Section/Segment/Route ID Selected Date of June 2019 Current hourly interval visualized in spatial view	Chart view for TTI and Speed for full day (24 intervals / day)
Daily	30 values per month for TTI and Speed in CSV	Section/Segment/Route ID Current Date of June 2019 visualized in spatial view	TTI and Speed for full month (30 intervals / month)
Monthly	12 values per year for TTI and Speed in CSV	Section/Segment/Route ID Selected Year Current Month visualized in spatial view	TTI and Speed for full year (12 intervals / year)
Yearly (lowest granularity)	3 values for TTI and Speed in CSV	Section/Segment/Route ID Current Year	TTI and Speed for 3 years

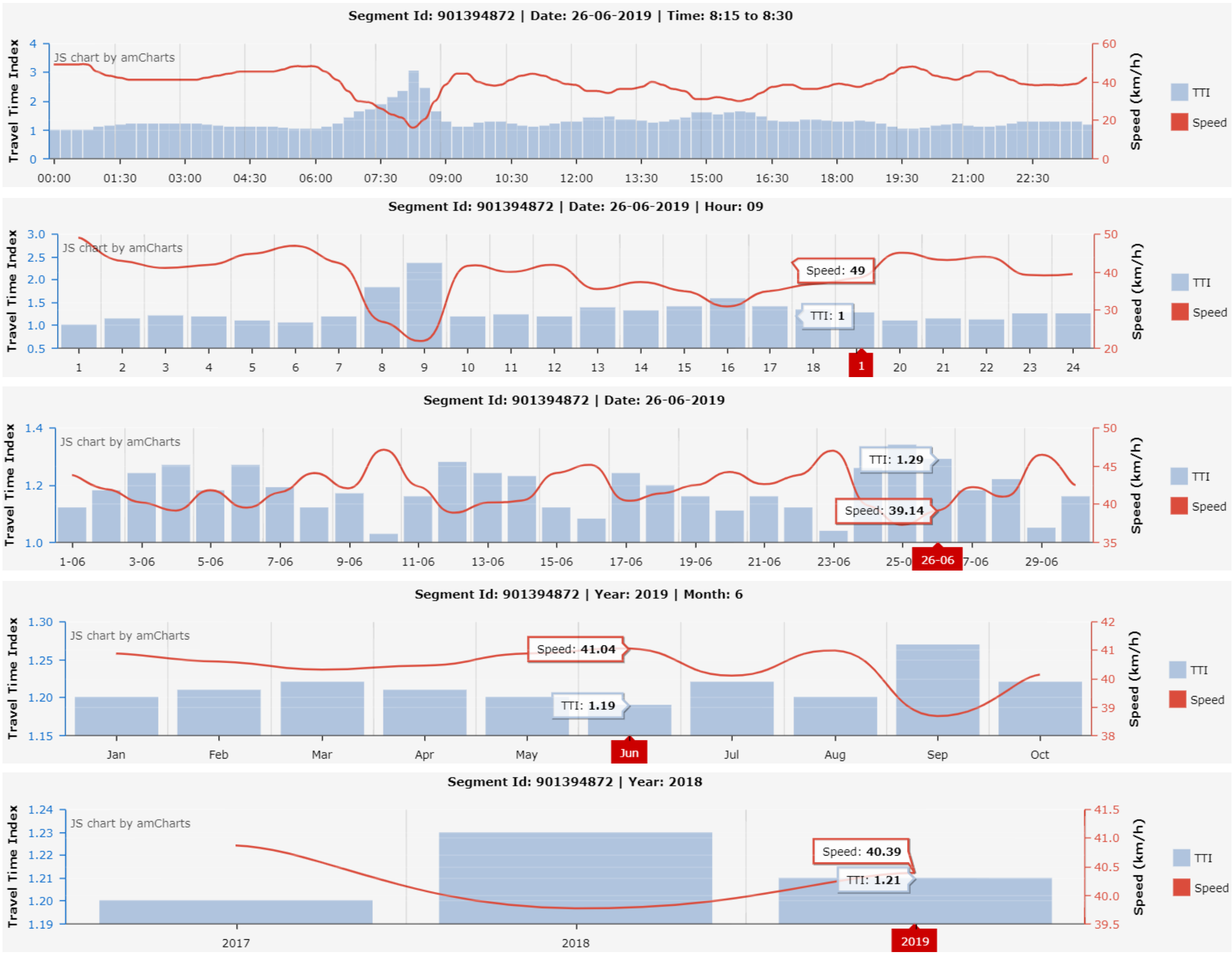


Figure 25: Graph view for same segment for all 5 temporal aggregates, from top to bottom; 15min, hourly, daily, monthly and yearly. Interactive popup over the graph on hover can also be seen.

5.7. Basemaps

Four built in basemaps from Mapbox have been incorporated in the prototype. Only those basemaps were included in the visualization that allowed good contrast with the data. These include the 'dark' and 'light' basemaps. Both of the basemaps are plain colored and allow a dark or light background, respectively. Location labels are subtle and do not conflict with the data. The dark basemap is suitable for general data visualization, while light basemap is very suitable for identifying darker data values (i.e. traffic congestion or low speed areas). The 'satellite' basemap allows users to see satellite imagery overlaid under the road network. This is particularly useful if traffic planners want to see landuse and landcover features with the traffic data. However, areas with greenery may conflict with low data values in diverging color scheme (which are green as well). Figure 23 shows an example of this. The 'navigation night' is also a dark colored basemap with focus on Point of Interest (POI), road and highway labels. It also shows road levels from Mapbox and is particularly interesting with the section spatial aggregate. Figure 26 shows a small view in the different basemaps. Among other maps not included were ‘outdoors’ and ‘streets’.

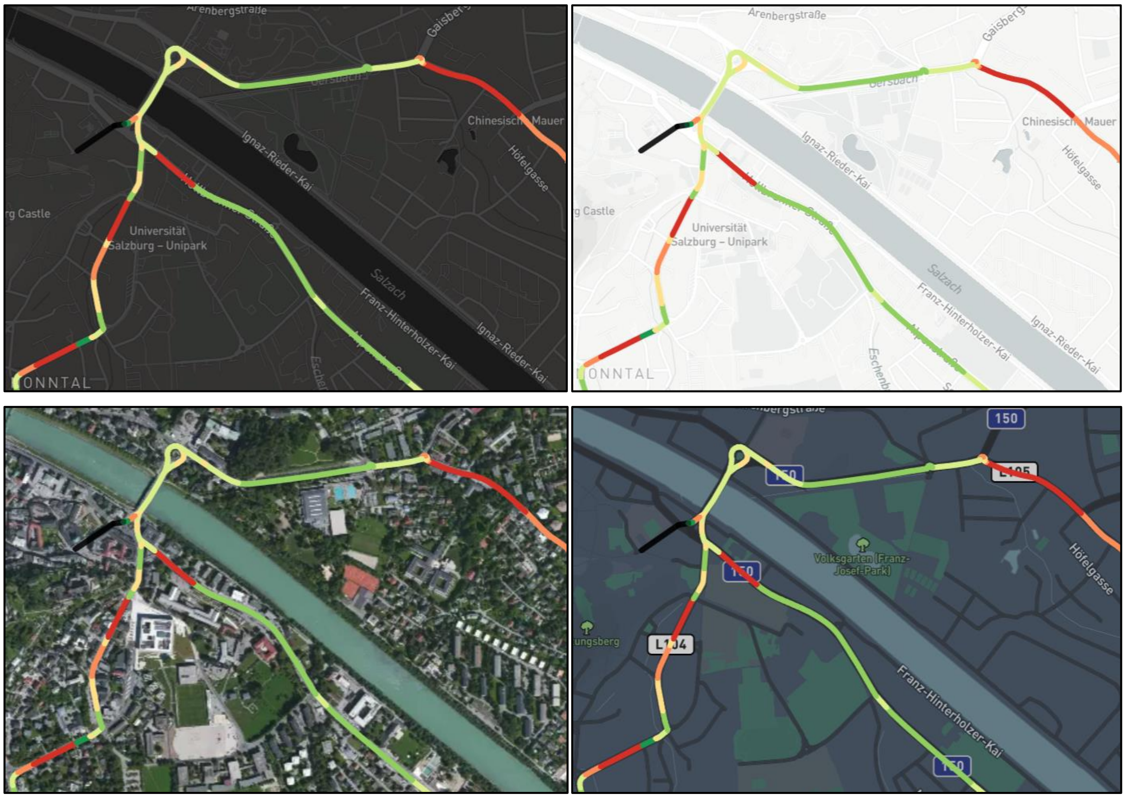
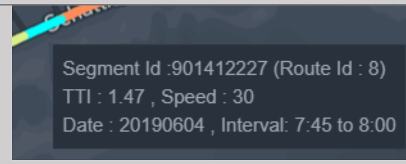
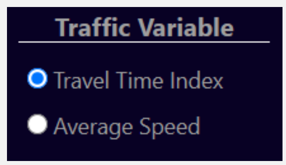
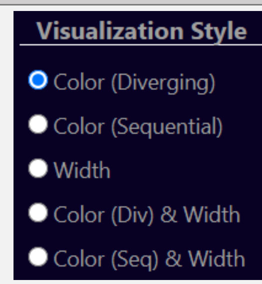
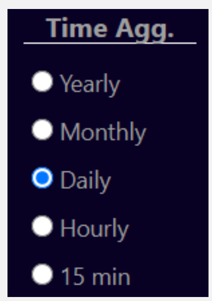
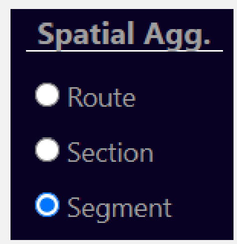
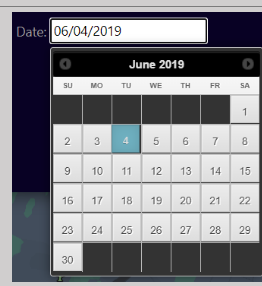
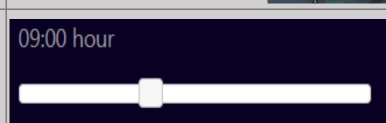
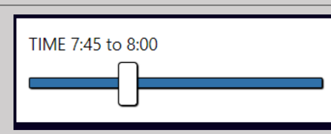


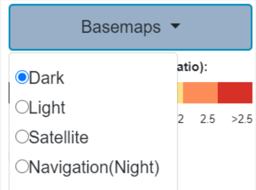
Figure 26: Basemaps used in the traffic visualization prototype. Dark basemap (top left), Light basemap (top right), satellite basemap (bottom left) and Navigation Night basemap (bottom right).

5.8. Interactive Elements

Interactive elements are the backbone of the developed prototype, they allow users to communicate with the visualization to enhance the experience of traffic data exploration and investigation. This greatly helps in visual analytics for investigation of traffic congestion. Table 7 shows a comprehensive summary with screenshots of the interactive elements, their interaction type, functionality offered and a snapshot from the user interface. Thus, these combined views give a dashboard design framework to the prototype.

Table 7: Functionality of interactive elements embedded in the visualization prototype

User Interface	Function	Interaction	Snapshot from the visualization prototype
Spatial View	View Manipulation	Mouse click, drag, scroll	Pan, Zoom, Tilt (can allow spatial data selection as well by controlling view)
	Highlight	Mouse Hover	Highlights segment that is hovered
	Data information popup		Shows: ID, TTI, Speed Date, Time 
Selection Menu (left panel of user interface)	Traffic Data Selection	Radio Button	
	Vis. Style Selection		
	Spatial Agg. Selection	Radio Button	 
	Temporal Agg. Selection		
Selectors triggered by temporal Aggregates	Temporal Data Filtering/ Selection	Drop down menus	 
		Calendar (Date Selection)	
		Time Sliders (Hourly/15 min interval selection)	  Can be animated by left and right keys

Right Panel	Legends	Automatic Update	Dynamically updated according to the traffic attribute and visualization style (see table 5)
	Basemap Selector	Drop down menu	
Graph View	Temporal Data View	Mouse Click	Graph according to the temporal aggregate is generated in a window at the bottom of the user interface by clicking the segment/section/route
		Hover	Data values show as a pop-up at hover (figure 25)
		Click	Clicking the legend in graph can allow removing or adding TTI or Speed to the graph plot

5.9. Prototype Summary

Sections 5.1 – 5.8 have comprehensively stated the design concepts used in the traffic visualization prototype development. The data files used are property of Salzburg Research, hence only the headers from data file, data format and size of dataset (table 8) have been discussed in the thesis. The attribute data is saved in separate CSV files for three spatial aggregates; routes (with route_id as primary key), sections (with section_id as primary key), segments (with segment_id as primary key) for June 2019. Similarly data for aggregate yearly and monthly values is saved in three separate CSV files. The spatial data is saved as a GeoJSON file in which the segment line geometry is saved, each segment has a segment_id, section_id and route_id. The programming of the prototype links these foreign keys to primary key in the data attribute CSV files. These files pass the data to deck.gl for rendering the visualization. A transition time of 0.5 sec is set between all selections' options (e.g. spatial aggregates, temporal aggregates and selection etc.). The data loaded from the CSV is also passed to AmCharts for generation of charts. The Javascript code for the visualization prototype is in Appendix III, it was hosted online (https://arslanaslam92.github.io/Traffic_Visualization/) to share it with users for the user evaluation study. Figure 27 shows the visualization prototype interface with a short explanation (also used as an introduction in the user evaluation study).

Table 8: Data values handled by the traffic visualization prototype

Travel Time Index (TTI) and Average Speed

	Aggregates	Segment (825)	Section (120)	Route (9)
TTI and Speed	15 min	5534190	703093	53190
	Hourly	1529550	198000	14850
	Daily	194670	18000	1080
	Monthly	115875	12000	900
	Yearly	13905	1440	81

The main user interaction and selection menu. The tasks and questions in the study will be regarding these selections and how they affect the traffic data visualization:

Traffic Variable – what traffic data to see?
Travel Time Index: ratio of selected travel time to free flow travel time
e.g. TTI of 2 means that a 10 minute journey would take 20 minutes instead.
Average Speed: Average speed (km/h) of observed vehicles.

Visualization Style – how the traffic data is visualized?
There are 5 available styles that allow you to change the color scheme, the road width or a combination of both. Each style offers a unique way to explore the data set. The second part of this study will mainly focus on how these visualization styles compare to each other and help you in performing the required tasks.

Spatial Aggregate – what spatial aggregation will be applied to the road features?
9 routes (largest road length)
120 sections (smaller than routes - starts at intersection of major roads with a route)
951 segments (smallest road length - starts at intersection of small roads with a route)

Time Aggregate – what temporal aggregation will be applied to the traffic data?
Yearly averages: from 2017 - 2019
Monthly averages: from October 2017 - October 2019
Daily dataset is just for the month of June 2019, with data in unit of daily average, hourly or 15 minute intervals - for all 30 days of the month.
Each time aggregate opens up it's own time selector

Map legend and traffic variable units. Also the option for user to change the basemap.

The main map view to spatially visualize and explore the traffic data (zoom and pan functions are applicable).

Hover window which shows ID, TTI, speed and time information of the route/ section/ segment over which the mouse pointer is. Note: Hovering over road features highlights segments only.

The graph view generated on clicking a road feature. It displays traffic variable information according to the selected spatial and temporal resolution which is also mentioned in the graph title. (Note: if you change the time aggregate click on the segment/section/route again for updated graph.

Figure 27: The user interface of the developed traffic visualization with a short description

6. Results and Discussion

This section covers the last part of the thesis related to research objective 3 i.e. the evaluation of the developed prototype. It is the final phase of the methodology as represented by blue boxes in the methodology flow chart (figure 5). The traffic visualization methods and tools evaluated in chapter 4 were adapted to the line based traffic data from Salzburg Research. The design concepts for the visualization prototype incorporated the most suitable tools and methods to support its ability to visualize multi-dimensional traffic data and provide users with different interactive options to further explore the dataset and help interpret it. These design concepts and their implementation was discussed in chapter 5. The results from this prototype and discussion on them will be presented in this section, through two methods.

Firstly, the ability of the visualization prototype to visualize traffic data in general and explore traffic congestion issues will be demonstrated through multiple examples and tasks. These tasks directly relate to traffic issues outlined in the research objectives in section 1.2 which were also deemed relevant by experts in the initial user requirements study (section 4.3).

Secondly, a comprehensive user evaluation study was designed and circulated with two user groups. These users were asked to perform the same set of traffic congestion identification tasks that have been mentioned above. These tasks not only explore traffic congestion but do so by using different temporal selections and aggregates, different spatial aggregates, different traffic attributes and different visualization styles. Thus it was attempted to exhibit the functionality of all the interactive traffic visualization options embedded in the prototype. The number of users that were able to correctly answer the questions (related to these tasks) was measured, giving an idea of the practical applications of the traffic visualization.

In addition to measuring the correct answers from users, they were also asked to rank and evaluate the five visualization styles, the two traffic attributes, the capability of the prototype to perform the different types of traffic congestion related tasks, usability of the interactive features and overall user experience. This ranking was based on different characteristics for each, and gave a comprehensive idea of the usability and functionality of the prototype.

The user evaluation study was shared among two user groups. The first group were professionals from the domain of traffic analysis and traffic planning. These users are domain experts for traffic related issues and major stake holders in decision making related to traffic problems and their solutions, however they had comparatively lesser experience with using GIS applications. Academic research departments in the field of traffic planning were also included in this user group. The focus of this user group was to critically evaluate the prototype for research and exploration of traffic congestion issues and its potential to support decision making process in traffic management. This user group had 10 respondents in the evaluation and is referred to as the 'traffic users'. The second user group were professionals and academia in the domain of GIS and cartography. These users were people who have worked with maps and web based GIS applications for a long time, but have lesser knowledge of traffic data. Hence their knowledge to use map based visualization frameworks is high. This user group acted as a control group for the evaluation answers, since their interest in traffic congestion problem was to be lesser than the first user group. Hence their focus would be more on the visualization and its interactive features as a web GIS application. These are people who could possibly use the map for route planning and congestion identification for day to day travelling. There were 35 respondents from this user group called 'GIS users'.

The user evaluation study was designed using soSci (SoSci Survey, n.d.). Figure 27 was used as a short introduction combined with other descriptive text. For the tasks, users were given instructions of what visualization style, spatial and temporal aggregate, temporal selection and traffic attribute to use. In some tasks the users were partially free to use some of the options with their own preference. Each set of tasks was followed by few related evaluation questions. The latter used a Likert scale ranging from one to four. The sections hereon simultaneously discuss the demonstration of these tasks and present results for relevant tasks from the user evaluation study available in Appendix IV.

6.1. Evaluation of Visualization Styles

The first task for the users was to identify the segment which was most congested on a particular day. The task had five parts, each part needed to be answered using one of the five visualization styles. The date selection to be used was mentioned to the user. The time taken by the user was measured as well, to establish a time based assessment of the visualization styles. The dates for the questions were chosen in such a way that each day showed around the same number of segments in the highest data class of TTI. This would make the different questions unbiased, and time would depend mostly on how difficult or easy users found to identify segments with highest traffic congestion. The tasks were simple and focused towards getting the users familiarized with the visualization styles. On date selection, users could identify which segments were in the highest TTI class, e.g. red color, dark purple color or thickest width. Then users could use the hover popup to identify the segment id. Question 1 in the user evaluation study shows this task. Figure 28 shows demonstration of the correct answers, while figure 29 shows a graph of the time it took (seconds) for the users from both user groups to answer the questions. From figure 29 we can easily see that the traffic users answered the questions faster as compared to GIS users. The first task shows a very high time (outlier, due to learning effect) for GIS users which would mean although they are adapted to web GIS applications but needed some time to familiarize with the traffic visualization concepts as this was the first task of the user study. Traffic experts on the other had are more familiar with such applications. However the learning effect applied to both user groups to some extent specifically for the first task.

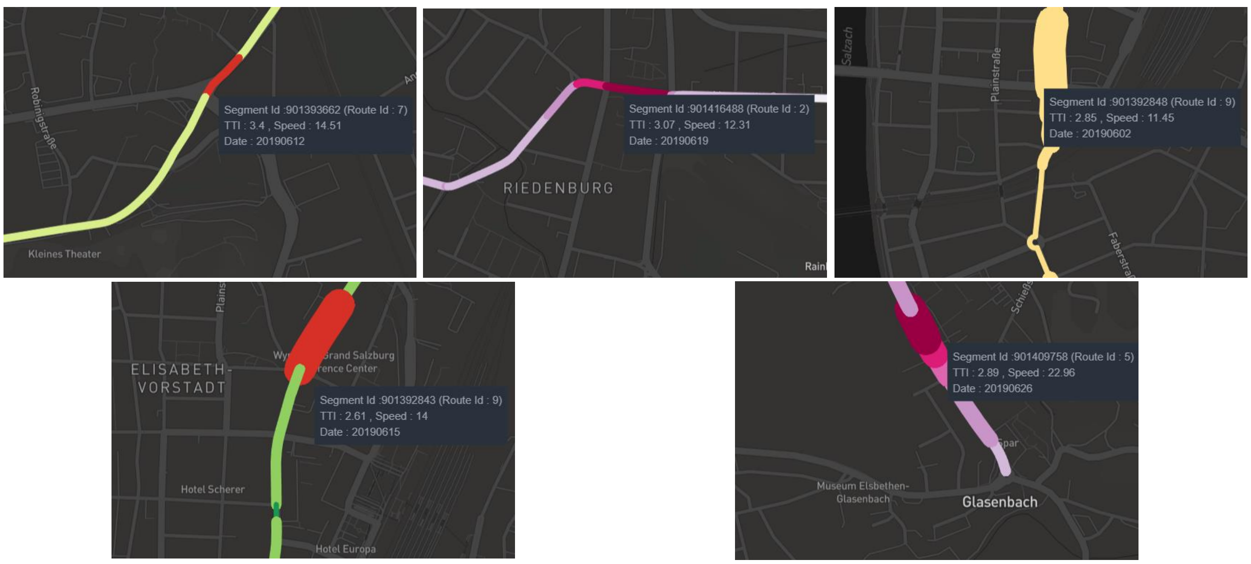


Figure 28: Demonstrations of five tasks of question 1a to 1e (top left to bottom right)

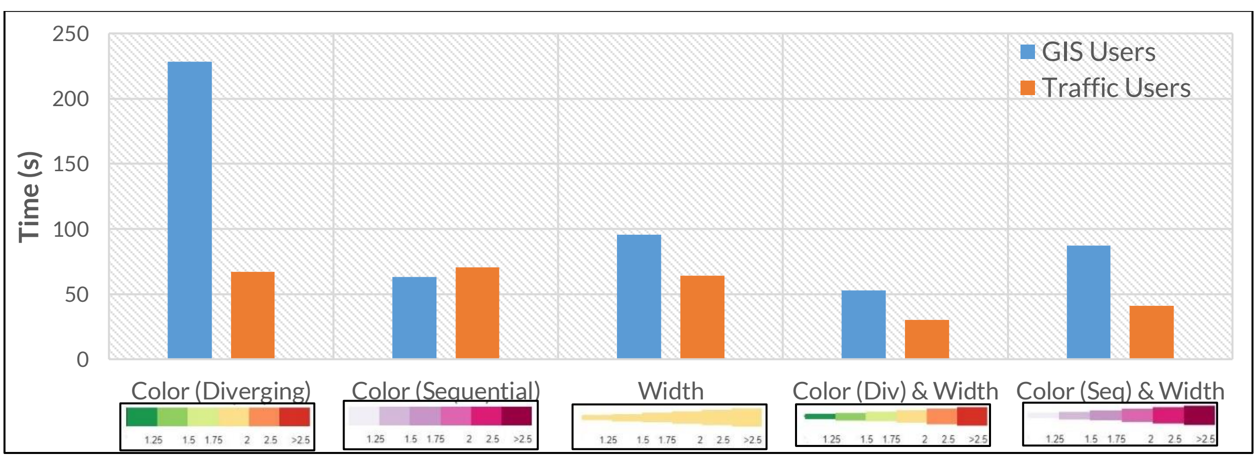
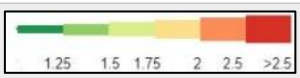
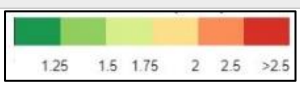
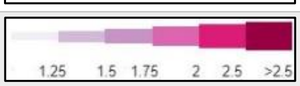
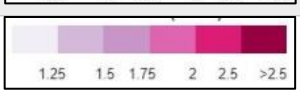
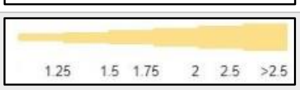


Figure 29: Results of time taken to answer each part of question 1

From figure 29 it can be easily established that the width visualization style took the most time for both users. This means that the users did not find it easy to use. On the other hand for both user groups, the visualization style of diverging ‘color & width’ took the least time. This could mean that users found it easy to use. The next set of questions further investigates how users ranked the visualization styles.

Question 2 of the user evaluation study asked the users to rank the visualizations styles in comparison to each other (i.e. give positions from 1-5). This would give an absolute ranking of which styles the users liked or preferred. Table 10 shows the results of this ranking. Interestingly, the final ranking average for both user groups were the same. They ranked the combination of diverging ‘color & width’ as the most liked and preferred style. This shows that the innovative style of using two visual variables received positive feedback from the users and improved their cognitive ability to identify traffic congestion areas. The width visualization style was ranked lowest. The sequential diverging color was ranked at a second preference, while the use of sequential ‘color & width’ and color was ranked at third and fourth, respectively. Within each color scheme used, the combination of that color scheme with width was ranked higher than the color scheme alone, this further confirms that users liked visualization style using two visual variables.

Table 9: Ranking of the visualizations styles by both user groups. Average Rank and first position (%).

Visualization Style		**Average Rank (GIS Users)**	**Percentage Rank 1 (%)**	**Average Rank Traffic**	**Percentage Rank 1 (%)**
Color (Div) & Width		1.51	84.0	1.62	61.5
Color (Diverging)		2.46	36.0	2	30.8
Color (Seq) & Width		2.74	16.0	3.08	0.0
Color (Sequential)		3.89	0.0	3.54	7.7
Width		4.40	4.0	4.77	0.0

Additionally the three categories of visualization styles (according to visual variables used i.e. color, width, ‘color & width’) were also rated on a Likert scale from one to four over three characteristics, with the use of word pairs to define both extremes of the scale. These three characteristics were: (1) progressiveness, to measure if users found this method to be conventional or innovative; (2) likeness, to further measure user preference; (3) difficulty level, to measure how simple was it to understand the visualization and discover data values. These results are shown in figure 30 for both users groups. Results for ‘color & width’ are shown in green bars, using a different pattern for the GIS user group, similarly, results for color are shown in orange, while results for width only are shown in blue. It can be easily seen that users found ‘color & width’ the most simple, the most likeable and also very innovative. This stands true with the hypothesis in section 5.4 that using two visual variable can prove to be a better approach to visualize traffic and help in identifying traffic congestion (high data values). Width was found to be most unappealing and complicated, but scored better in the progressiveness rating. Whereas color was found to be most conventional which is true as seen in section 4.1.2. Since users are familiar with using color in line based traffic visualization, they still gave it a good rating for likeness and found it to be simple. Overall, the ‘color & width’ style ranked best, and within the two color schemes, use of diverging scheme with width received the highest rank (table 9).

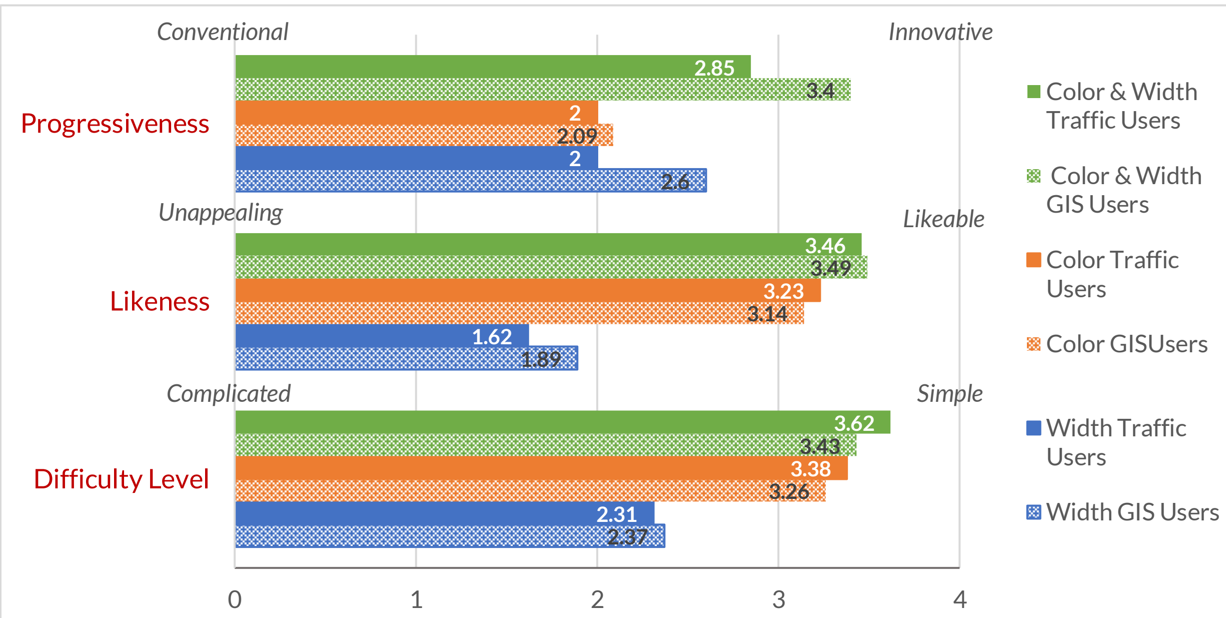


Figure 30: Rating of the visualization style categories

The next section outlines tasks related to traffic congestion identification that the users performed. In these tasks the users were free to use any of the five visualization styles. At the end of the tasks the users were asked again (optional answer), that which visualization style did they prefer using when given a free choice. The popularity and acceptance of the diverging color scheme can be measured again from the fact that 85% traffic users chose it again, (out of 7 respondents, 4 chose diverging ‘color & width’, while 2 chose just diverging color). Similarly 92% GIS users chose it as well (out of 25 respondents, 11 chose diverging ‘color & width’, while 12 chose just diverging color).

6.2. Traffic Congestion Identification and Exploration Tasks

This sections discusses one of the most important objectives of the thesis i.e. the identification and exploration of traffic congestion. These tasks have been mentioned in the research objectives, as well as highlighted in the user requirements study, and the design concepts for the prototype development were implemented keeping these tasks in mind. The subsections of 6.2 presents a demonstration and discussion on performing these tasks. Most of these tasks were also incorporated in the user study for the users to answer. Table 10 shows the questions and percentage of users from both user groups that correctly answered these tasks. As it can be observed, the percentages of correct answers were very high in most cases. This meant that a vast majority of users correctly identified traffic congestion using the visualization prototype. Which is partially a measure of the good practicality and functionality of the prototype for traffic congestion identification and exploration.

Table 10: Percentage of correct answers to traffic congestion questions from both user groups.

Q No.	Questions and Q No. (from user evaluation study)	Correct Answers	
		(Traffic Users %)	(GIS Users %)
6	Which day was most congested on this section? (further discussed in 6.2.1)	100.0	88.6
7	Most congested time of this day (further discussed in 6.2.1)	83.3	82.9
10	Which route was most congested on this time? (further discussed in 6.2.2)	90	85.7
11	Most congested part of the route? (further discussed in 6.2.2)	66.7	85.0
9	Duration of congestion event? (further discussed in 6.2.3)	72.7	80.0
8	Spatial patterns of congestions (which routes are congestion on 2 compared days) (further discussed in 6.2.4)	75	83.6

6.2.1. Temporal Exploration of Traffic Congestion

If a traffic planner/analyst is looking at a specific road, and wants to temporally identify what day, or days on this road section were the most congested, then the visualization prototype can be used for answering this. Since the prototype also allows changing temporal data aggregates, this question can be potentially answered at a macro level e.g. if a huge dataset is present, the user can switch to 'year' temporal aggregate from the radio button selection and then click on a specific segment, section or route to open the temporal graph view and look at the peak value. This identifies the specific year, the user can then apply temporal selection/filtering method to visualize values of that year using the drop down menu. From this year clicking the same segment/section/route will open the monthly graph and most congested month can then be identified and switched to in the spatial view. This process can be further carried on using a drill down approach to reach a micro level i.e. the 15 min interval that was most congested. However for the demonstration we start from the daily temporal aggregate as asked in Question 6 and end at the most congested time of that specific day as well (Question 7). The example is for section S-39852; on the daily temporal aggregate this section is clicked. The graph shows overview of the full month here and the date is then changed to 3 June 2019 as it is identified as most congested (highest TTI, and lowest speed). The time aggregate is then switched to hourly, or 15 min (user's choice) and the section is clicked again to show the overview of the whole day in hourly or 15 min intervals respectively. From the hourly aggregate graphs it can be easily seen that the time between 08:00 and 10:00 is most congested. So the answers 'around 08:00' and 'around 09:00' are considered correct. This is demonstrated in figure 31. The task used TTI traffic attribute.

Figure 31: Temporal exploration of traffic congestion

6.2.2. Spatial Exploration of Traffic Congestion

Another similar task could be to switch the spatial and temporal dimension from the previous task i.e. a traffic planner/analyst is investigating what road segment is most congested, at any specific time. In this case a direct approach (e.g. through segment or section visualization) or a drill down approach could be used as well. For the latter, routes represent the largest spatial aggregate, hence the most congested route can be identified at any selected time (over any time aggregate) in the spatial view. Once the route is identified the spatial aggregate can be changed from the drop down menu to sections or segments for a further micro analysis to identify which specific part of this route was most congested. This can give the traffic analyst a realistic idea regarding the intersections and road junctions between which traffic congestion exists. Question 10 and 11 of the user study were used to identify the most congested route on 19 June at 17:00 hourly interval and then further investigation using section/ or segment. Traffic attribute average speed was used for this task. It can be seen from figure 32 that route 1 is most congested and further investigation with sections and segments (figure 33) shows that the route was congested near the city center as well as the city outskirts, only middle part of the route was non congested. Hence the correct answer for both spatial aggregates was 'start of route' and 'end of route'. Note that figure 33 has the map view rotated by 90 degrees. It can also be seen how routes show the least level of detail, while sections show more detailed data and segments show most detailed data granularity.

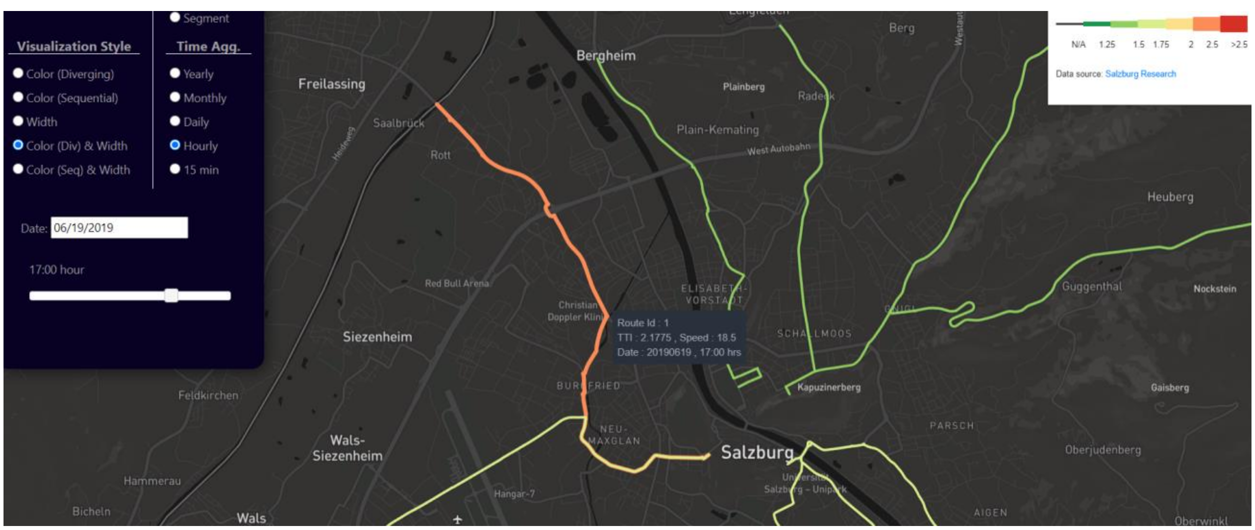


Figure 32: Spatial exploration of traffic congestion using routes.

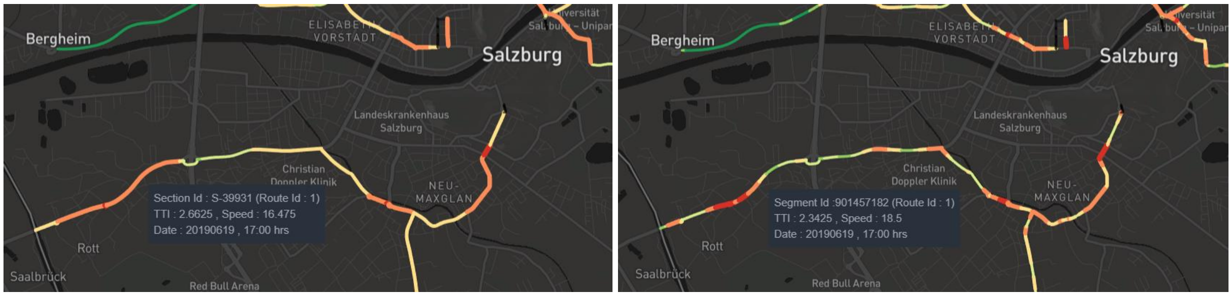


Figure 33: Spatial exploration of traffic congestion using sections (left) and segments (right).

6.2.3. Congestion Extent (Duration or Length)

This task can relate to exploration of the extent of congestion, in temporal dimension a traffic expert/analyst could explore the duration of the congestion event, while in the spatial dimension an estimate of the length of congested part could be identified. This also forms a major visual analytics task for traffic management and congestion identification. Using the prototype it is not possible to gain an exact numerical measurement of how much of the road was congested, however through visualization of segments (or sections in some cases) an almost realistic answer could be achieve. A good example of this is the task just demonstrated in the previous section in figure 33. It can be seen how much of a route 1 was congested at the selected time. Both segments and sections show a slightly different version of congestion.

On the other hand, the temporal dimension can be very accurately explored using the graph view. The most suitable time aggregate would be 15 min, as the peaks on the graph can help to investigate how long a congestion event lasted. Figure 31 shows an example using the hourly aggregate. However for question 9 it is demonstrated using 15 min temporal aggregate. Users were told a specific time selection and hinted towards an area to explore a congestion event using segment or section spatial aggregate to find out the duration of congestion. In the demonstration we use segment 901394184 from within this area and by clicking on it, it is observed from the graph that the congestion event starts around 07:00 and ends at 09:30 i.e. 2.5 hours. For some other neighboring segments it last 2 hours, as well as 3 hours. Hence 2 and 3 hours were the correct answers. Figure 34 shows a demonstration of this. TTI traffic attribute was used.

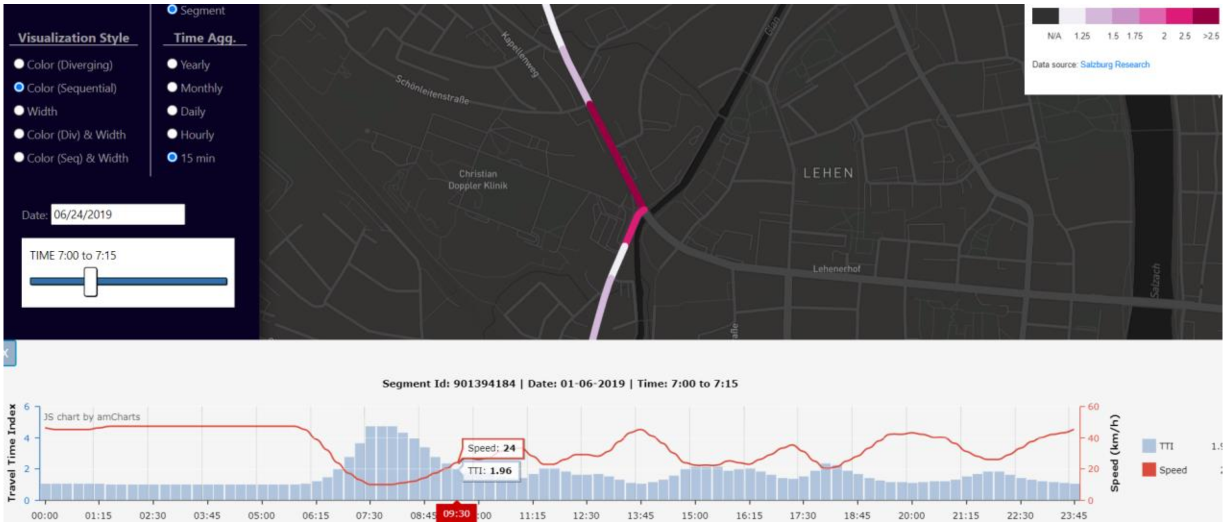


Figure 34: Exploring duration of a congestion event

6.2.4. Identification of Temporal and Spatial Patterns

This tasks also represents a very important phenomenon in traffic data visualization and exploration. Temporal patterns over a day could mean what is the rush hour time for the whole city or for a specific route. This could also lead to identification of two possible rush hour times e.g. morning and evening. Temporal patterns over a month could be used to identify patters of traffic on weekends as compared to weekdays. Macro patterns could be comparison over the year to see traffic information with regard to holiday season etc.

On the other hand spatial patterns could be used to explore if a certain area of the city gets congested more often, or if any certain segments or sections of the road are congested more often i.e. are traffic bottlenecks. This task required manual exploration of the data over different times, and along different routes. Some interesting discoveries are demonstrated in figure 35 to identify such patterns. Figure 35a shows the monthly graph of a specific segment for June 2019. In June 2019 the weekends are 1-2, 8-9, 15-16, 22-23 and 29-30 June. Note how traffic congestion is very low on most of these days as compared to weekdays. Especially the last three weekends show as data 'valleys' in the bar graph chart of TTI. Figure 35b shows the temporal graph for a segment showing rush hour times from 08:00-10:00 and 17:00-18:00. Figure 35c shows temporal graph of same date for a different segment showing different rush hour times i.e. only 08:00-11:00. Figure 35d and 35e show how on different days, at the same time interval (08:15-08:30) the traffic congestion across the city varies. In 35d (17 June) we see the north eastern part of the city as congested, while in 35e (26 June) it is northwestern part that is congested. This also partially answers question 8.

Additionally bottlenecks in all the routes show up as segments that are very frequently congested, e.g. segment 901416488 on route 2, and 901415662 on route 9. As this task would be extensive it was not asked in the user evaluation study.

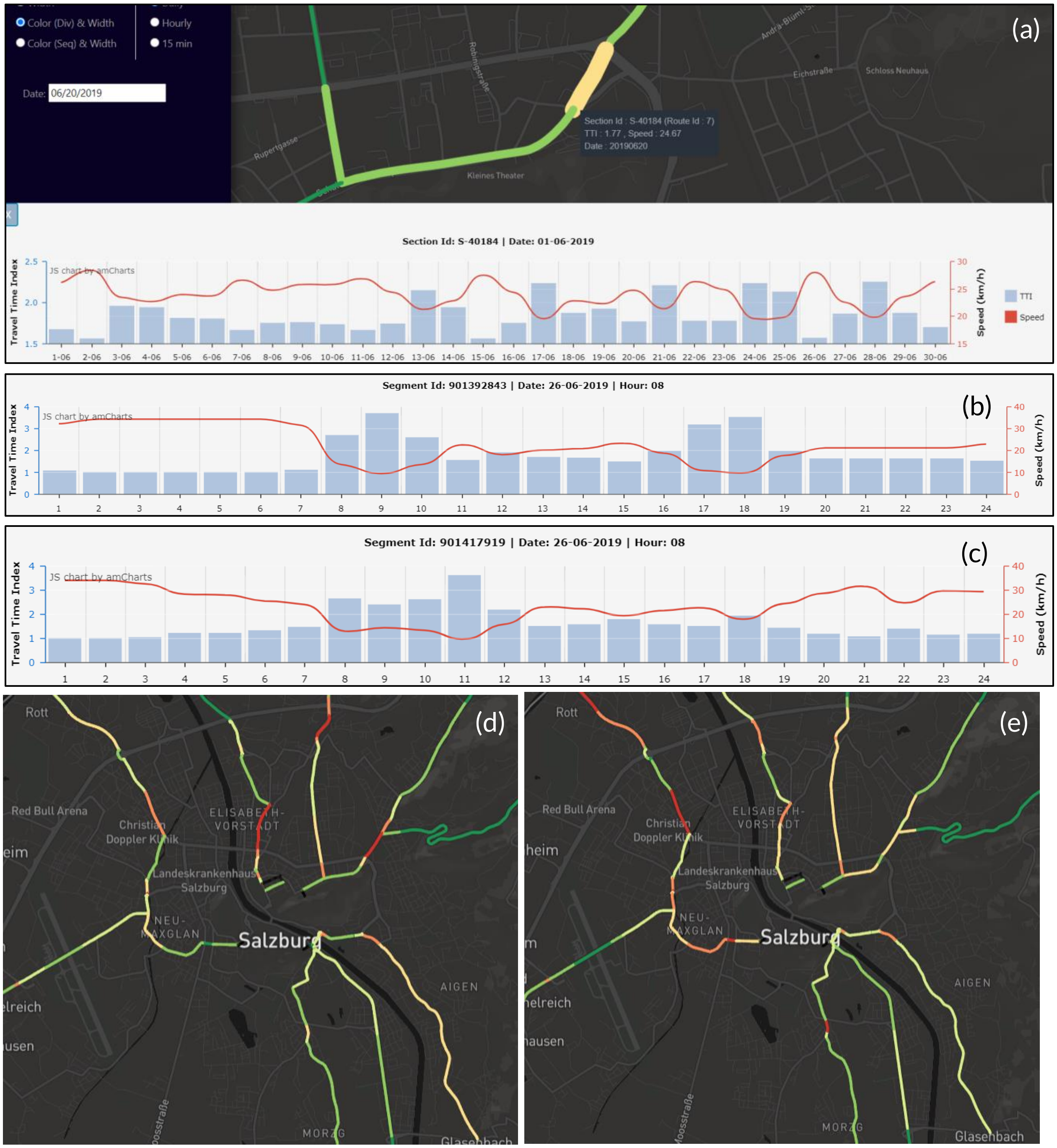


Figure 35: Exploring and visualizing spatial and temporal patterns of congestion

6.2.5. Propagation of Congestion Event

This tasks presents visualization of how a specific traffic congestion event propagates over time. This can lead to an animated effect. The hourly and 15 min time sliders are both controllable using the left and right keyboard keys. After identification of a specific congestion event, the user can see different phases of a traffic congestion event. Figure 36 shows an example of a traffic congestion event that happened near Gnigl on 3 June from 6 am to 12 pm. This specific feature of the prototype is particularly interesting and works best with the highest data granularity i.e. segments and 15 min interval. However in figure 36 screenshots are taken from the hourly interval since it would have made 24 images in 15 min interval. Here it can also be seen how neighboring segments relate to each other.

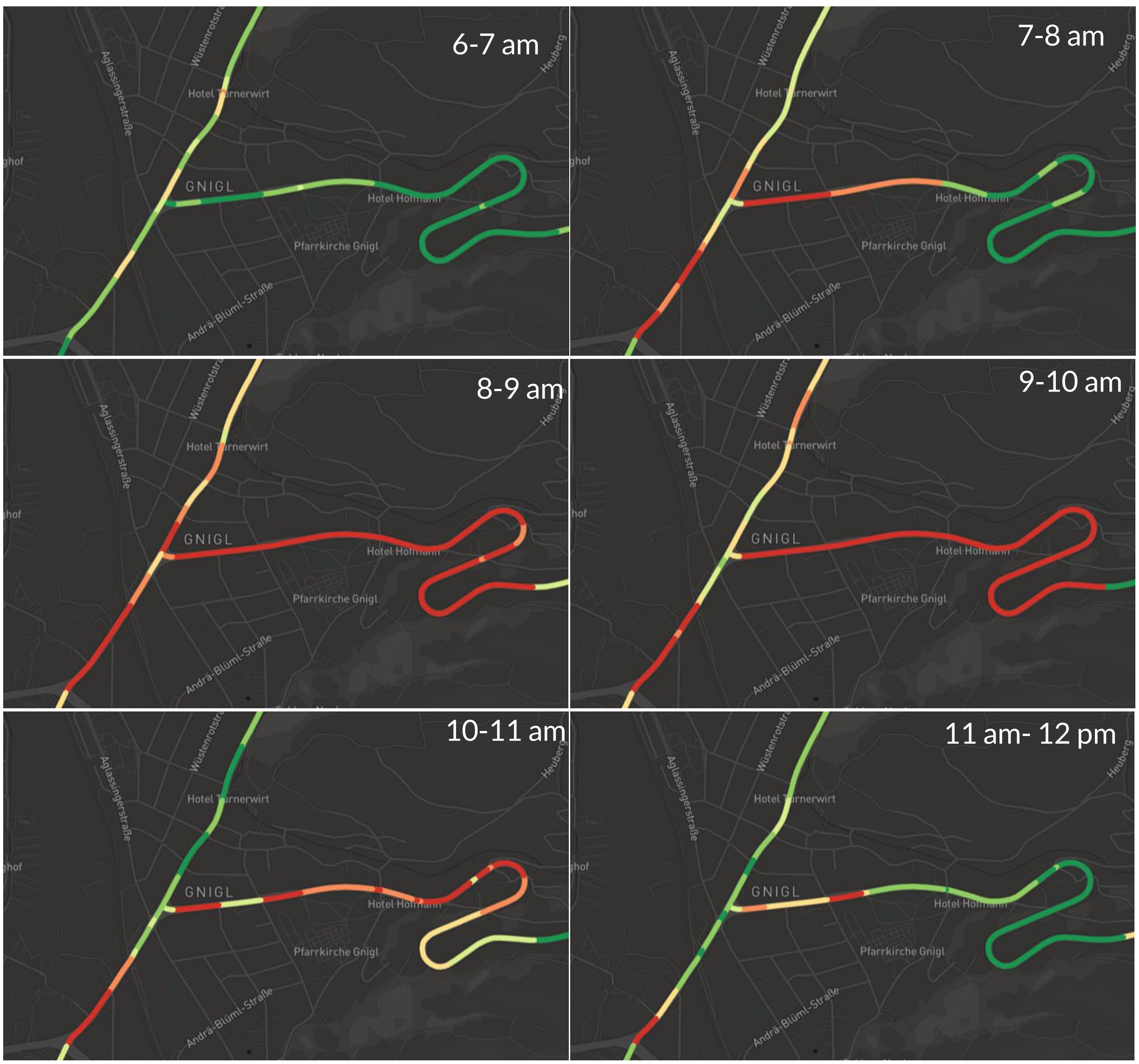


Figure 36: Propagation of a traffic congestion event

6.3. Evaluation from User Study

The first evaluation questions for the five visualization styles have already been covered in section 6.1. After performing the tasks in section 6.2, the users had enough familiarity and experience with the traffic visualization application to be able to answer evaluation questions regarding: (1) the two traffic attributes, (2) capability of the traffic visualization prototype to identify congestion (i.e. rating it on the tasks they had just performed), (3) practicality and usefulness of each of the interactive elements or selection options of the prototype, (4) overall experience. The results of these evaluations are presented in the following sections.

A Likert scale ranking was used again with four ranks; an even number of evaluation response options allowed elimination of the neutral middle values. Presser & Schuman (1980) researched on the number of response options for surveys and found that 10-20% of the respondents would chose the middle neutral option if it is present, compared to the same survey where it was not present. Additionally since our presentation of the users' responses was based on averaging the ratings from users, hence it does not matter much if the response options do not have a neutral value (MeasuringU, n.d.). This would encourage the users to give an opinion that will be useful towards the study instead of just being neutral, their response could be positive, or negative.

6.3.1. Traffic Attributes

Users were instructed to use a mix of both traffic variables to identify congestion, this enabled them to be able to evaluate both attributes. The users were asked if they preferred using average speed or TTI. The results are shown in figure 37. It shows that traffic users slightly preferred using speed. This maybe because of previous experience with speed based traffic visualizations. Whereas, the GIS users definitely preferred TTI over speed. This may be because as an index value, TTI is easier to understand.

Additionally the users were then asked to rank each attribute against three characteristics: difficulty, appropriateness, relatability. Difficulty level related to understanding this traffic attribute and discovering data values with it. Appropriateness referred to the scale (legend) and data classes used. This also covered the aspect that both TTI and speed had inverted legend colors. The relatability was a measure of how users could relate the information visualization to real world situations e.g. personal travelling/driving experiences. The results are shown in figure 38. Overall most of the rankings were very positive. In a scale of 4, almost all rankings were between 3 and 3.5. The GIS user group slightly found TTI difficult to understand and gave it a rank of 2.88, however figure 37 shows that GIS users still preferred TTI to speed. Relatability of TTI was also given a lower rank, especially by GIS users. This could be because the use of this congestion index is not very common as already mentioned in section 4.4. Speed was found more relatable to users since while travelling and driving and in conventional traffic visualizations and navigation applications speed is more commonly found as a traffic attribute. Overall both traffic attributes received good ranking and almost similar among them. Although traffic experts preferred to use average speed, as shown in a figure 37. They gave better ratings to TTI than GIS users. This also means traffic experts understand more what this index actually represents.

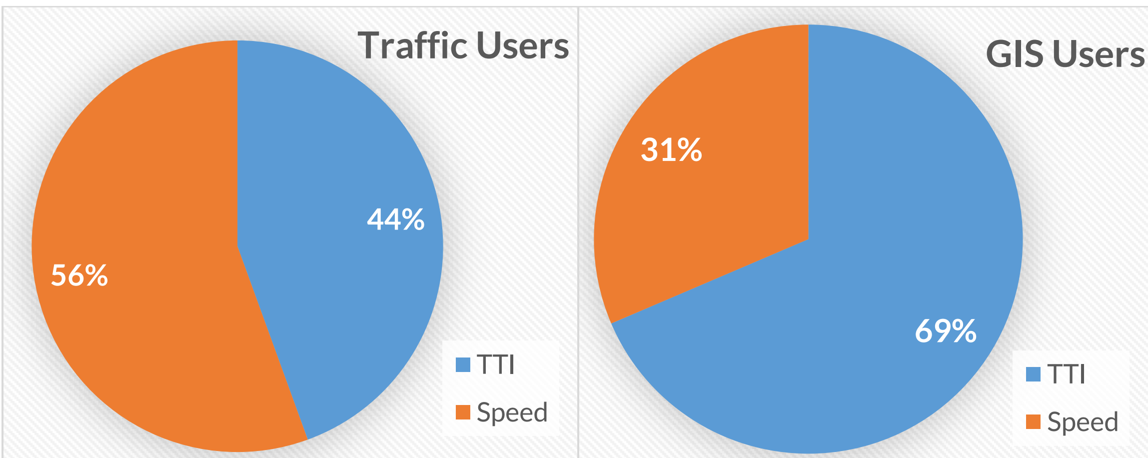


Figure 37: User preference of traffic attributes.

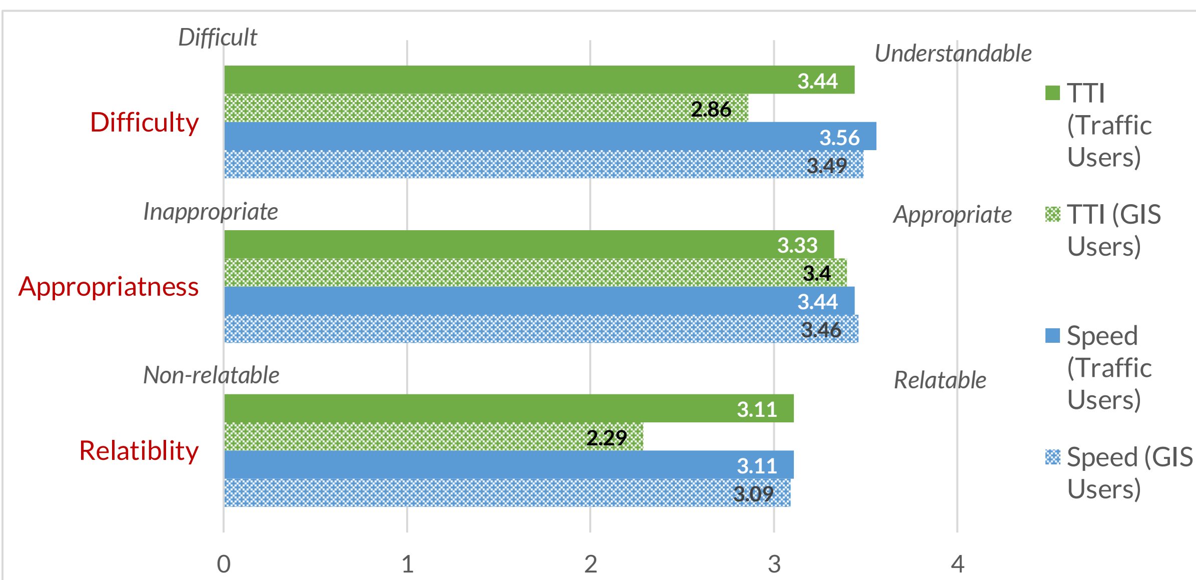


Figure 38: Ranking of traffic attributes

6.3.2. Capability to Identify Congestion

The users were asked to rank capability of the prototype to explore and investigate different aspects of traffic congestion through the tasks they performed from question 6 to 11. These tasks have been comprehensively demonstrated in section 6.2 as well and form part of visual analytics through the visualization prototype. Results are shown in figure 39. Overall the results are very positive, especially from the GIS user group. Since the traffic user group were domain experts, they gave a comparatively critical ranking. All rankings are mostly around 3 (out of 4). The least ranking given by traffic user group was for question 9 i.e. how long a congestion event was. However this task has been demonstrated in section 6.2.3. The positive rankings mean that both users groups were confident that the traffic visualization prototype was capable in identifying and visualizing traffic congestion and related spatial and temporal aspects.

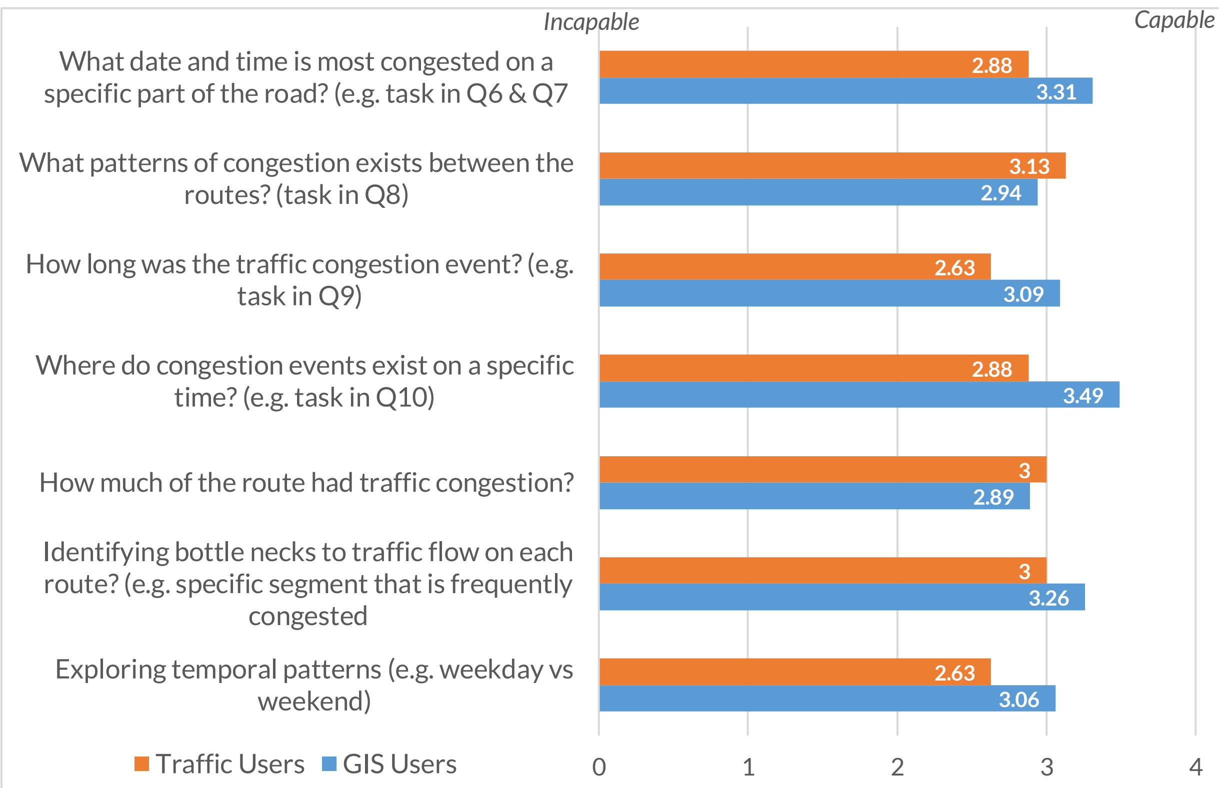


Figure 39: Ranking of capability of the traffic visualization prototype

6.3.3. Evaluation of Interactive Elements

Since part of the focus of this thesis has been on the 'interactive' aspect of visualizing traffic data. Many interactive elements were designed in the prototype to assist users in visual analytics tasks for traffic data visualization and exploration, table 7 from section 5.8 enlists all these interactive elements. The users were explicitly inquired about the usefulness of the interactive elements over a usefulness scale of one to four. The results are shown in figure 40. All of the interactive elements received very positive rankings. This is especially true for the temporal graphs on click and the ability to change temporal prototypes. This means the users found the features related to time dimension very useful. The data summary in popup and traffic attributes also received very good rating. Spatial aggregates options were well rated as well. Interestingly, the interactive elements purely related to functionality of the prototype to explore traffic congestion were rated better by traffic user group as compared to the GIS user group e.g. traffic attributes, temporal aggregates and spatial aggregates. This is mainly because they are the domain experts who would value functional features more than the interface/design features. Whereas the visualization styles and hover pop up options received better rating by GIS users. Basemaps received lowest rating by both user groups, this may also be because the users were just informed about the different basemaps at introduction but never instructed in the tasks to change basemaps so most users did not use different basemap at all. Overall the ratings were very positive, further increasing confidence that the prototype's interactivity provided desired results for visualization and exploration of traffic data.

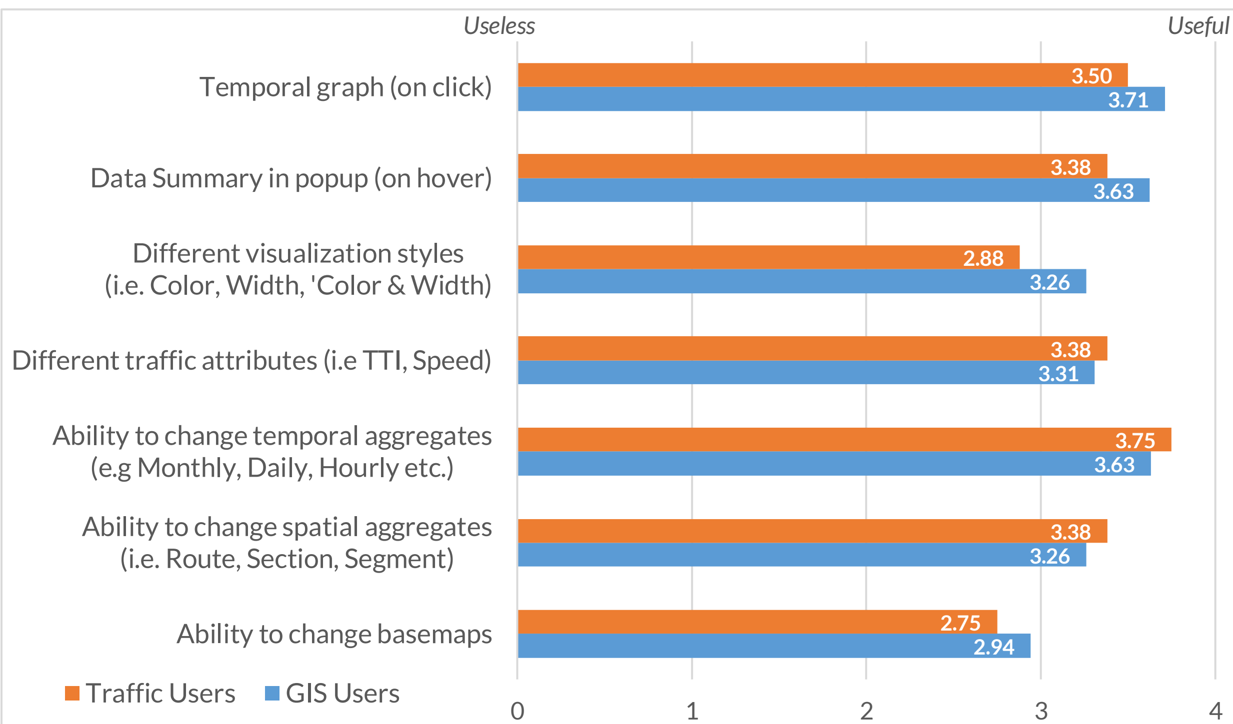


Figure 40: Ranking of interactive elements of the prototype

Figure 41 shows results of a further question on functionality of graphs. Making their importance more prominent as answered by both user groups. 77.8% traffic users and 91.4% GIS users agreed with the necessity of temporal graphs to support the spatial view.

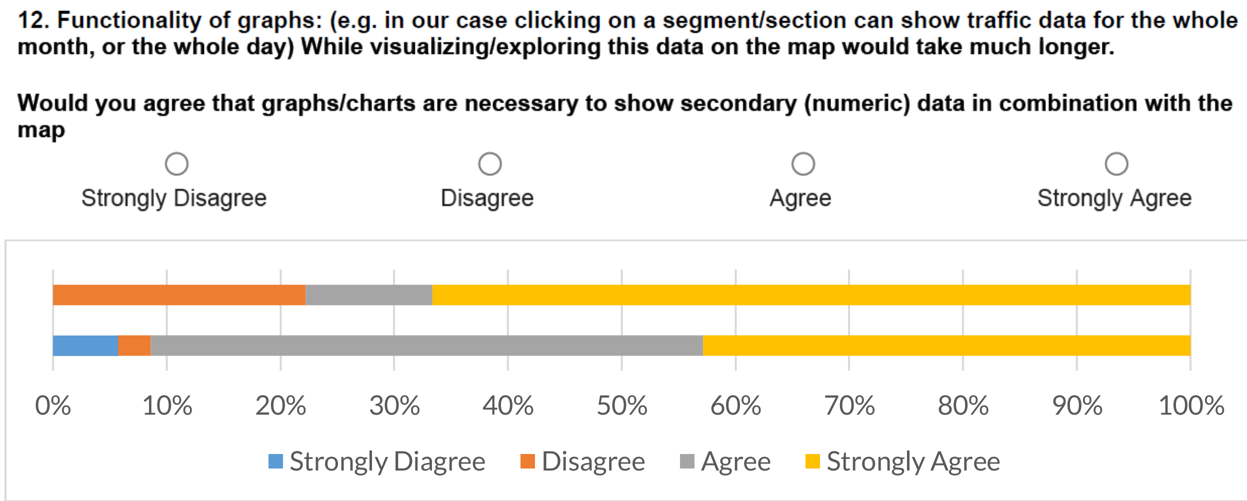


Figure 41: Necessity of temporal graphs for the traffic data visualization. Traffic users (top bar) and GIS users (bottom bar)

6.3.4. Overall User Experience

Lastly, the users were requested to give an overall rating to the prototype. This rating was based on three characteristics that were all very important. Creativity of the prototype was ranked, which shows how conventional did the users find this application. GIS users gave a very positive rank of 3.29, while traffic experts gave a slightly less positive response of 2.75. However this was still a positive response showing that new and innovative features were used in the prototype. Since the traffic visualization prototype was extensive and had many options and selections, the user interface was rated by users as well and it received positive ratings around 3 from both groups. This meant that users were satisfied with how intuitive the design of the prototype was. Lastly users were asked how difficult or simple was it to learn and use the prototype and their answers were positive here as well, which means they did not find the prototype too difficult to learn and use. On average it took traffic users 22 minutes, and GIS users 30 minutes to complete the user evaluation study which was active for 20 days. A last question in the study was an open ended optional question to give suggestions, feedback and other comments on the prototype. Many users gave positive reviews on features of the visualization prototype, this included the use of different visualization styles and faster rendering time upon changing any of the options. Additionally many users gave positive feedback on the user interface. GIS users particularly mentioned that such an application can be very useful for traffic planners. The users also gave constructive feedback for improvements in the prototype, these will be discussed as recommendations in chapter 7.

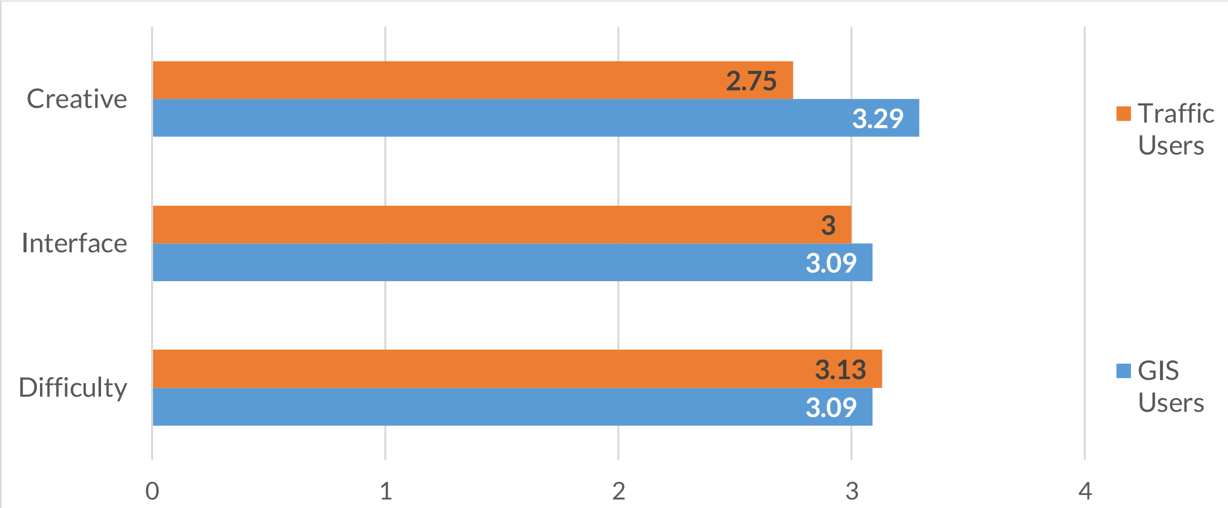


Figure 42: Overall ranking of the traffic prototype

Some examples of user feedback is mentioned below:

"I found the study very intuitive and it compels the user to explore the dashboard. I think the visualization styles are very nice and the transition is very fluid. Overall a good experience." – GIS user group

"Very interesting survey. I had a lot of fun playing with the application and exploring the different visualizations. I guess it can be very handy for traffic planners" – GIS user group

"Finding section IDs was too tedious. A search function (ID, street name) would be desirable. Other spatial granularities (zones) might be meaningful." – Traffic user group

"Nice tool for explorative purposes! For a real use-case I would simplify it further since if you're not used to interactive maps it could get a little complicated. But good job, also with color choice and interface design!" – GIS user group.

7. Conclusion and Recommendations

The conclusion to this thesis will be presented in line with the research objectives and research questions that were proposed in section 1.2. The first research objective involved evaluation of visualization methods and visualization tools that have been used in previous works for traffic data. This evaluation was done keeping research objective 2 in view. Since traffic data is spatio temporal in nature, it was studied according to dimensional data categories i.e. temporal visualizations, for spatial visualizations and spatio temporal visualizations. To answer research question 1a, these were discussed in section 4.1, the benefits and limitations of the visualization methods were discussed e.g. some induced visual clutter, while some were difficult to understand. In section 4.2, the question 1b was answered by studying visualization tools that are coupled with these visualization methods to enhance the functionality, interactivity and cognition of users. Such tools assist in basic visual analytics tasks as well e.g. multiple interactive elements, multiple coordinated views etc. At this point a short user requirements study was also conducted from traffic experts to gain insight on their exact needs from a traffic visualization framework. Additionally, most commonly used traffic attributes were surveyed as well. Two research gaps were identified, firstly, visualizations that use different spatial aggregations for road network based traffic data were limited. Secondly use of TTR measures or traffic congestion indices for traffic visualizations was limited as well.

The second research objective focused on the design concepts to be incorporated for the development of a web GIS based traffic visualization prototype. The traffic data from Salzburg Research for the city of Salzburg was used and post processed. Travel Time Index (TTI), a TTR measure specifically suitable to identify traffic congestion exploration was used for the visualization (discussed in section 5.3). Research question 2a was answered through development of visualization styles that used combination of two visual variables for line based data on the road network (discussed in section 5.4). Additionally the traffic attribute implemented use of multiple spatial and temporal data aggregates to visualize the data. This feature gave a very dynamic and interactive approach for traffic planners to explore traffic congestion. Multiple spatial and temporal aggregates would allow micro analysis e.g. congestion on small road segments in the city center, and macro analysis e.g. congestion between major intersections within city boundaries etc. The temporal aggregates were very useful to explore the data over a month, a day, or every hour of the day etc. Research question 2b about spatial and temporal aggregates has been discussed in detail in section 5.5 and 5.6. Lastly as an answer to research questions 2c, the functionality of interactive elements was implemented in the prototype. This formed the basis of human computer interaction. The interactive elements included a selection menu for different visualization styles, temporal aggregates, spatial aggregates and multiple traffic attributes. These were coupled with a linked spatial and temporal view to complete the user interface shown in figure 27. Deck.gl, an open source and computationally powerful visualization framework was used for the development.

These functionalities enabled the traffic visualization to enhance human cognitive abilities and have basic visual analytics features such as fast rendering of a large, multi-dimensional dataset to allow user friendly data exploration. In research objective 3, this visualization prototype was subject to evaluation from a user study from two users groups, traffic experts (primary user group), and GIS professionals (control user group). The ability of the prototype to identify and explore traffic congestion was comprehensively demonstrated in chapter 6. The traffic congestion tasks included spatial identification and exploration of traffic congestion at a specific time, temporal identification and exploration of traffic congestion at a specific location, observing extent of congestion through time and space, identifying temporal and spatial patterns and visualizing how a traffic congestion event propagates. The users were asked to evaluate the prototype from multiple perspectives. Firstly, in evaluation of visualization styles, the use of both 'color & width' with a green to red diverging color scheme was unanimously ranked as the most preferred among the other styles. Users found it to be innovative, likeable and simple to understand. This agreed with the hypothesis that users would prefer this visualization style. Among the traffic attributes, users gave reasonably positive feedback on TTI as an innovative approach to identify traffic congestion. Users though it was understandable, and relatable to road conditions. The users performed traffic congestion identification and exploration tasks with 80% traffic users and 84% of the GIS users being able to correctly identify traffic congestion areas and time. The users also evaluated the capability of the prototype for solving these tasks by giving a positive ranking for each of the tasks. These tasks have been demonstrated in section 6.2. Furthermore the users were asked to evaluate interactive elements in the prototype as well. Majority of the interactive elements received very positive ranking specially the feature of dynamic temporal aggregation, and graphs in temporal view. This emphasized how important and useful these elements are and supports the reasons from the design phase to implement them in the prototype. Positive rankings increased confidence in the visualization and design concepts used. Lastly the users were asked for their overall experience, they found the prototype to be reasonably innovative, simple to use, and with an intuitive user interface.

This thesis has overall discussed how interactive traffic visualization concepts can be used to explore and interact with traffic data. The developed prototype has used historical data from a specific city. However the concept behind the developed prototype was to present design concepts for a new and innovative way to visualize and interact with traffic data for support in identification and exploration of traffic congestion. Such an application will be of great help to traffic planners and traffic management authorities who can use it to support them in the decision making process. Such an application can be easily adapted to provide traffic visualizations for other cities, and possibly incorporate real-time traffic data as well.

7.1. Recommendations

As recommendations we firstly discuss planned improvements and also suggestions form the user groups. The first and foremost is to point out a technological limitation of deck.gl while rendering the 'color & width' visualization style. Here, since the width of road segment increases for high TTI or low speed values, it overlaps with the neighboring segment. Since some segments are very small this problem can cause a visual conflict, hence it is a possible suggested improvement. The sections ID's are very long and confused some users, this could be solved by following a different naming framework for the segments. Another useful feature to add to the application would be a possibility to compare two segments, sections or routes through time, this could be achieved by possibly opening two graph windows simultaneously to make the comparison through temporal graphs. Lastly, and most importantly, although the prototype does have temporal filtering/selection options, it currently does not have a proper spatial filtering/selection option. This could be achieved by applying spatial databases and giving the user an option for spatial querying.

A complete visual analytics framework can be very complex and detailed with a lot of functionality, in regards to that, the developed prototype only offers basic visual analytics tasks. There is room for improvements for this visualization framework, these could include incorporation of near real-time data from traffic sensors and FCD. This would allow visualization of realistic road congestion levels, while also given the functionality to compare them to historical data. Furthermore, data of traffic events and incidents, such as traffic light intersections and traffic accidents could be incorporated as another layer. This could allow traffic experts to explore how congested traffic and congestion event propagation spatially correlates to traffic incidents. Another useful data that can be incorporated is traffic flow data which represents number of cars moving through a road section or specific location. This dataset can also be used to develop spatial and temporal correlations with the current data allowing deeper analysis possibilities.

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Appendix I – User Requirements Study

Assessment of Data and Visualization needs for Traffic Analysis Tool

Student Name: Arslan Aslam

Student Affiliations:

- Salzburg Research, Salzburg, Austria
- Technische Universität Wien, Vienna, Austria
- Technische Universität München, Munich, Germany

The following questionnaire is for a master's thesis study aimed at development of an exploratory traffic data analysis tool for traffic experts. This tool will allow traffic experts to explore, interact with and analyze traffic data to support in interpretation and understanding of traffic issues. A prerequisite for this it is to understand the needs of traffic experts. These include the traffic data requirements, preferred types of analysis etc. Hence the questions below are focused in assessing specific needs of traffic experts to help in design considerations for this exploratory data analysis tool. The goal of the tool is to empower traffic experts to be able to carry out traffic analysis without the need of a data scientist, this is further visualized in Figure 1.

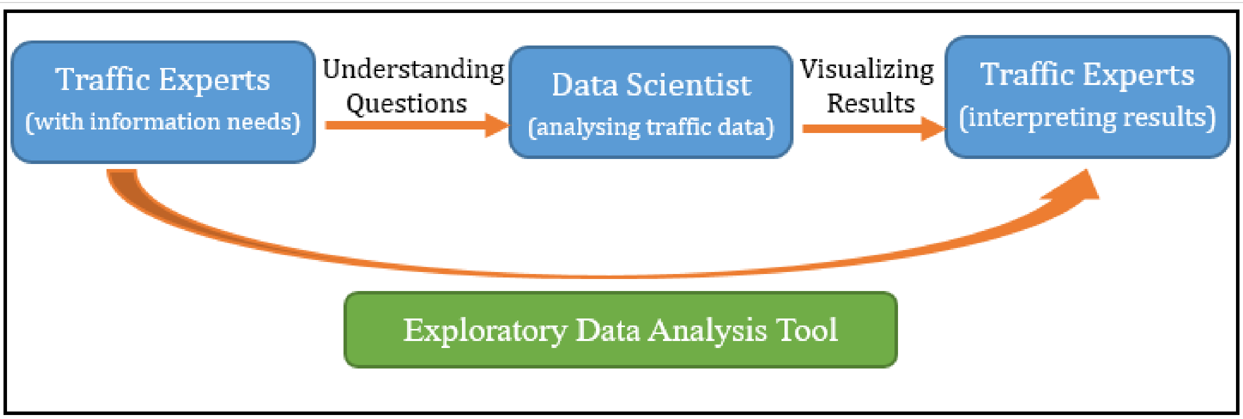


Figure 1: The purpose served by the prototype exploratory data analysis tool is to make the traffic experts independent in analyzing traffic data and extract their information needs. This removes the need of a data scientist for this task.

1. What kind of traffic data is used? Which additional traffic data would be useful for your daily work?

2. How useful are visual analysis for traffic experts?
   a. Which visual analysis are currently in use?
   b. Are these analysis static or dynamic (for example, a static analysis could be where the user can enter parameters to download a dataset and then visualize them separately. However a dynamic analysis could be where the data selected is simultaneously visualized)

   c. In case of static analysis, do you feel a need that visualizations allowing dynamic analysis ability would be helpful, and how?

3. What kind of visual analysis through maps/spatial representation would assist your daily work?
   a. Would exploring the dimension of time be necessary for such visual analysis e.g. browsing through archive data? Aggregating traffic data on different time intervals?
   b. Would spatial queries be necessary to achieve this? What kind of spatial queries would you use the system for?

4. What kind of spatial patterns are traffic experts searching for in traffic data?

5. What kind of temporal patterns are traffic experts searching for in traffic data?

Below is a list of questions that could be answered with an exploratory data analytics tool. What do you think are relevant questions? Do you like to add any comments/modifications/ suggestions to these questions? Additionally, if you would like to add more questions being of interest to you, please state them as well.

6. What was the most congested day on a route? What particular section of the route was congestion affected?
   Comments/Suggestions/Modifications:

7. Patterns between congestion on routes (are all routes congested on certain days). If one route was congested, how was the traffic flow on others?
   Comments/Suggestions/Modifications:

8. How long does did the congestion last? (a few hours? The whole day?)
   Comments/Suggestions/Modifications:

9. What bottle necks/ temporal patterns exist in traffic flow?
   Comments/Suggestions/Modifications:

10. Where/when were drivers over-speeding the most?
    Comments/Suggestions/Modifications:

    Further Questions:

Appendix II – Data Format

Header of the data file for segments:
(Sections and Routes had similar data files)

timestamp, segment_id, TTI0000, TTI0015, TTI0030, TTI0045, TTI0100, TTI0115, TTI0130, TTI0145, TTI0200, TTI0215, TTI0230, TTI0245, TTI0300, TTI0315, TTI0330, TTI0345, TTI0400, TTI0415, TTI0430, TTI0445, TTI0500, TTI0515, TTI0530, TTI0545, TTI0600, TTI0615, TTI0630, TTI0645, TTI0700, TTI0715, TTI0730, TTI0745, TTI0800, TTI0815, TTI0830, TTI0845, TTI0900, TTI0915, TTI0930, TTI0945, TTI1000, TTI1015, TTI1030, TTI1045, TTI1100, TTI1115, TTI1130, TTI1145, TTI1200, TTI1215, TTI1230, TTI1245, TTI1300, TTI1315, TTI1330, TTI1345, TTI1400, TTI1415, TTI1430, TTI1445, TTI1500, TTI1515, TTI1530, TTI1545, TTI1600, TTI1615, TTI1630, TTI1645, TTI1700, TTI1715, TTI1730, TTI1745, TTI1800, TTI1815, TTI1830, TTI1845, TTI1900, TTI1915, TTI1930, TTI1945, TTI2000, TTI2015, TTI2030, TTI2045, TTI2100, TTI2115, TTI2130, TTI2145, TTI2200, TTI2215, TTI2230, TTI2245, TTI2300, TTI2315, TTI2330, TTI2345, averageTTI, direction_1, v0000, v0015, v0030, v0045, v0100, v0115, v0130, v0145, v0200, v0215, v0230, v0245, v0300, v0315, v0330, v0345, v0400, v0415, v0430, v0445, v0500, v0515, v0530, v0545, v0600, v0615, v0630, v0645, v0700, v0715, v0730, v0745, v0800, v0815, v0830, v0845, v0900, v0915, v0930, v0945, v1000, v1015, v1030, v1045, v1100, v1115, v1130, v1145, v1200, v1215, v1230, v1245, v1300, v1315, v1330, v1345, v1400, v1415, v1430, v1445, v1500, v1515, v1530, v1545, v1600, v1615, v1630, v1645, v1700, v1715, v1730, v1745, v1800, v1815, v1830, v1845, v1900, v1915, v1930, v1945, v2000, v2015, v2030, v2045, v2100, v2115, v2130, v2145, v2200, v2215, v2230, v2245, v2300, v2315, v2330, v2345, v_avg, v85, route_id, section_id

Appendix III – JavaScript Code

```
let timestamp = -1;
let trafficVariable = 1; // 1=ttiSelected, 2=speedSelected
let visType = 1;        // 1=color1, 2=color2, 3=width, 4=both1, 5=both2
let selectedTime = 0;
let spatialLayer = 0;   // 0 : segment, 1: Sections, 2: Routes
let allRoutesData = [];
let filteredData = []; // applies getkey and saves
let yearChange = 0;
let monthChange = 0;
let dateSlider = "FALSE";
let currentSelectedSpatial = "Segment";

let roadDirection  = "FALSE";
$( function() {
  $( "#datepicker" ).datepicker({
  onSelect: function(dateText) {
    console.log("Selected date: " + dateText + "; input's current value: " + this.value);
    let currentDate = $("#datepicker").datepicker("getDate");
    var formatted = $.datepicker.formatDate('yymmdd', currentDate);
    console.log(formatted);
    timestamp = formatted;
    roadDirection = "FALSE";
    console.log(roadDirection);
    filterData(formatted);
    redraw();
  }
}).on('change', function(){
  console.log("DATE CHANGED");
});
 $('#datepicker').datepicker("setDate", new Date('1 June 2019'));

var handle = $( "#custom-handle" );
$( "#timeSlider" ).slider({
  min: 0,
  max: 1440,
  value: selectedTime,
  step: 60,
  slide: function( event, ui ) {
    // handle.text( ui.value );
    var hours = Math.floor(ui.value / 60);
    if(hours.toString().length == 1) hours = '0' + hours;
    selectedTime = hours;
    redraw();
    $('#something').html(hours);
  }
});
} );
const {DeckGL, GeoJsonLayer} = deck;
let check = "GOr";
const TTI_COLOR = d3.scaleThreshold()
.domain([0.8, 1.251, 1.51, 1.751, 2.01, 2.51, 14])
.range([
  [0, 0, 0, 127],[26, 152, 80],[145, 207, 96],[217, 239, 139],
  [254, 224, 139],[252, 141, 89],[215, 48, 39]]);

const SPEED_COLOR = d3.scaleThreshold()
.domain([1, 10.01, 20.01, 30.01, 40.01, 50.01, 95.01])
.range([
  [0, 0, 0, 127],  [215, 48, 39],  [252, 141, 89],
  [254, 224, 139],  [217, 239, 139],  [145, 207, 96],
  [26, 152, 80],  [0, 51, 0]  ]);

const TTI_COLOR2 = d3.scaleThreshold()
.domain([0.8, 1.251, 1.51, 1.751, 2.01, 2.51, 14])
.range([
```

```
 [0, 0, 0, 127], [241, 238, 246],[212, 185, 218],
 [201, 148, 199], [223, 101, 176],
 [221, 28, 119], [152, 0, 67] ]);

const SPEED_COLOR2 = d3.scaleThreshold()
.domain([1, 10.01, 20.01, 30.01, 40.01, 50.01, 95.01])
.range([
 [0, 0, 0, 127], [152, 0, 67], [221, 28, 119],
 [223, 101, 176], [201, 148, 199], [212, 185, 218],
 [241, 238, 246], [0, 51, 0] ]);

const TTI_WIDTH = d3.scaleThreshold()
.domain([0.8, 1.251, 1.51, 1.751, 2.01, 2.51, 14])
.range([2, 10, 20, 30, 40, 50, 60]);

const SPEED_WIDTH = d3.scaleThreshold()
.domain([1, 10.01, 20.01, 30.01, 40.01, 50.01, 95.01])
.range([2, 60, 50, 40, 30, 20, 10]);

changelegend();
$('input[type=radio][name=optradio]').change(function() {
 if (this.value == 'daily') {

 $('#calendar').show();
 $('#dateSlider').hide();
 $('#timeSliderContainer').hide();
 $('#year-month').hide();

 let currentDate = $("#datepicker").datepicker("getDate");
  var formatted = $.datepicker.formatDate('yymmdd', currentDate);
  console.log(formatted);
  timestamp = formatted;

 roadDirection = "FALSE";
 if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
  loadRouteData();
  spatialLayer = 2;
 }
 else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
  loadSegmentData();
  spatialLayer = 0;

 }
 else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
  loadSectionData();
  spatialLayer = 1;
 }
 console.log(timestamp);
 filterData(timestamp);
 redraw();
 }
 else if (this.value == '15min') {
  $('#timeSliderContainer').hide();
  $('#calendar').show();
  $('#dateSlider').show();
  $('#year-month').hide();
 }
 else if (this.value == 'hourly'){
  $('#calendar').show();
  $('#dateSlider').hide();
  $('#timeSliderContainer').show();
  $('#year-month').hide();
 }

 else if(this.value == 'yearly'){
  console.log("IN YEARLY");
```

```
  $('#calendar').hide();
  $('#dateSlider').hide();
  $('#timeSliderContainer').hide();
  $('#year-month').show();
  $('#yearSelector').show();
  $('#monthSelector').hide();
 }
 else if(this.value == 'monthly'){
  $('#calendar').hide();
  $('#dateSlider').hide();
  $('#timeSliderContainer').hide();
  $('#year-month').show();
  $('#yearSelector').show();
  $('#monthSelector').show();

 }

 if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
  loadRouteData();
  spatialLayer = 2;
 }
 else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
  loadSegmentData();
  spatialLayer = 0;

 }
 else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
  loadSectionData();
  spatialLayer = 1;
 }
});

$('input[type=radio][name=variableRadio]').change(function() {
 if(this.value == 'ttiSelected'){
  trafficVariable = 1;
  changelegend();
 }
 else if(this.value == 'speedSelected'){
  trafficVariable = 2;
  changelegend();
 }
 redraw();
});

$('input[type=radio][name=typeRadio]').change(function() {
 if(this.value == 'colorSelected'){
  visType = 1;
  changelegend();
 }
 else if(this.value == 'color2Selected'){
  visType = 2;
  changelegend();
 }
 else if(this.value == 'widthSelected'){
  visType = 3;
  changelegend();
 }
 else if(this.value == 'bothSelected'){
  visType = 4;
  changelegend();
 }
 else if(this.value == 'both2Selected'){
  visType = 5;
  changelegend();
 }
 redraw();
```

```
});

$('input[type=radio][name=spatioradio]').change(function() {

  if(this.value == 'route'){
    loadRouteData();
    spatialLayer = 2;
    currentSelectedSpatial = "Route";
  }
  else if(this.value == 'segment'){
    loadSegmentData();
    spatialLayer = 0;
    currentSelectedSpatial = "Segment";

  }
  else if(this.value == 'section'){
    loadSectionData();
    spatialLayer = 1;
    currentSelectedSpatial = "Section";
  }
});

$('input[type=radio][name=bmapRadio]').change(function() {

  if(this.value == 'dark'){
    deckgl._map._map.setStyle('mapbox://styles/mapbox/dark-v10');
  }
  else if(this.value == 'light'){
    deckgl._map._map.setStyle('mapbox://styles/mapbox/light-v10');
  }
  else if(this.value == 'satellite'){
    deckgl._map._map.setStyle('mapbox://styles/mapbox/satellite-v9');
  }
  else if(this.value == 'navigationn'){
    deckgl._map._map.setStyle('mapbox://styles/mapbox/navigation-guidance-night-v4');
  }
  console.log(basem);
});

$('#year-value').on('change', function() {
  dateChange = 0;
  if(yearChange == 0){
    yearChange = 1;
  }
  else{
     yearChange = 0;
  }
  filterAggData();
  redraw();
});

$('#month-value').on('change', function() {
  if(monthChange == 0){
    monthChange = 1;
  }
  else{
     monthChange = 0;
  }
  filterAggData();
  redraw();
});

function changelegend(){
 if($('input[type="radio"][name="typeRadio"]:checked').val() == 'colorSelected'){
       if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
     legend1();
```

```
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
    legend2();
    }
  }
  else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'color2Selected'){
      if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
    legend3();
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
    legend4();
    }
  }
  else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'widthSelected'){
   if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
    legend5();
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
    legend6();
    }
  }
  else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'bothSelected'){
      if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
    legend7();
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
    legend8();
    }
  }
   else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'both2Selected'){
  if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
    legend9();
    }
   else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
    legend10();
    }
  }
}
var deckgl = new deck.DeckGL({
  initialViewState: {
    longitude: 13.0385674,
    latitude: 47.8013466,
    zoom: 13,
    pitch: 0,
    minZoom: 2,
    maxZoom: 20
  },
  controller: true,
  mapboxApiAccessToken: 'pk.eyJ1IjoiYXJzbGFuYXNsYW0iLCJhIjoiY2p3eHluaTc0MDY2bTN5dGE5MmFreDVhNiJ9.m7-
X9A_ArfFo7elXXyaSIQ',
  mapStyle: 'mapbox://styles/mapbox/dark-v10',
  pickingRadius: 5,
  layers: [],
  getTooltip
});
loadSegmentData();

function loadSegmentData(){
  console.log('LOAD SEGMENT');
  let currentDate = $("#datepicker").datepicker("getDate");
  console.log(currentDate);
  var formatted = $.datepicker.formatDate('yymmdd', currentDate);
  console.log(formatted);
  dateSelected = formatted;
  console.log(dateSelected);
```

```
  console.log($('input[type="radio"][name="optradio"]:checked').val());
  if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly' || $('input[type="radio"][name="optradio"]:checked').val() ==
'monthly'){

    console.log("inYearly");
    $('#year-month').show();

    d3.csv('https://raw.githubusercontent.com/ArslanAslam92/files/master/segmentt_agg.csv')  //all FALSE
    .then(data => {
      allRoutesData = data;
      roadDirection = "FALSE";
      filterAggData();
      redraw();
    });
  }
  else{
    d3.csv('https://raw.githubusercontent.com/ArslanAslam92/files/master/june19_insegmenttt.csv')  //all FALSE
    .then(data => {
      allRoutesData = data;
      const unique = [...new Set(data.map(item => item.timestamp))];
      timestamp = data[0].timestamp;
      if(dateSlider == "FALSE"){
        initTimeSlider(d3.select('#dateSlider'));
        dateSlider = "TRUE";
      }
      roadDirection = "FALSE";
      filterData(dateSelected);
      redraw();
    });
  }

}

function loadRouteData(){
  let currentDate = $("#datepicker").datepicker("getDate");
  var formatted = $.datepicker.formatDate('yymmdd', currentDate);
  console.log(formatted);
  dateSelected = formatted;

  console.log('LOAD ROUTE');
  console.log($('input[type="radio"][name="optradio"]:checked').val());
  if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly' || $('input[type="radio"][name="optradio"]:checked').val() ==
'monthly'){
    console.log("inYearly");
    $('#year-month').show();
    d3.csv('https://raw.githubusercontent.com/ArslanAslam92/files/master/route_agg.csv')
    .then(data => {
      allRoutesData = data;
      roadDirection = "FALSE";
      filterAggData();
      redraw();
    });
  }
  else{
    d3.csv('https://raw.githubusercontent.com/ArslanAslam92/files/master/june19_inroute.csv')   //ingoing
    .then(data => {
      allRoutesData = data;
      const unique = [...new Set(data.map(item => item.timestamp))];
      timestamp = data[0].timestamp;
      if(dateSlider == "FALSE"){
        initTimeSlider(d3.select('#dateSlider'));
        dateSlider = "TRUE";
      }
      roadDirection = "FALSE";
      filterData(dateSelected);
      redraw();
```

```
    });
  }
}

function loadSectionData(){
  console.log('LOAD SECTION');
  let currentDate = $("#datepicker").datepicker("getDate");
  var formatted = $.datepicker.formatDate('yymmdd', currentDate);
  console.log(formatted);
  dateSelected = formatted;
  if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly' || $('input[type="radio"][name="optradio"]:checked').val() ==
'monthly'){
    console.log("inYearly");
    $('#year-month').show();
    d3.csv('https://raw.githubusercontent.com/ArslanAslam92/files/master/section_agg.csv')
    .then(data => {
      allRoutesData = data;
      roadDirection = "FALSE";
      // filterData('20190601');
      filterAggData();
      redraw();
    });
  }
  else{
    d3.csv('https://raw.githubusercontent.com/ArslanAslam92/files/master/june19_insection.csv')  //ingoing
    .then(data => {
      allRoutesData = data;
      const unique = [...new Set(data.map(item => item.timestamp))];
      timestamp = data[0].timestamp;
      if(dateSlider == "FALSE"){
        initTimeSlider(d3.select('#dateSlider'));
        dateSlider = "TRUE";
      }
      roadDirection = "FALSE";
      filterData(dateSelected);
      redraw();
    });
  }
}

function redraw() {
  console.log("REDRAW");

  const layers = [
  new GeoJsonLayer({
    id: 'geojson',
    data: 'https://raw.githubusercontent.com/ArslanAslam92/files/master/segments.json',
    stroked: true,
    filled: true,
    extruded: false,
    wireframe: true,
    autoHighlight: true,
    highlightColor: '#000480',
    lineJointRounded: true,
    lineWidthMinPixels: 3,
    parameters: {
      depthTest: true
    },
    getLineColor: getLineColor,
    getLineWidth: getLineWidth,
    getElevation: 2000,
    pickable: true,
    onClick: (event) =>{
      console.log(event);
      console.log(event.object.properties.segment_id);
      if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
```

```
      getDataForGraph(event.object.properties.route_id);
    }
    else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
      getDataForGraph(event.object.properties.section_id);
    }
    else{
      getDataForGraph(event.object.properties.segment_id);
    }
    $('.graph-panel').show();
  },

  updateTriggers: {
    getLineColor: {timestamp,selectedTime,spatialLayer,trafficVariable,visType,yearChange,monthChange},
    getLineWidth: {timestamp,selectedTime,spatialLayer,trafficVariable,visType,yearChange,monthChange}
  },

  transitions: {
    getLineColor: 500,
    getLineWidth: 500
  }
  })
 ];

 deckgl.setProps({layers});
}
function getKey(keyProps) {
 let keyId ;
 if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
  keyId = `${keyProps.route_id}`;
  return keyId;
 }
 else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
  keyId = `${keyProps.segment_id}`;
  return keyId;
 }
 else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
  keyId = `${keyProps.section_id}`;
  return keyId;
 }
 else{
  keyId = `${keyProps.segment_id}`;
  return keyId;
 }
}
function getRouteKey(keyProps){
 var route_id = `${keyProps.segment_id}`
 return segment_id;
}

function getLineColor(f) {
 let colorOptionEnabled = false;
 let colorOption2Enabled = false;
 if($('input[type="radio"][name="typeRadio"]:checked').val() == 'colorSelected'){
  colorOptionEnabled = true;
 }
 else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'color2Selected'){
 colorOption2Enabled = true;
 }
 else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'bothSelected'){
 colorOptionEnabled = true;
 }
  else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'both2Selected'){
 colorOption2Enabled = true;
 }
 else{
```

```
  colorOptionEnabled = false;
  colorOption2Enabled = false;
 }

 if(colorOptionEnabled){
  let timeInterval,hour,columnNamesForHour ;
  if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
    hour = selectedTime;
  //console.log(hour);
  columnNamesForHour =  timeline.filter(function (el) {
   return el.hour == hour;
 });
 }
 else{
  timeInterval = getDateInterval(selectedTime);
 }

 const key = getKey(f.properties);
 let currentFeatureData = []; //this will save data of one segment/route/selection
 if(filteredData.length != 0){
  if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
    currentFeatureData = filteredData.filter(function (el) {
       return el.route_id == key
      });
  }
  else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
    currentFeatureData = filteredData.filter(function (el) {

      return el.segment_id == key
    });
  }
  else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
    currentFeatureData = filteredData.filter(function (el) {

      return el.section_id == key
    });
  }

  if(currentFeatureData.length != 0){
    if($('input[type="radio"][name="optradio"]:checked').val() == '15min'){
      if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
       return TTI_COLOR(currentFeatureData[0][timeInterval.name]);
      }
      else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
       return SPEED_COLOR(currentFeatureData[0][timeInterval.speed]);
      }
    }
    else if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
      if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
       let ttiValueArray = [];
       columnNamesForHour.forEach(column => {
        let ttiColumnValue = currentFeatureData[0][column.name];
        ttiValueArray.push(parseFloat(ttiColumnValue));
       });
       const sum = ttiValueArray.reduce((a, b) => a + b, 0);
       const avg = (sum / ttiValueArray.length) || 0;
       return TTI_COLOR(avg);
      }
      else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
        let speedValueArray = [];
        columnNamesForHour.forEach(column => {
          let ttiColumnValue = currentFeatureData[0][column.speed];
          speedValueArray.push(parseFloat(ttiColumnValue));
        });
        const sum = speedValueArray.reduce((a, b) => a + b, 0);
```

```
      const avg = (sum / speedValueArray.length) || 0;
      return SPEED_COLOR(avg);
    }
   }
   else if($('input[type="radio"][name="optradio"]:checked').val() == 'daily'){
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
     return TTI_COLOR(currentFeatureData[0]['averageTTI']);
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
     return SPEED_COLOR(currentFeatureData[0]['v_avg']);
    }
   }
   else if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly'){
    console.log("IM IN YEAR INSIDE COLOR");
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
     return TTI_COLOR(currentFeatureData[0]['TTI']);
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
     return SPEED_COLOR(currentFeatureData[0]['v']);
    }

   }
   else if($('input[type="radio"][name="optradio"]:checked').val() == 'monthly'){
    console.log("IM IN YEAR INSIDE COLOR");
    console.log(currentFeatureData);
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
     return TTI_COLOR(currentFeatureData[0]['TTI']);
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
     return SPEED_COLOR(currentFeatureData[0]['v']);
    }
   }
  }
  else{
   return TTI_COLOR(0);
  }
 }
 else{
  return TTI_COLOR(0);
 }
 }

 if(colorOption2Enabled){
  let timeInterval,hour,columnNamesForHour ;
  if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
   hour = selectedTime;
  //console.log(hour);
  columnNamesForHour =  timeline.filter(function (el) {
   return el.hour == hour;
  });

 }
 else{

  timeInterval = getDateInterval(selectedTime);
 }

 const key = getKey(f.properties);
 let currentFeatureData = []; //this will save data of one segment/route/selection
 if(filteredData.length != 0){
   if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
    currentFeatureData = filteredData.filter(function (el) {
      return el.route_id == key
     });
  }
```

```
else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
  currentFeatureData = filteredData.filter(function (el) {
    return el.segment_id == key
  });
}
else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
  currentFeatureData = filteredData.filter(function (el) {
    return el.section_id == key
  });
}

if(currentFeatureData.length != 0){
  if($('input[type="radio"][name="optradio"]:checked').val() == '15min'){
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
      return TTI_COLOR2(currentFeatureData[0][timeInterval.name]);
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
      return SPEED_COLOR2(currentFeatureData[0][timeInterval.speed]);
    }

  }
  else if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
      let ttiValueArray = [];
      columnNamesForHour.forEach(column => {
        let ttiColumnValue = currentFeatureData[0][column.name];
        ttiValueArray.push(parseFloat(ttiColumnValue));
      });
      const sum = ttiValueArray.reduce((a, b) => a + b, 0);
      const avg = (sum / ttiValueArray.length) || 0;
      return TTI_COLOR2(avg);

    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
        let speedValueArray = [];
        columnNamesForHour.forEach(column => {
          let ttiColumnValue = currentFeatureData[0][column.speed];
          speedValueArray.push(parseFloat(ttiColumnValue));
        });
        const sum = speedValueArray.reduce((a, b) => a + b, 0);
        const avg = (sum / speedValueArray.length) || 0;
        return SPEED_COLOR2(avg);
    }
  }
  else if($('input[type="radio"][name="optradio"]:checked').val() == 'daily'){
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
      return TTI_COLOR2(currentFeatureData[0]['averageTTI']);
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
      return SPEED_COLOR2(currentFeatureData[0]['v_avg']);
    }
  }
  else if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly'){
    console.log("IM IN YEAR INSIDE COLOR");
    console.log(currentFeatureData);
    if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
      return TTI_COLOR2(currentFeatureData[0]['TTI']);
    }
    else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
      return SPEED_COLOR2(currentFeatureData[0]['v']);
    }
  }
  else if($('input[type="radio"][name="optradio"]:checked').val() == 'monthly'){
    console.log("IM IN YEAR INSIDE COLOR");
    console.log(currentFeatureData);
```

```
        if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
          return TTI_COLOR2(currentFeatureData[0]['TTI']);
        }
        else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
          return SPEED_COLOR2(currentFeatureData[0]['v']);
        }
      }
    }
    else{
      return TTI_COLOR2(0);
    }
  }
  else{
    return TTI_COLOR2(0);
  }
  }
  else{
    return [254,224,139];
  }
}
function getLineWidth(f) {

  let lineWidthEnabled = false;
   if($('input[type="radio"][name="typeRadio"]:checked').val() == 'widthSelected'){

    lineWidthEnabled = true;
  }
  else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'bothSelected'){
   lineWidthEnabled = true;
  }
   else if($('input[type="radio"][name="typeRadio"]:checked').val() == 'both2Selected'){
   lineWidthEnabled = true;
  }
  else{
    lineWidthEnabled = false;
  }
  if(lineWidthEnabled){
    let timeInterval,hour,columnNamesForHour ;
    if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
      hour = selectedTime;
    columnNamesForHour =  timeline.filter(function (el) {
      return el.hour == hour;
   });

  }
  else{

    timeInterval = getDateInterval(selectedTime);
  }
  const key = getKey(f.properties);
  let currentFeatureData = []; //this will save data of one segment/route/selection
  if(filteredData.length != 0){


     if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
      currentFeatureData = filteredData.filter(function (el) {
          return el.route_id == key
        });
    }
    else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
      currentFeatureData = filteredData.filter(function (el) {

        return el.segment_id == key
      });
    }
```

```
else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
 currentFeatureData = filteredData.filter(function (el) {

   return el.section_id == key
 });
}

if(currentFeatureData.length != 0){
 if($('input[type="radio"][name="optradio"]:checked').val() == '15min'){
  if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
   return TTI_WIDTH(currentFeatureData[0][timeInterval.name]);
  }
  else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
   return SPEED_WIDTH(currentFeatureData[0][timeInterval.speed]);
  }
 }
 else if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){

  if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
   let ttiValueArray = [];
   columnNamesForHour.forEach(column => {
    let ttiColumnValue = currentFeatureData[0][column.name];
    ttiValueArray.push(parseFloat(ttiColumnValue));
   });
   const sum = ttiValueArray.reduce((a, b) => a + b, 0);
   const avg = (sum / ttiValueArray.length) || 0;
   return TTI_WIDTH(avg);

  }
  else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
    let speedValueArray = [];
    columnNamesForHour.forEach(column => {
     let ttiColumnValue = currentFeatureData[0][column.speed];
     speedValueArray.push(parseFloat(ttiColumnValue));
    });
    const sum = speedValueArray.reduce((a, b) => a + b, 0);
    const avg = (sum / speedValueArray.length) || 0;
    return SPEED_WIDTH(avg);
  }
 }
 else if($('input[type="radio"][name="optradio"]:checked').val() == 'daily'){
   if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
   return TTI_WIDTH(currentFeatureData[0]['averageTTI']);
  }
  else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
   return SPEED_WIDTH(currentFeatureData[0]['v_avg']);
  }
 }
 else if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly'){
  console.log("IM IN YEAR INSIDE COLOR");
  console.log(currentFeatureData);
  if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
   return TTI_WIDTH(currentFeatureData[0]['TTI']);
  }
  else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
   return SPEED_WIDTH(currentFeatureData[0]['v']);
  }

 }
 else if($('input[type="radio"][name="optradio"]:checked').val() == 'monthly'){
  console.log("IM IN MONTH INSIDE COLOR");
  console.log(currentFeatureData);
  if($('input[type="radio"][name="variableRadio"]:checked').val() == 'ttiSelected'){
   return TTI_WIDTH(currentFeatureData[0]['TTI']);
  }
```

```
        else if($('input[type="radio"][name="variableRadio"]:checked').val() == 'speedSelected'){
          return SPEED_WIDTH(currentFeatureData[0]['v']);
        }
      }
    }
    else{       //if current feature data length is zero
      return 5;     //show this width for no data
    }
  }
  else{       //if filtered data length is zero
    return 5;     //show this width for no data
  }
  }
  else{       //if line width not enabled. i.e. this set width for when colors are enabled
    return 15;
}
}

function initTimeSlider(container) {
  const inputValue = container.append('div').text(`Time: ${selectedTime}`)
  const input = container.append('input').attr('type', 'range')
  .attr('min', 0)
  .attr('max', 95)
  .attr('step', 1)
  .attr('value', selectedTime)
  .on('input', () => {
    timeval = input.property('value');
    console.log(timeval);
    console.log(selectedTime);

    selectedTime = timeval;

    console.log(selectedTime);
    let tInterval = getDateInterval(selectedTime)
    inputValue.text(`TIME ${tInterval.start} to ${tInterval.end} `);
    redraw();
  });
}


function getDateInterval(time){
  let timeIntervalIndex = timeline.findIndex(x => x.index == time);
  let timeInterval = timeline[timeIntervalIndex];
  return timeInterval;
}
function getHour(time){
let timeIntervalIndex = timeline.findIndex(x => x.index == time);
let timeInterval = timeline[timeIntervalIndex];
return timeInterval.hour;
}
function filterData(date){
  console.log(date);
  console.log(allRoutesData);
  console.log(roadDirection);
  if(date == null || date == ""){
    date = "20190601";
  }
  console.log(date);
  if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
    filteredData = allRoutesData.filter(function (el) {
      return el.timestamp == date;
    });
  }
  else{
    filteredData = allRoutesData.filter(function (el) {
```

```
      return el.timestamp == date &&
      el.direction_1 == roadDirection;
    });
  }
  console.log(filteredData);
}
function filterAggData(){
  // alert($('#year-value').val());
 if($('input[type="radio"][name="optradio"]:checked').val() == 'yearly'){
  filteredData = allRoutesData.filter(function (el) {
      return el.year == $('#year-value').val() &&
      el.direction_1 == roadDirection && el.month == 0 ;
    });
    console.log(filteredData);
 }
 else{
  filteredData = allRoutesData.filter(function (el) {
      return el.year == $('#year-value').val() &&
      el.direction_1 == roadDirection && el.month == $('#month-value').val() ;
    });
  console.log(filteredData);
 }
}

function getTooltip(info) {
  const props = info.object ? info.object.properties : null;
  let content = '';
  let infoString = undefined;
  let timeInterval,hour;
  if (props) {
    if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
      hour = selectedTime;
      columnNamesForHour =  timeline.filter(function (el) {
       return el.hour == hour;
     });
    }
    else{
      timeInterval = getDateInterval(selectedTime);
    }
    const key = getKey(props);
    let r = undefined;
    let f = undefined;

    let tti = undefined;
    let speed = undefined;
    let date = undefined;
    let direction = undefined;
    let hours = undefined;

    let currentFeatureData = [];
    if(filteredData.length != 0){
        if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
          currentFeatureData = filteredData.filter(function (el) {
              return el.route_id == key
            });
        }
        else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
          currentFeatureData = filteredData.filter(function (el) {

            return el.segment_id == key
          });
        }
        else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
          currentFeatureData = filteredData.filter(function (el) {
```

```
          return el.section_id == key
        });
      }
     if(currentFeatureData.length != 0){
      if($('input[type="radio"][name="optradio"]:checked').val() == '15min'){
        tti = currentFeatureData[0][timeInterval.name];
        speed = currentFeatureData[0][timeInterval.speed];

        infoString = `<big>TTI : ${tti} , Speed : ${speed}<br>Date : ${currentFeatureData[0]['timestamp']} , Interval:
${timeInterval.start} to ${timeInterval.end}</big>`;
      }
      else if($('input[type="radio"][name="optradio"]:checked').val() == 'hourly'){
        let ttiValueArray = [];
        let speedValueArray = [];
        let direction = "";
        let datadate;
        columnNamesForHour.forEach(column => {
          let ttiColumnValue = currentFeatureData[0][column.name];
          let speedColumnValue = currentFeatureData[0][column.speed];
          direction = currentFeatureData[0]['direction_1'];
          datadate = currentFeatureData[0]['timestamp'];
          ttiValueArray.push(parseFloat(ttiColumnValue));
          speedValueArray.push(parseFloat(speedColumnValue));
        });
        const sum = ttiValueArray.reduce((a, b) => a + b, 0);
        const avg = (sum / ttiValueArray.length) || 0;

        const speedSum = speedValueArray.reduce((a, b) => a + b, 0);
        const speedAvg = (speedSum / speedValueArray.length) || 0;
        tti = avg;
        hours = hour;
        speed = speedAvg;
        infoString = `<big>TTI : ${tti} , Speed : ${speed}<br>Date : ${datadate} , ${hours}:00 hrs </big>`;
      }
      else if($('input[type="radio"][name="optradio"]:checked').val() == 'daily'){
        tti =currentFeatureData[0]['averageTTI'];
        speed =currentFeatureData[0]['v_avg'];
        infoString = `<big>TTI : ${tti} , Speed : ${speed}<br>Date : ${currentFeatureData[0]['timestamp']} </big>`;
      }
      else if ($('input[type="radio"][name="optradio"]:checked').val() == 'yearly'){
        tti =currentFeatureData[0]['TTI'];
        speed =currentFeatureData[0]['v'];
        infoString = `<big>TTI : ${tti} , Speed : ${speed}<br>Year : ${$('#year-value').val()} </big>`;
      }
      else if ($('input[type="radio"][name="optradio"]:checked').val() == 'monthly'){
        tti =currentFeatureData[0]['TTI'];
        speed =currentFeatureData[0]['v'];
        infoString = `<big>AVG TTI : ${tti} , Speed : ${speed}<br>Year : ${$('#year-value').val()} , Month: ${$('#month-
value').val()} </big>`;
      }
    }
    else{
     r = undefined;
     f = undefined;
    }
  }

 let content = "" ;
 if ($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
   content = `<big>Route Id : ${props.route_id} </big>`;
 }
 else if ($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
   content = `<big>Section Id : ${props.section_id} (Route Id : ${props.route_id}) </big>`;
 }
 else{
```

```
content = `<big>Segment Id :${props.segment_id} (Route Id : ${props.route_id}) </big>`;
 }
 if (infoString) {
content += `
<div>
</div>
<div>${infoString}</div>
`;
} else {
 content += `<div>no accidents recorded in <b>${timestamp}</b></div>`;
}
return {html: content};
} else {
 return null;
}
}
function getDataForGraph(key){

 let currentFeatureData = [];
 if(filteredData.length != 0){
  if($('input[type="radio"][name="spatioradio"]:checked').val() == 'route'){
   if($('input[type="radio"][name="optradio"]:checked').val()  == 'yearly'){
    currentFeatureData = allRoutesData.filter(function (el) {
     return el.route_id == key && el.direction_1 == roadDirection && el.month == 0;
    });
    drawYearlyGraph(currentFeatureData,key);
   }
   else if($('input[type="radio"][name="optradio"]:checked').val()  == 'monthly'){
    currentFeatureData = allRoutesData.filter(function (el) {
     return el.route_id == key && el.year == $('#year-value').val() && el.direction_1 == roadDirection && el.month != 0;
    });
    drawMonthlyGraph(currentFeatureData,key);
   }
   else if($('input[type="radio"][name="optradio"]:checked').val()  == 'daily'){
    currentFeatureData = allRoutesData.filter(function (el) {
     return el.route_id == key && el.direction_1 == roadDirection;
    });
    drawDailyGraph(currentFeatureData,key);
   }
   else if($('input[type="radio"][name="optradio"]:checked').val()  == 'hourly'){
    currentFeatureData = filteredData.filter(function (el) {
     return el.route_id == key
    });
    drawHourlyGraph(currentFeatureData[0],key);
   }
   else{
    timeInterval = getDateInterval(selectedTime);
    currentFeatureData = filteredData.filter(function (el) {
     return el.route_id == key
    });
    drawGraph(currentFeatureData[0],key);
   }
  }
   else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'section'){
    if($('input[type="radio"][name="optradio"]:checked').val()  == 'yearly'){
    currentFeatureData = allRoutesData.filter(function (el) {
     return el.section_id == key && el.direction_1 == roadDirection && el.month == 0;
    });
    drawYearlyGraph(currentFeatureData,key);
   }
   else if($('input[type="radio"][name="optradio"]:checked').val()  == 'monthly'){
    currentFeatureData = allRoutesData.filter(function (el) {
     return el.section_id == key && el.year == $('#year-value').val() && el.direction_1 == roadDirection && el.month != 0;
    });
    drawMonthlyGraph(currentFeatureData,key);
```

```
    }
    else if($('input[type="radio"][name="optradio"]:checked').val()  == 'daily'){
     currentFeatureData = allRoutesData.filter(function (el) {
       return el.section_id == key && el.direction_1 == roadDirection;
     });
     drawDailyGraph(currentFeatureData,key)
    }
    else if($('input[type="radio"][name="optradio"]:checked').val()  == 'hourly'){
      currentFeatureData = filteredData.filter(function (el) {
       return el.section_id == key
     });
     drawHourlyGraph(currentFeatureData[0],key);
    }
    else{
     timeInterval = getDateInterval(selectedTime);
     currentFeatureData = filteredData.filter(function (el) {
       return el.section_id == key
     });
     drawGraph(currentFeatureData[0],key)
    }
  }
  else if($('input[type="radio"][name="spatioradio"]:checked').val() == 'segment'){
    if($('input[type="radio"][name="optradio"]:checked').val()  == 'yearly'){
     currentFeatureData = allRoutesData.filter(function (el) {
       return el.segment_id == key && el.direction_1 == roadDirection && el.month == 0;
     });
     drawYearlyGraph(currentFeatureData,key);
    }
    else if($('input[type="radio"][name="optradio"]:checked').val()  == 'monthly'){
     currentFeatureData = allRoutesData.filter(function (el) {
       return el.segment_id == key && el.year == $('#year-value').val() && el.direction_1 == roadDirection && el.month != 0;
     });
     drawMonthlyGraph(currentFeatureData,key);
    }
    else if($('input[type="radio"][name="optradio"]:checked').val()  == 'daily'){
     currentFeatureData = allRoutesData.filter(function (el) {
       return el.segment_id == key && el.direction_1 == roadDirection;
     });
     drawDailyGraph(currentFeatureData,key);
    }
    else if($('input[type="radio"][name="optradio"]:checked').val()  == 'hourly'){
      currentFeatureData = filteredData.filter(function (el) {
       return el.segment_id == key
     });
     drawHourlyGraph(currentFeatureData[0],key);
    }
    else{
     timeInterval = getDateInterval(selectedTime);
     currentFeatureData = filteredData.filter(function (el) {
       return el.segment_id == key
     });
     drawGraph(currentFeatureData[0],key);
    }
  }
     console.log(currentFeatureData);
    }
  }

  function drawGraph(data,key){
    console.log(data);
    let labels = Object.keys(data);
    labels = labels.slice(2, 98);
// console.log(labels);
labels = labels.map(function (x) {
  let slice = x.slice(3, 7);
```

```
  slice = slice.replace(/(..)/g, '$1:').slice(0,-1)
  return slice;
});
let values  = Object.values(data);
let ttivalues = values.slice(2, 98);
let speedValues = values.slice(100, 196);

var intValues = ttivalues.map(function (x) {
  return parseFloat(x);
});
var intSpeedValues = speedValues.map(function (x) {
  return parseInt(x);
});
let chartData = []

for( let i = 0; i < labels.length ; i++){
  chartData.push({
    'time': labels[i],
    'value': intValues[i],
    'speed' : intSpeedValues[i]
  })
}

var chart = AmCharts.makeChart("chartdiv", {
  "type": "serial",
  "theme": "light",
  "titles": [{
    "text": currentSelectedSpatial+' Id: ' + key + ' | Date: ' +timestamp.substring(8,6)+'-'+timestamp.substring(6,4)+'-
'+timestamp.substring(4,0) + ' | Time: ' + timeInterval.start + ' to ' + timeInterval.end,
    "size": 12
  }],
  "backgroundColor": "#DCDCDC",
  "dataProvider": chartData,
  "minMarginBottom": 60,
  "valueAxes": [{
    "id":"v1",
    "gridColor": "#FFFFFF",
    "axisColor": "#0066CC",
    "color": "#0066CC",
    "title": "Travel Time Index",
    "gridAlpha": 0.2,
    "dashLength": 0,
    "position": "left"
  },{
    "id":"v2",
    "gridColor": "#FFFFFF",
    "axisColor": "#db4c3c",
    "color": "#db4c3c",
    "title": "Speed (km/h)",
    "gridAlpha": 0.2,
    "dashLength": 0,
    "position": "right"
  }],
  "gridAboveGraphs": true,
  "startDuration": 1,
  "graphs": [{
    "title": "TTI",
    "fillAlphas": 1,
    "lineColor": "#B0C4DE",
    "fillColors": "#B0C4DE",
    "valueAxis": "v1",
    "balloonText": "[[title]]: <b>[[value]]</b>",
    "type": "column",
    "valueField": "value"
},
{
```

```
   "title": "Speed",
   "balloonText": "[[title]]: <b>[[value]]</b>",
   "valueAxis": "v2",
   "lineColor": "#db4c3c",
   "lineThickness": 2,
   "type": "smoothedLine",
   "valueField": "speed"
}],
"chartCursor": {
  "categoryBalloonEnabled": true,
  "cursorAlpha": 0,
  "zoomable": false
},
"categoryField": "time",
"categoryAxis": {
  "gridPosition": "start",
  "gridAlpha": 0.1
},
"legend": {
  "position": "right",
  "spacing": 20,
}
});
}


function closeGraph(){
  $('.graph-panel').hide();
}

function hideAllLegends(){
  $('.legend-1').hide();
  $('.legend-2').hide();
  $('.legend-3').hide();
  $('.legend-4').hide();
  $('.legend-5').hide();
  $('.legend-6').hide();
  $('.legend-7').hide();
  $('.legend-8').hide();
  $('.legend-9').hide();
  $('.legend-10').hide();
}

function legend1(){
  hideAllLegends();
  $('.legend-1').show();
}

function legend2(){
  hideAllLegends();
  $('.legend-2').show();
}

function legend3(){
  hideAllLegends();
  $('.legend-3').show();
}

function legend4(){
  hideAllLegends();
  $('.legend-4').show();
}

function legend5(){
  hideAllLegends();
  $('.legend-5').show();
```

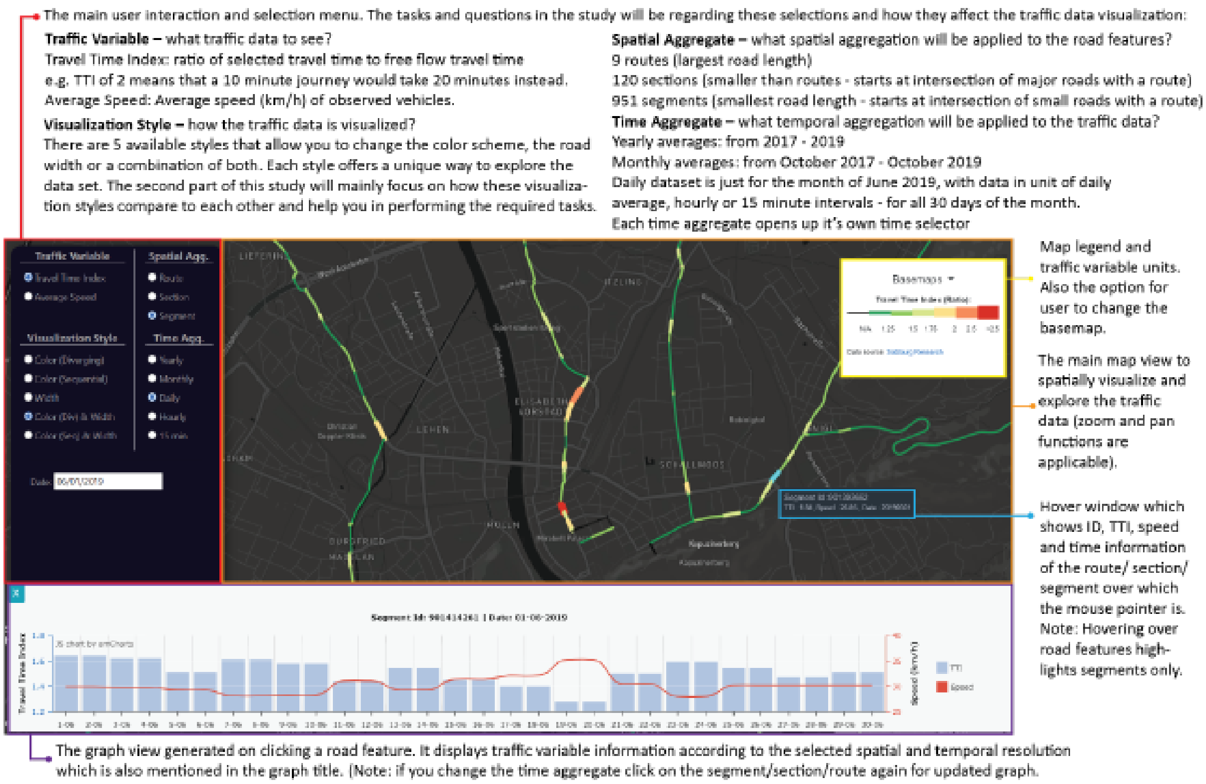
```
}

function legend6(){
  hideAllLegends();
  $('.legend-6').show();
}

function legend7(){
  hideAllLegends();
  $('.legend-7').show();
}

function legend8(){
  hideAllLegends();
  $('.legend-8').show();
}

function legend9(){
  hideAllLegends();
  $('.legend-9').show();
}

function legend10(){
  hideAllLegends();
  $('.legend-10').show();
}
```

Full code files are available at:
https://github.com/ArslanAslam92/Traffic_Visualization

Appendix IV – User Evaluation Study

Introduction

This user evaluation study is based on a research application developed to evaluate ways of visually exploring traffic data on a map. It is part of the master's thesis titled "Evaluation of methods and tools for interactively visualizing and exploring traffic data". Traffic data from the city of Salzburg has been used for the developed application. The study has 2 parts associated with each other; firstly it will require you to perform tasks using tools and features within the prototype (e.g. discovering the answers to specific traffic related questions). The second part will need you to evaluate the experience of different interactive features and visualization methods you used. An initial screenshot view of the application with description is given below:



Please go through the above screenshot and description thoroughly to get an idea of the features and interactive elements of the prototype. The map takes 0.5 second to update on changes from the left selection panel. The web link for the prototype is given below:
[Traffic Visualization Application Prototype]

Please take a couple of minutes to get familiarized with the interface and the features, and move on to the next page for the tasks and further evaluation. From here on, instructions are written in red font, while hints are mentioned in green fonts. To visit a previous page or visit this first page again please use the "Back" button at the bottom of the survey. Do not use to browser's back button.

Note: The data used within the traffic application is property of Salzburg Research and is not to be shared further. The data collected from your responses in the evaluation study will only be used for the purpose of this research. For any queries please contact arslanaslam2903@gmail.com. Thank you for taking part in this survey!

1.

This section explores the Traffic Variable Travel Time Index with each of the five visualization styles.

Please refresh the traffic visualization application before starting the task as it requires the default selections which are:

- Traffic Variable = Travel Time Index
- Time Aggregate = Daily
- Spatial Aggregate = Segment

The Visualization Style and date selection is mentioned in each sub-question. The time taken to answer each sub-question of this task will be recorded automatically to establish a comparison between each Visualization Style (please answer them in sequence).

Hint: In each sub questions 3-4 segments would be in the highest legend category (i.e. red, or dark purple or thickest). Find the highest among them and use the hover popup to see the segment ID. (You may note it down, or just remember the last 2-3 numbers of the ID to help you answer among the options given.

Click Here to Start Automatic Time Recording

Select the Visualization Style: **Color (Diverging)** and Date: **12 June, 2019**
Which Segment ID has the highest Travel Time Index?

901394214

901393662

901418171

Select the Visualization Style: **Color (Sequential)** and Date: **19 June, 2019**
Which Segment ID has the highest Travel Time Index?

901393448

901405235

901416488

Select the Visualization Style: **Width** and Date: **2 June, 2019**
Which Segment ID has the highest Travel Time Index?

901418672

901409777

901392848

Select the Visualization Style: **Color (Div) & Width** and Date: **15 June, 2019**
Which Segment ID has the highest Travel Time Index?

901392843

901393976

901409999

Select the Visualization Style: **Color (Seq) & Width** and Date: **26 June, 2019**
Which Segment ID has the highest Travel Time Index? (Hint: You may have to zoom out a little)

901409758

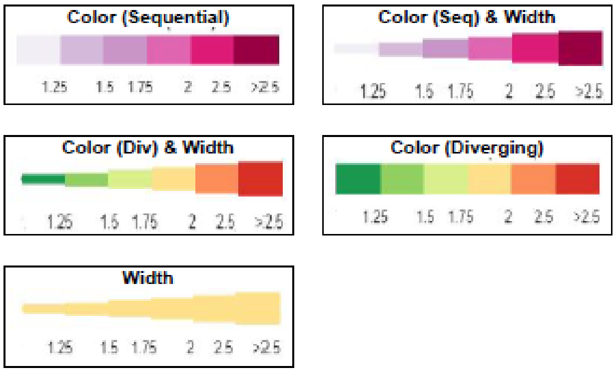
901268880

901389664

The questions on this page are related to the set of tasks you just performed in the previous page. However please feel free to explore the traffic application again after reading each question to better answer.

2. How would you rank the visualization styles in comparison to each other?

(Drag and drop into the list to the right. 1 means best, while 5 means worst)

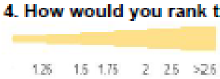


1
2
3
4
5

3. How would you rank the Color visualization styles over the following characteristics?

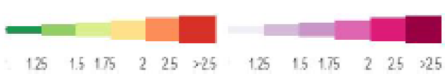
Difficulty Level (i.e. understanding the visualization and discovering data values	Complicated	○	○	○	○	Simple
Likeness (i.e. would you prefer using this visualization method)	Unappealing	○	○	○	○	Likeable
How progressive is this style to visualize line based traffic data?	Conventional	○	○	○	○	Innovative

4. How would you rank the Width visualization style over the following characteristics?



Difficulty Level (i.e. understanding the visualization and discovering data values	Complicated	○	○	○	○	Simple
Likeness (i.e. would you prefer using this visualization method)	Unappealing	○	○	○	○	Likeable
How progressive is this style to visualize line based traffic data?	Conventional	○	○	○	○	Innovative

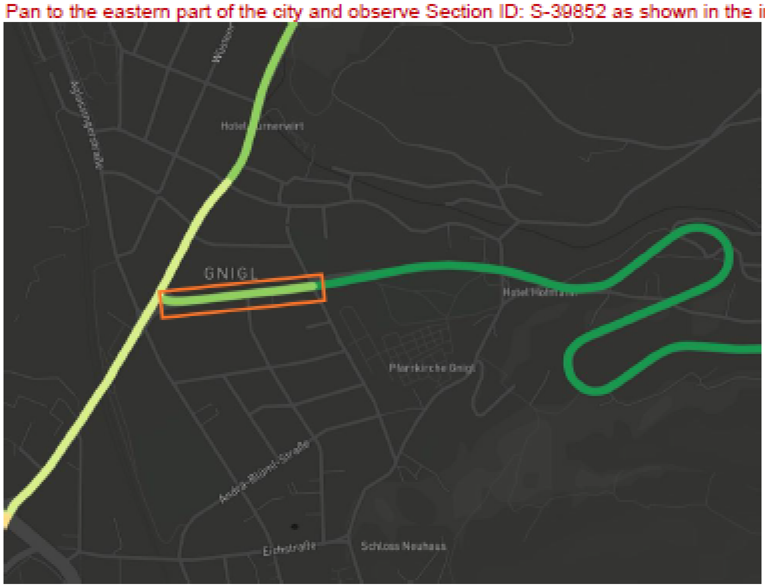
5. How would you rank the combination of Color and Width visualization styles over the following characteristics?



Difficulty Level (i.e. understanding the visualization and discovering data values	Complicated	○	○	○	○	Simple
Likeness (i.e. would you prefer using this visualization method)	Unappealing	○	○	○	○	Likeable
How progressive is this style to visualize line based traffic data?	Conventional	○	○	○	○	Innovative

6. In this section we will visualize and explore traffic congestion cases using Traffic Variable: Travel Time Index

Traffic Variable: **Travel Time Index,** Time Agg: **Daily**, Spatial Agg: **Section,** Visualization Style: your preference
Pan to the eastern part of the city and observe Section ID: S-39852 as shown in the image below.

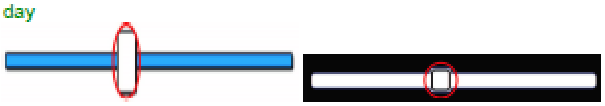


Which day was most congested on this section?
(Hint: Click on the section S-39852 and look for the highest TTI value in the graph)

- ◯ 13 June, 2019
- ◯ 3 June, 2019
- ◯ 24 June, 2019
- ◯ 18 June, 2019

7. Identify the most congested time of the day you selected.

Time Agg: **Hourly or 15 min** and **Date: (your answer for previous question)**
(Hint: click on the same section again. In Hourly/15 min mode the graph will shows values for the whole day)
OR Click on the Hourly/15 min slider (as encircled in image below) and use left/right arrow keys to animate through the day



- ◯ around 09:00
- ◯ around 08:00
- ◯ around 14:00
- ◯ around 16:00
- ◯ around 23:00

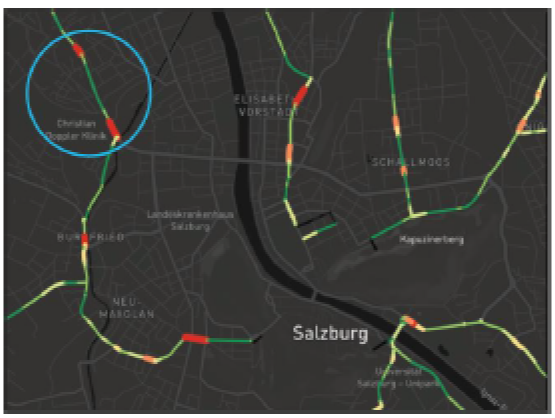
8. With the help of 2 case studies, can you identify spatial patterns of congestion among the 9 routes of the city?

Traffic Variable: **Travel Time Index**, Time Agg: **15 min** time: **8:15-8:30**, Spatial Agg: **Section**, Visualization Style: your choice

Explore the dates of **26 June and 24 June**
Which routes of the city were congested? I.e. had a dominant part of the route with TTI of 2 or higher? - You can select multiple routes.

- ☑ **26 June**
  - ☐ Route 1
  - ☐ Route 9
  - ☐ Route 8
  - ☐ Route 7
  - ☐ Route 5
- ☑ **24 June**
  - ☐ Route 1
  - ☐ Route 9
  - ☐ Route 8
  - ☐ Route 7
  - ☐ Route 5

9. Lets study the congestion pattern on 24 June closely towards the North East on route 1, near Christian Doppler Klinik as encircled in the image below:



Traffic Variable: **Travel Time Index**, Time Agg: **Hourly/15 min** , Spatial Agg: **Section/Segment**, Visualization Style: your choice

How long did the congestion last in this area? (Hint: the traffic congestion (i.e. TTI of 2 or higher) starts around 07:00)

- ◯ 1 Hour
- ◯ 2 Hours
- ◯ 3 Hours
- ◯ 4 Hours
- ◯ Other ____________________

10. In this section we will visualize and explore traffic congestion cases using Traffic Variable: Average Speed

Traffic Variable: **Average Speed,** Time Agg: **Hourly,** Date: **19 June, 2019**, Time: **17:00,** Spatial Agg: **Route,** Visualization Style: your choice

Which route was most congested on this time? (Hint: Use the hover popup to find Route ID)

- ◯ Route 1
- ◯ Route 9
- ◯ Route 2
- ◯ Route 5

11. Identify the most congested part of the route you selected?

Spatial Agg: **Section or Segment** and explore the route which you answered to the previous question

Most congested segment or section ID on this route? (Also see how the answer differs for segments and sections)

☑ **Segment – Spatial Aggregate**

- ☐ Start of the route (i.e near city center)
- ☐ Mid Part of the route
- ☐ End of the Route (i.e towards city outskirts)

☑ **Section – Spatial Aggregate**

- ☐ Start of the route (i.e near city center)
- ☐ Mid Part of the route
- ☐ End of the Route (i.e towards city outskirts)

12. Functionality of graphs: (e.g. in our case clicking on a segment/section can show traffic data for the whole month, or the whole day) While visualizing/exploring this data on the map would take much longer.

Would you agree that graphs/charts are necessary to show secondary (numeric) data in combination with the map

○ Strongly Disagree ○ Disagree ○ Agree ○ Strongly Agree

13. In questions 6-11 related to exploration of traffic congestion cases, you were free to choose the Visualization Style. Did you use the same one you ranked first earlier? If not, which visualization style did you prefer to use?

[Please choose]

14. The previous questions required you to visualize and explore traffic congestion events using 2 different traffic variables. Which traffic variable would you prefer to use for these tasks?

[Please choose]

15. How would you rank the Traffic Variable: Travel Time Index over the following characteristics?

Difficulty Level (i.e. understanding the visualization and discovering data values)	Difficult	○	○	○	○	Understandable
Appropriateness of scale used (i.e. legend classes)	Inappropriate	○	○	○	○	Appropriate
Relatable to real world situations (i.e. were you able to establish the link of this traffic variable to your personal travelling/driving experiences?))	Non-relatable	○	○	○	○	Relatable

16. How would you rank the Traffic Variable: Average Speed over the following characteristics?

Difficulty Level (i.e. understanding the visualization and discovering data values)	Difficult	○	○	○	○	Understandable
Appropriateness of scale used (i.e. legend classes)	Inappropriate	○	○	○	○	Appropriate
Relatable to real world situations (i.e. were you able to establish the link of this traffic variable to your personal travelling/driving experiences?))	Non-relatable	○	○	○	○	Relatable

17. Finally let's evaluate the overall user experience and functionality of the traffic visualization application.

Rank the capability of the application to carry out the following tasks:

What date and time is most congested on a specific part of the road? (e.g. similar to tasks performed in question 6 & 7)	Incapable	○	○	○	○	Capable
What patterns of congestion exists between the routes? (e.g. similar to task performed in question 8)	Incapable	○	○	○	○	Capable
How long was the traffic congestion event? (e.g. similar to task performed in question 9	Incapable	○	○	○	○	Capable
Where do congestion events exist on a specific time? (e.g. similar to task performed in question 10)	Incapable	○	○	○	○	Capable
How much of the route had traffic congestion? And is congestion on a segment/section related to neighboring segments/sections? (e.g. similar to task performed in question 11)	Incapable	○	○	○	○	Capable
Identifying bottle necks to traffic flow on each route? (e.g. a specific segment/section that is very frequently congested)	Incapable	○	○	○	○	Capable
Exploring temporal patterns (e.g. traffic flow on weekdays vs weekends)	Incapable	○	○	○	○	Capable

18. How would you rank the utility of each interactive feature of the application?

	Useless			Useful
Graph on clicking road features	○	○	○	○
Data Summary in popup on hover	○	○	○	○
Different visualization styles (i.e. Color, Width and combination of both)	○	○	○	○
Different traffic variables (i.e TTI, Speed)	○	○	○	○
Ability to change temporal granularity (e.g Monthly, Daily, Hourly etc.)	○	○	○	○
Ability to change spatial granularity (i.e. Route, Section, Segment)	○	○	○	○
Ability to change basemaps	○	○	○	○

19. How would you rank the application over the following characteristics:

How difficult or simple was it to learn and use?	Complicated	○	○	○	○	Simple
How did you find the user interface	Confusing	○	○	○	○	User-Friendly

How creative do you find this traffic application? Conventional ○ ○ ○ ○ Innovative

20. Please feel free to write down any further comments, suggestions or review on the traffic visualization application or this user evaluation study

Last Page

Thank you for completing this questionnaire!

We would like to thank you very much for helping us.

Your answers were transmitted, you may close the browser window or tab now.

M.Sc. Cartography Arslan Aslam, Technische Universität München – 2020