Traffic Visualization
Applying Information Visualization Techniques to Enhance Traffic Planning

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Abstract: Poor planning is a primary cause of transportation problems globally. Road traffic congestion results in severe economic and environmental costs in cities around the world. In this paper, we present a space-time visualization to provide city's decision-makers the ability to analyse, explore, investigate and uncover important "city events" in an understandable manner for city planning activities. In order to achieve this goal, an interactive Web mashup visualization prototype is presented which integrates several visualization techniques to give a rapid overview of traffic data. Our interviews with traffic control authorities of the city of Oulu revealed that they need visualization tools to support their planning activities and our visualization mashup suits their needs and brings significant improvements to their current tools. We illustrate our approach as a case study for traffic visualization systems, using datasets from the city of Oulu that can be extended to other city planning activities.

1   INTRODUCTION

The number of cars in the world is predicted to increase rapidly over the coming decades. Estimates suggest that by 2030, the world motor vehicle fleet will have risen from 808 million in 2002 to 1.3 billion vehicles [7]. Indeed, transportation appeared as one of the biggest infrastructure challenges according to a recent study conducted across 25 worlds largest cities with 522 stakeholders, where 69% had ten years of experience in city infrastructure, and poor planning appeared as second in the top five list of main causes for transportation problems [5]. Furthermore, the most frequently mentioned solution is the reorganization or revitalization of the existing infrastructure suggested by 33% of stakeholders. Other suggestions include building new roads and facilities [5]. However, creating new transport facilities is costly, whereas incremental improvements to the current systems is more pragmatic.

City's transportation systems can now be accessed by mobile, desktop or web applications. As more data becomes available, there is a need for more data-driven transportation systems [12] especially to improve traffic data analysis, and evaluation for traffic

quality determination [11, 4] and congestion [1]. Our work leverages previous research on the integration, analysis and visualization of traffic data within geographic information systems (GIS) [3, 8] using spatial and temporal dimensions to provide user specified aggregation levels [10]. These approaches have used one or more visualization techniques including line charts, maps or images [12], but provide limited interactivity for users and static levels of aggregation. Our work aims to provide a solution that can support a rapid overview using dynamic levels of aggregation of temporal and spatial data to explore and compare traffic events to increase user's awareness by combining several visualization techniques. We explore Hornbaek and Hertzum's definition of overview [6] in which an "Overview is an awareness of *an aspect* of an information space, acquired by *a process at a time*, useful for *a task* with *an outcome*, and provided by a *view transformed visualization*".

We argue that the availability of visualization tools can improve work activities for decision-makers such as traffic planners, police officers and city planners dealing with transportation issues in their everyday planning activities. Together with the ability to explore, compare and analyze real traffic data in a more

intuitive manner, information visualization can increase the awareness of traffic issues and the quality of decision-making [11]. Information Visualization hence becomes an important factor to consider when designing for decision-making activities. Indeed, information visualization aims to amplify a user's cognitive understanding of information through a visual representation of data [2]. The main contribution of this work is a novel interactive space-time visualization that applies several visualization techniques to analyze, explore, investigate and uncover road traffic events. A Web mashup visualization prototype has resulted from our development and the lessons learned from our preliminary evaluation. We expect that future traffic management systems will promote awareness and understanding of traffic data to facilitate interpretation and exploration of interesting traffic events, to improve traffic planning systems and city decision-making activities.

In this paper, we first introduce our case study problem of using an Oulu traffic dataset to create a space-time visualization prototype for decision-makers working with transportation systems. We describe the methods and tools used to build our prototype. We describe our results by comparing our design to the Oulu' current system and present a preliminary evaluation made by a group of Oulu decision-makers. Finally, we conclude and present our future work aims.

2 CASE STUDY

Our primary aim is to provide a mashup-based visualization using a combination of data mining, visualization techniques and Web-based tools to help decision-makers in their exploration of temporal traffic data. This can help them to detect and understand problematic and interesting events that should be taken into account in city planning activities.

2.1 Requirements

To explore historical traffic data, decision-makers need to *navigate data with respect to time and space*. Decision-makers must be able to understand local traffic state from different time periods, such as during rush hours or special events if they want to improve traffic planning activities. They must be able to see an overview of a certain time period, e.g., a week or a day, for a specific region of the city. The *visualization must be interactive and flexible* to enable users to dynamically refine the view of the dataset. This allows them to concentrate on the problem they are trying

to understand, in a specific moment, while hiding the less useful information. Finally, the atomic visualization elements that compose the visualization mashup must be synchronized to help the user to isolate useful information.

2.2 Oulu case study

The Oulu city traffic case study allows us to demonstrate the feasibility of our space-time interactive visualization prototype using the Oulu traffic dataset. We demonstrate our prototype and illustrate its potential, using a dataset with a minute resolution of traffic data from the city of Oulu collected over a one month period (May 26th, 2011 to June 21st, 2011). This dataset is composed of approximately 600,000 traffic records in total, for all of the intersections with traffic lights (77 traffic intersection locations) and detector lane-locations in intersections (4-32 lane detectors in each intersection).

Our current implementation uses traffic counter data hence it displays traffic volume in terms of number of vehicles in a given time frame. A future refinement can be the extension with pedestrian data extracted from the Oulu Wi-Fi Hotspot and Bluetooth data. From Wi-Fi and BT data, the pedestrian traffic might be approximated and hence employed in a similar manner to the vehicular traffic at intersections. Interviewing some decision-makers of the city of Oulu, we outlined the following use cases.

- **Traffic planning: re-programming of traffic lights.** With the *current system* users have to export history data for any given intersection. Then, they have to import this data to Excel to calculate statistics. Using these statistics, they calculate new optimal timing and re-program specific traffic lights. They can analyse 20 traffic lights at a time. With *our visualization* users can select a time frame of interest to facilitates exploration of traffic events. For example, Figure 2 shows a time frame selection from June 9th to June 15th, 2011. This selection refreshes both chart and map visualizations. Furthermore, users can see the total amount of traffic immediately for day/night periods, days, weeks, and per intersection separately. They can use these data to evaluate the traffic lights and request a re-programming to specific traffic lights immediately. In addition, a combination between road traffic and pedestrian data in real-time can be supported for our visualization that resulted to be important for our decision-makers

- **Police: movement of units in the field.** Mid summer is one of the major holidays in Finland
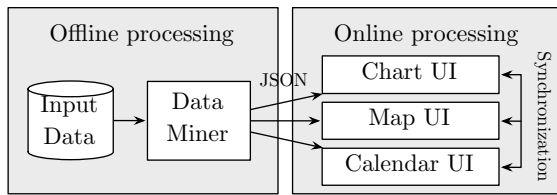
Figure 1: System architecture

when people are leaving the cities and travel to the countryside. Based on their experience, police historically knows when, how and to where people are leaving the city and supply traffic police units to specific places in the field when it is needed. However, if their guess fails, a replacement of units has to be done, which is time consuming. Using our *visualization* they can see the traffic waves and their development over time. If real-time data is available, they can immediately see trends and react to the current change of masses. Time is the most important factor in this situation.

In Sections 4.1 and 4.2 we explain in detail the current system used in Oulu and the decision-makers' evaluation of the current implementation.

3 DESIGN APPROACH

In this Section we propose a system architecture (see Figure 1) that provides the aforementioned interactive visualization mashup. The high-level architecture is composed of two components, the Data Miner and Web Mashup Front-end.

- *Input Data*. In order to get the input data for our Data Miner, it was necessary to clean, pre-process and rearrange the Oulu dataset according to the needed visualization input.

- *Data Miner*. In the Oulu case study, we sorted the input data for each intersection/base station considering time and intersection order/id to generate JSON files as output to be imported from our web user interface. *Data Miner* module is responsible for producing the JSON files from the raw Input Data of the original dataset.

- *Web Mashup Front-end*. Our visualization design follows Shneiderman's visual information seeking mantra [9], "overview first then details on demand". In order to provide an accessible overview with dynamic levels of aggregation of temporal and spatial information, we started sketching

our ideas to combine three different visualization techniques using UI web-based components:

- *Chart UI:* that facilitates analysis and exploration of traffic variations flow for all intersections, a specific intersection or selected regions. We implemented our time line using Highstock API (`http://www.highcharts.com/products/highstock`), a JavaScript library to visualize timeline Charts.

- *Map UI:* each intersection is placed in the Oulu city map using circles. The color of each circle indicates the traffic volume on that intersection for a specific period of time. We implemented the map visualization using the Google Maps API.

- *Calendar UI:* we additionally integrate a calendar view to illustrate the traffic variation flow using the calendar cells and a color scale per day. We used D3.js (`http://d3js.org/`), a JavaScript library for visualizations.

3.1 Preliminary Visualization

Figure 2 shows the visualization of Oulu traffic described above. First, the chart (see Figure 2a) visualizes the total traffic volume in terms of number of vehicles with respect to time from 26th May to June 21st, 2011. In addition, a grey background is used to represent missing data from the original dataset. Second, the map (see Figure 2b) shows a spatial representation of the average volume of traffic with respect to intersections during a specific period of time. Third, the calendar representation (see Figure 2c) shows the mean traffic volume in which each day is coloured according to the number of vehicles. Our visualization mashup has the following functionalities:

- *Meta Overview*. This Meta overview is presented using the three different visualizations of spatial and temporal traffic data.

- *Zoom*. Due to the size of our dataset, we restricted different levels of aggregation on our chart UI as follows: per day (1D), per week (1W) and the entire month. A spatial zoom is also provided by the map visualization using the Google Maps API.

- *Interactive Filtering*. Users may wish to focus on a specific intersection, specific time or specific period of time (see Figure 2). On the one hand, the user can select a specific point or specific region in the chart view that will refresh/synchronize a particular selection point in both chart and map visualizations. On the other hand, selecting a marker (circle) in the map will refresh and synchronize
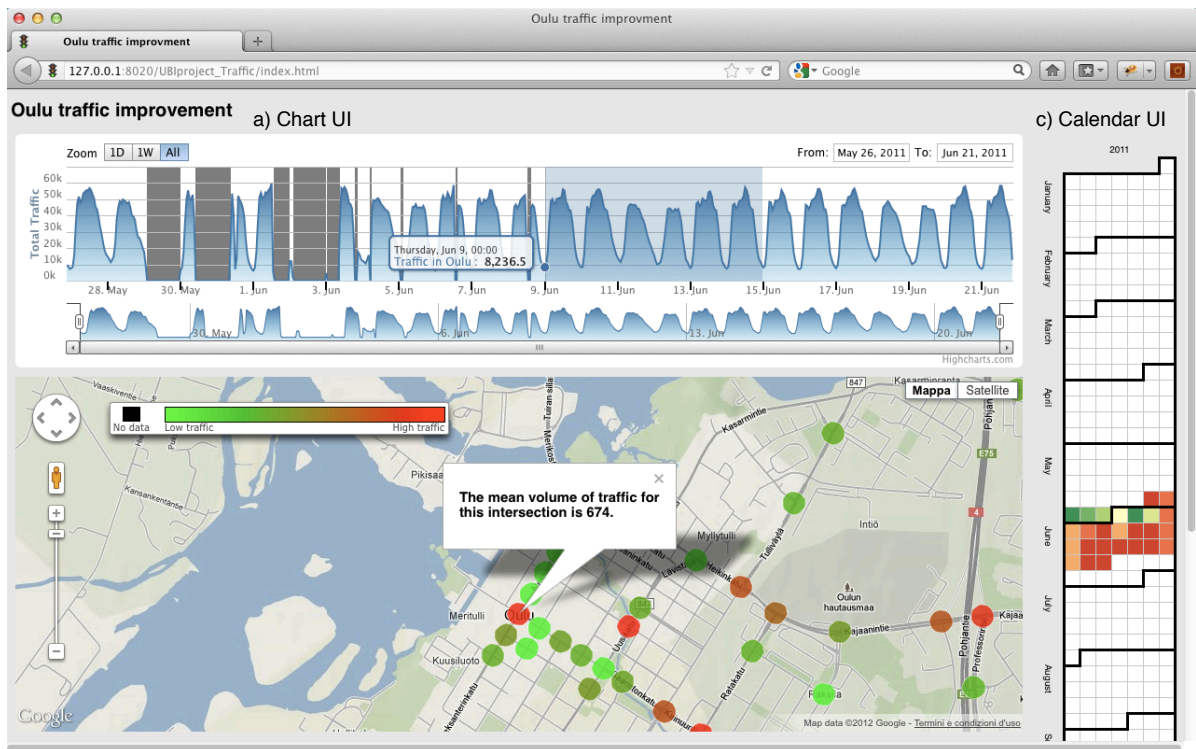
Figure 2: Traffic flow visualization combining: a) chart; b) map; and c) calendar visualizations

the selection in the Chart UI adding the area related to the intersection. In addition, a specific intersection selected in the map will be added to the main chart view as an additional line to facilitate users' interpretation.

- *Details on Demand.* Users can get details regarding the amount of traffic about a specific intersection or time represented by a marker by selecting it from either the chart or map visualizations.

4 RESULTS AND COMPARISON

In order to validate the decision-makers' requirements we visited the local center of traffic control in Oulu. They showed us the system they currently use to support their work. Then, we showed them the preliminary implementation of our visualization mashup for a preliminary evaluation. In Section 4.1 their current system is described and in Section 4.2 their comments about our system are reported.

4.1 Current System

Currently, historical data are summarized using traffic reports but neither graphical nor statistical repre-
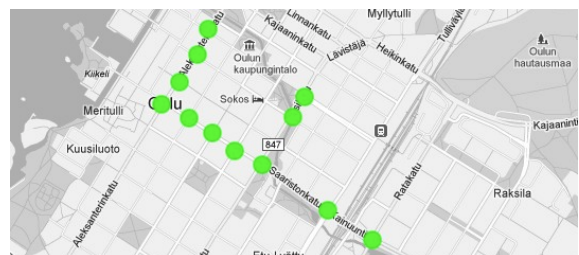

Figure 3: Representation of the current traffic system in Oulu

sentations are available, except for a black/white map as the one shown in Figure 3, which is a representation of their current system – we were not allowed to take pictures. Each point on the map corresponds to an intersection and the color of each intersection only refers to their location. Hence, no visual information about the traffic intensity is provided. To get intersection history data, they must repeat use a repetitive manual process based on Excel to generate graphs about their intersection selection using the exported data from their current system. The steps they follow to get intersection history data is:

1. the selection of one intersection from their system

2. select the properties they are interested in

3. select time/data

4. export data as a table

5. import data into a spreadsheet

6. generate graphs using the spreadsheet program.

They must repeat all the above steps if other intersection information is needed. The interviews brought three specific user groups to our attention.

Traffic management employee. They have to export data to Excel and do manual processing to generate statistics regarding the traffic data. Since no data analysis is easily available their traffic light reprogramming activity is slow. So, graphical and real-time statistical analysis of traffic data is needed and they have been told that adding these features to the current system is too expensive.

Traffic police officer. Real-time calculation of the traffic data is valuable information for police group management activities to forecast traffic behaviour. This will provide the opportunity to place units ahead where the masses are moving. In addition, he considers that pedestrian traffic can be very valuable and interesting if that information can be available in real-time settings. This would apply especially during local special occasions (e.g. exhibitions or rock concerts), which draw a lot of pedestrians to one location.

City planner. Apart from the traffic data, city planners consider pedestrian traffic estimation as valuable information for decisions and city designs. Currently, they place someone at one intersection to count manually the amount of people. This is both slow and can be misleading if wrong intersections (not the popular ones) are chosen for monitoring.

4.2 Preliminary evaluation

We also showed our prototype to the interviewees to get feedback. We ran our visualization mashup on a laptop using our dataset. In general, it was seen as much better than their current system or any of the recent "demos" that they have seen over the last year. They were enthusiastic about the possibility of getting a tool like this one and they had even requested similar improvements introduced in our design to their current tools. In addition, they helped us to identify improvement ideas for our proposed visualization design aimed for the identified user groups mentioned in Section 4.1.

Traffic management employee. The traffic management employees use a statistical model of Oulu with adjusted traffic capacity per road. Our tool could be combined with this model to estimate traffic data. However, our sensor dataset did not match the capacity or the organization of the intersections

Traffic police officer. For the traffic police officer:

- statistical traffic volume can be combined to their accident database with location information. This will provide them with more insights about traffic consequences

- statistical estimation of traffic for areas where there are not sensors available would be useful

- separation of road traffic between light and heavy vehicles is desired

- reading back sensor data from Nokia maps, would enlarge the sensor coverage

City planner. The most important issue for the traffic city planner is a combination between road traffic and pedestrian data in real-time. This can give the opportunity to offer optimal places for companies to set their outlets based on the amount of pedestrian traffic around the city.

5 CONCLUSIONS AND FUTURE WORK

We described our case study for a space-time visualization of traffic data in the city of Oulu. We found that current traffic control authorities have traffic data for decades but they do not have proper tools to facilitate data interpretation and discover problems. We have applied several visualization techniques and presented our exploratory visualization design by building a Web mashup prototype and validating it by interviewing three different decision-makers in Oulu.

We argue that a proper combination of different visualization techniques that consider multiple data dimensions, and an interactive synchronization between space-time visualizations. This can support data analysis, exploration, and evaluation of traffic data to reveal trends regarding interesting traffic events. In future work, we will address some limitations that affect our current implementation: *(i)* our tool needs to be combined with city statistical models that adjusts traffic capacity per road to support estimation of traffic data; *(ii)* at the moment there are not mechanisms to collect trends from the visualization; *(iii)* our implementation does not allow to save the

current status during the exploration activity; *(iv)* currently our implementation refers only to traffic data but, according to decision-makers' needs, it can be easily extended to pedestrian information. A multiple combination of these different types of data and external related-city data (*e.g.*, noise and accidents) may also be interesting; *(v)* finally, real-time data needs to be available to support real-time decision-making activities. This paper is our first step towards a holistic urban planning system to empower city management activities.

ACKNOWLEDGEMENTS

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