Chapter 2
Background and Related Work

Vehicle traffic has been an important research issue. Numerous studies have been conducted providing insights from various levels and perspectives. Researchers analyze traffic in terms of speed, flow rate, density, volume, occupancy, congestion, etc.

Traffic *density* is the number of vehicles within unit length of a roadway. This parameter is a measure of effectiveness of many traffic systems. O*ccupancy* is a variable which is an indicator of traffic density. It is the fraction of time, out of the total observation period, within which the location where measurement was performed was occupied by vehicles. *Level of Service* is a qualitative measure that expresses traffic situations in terms of travel time, speed, safety, freedom to maneuver, convenience, traffic interruptions etc. There are six categories of LOS labelled by letters A (the best condition) to F (heavily congested flow with traffic demand exceeding the road capacity) [1]. *Capacity* is the maximum theoretical traffic flow rate that a road section is able to accomplish under a certain set of environment, road and traffic conditions. A *number of cycles* waited to pass through a signal is a good indicator of congestion on a signalized approach. Sometimes this measure offers improved sense for congestion ahead than the measured travel time for both, drivers and traffic operators.

The work related to ours covers several areas of research: *traffic congestion and congestion level estimation, Intelligent Transport Systems, traffic data visualization*, *maps as visualization tools*, and *digital map processing*.

2.1 Traffic Congestion

Generally, traffic can be "free" or "congested". The issue of road traffic congestion is important and pervasive. As a phenomenon, congestion is defined in many different ways. Morris J. Rothenberg defines urban highway congestion as "a condition

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in which the number of vehicles attempting to use a roadway at any given time exceeds the ability of the roadway to carry the load at generally acceptable service levels" [2]. Another definition is given by Zhicai et al. [3]. According to them, congestion is a condition which emerges when there is a great reduction in the average velocity (with respect to the free flow), rise in travel time, stop-and-go of vehicle (in addition to increased and frequent velocity variety) as well as when increase in density appear. They mentioned two types of congestion, driven by demand and driven by supply, and studied the socio-economic impact.

2.2 Methodologies for Estimating Congestion Level

Some of the factors that cause traffic congestion are accident, construction work, bad weather and poor traffic signal timing. There are various methodologies for estimating congestion level. Thianniwet et al. [4] proposed a method with 91.29 % accuracy for congestion level measurement using *vehicle movement patterns*. The vehicles' velocities were collected from participants' GPS devices through mobile data networks. The data were sent to the learning model, processed and represented using *sliding windows technique* and *decision tree*. The first technique is used to capture the consecutive moving average velocities, called moving patterns. Human judgments were used to categorize the traffic congestion levels into: light, heavy, and were highly consistent with the results gained by the authors.

Pattara-Atikom, Pongpaibool and Thajchayapong [5] categorized three levels of congestion on main roads in Bangkok utilizing the *weighted exponential moving averages of vehicle speed* gained from GPS data and implementing *threshold technique*. Data were gained from GPS device in a vehicle, and image processing video camera mounted on a vehicle's dashboard. The measured average velocities were grouped into three congestion levels, i.e., red, yellow, and green. The algorithm has error of around one third of a congestion score with 35.29 % over-estimation, 17.65 % underestimation, and 47.066 % correct estimation. There are several benefit of this technique for congestion level classification. Comparing to existing techniques it is comprehensible, straightforward, with minimum requirement of input data (merely vehicle velocity), being measurable and appropriate to automated report, and being compatible with existing traffic report systems in Bangkok.

Traffic congestion level can also be determined using different parameters like *travel time, travel time index, travel delay, travel ratio index*, *speed reduction index,* etc. In concept of Level of Service, it is considered that congestion occurs when V/C (volume over capacity ratio) exceeds a certain threshold. B. S. Kemer categorized traffic pattern into *free* and *synchronized flow*, and *wide moving jam* [6]. Travel Time Index is expressed as the ratio of real travel time to free flow travel time [7].

J. Lu and L. Cao [8], and Pongpaibool et al. [9] used *fuzzy logic* as a tool for congestion level estimation. J. Lu and L. Cao evaluated congestion from *traffic flow* information based on *adaptive neuro-fuzzy inference system* and series of fuzzy logic rules. They consider level of congestion as a continuous variable changing from free flow to traffic bottleneck. Pongpaibool et al. designed a system which identifies three levels of traffic congestion in Bangkok from data gained via *image processing* using manually set *fuzzy logic* and adaptive *neuro-fuzzy techniques*. As inputs for the fuzzy logic technique they used traffic *volume* and *velocity*, as well as human estimation of the congestion level. The traffic data acquisition was performed utilizing vehicle detection and tracking software, which took a signal from the road-traffic cameras. The results they achieved had 88.79 % accuracy or manually tuned fuzzy logic, and 75.43 % accuracy when adaptive neuro-fuzzy technique was applied.

Combining various factors such as speed, volume, density, travel time, etc. can be another way for quantifying congestion. One of the traffic parameters which can be directly implemented for determining the level of congestion is *traffic density*. There are various historic and real time methods being used by researchers for short term prediction of traffic density including, statistical methods, machine learning techniques and model based techniques.

One way to categorize the approaches for congestion level estimation is by: using ***historical*** traffic data or using ***real-time*** data. ExTrac system proposed by Damaiyanti et al. [10] extracts traffic congestion data from historical traffic data and answers the queries about them. The problem with enormous amount of collected historical traffic data (which usually occurs when the patterns are obtained from great quantity of historical traffic data with different features) they solved by creating an efficient data structure model of traffic congestion patterns in spatio-temporal heatmap[1]. They converted collected speed data into congestion degree values, created matrices and summarized them by applying MapReduce framework. The authors used NoSQL database for storing the traffic patterns.

Padiath et al. [11] used *historic and Artificial Neural Network technique* for predicting traffic density on roads in Chennai. Data for this study were gathered using videographic technique from a 1 km three lane road in the Rajiv Gandhi, Chennai, India. Pongnumkul et al. [12] applied historical traffic data patterns and rendered them spatially in a *grid*. Diker and Nasibov used *historical traffic patterns* of the road segments and clustered them according to road traffic congestion [13]. The technique they used was *Fuzzy Neighborhood Density-Based Spatial Clustering of Applications with Noise* (*FN-DBSCAN*).

2.3 Intelligent Transportation Systems

Congestion can be referred as traffic demand exceeding the road infrastructure capacity. Since adding supplementary roadway infrastructure to meet the rising population possessing vehicles is limited, and increasing the infrastructure will not correspond to the increase in traffic demand, congestion issue is progressively

[1] Heatmaps are a method for representing spatial data that identifies the high-occurrence regions without complicating the overall view.

solved by implementing Intelligent Transportation System (ITS) [11]. ITS control strategies include estimating flow on roadways, dynamically retiming traffic signals, handling traffic incidents, and conveying information to travelers about travel conditions, alternative routes, and alternate modes [70, 71]. Its aim is to diminish traffic load, improve safety, economic vitality, transportation efficiency, and environmental pollution. The system comprises advanced data transfer and communication technology, wide diversity of static and dynamic sensors, and computer control technology. The core of ITS is the acquisition of traffic related data in order to estimate the traffic. Besides traffic management, it also offers traffic reporting to advice travelers. System implements vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) (vehicle-to-road V2R) communication. Examples of major applications are TrafficCast using BlueTOADs, Palm Beach County, Florida [14]; RITIS [15] using cameras, in USA; Signal Performance Metrics (UDOT) [16]; TRANSGUID in San Antonio, United States; a road traffic information communication system (VIC) in Tokyo, Japan; Electric Road Pricing (ERP) in Singapore; ROMANSE system in Southampton United Kingdom and Germany with its FCD system.

Traffic monitoring and control problems are extensively solved with Intelligent Transportation Systems (ITSs), as well as Information and Communication Technologies (ICTs). With an intention to facilitate assessment of signal operations quality, researchers have developed various data performance measures.

Balke et al. [17] developed a system, called the Traffic Signal Performance Monitoring System (or TSPMS for short) in order to obtain data from both, the traffic signal system, and the detection system to generate traffic performance measures in real time. The performance measures they generated were: cycle time, time to service, queue service time, interval duration, number of vehicles entering per interval, yellow and all-red violation rates, and phase failure rate.

Highway Capacity Manual 2010 [18] supplies the methods for estimating the performance of a signalized intersection which include computing V/C, saturation flow rate, delay, and three determining LOS. Liu et al. [19] introduced a system, named SMART-SIGNAL (Systematic Monitoring of Arterial Road Traffic Signals) which collects and archive event-based traffic signal data on 11-intersection corridor along France Avenue in Minneapolis, MN. Utilizing these data, SMART-SIGNAL can generate time-dependent performance measures such as intersection queue length and arterial travel time for intersections as well as arterials. The empirical results which authors gained for these measures are greatly consistent with the observed data.

Bezuidenhout et al. [20] offered a new model for queue prediction which relied on the data obtained from a loop detector set at the stop line of signalized intersection. Zaiat et al. [21] introduced intelligent transport system which is potentially very beneficial tool and can help authorities and other decision makers to facilitate transport monitoring and management. It can supply the required information for strategic planning, particularly in case of emergency events. The authors' approach allows Level of Service (LOS) analysis for different transportation modes at geographic abstraction of three levels, from entire monitored region to its sub-areas.

They performed test using input data from road sensors encompassing traffic volume, average speed and lanes occupancy rate. Then using the road LOS calculation methods, they selected one of these values and attributed to a letter from “A” to “F”, designating road LOS.

Sen et al. [22] envisioned a system where the used technique includes a pair of road side acoustic sensors. They used Doppler shift of the honk frequency to estimate the vehicle’s speed, and thus to calculate road congestion. Using more than 18 h of road-side recordings, they demonstrated that the technique is effective in real conditions. By implementing the vehicle speed distribution, and the number and duration of honks, authors also classified traffic state as either free-flowing or congested with a threshold-based categorization correctness of 70–100 %.

Most travel information systems work by acquiring data from a variety of sensors such as vehicle tracking units, loop detectors, camera, infrared detectors, RFID tags, laser scanners, ultrasonic, radar, GPS tracking units and cellphones. These data are processed centrally and updates are transferred to travelers using a variety of channels. Hence, the main traffic information comes from various transportation management departments and part of the transportation business and is basically announced to meet their own need. In contrast, the dynamic transportation information aimed for the general public seems to be less. Many drivers disregard these data, considering them obsolete or not applicable. Instead of using these information, researchers started to gain travel information automatically from current road users from the mobile network or users’ mobile devices. They found that these data have advantages over data collated via sensors.

Vehicular ad-hoc networks (VANETs) is very important segment of ITS. Vehicular ad hoc network (VANET), is the state of the art technology that is part of wireless ad hoc networks which may use vehicles as mobile nodes. The advantage of VANET is rapidly changeable topology which allows dynamic route planning. This can prevent clogging of vehicles in bad circumstances like accidents, fog, etc. by providing alert messages and warnings. As a component of Intelligent Transport Systems (ITSs) its main objective is to provide safety, comfort in traffic, improve decision making processes and introduce innovative effective real-time information for the drivers.

There are mainly two types of communication in VANET: Inter-Vehicular (V2V) and vehicle-to-infrastructure (V2I) or vehicle-to-Roadside Unit (V2R) wireless communication.

A promising new approach for diminishing congestion, is *Virtual Traffic Lights* (VTL). It is introduced with an intention to replace the physical traffic signals and convey virtual traffic information to the driver inside the car in a manner which won’t compromise driving security [23, 24]. This is achieved by using technology mounted inside the cars which enable drivers to self-organize on the intersections. Such organization also implies decrease of the urban traffic congestion issue. The technology implemented is V2V communications and DSRC.

Nakamurakare et al. [25] implemented VTL system on Android based mobile phones. Without any help of the intersection, merely by using V2V communication, conflicts on intersections are detected and resolved in ad hoc manner. It makes use of and operates based on the input provided by the built-in modules such as GPS, Map database, and NTP server (for time synchronization). Two different map formats are used in the implementation: XML format used in VTL module and Google Map™ format used for display purpose. The simulation results they got have proved that the VTL can improve the traffic flow up to 60 %.

2.4 Traffic Data Visualization and Visualization Tools

The big amount of traffic data stored in transportation databases impedes human understanding and extracting traffic patterns from these data directly. Taking into consideration the heterogeneity of such complex and large data such as transportation data, data visualization is substantial and inevitable for their analysis. It alleviates the process of detecting the structure, features, anomalies, patterns, and inter-connections in complex data, which is generally complicated. Visualization stipulates various visual forms and different interactions for data representation. It not only offers a qualitative overview of complex data sets, but it can also facilitate the identification of areas of interest and parameters for more specific quantitative analysis. This motivated some researchers to focus on creating visualization tools to assist human in understanding traffic patterns.

Shekhar et al. [26] introduced a web-based visualization package (CubeView) for monitoring sensor network measurements collected from the freeway system in Minneapolis—St. Paul (Twin-Cities) metropolitan area. The system is developed for the Minnesota Department of transportation (MNDOT). It offers extraction of patterns and rules from the historical data to support decision making. The sensor network comprises approximately 900 stations. Depending on the number of lanes, sensors incorporate one to four loop detectors. Sensors observe the *occupancy* and *volume* of traffic on the road and these data are sent to the Traffic Management Center. In CubeView, raw data obtained by loop detectors are saved in binary format, converted into text data and later stored into database servers. After querying the database, data are represented using *clusters*, *classes* and *cube view*. Patterns are rendered using *graph*, *charts*, and *detector maps*. Congestion can also be visualized. The transportation visualization tools can be used by traffic managers, traffic engineers, travelers and commuters, as well as researchers and planners.

Piringer et al. [27] studied the surveillance videos in a tunnel. They automatically detected and prioritized different types of events and marked them in space and time. For each event, users could check the original videos. Zaiat's et al. [21] approach includes several visualization tools: a *map-based view* on the local transport systems performance state; filtering the information on the dashboard by transport domains, modes, components; aggregations for any LOS and geographic abstraction; and *charts view* of the transport system behavior over time.

Lu et al. [28] proposed the Advanced Interactive Traffic Visualization System (AITVS) which presents data cube visualization tools for real-time and historical pattern analysis. It is a web-based visualization system introducing innovative visualization components like spatial and temporal *plots* and *data cube* to analyze and monitor traffic conditions, volume, speed, and occupancy, and thus to overcome the disadvantages of other existing systems. AITVS is more oriented to traffic analysts and managers then to travelers, similar to our proposed web applications.

Pack [29] proposed a web-based visual analytics system for observing and identifying main bottlenecks. It implements variety of visualization tools: a dashboard with map and a popup window for displaying the travel time index, different contour plots, interactive animated map for showing average speeds, travel times, reliability etc., interactive charts and graphs, and performance summary table. As part of the bottleneck ranking very interesting visualization tool is the time spiral graphic which shows the time of occurrence and how long the bottleneck became until it ended (Fig. 2.1 adopted from [29]).

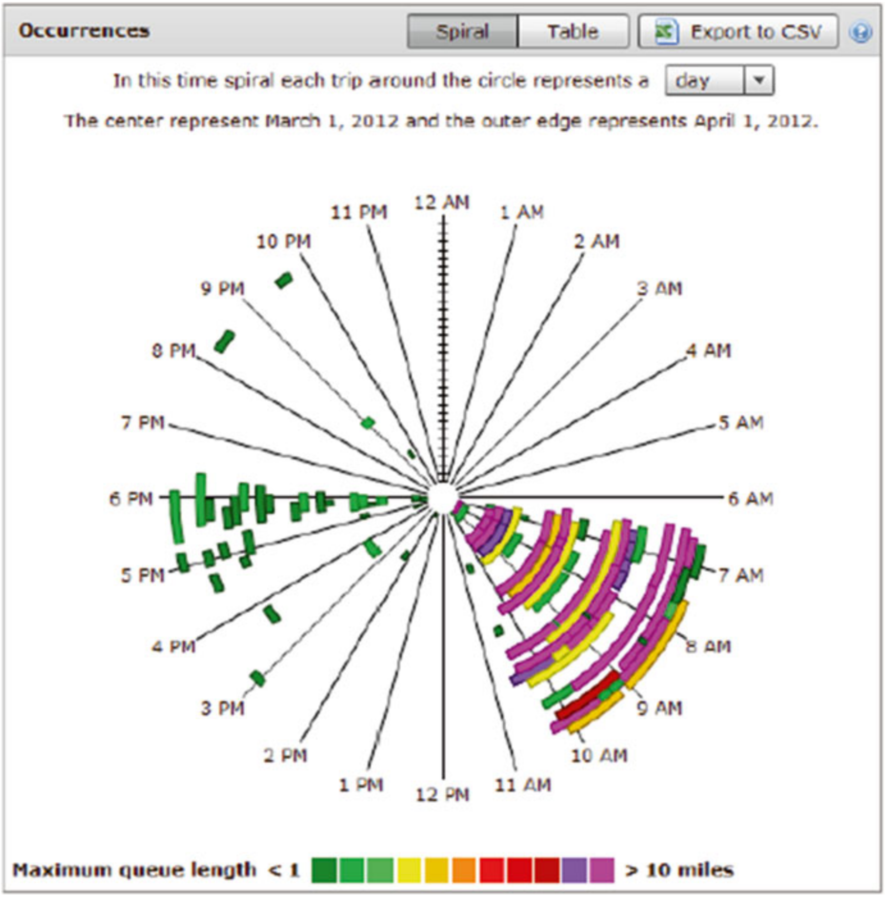

Fig. 2.1 Time spiral graphic showing when a bottleneck occurred and how long it became during that time (Adopted from [29])

Generally, Web-based traffic visualization tools are easily accessible and can be used for simplifying complex and monotonous statistical data providing beneficial information to traffic professionals as well as travelers.

Numerous visualization tools have been implemented specifically for *congestion level analysis and interpretation*. An example for *congestion level estimation and representation* is CongestionGrid [12]. It is a platform which automatically acquires current congestion data from a traffic data provider and enables users to visualize the historical patterns by displaying them in a *grid*. CongestionGrid allows users to explore the temporal traffic patterns by viewing the congestion data of a certain week or an aggregation of data over a period of time. This approach for visual representation of the traffic states is very similar to visual representation used in our web application for congestion estimation, implementing red, yellow, and green colored cells which correspond to high, normal and low traffic, respectively (Fig. 2.2 adopted from [12]). The advantage of our application is that it offers more precise representation of the level of congestion and alerts the user when the level of congestion is above certain threshold. Another difference is that our application works with real-time traffic data.

Diker and Nasibov [13] and Yoon et al. [30] used *maps*, *graphs* and *clusters* as visualization tools. Diker and Nasibov arranged road segments according to certain traffic congestion level into clusters, and Yoon, besides threshold-based quadrant clustering, used *spatio-temporal traffic status plots* of trace data.

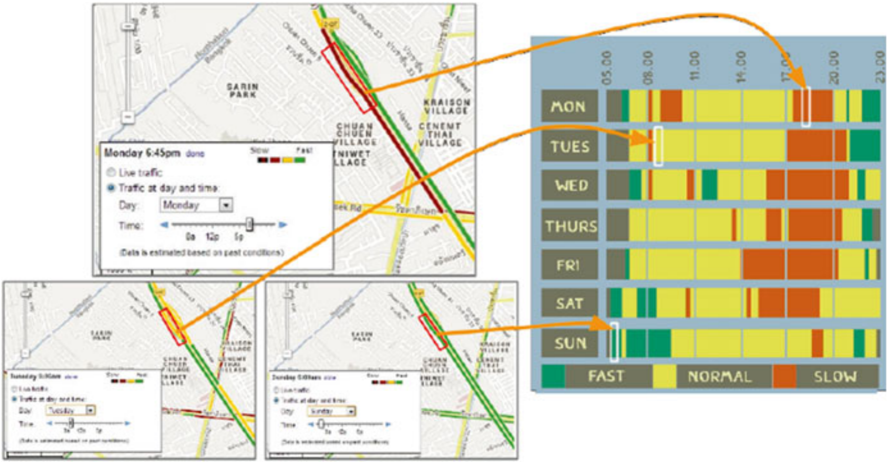

Fig. 2.2 Manual creation of CongestionGrid from Google Maps™'s historical traffic data. CongestionGrid automatically collects current congestion data from a traffic information provider (Google Maps™ Traffic Layer) and allows users to explore and visualize the historical weekly patterns of traffic data, or an aggregation of data over a period of time, by spatially arranging them in a grid. The traffic states are denoted by *red, yellow,* and *green* colors, representing high, normal and low traffic, respectively. (Adopted from [12]). *Map © 2015 Google Inc, used with permission. Google and the Google logo are registered trademarks of Google Inc.*

Wang et al. [31] utilized traffic trajectories (as major type of traffic data received from road sensors) as well as incidents, road speed, and traffic jams as a source for visualization. This model implemented in Beijing also structures the relationships between traffic jams. Traffic trajectories visual analysis most often requires *aggregation* such as *density map* [32]. Density map plots the trajectory density and enables "hot" spots detection. Some of the techniques that authors used are: *propagation graph* level estimation, traffic jam density *visualization on a map* (OpenStreetMap), *topological filters*, *temporal and size filters*, *map matching* etc. In order to visualize propagation graph, authors applied *animation*, *flow map* and *graph layout techniques*. The system introduces five views for visualization: (1) pixel-based road velocity view, to show the speeds and events; (2) graph list view for displaying propagation graphs; and (3) the graph projection view to render propagation graphs' topological relationships; (4) spatial view to represent the traffic congestion density, as well as the propagation path of one designated graph; and (5) multi-faceted filter view, which offers filtering by time, space, size and topology, and through sorting by size and similarity presents structured representation of the propagation graphs. First they estimated free flow speed for every road segment, and by considering relatively low road-velocity they automatically detected traffic congestion events at roads. The interaction of these events in propagation graphs depicted the spatial and temporal propagation of traffic jam.

Unlike this approach, Pack et al. [33] and Khotanzad [59] instead of traffic trajectories, analyzed transportation incident datasets. They designed web-based, visual analytics tool called *Incident Cluster Explorer*. It is an application that provides an integrated view interface to illustrate the spatial, temporal and multi-dimensional features of the incidents. Users' interaction is supported by including options for selection, filtering and incidents clustering, and accordingly focus on a smaller dataset. Simultaneous interactions between multiple visualization tools are possible, such as *histograms*, *interactive maps*, *two-dimensional and parallel coordinates plots*. Figure 2.3 (adopted from [33]) displays an interactive histogram for chosen variable "incident type" in the data set along with an icon mode map representation.

To visualize relationships between a selected pair of variables authors used either *scatter plot mode* or *grid mode*. Also, two mapping modes are allowed: *icon mode* and *heat mode*. In contrast to some websites (FARS) which presents a substantial row data and do not propose any visualization possibility, leaving this complicated task to the user who can only download them, this application is much more comprehensive, sophisticated and user-friendly. Another advantage of this tool over other commercial data visualization products such as Spotfire [34, 62] and Tableau [35, 63] is using the *heat maps* in order to render data on a map to avoid occlusion and overcrowding when it comes to large datasets such as transportation incident data.

Anwar et al. [36, 68] introduced a straightforward method called *Traffic Origins*, to visualize the impact road incidents have on congestion and on vehicle flow in their vicinity, as well as the cascading influence multiple incidents may have on a road network. The incident location is designated with an expanding circle

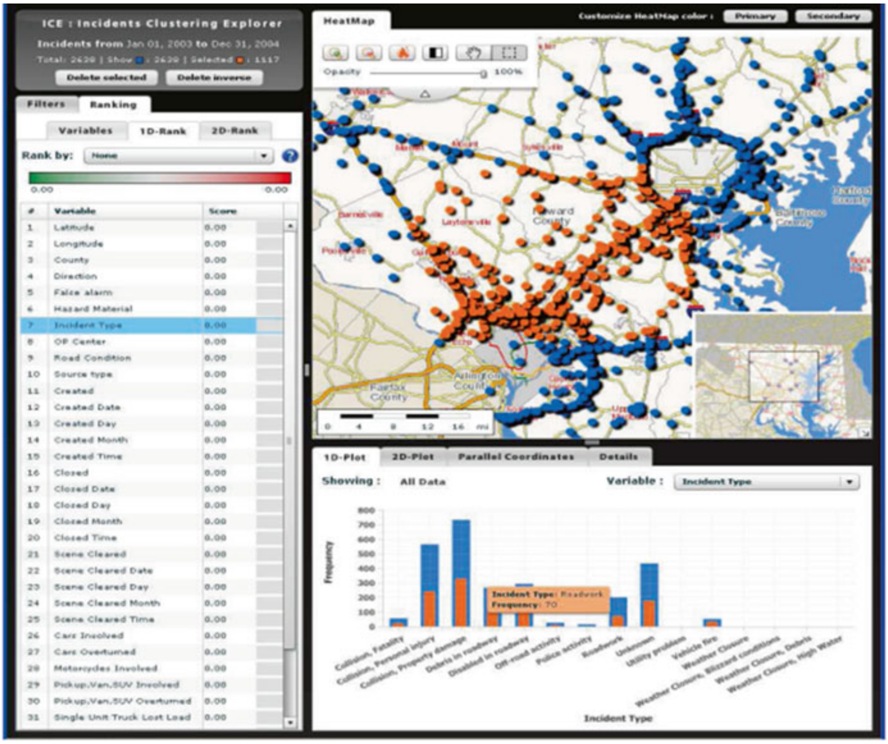

Fig. 2.3 Interactive histograms and maps are linked together. By clicking on any of the histogram bars, the incidents related to that category are highlighted in the map interface. On the contrary, the user may select a set of incidents on the map and the selected incidents are emphasized within the histogram as a highlighted subset. All rendered incidents on the map are colored in blue, and the selected incidents are represented in orange color (Adopted from [33])

immediately before a traffic incident occurs, to reveal the basic traffic flow map, and it recedes when the incident ends. They created attractive visualization in order to help traffic management controllers easily understand and access traffic and congestion data and enjoy it.

2.5 Maps as Traffic Visualization Tools

Maps are used as tools for visualization to a greater extent in traffic analysis and management as mentioned in the previous examples of applications. Denaxas et al. [37] introduced a system for assessing real-time traffic speed that retrieves the information from GPS sensors mounted in public transport fleet and renders it as color-coded segments of the road network on interactive map implementing Google Maps™ API.

A system designed by Nokia, TrafficWorks [38], collects real-time location and velocity data from GPS assisted mobile devices in vehicle. Travelers can be notified about historical, actual and future congestion levels on routes of their interest via interactive mobile map application. Chin-Hooi et al. [39] proposed a proof-of-concept system built for the traffic information system in the Klang Valley, Malaysia. The system could help drivers plan their routes and reduce traffic congestion. The diagrams demonstrate the strengths of using map-based visualization techniques to convey traffic information. It is applicable on PDA, smart phones, and computers.

Maps like Google Maps™ [40], and maps for Thailand: Traffy [41], BKKtraffic.com [42], and Longdo Map [43], supply live traffic congestion level presentation. In addition to live traffic, Google Maps™ also allows users to examine weekly traffic patterns on the map offering cumulative historical data in "Traffic at day and time" feature.

With increased precision and better reliability compared to conventional techniques, the mobile supported localization is progressively used for traffic congestion estimation service (TES) [44]. The authors of this service presented three techniques (based on mobile cell ID, based on received signal strength indicator (RSSI) and Timing Advance (TA) localization) to improve the localization precision and hence increase the trustworthiness of the estimated traffic situation. They evaluated collected statistics of all implemented techniques. The mobile assisted positioning system is then applied for TES. Server side component of the service detects and estimates congestions, and the client side is responsible for inquiring and then rendering congestion status to the user. It uses map for displaying color-coded segments of the road to the mobile subscriber where green, orange and red indicate different traffic situations, along with the average speeds of the surrounding vehicles and the distance to the congested area.

For analyzing *complex traffic trajectory data* Guo et al. [45] introduced interactive visual analytics system named Triple Perspective Visual Trajectory Analytics (TripVista) aimed for visualizing microscopic traffic trajectory data at an intersection. Using the triple perspective design philosophy (spatial, temporal and multidimensional views) as the base of the system, they designed several visualizations and convenient interactions. The system gathers traffic data at intersection through several laser scanners and some other auxiliary devices which provide more information comparing to data gained through video. The system interface is composed of three coordinated views: the traffic view for rendering spatial data, the ThemeRiver including glyphs and scatterplots for depicting temporal changes, and the parallel coordinates for multi-dimensional presentation (Fig. 2.4 adopted from [45]).

Each of the views provides appropriate users interactions. For example, selections are integrated into the traffic view. Besides, normal brushing, directional brushing is allowed to select trajectories with a certain shape. Other components of the view are ring-style sliders which are placed on top of the trajectories. The density of the trajectories is represented with histograms. Ring perimeter presented along with the histograms, from the other side, provides supplementary information regarding the traffic, for example to select the U-turn trajectories with ring sliders (Fig. 2.5 adopted from [45]).

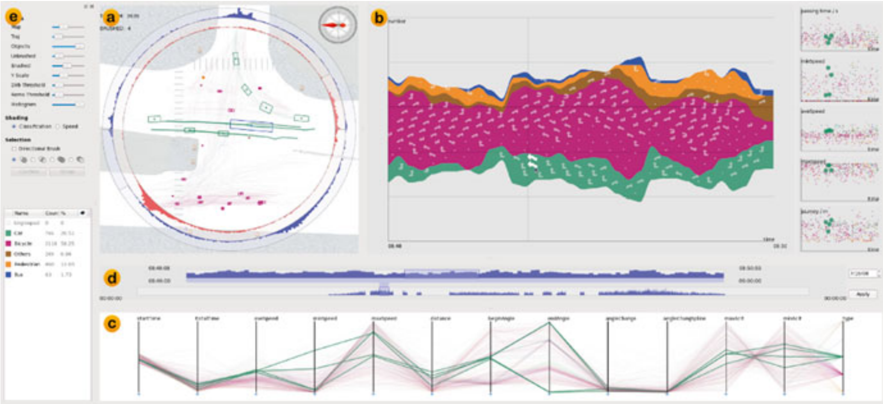

Fig. 2.4 Interface of Triple Perspective Visual Trajectory Analytics (TripVista) visualizing traffic trajectory data at a road intersection. The interface is composed of: (**a**) Spatial traffic view showing geometrical trajectory information; (**b**) Temporal views of ThemeRiver and scatterplots; (**c**) Parallel coordinates plot showing multiple properties of the multi-dimensional data; (**d**) Time sliders for two-level time range selection; (**e**) Control panel for system parameter settings and data classification. (Adopted from [45])

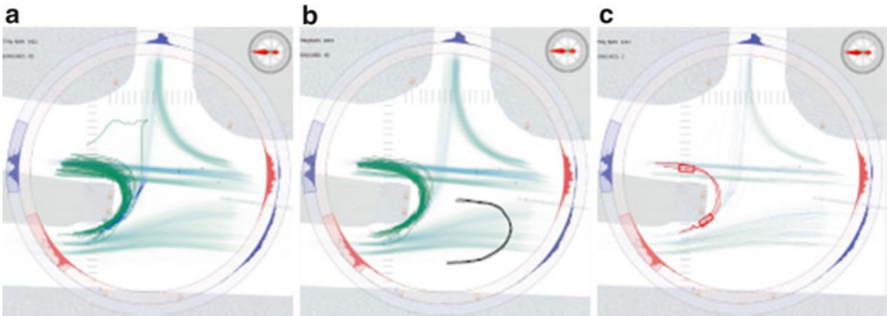

Fig. 2.5 Ring perimeter provides supplementary information regarding the traffic, enables investigation of U-turn Patterns (**a**) Select the U-turn trajectories with ring sliders; (**b**) Select the U-turn trajectories using directional brush; (**c**) Replay the scene (U-turn patterns in *red*) (Adopted from [45])

Speed is crucial for pattern examination, thus authors use another shading mode called *speed*. Here they permit the trajectory gradually to change colors while being drawn (Fig. 2.6c) adopted from [45]).

The ThemeRiver view supports user interactions such as mouse-hovering highlighting, glyph brushing and zooming. This complex design of the system for traffic data analysis is a beneficial, effective, and novel tool for the user, not only to comprehend regular traffic models (shapes), but also to reveal inappropriate behaviors.

There are maps which incorporate more *social forms of travel information* [9, 28, 46, 47]. For example digital traffic sensors are implemented with an aim to support

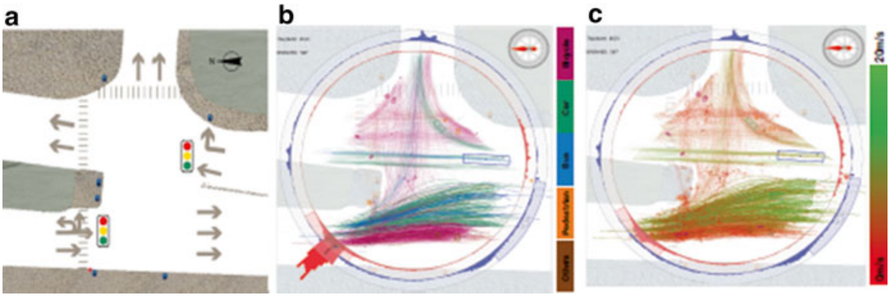

Fig. 2.6 TrafficView: (**a**) The map of the road intersection where the data is collected. The arrows on the map indicate the permitted traffic directions and the traffic light configurations; (**b**) Traffic view colored according to object types (bicycles are colored in *purple*, car in *green*, bus in *blue*, pedestrian in *orange* and others in *brown*); (**c**) Traffic view—colored according to speed variation (starting from 0 to 20 m/s, the colors representing the speed gradually change from red to green respectively) (Adopted from [45])

Table 2.1 Expenses for implementation of different sensors

Device	Cost
Vehicle loop detector	$700 for a loop
Controller	$2500
Controller cabinet	$5000
Fiber optic cable per mile	$300,000 and 10 % of the original installation cost for annual maintenance as of 1999
CCTV camera	$150–$250
Imaging-based sensing	$10–20 K per installation
Magnetic sensor-based solutions	Relatively inexpensive, they also make assumptions of traffic orderliness, unreliable for motorcycles
Pairs of inductive loop detectors (can be used to identify vehicles based on their length)	Several thousands of U.S.$ per installation-very expensive for widespread deployment and maintenance even in developed countries

travelers to share their insights and illustrate the traffic network more dynamically and proactively.

Traditional approaches for traffic information acquisition rely on a fixed sensor infrastructure. This infrastructure has high price for maintenance and deployment [30] (Table 2.1). Consequently, the traffic data coverage is restricted to main roads as well as major and vital intersections. Since this limited information impedes efficient traffic management, new approaches and applications for moderating traffic congestion are being developed.

An example of application that demonstrates the technical feasibility of obtaining sensor data and real-time traveler information regarding the road situations from active drivers is TrafficPulse [47]. It is a Volunteered geographic information (VGI) mobile application for transportation. It has a GIS platform and incorporates GPS, camera, accelerometer, and compass. The information could be shared via visualization module which supplies users with four mapping possibilities. Mapping near-by users allows users to update their current traffic condition at near real-time. Mapping latest trace enables users to review their latest traces and times spent on them. Mapping near-by public transit stations lets users to visualize the relative orientations between transit stations and their actual locations, so that they can find the nearest stations faster. Mapping events enables users to make faster decisions and help them avoid traffic congestions. The authors not only developed advanced application for smart phones that broadens the possibilities for gathering data from different sources, but also paid attention to the privacy issue, and permit users to view only their own trace when using mapping latest trace function; or to view texts like shared contents in mapping events. The system works with real-time data, but since not all smart phones have constant Internet access, it collects offline and Wi-Fi location data as well.

Hardings et al. [46] introduced iPhone application OurTravel which can be used by the users as a tool for viewing and reporting information about traffic incidents such as the type of incident (congestion, crash, road works), and exchanging personal messages or presumed delay time. They also used plots, highlight clustering around common journey end-points. The interface includes Google Maps™.

Beáta Balázsi et al. [48] introduced a prototype, Sparrow, mainly anticipated for the drivers' community, although it can be also implemented by traffic managers and analyzers. The main goal of their project is the development of a software system for broadcasting, monitoring and managing traffic data. The system is composed of a server, client application for Android based mobile phones with simple interface for reporting and displaying traffic related events, web application for the system administrators, and web application for data management and analysis. Events that can be reported cover: incidents, traffic cameras, road blockades etc. What is common with other similar applications, is that the Sparrow uses a predefined camera database, but unlike majority of that applications, it also enables users to report events in real-time. Comparing to other existing similar applications, Sparrow covers much more functionalities (map view, data clustering, filtering, visual and audio announcements), and specialized user interface which doesn't impede the driving. Besides, most approaches with camera database use only predefined databases [49], or are regions specific or limited by countries [50], which is not the case with this application. If we make a parallel with similar applications like Waze for example, which implements social networks and real time event reporting, these applications don't report only traffic related events which encumbers event filtering.

Clustering in Sparrow is classification approach implemented with an aim to properly display huge quantities of information on Google Maps™ (Fig. 2.7 adopted from [48]). To solve the issue with time-consuming standard clustering algorithms, the project uses map-reduce functions.

The client-server communication is realized with RESTful web. Other techniques that the project provides for managing different data sources are analysis and optimization via the DataMining UI. Administrators are permitted to run four types

Fig. 2.7 Map view, data clustering, filtering (administration user interface). The Sparrow software incorporates a web-based administration user interface, which permits the system administrator to analyze all the available traffic incidents and cameras on a map. The events are clustered with an aim large quantities of data to be correctly represented (Adopted from [48])

of filtering: filtering by date and reliability number, filtering duplicates, and aggregating events of the same type in a given radius.

Other examples of this type of map visualization are: INRIX Traffic [51], MIT CarTel [52] (and iCartel for iPhones). INRIX Traffic takes into consideration accidents, congestion, events, and historical traffic patterns and updates them every minute.

CarTel is a computing system intended to collect data from sensors located on mobile units such as cars and mobile phones, and then processes, delivers, and visualizes them utilizing trace, interest region or images, and hotspots for congestion depicted on the map. It is deployed on six cars, in Boston and Seattle. The system incorporates commute travel time analysis, image acquisition and their implementation as a visualization tool (Fig. 2.8 adopted from [52]).

Majority of the gathered data are geo-spatial, and the basic data segmentation abstraction is a *trace*. Traces include all sensor data collected during one trip. This library provides two classes of interfaces: (1) searching for traces using spatial queries (Fig. 2.8a) and (2) overlaying geographic characteristics on Google Maps™ for a given trace. Figure 2.8b shows the speed overlay (travel delay) as a color-coded sequence of trace's segments compatible with the vehicles' route and speed. When data are stored chronologically and user wants to find all traces for her/his travel, it is possible to "visually query" the data by means of graphically defined "interest regions" and operators (Fig. 2.8a).

Fig. 2.8 The CarTel portal, depicting the user's: (**a**) querying for traces corresponding to user's commute and (**b**) viewing the speed overlay for one trace as a color-coded sequence of trace's segments compatible with the vehicles' route and speed (Adopted from [52]). *Map © 2015 Google Inc, used with permission. Google and the Google logo are registered trademarks of Google Inc.*

Fig. 2.9 The CarTel portal, showing a street-level view just prior to a turn (Adopted from [52]). *Map © 2015 Google Inc, used with permission. Google and the Google logo are registered trademarks of Google Inc.*

The portal offers the user more comprehensive contextual understanding of the travelled road by rendering geo-coded, street-level images of the location on Google Maps™ (Fig. 2.9 adopted from [52]). For this purpose a camera is integrated in sensor package installed in the vehicle.

Figure 2.10 (adopted from [52]) shows ten hotspots with highest congestion level. According to authors' results, in Seattle many sections of I-5 demonstrate high speed deviation during travel times. Similarly, I-93 is a key area of congestion in Boston.

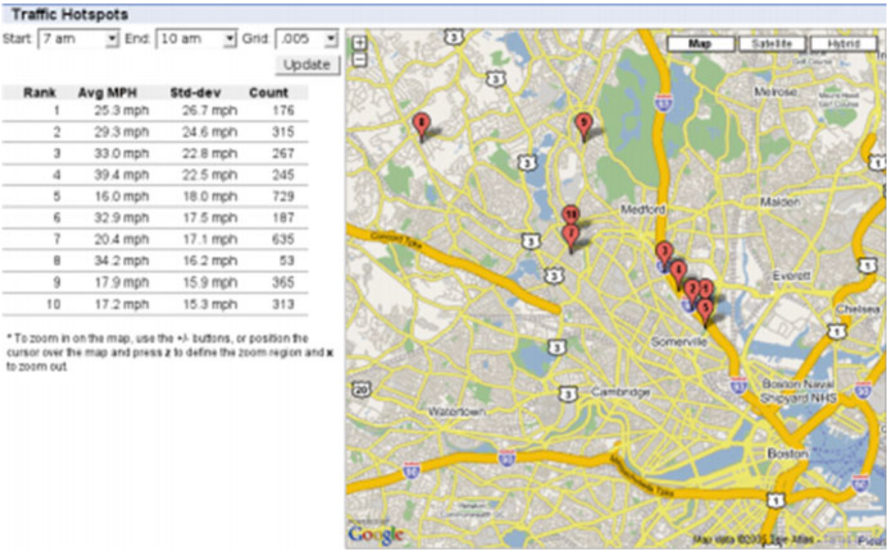

Fig. 2.10 The CarTel portal, showing ten traffic hotspots for the Boston area (Adopted from [52]). Map © 2015 Google Inc, used with permission. Google and the Google logo are registered trademarks of Google Inc.

Despite Google Maps™, Nokia Here Map is another example which offers road congestion evaluation in real time [46]. Comparing to Google Maps™, traffic information on Nokia Here is more comprehensible and better presented. The traffic incidents are displayed in list format. It provides a view of the actual congestion, road constructions, accidents and other events [53]. Furthermore, Waze is similar social mobile travel application that presents travel information generated by users to Google Maps™ [54]. It also enables travelers to communicate contextualized reports concerning congestion, delays or other journey experiences.

Volunteered geographic information (VGI) systems for transportations, such as previously mentioned CarTel [52], Google Map™ Mobile [55], Microsoft Research Nericell [56], consider that mobile devices perform *opportunistic sensing* which means they passively collect information, their state is automatically detected; and *participatory sensing* meaning human take part in data collection and participate in significant decision stages of the sensing system.

CarTel, is an example for opportunistic sensing in Boston and Seattle which monitors probe vehicles with built in GPS receivers, and transfers data back via opportunistic network connections.

NeriCell is another representative of these systems in Bangalore which applies Smartphones for monitoring road and traffic conditions. The mobile nodes are rich in sensors like GPS, Bluetooth, accelerometer, cellular radio, microphone to collect data, and there is no human interpretation involved in data collection.

Regarding its focus Waze.com is the most similar system to TrafficPulse [47], encompassing opportunistic and participatory sensing components. It records traces and provides a navigation along the route to a destination. Besides that, its user-friendly GUI allows users to contribute and visualize traffic data. Authors of TrafficPulse also intend to turn it into a social network-based platform. By offering beneficial information from the system, users are motivated to share their information and vice versa, the system can be improved by getting feedback from the users.

2.6 Digital Map Processing

The aim of digital map processing is to create raster or vector image from map images by simply using map's geographic features. One way to accomplish this is by first separating geographic-feature layers from map images using the method of grouping image pixels which possess similar colors. Other approaches use recognition of individual geographic characteristics (Fig. 2.11 adopted from [57]).

Chiang et al. [32] describe several techniques for map processing like color image segmentation, histogram thresholding, color space clustering, approaches based on region, template matching etc. Technique which is also applied in our application for congestion estimation is *histogram thresholding*. It is a technique which uses histograms of color values found in an image to identify frequently occurring values or value ranges. These values are representatives of probable color classes. *Template matching*, is knowledge-based recognition technique that could for example extract road lines, characters, and symbols from a map.

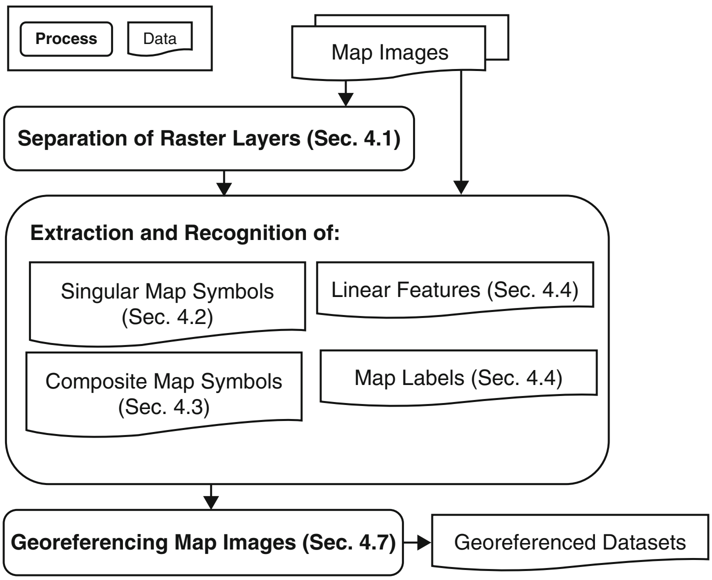

Fig. 2.11 An example map processing workflow (Adopted from [57])

Linear feature extraction and recognition techniques usually comprise separation of raster layers, and the categorization of linear features from each raster layer. Raster layers separation is usually based on histogram thresholding. One example is to extract “raw” road layers. In this context, there are some techniques that exploit more sophisticated processes for extracting the raster layers. Instead of thresholding the grayscale histogram, these methods use the RGB space and often involve user interaction. However, processes involving user interaction, such as manually determining color thresholds (Salvatore and Guitton [58]) (similar to our program for congestion estimation) or labeling colors of all line-background combinations (Khotanzad and Zink [59]) are complex, challenging, and time-demanding. Other methods for line detection prefer minimum user input or avoid relying heavily on user input (ex. manually specify the start and end points of each linear feature) in pixel-force field algorithm.

It can be concluded that processing maps is difficult and complicated. The main reason for it are the complex overlapping data which are contained in maps. Hence, minimizing the user effort in map processing and enabling users to put on their proficiency is significant. Developing efficient interactive techniques, can significantly improve human understanding of map representations and facilitate their integration in many applications.

This section reflects an intensifying need to bring together existing technologies and show how they are related and can complement each other for better transport operation analysis. It demonstrates how variety of sensors which are part of the Intelligent Transport Systems are implemented here. From the analysis of the implemented sensing it can be noticed that in the cities of the developing world, where road conditions are not good, rich sensing is critical. For example, the accelerometer is used to detect potholes and the microphone to reveal honking. Developed countries on the contrary, have high quality roads, and well managed traffic. The traffic conditions there can be defined by the velocity and volume of vehicles, more than by acceleration for instance.

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