Visualizing Real-Time and Archived Traffic Incident Data

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Abstract

The volume of data associated with a single transportation incident is difficult to comprehend, and existing systems often fail to equip users with the tools to rapidly make sense of this data. The consequences of delayed decision-making or misinterpreting data can be life threatening. A tool that gives the incident manager the ability to grasp the entire picture of an incident in a minimal amount of time is essential to facilitate quick decision-making.

The Transportation Incident Management Explorer (TIME) visualizes real-time and historic traffic incident data. Temporal data are rendered as timelines and geospatial data are plotted on an interactive map, providing users freedom to explore regions affected by an incident. TIME reduces the chance of missing critical information, enables users to correlate events, and quickens the time needed to comprehend the many simultaneous events that occur during the management of an incident.

1. Introduction

Traffic management centers around the world use real-time incident management systems to record and coordinate emergency response to transportation events. The records produced by these systems include the time and location of the incident, the number of vehicles involved, agency notifications, lane closures, and many other properties and their effects on traffic conditions. Proper decision-making depends on the traffic incident manager's ability to rapidly understand the complete story of each incident, but existing tools have failed to make this an easy task. Most incident management systems require an operator to navigate through several pages of free text, tables, graphs, and maps to even begin to get an idea of what is being done to manage an incident. This process can be time consuming and error prone. A tool that mitigates these problems can streamline the incident management process and lead to faster accident scene clearance times and ultimately to safe roads.

This paper presents the Transportation Incident Management Explorer (TIME), an application that visualizes the temporal and spatial data associated with incident logs, presenting, on a single webpage, the events recorded during incident management. TIME is meant to help incident managers quickly assess a situation and make informed decisions. The system works with live data, providing up-to-the-second visualizations of an active incident, but it can also handle archived data, facilitating after-action reviews and allowing individuals to quickly understand the consequences of the actions taken in response to past transportation incidents.

1.1. The Nature of Incident Management Data

Incident management records contain several *types* of data. These include:

1) *Temporal data*
   a) *Time points*: Events that occurred at an instant in time.
   b) *Time-intervals*: Events that have start and end times.
2) *Spatial data*
   a) *Geographic data*: Any items that contain latitude and longitude coordinates.
   b) *Relative positioning data*: While relative positioning can be derived from latitude and longitude, certain items in the dataset only include information about their positioning relative to similar items.
3) *1-Dimensional data*: Data that are described by plain text or numerical values and have no temporal or spatial attributes.

These data *types* manifest themselves throughout the dataset in the various *categories* of data recorded by incident management systems. These *categories* include:

1) *Communication Logs*: The communications between incident managers occur at discrete points in time.

2) *Variable Message Signs*: Incident managers can post messages on variable message signs (VMS) located alongside highways. These messages can be active for arbitrary time intervals, and the signs are geolocated.

3) *Responders*: Agency response records consist of both discrete and interval time data; incident managers note the time an agency is notified and the window of time when an agency's dispatched unit is on scene.

4) *Lane Status*: Records of lane openings and closures are represented as time intervals. The configuration of the highway (number of on-ramps, shoulders, etc.) also provides relative spatial information about the lanes.

5) *Detector Data*: Traffic detectors along the road record vehicle counts and speeds. Detector readings are

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coupled with their absolute location on the road and their relative position with other detectors based on mile-markers.

6) *Miscellanea*: Various 1-dimensional data are also stored by incident management software. Among these records are the number of vehicles involved in the incident, the weather conditions when the incident occurred, the severity rating assigned to the incident, and a number of other fields.

1.2. Existing Systems

There are currently no software packages that can claim to be incident management *visualizations*. While many incident management *systems* exist, for the most part these tools are little more than a series of electronic forms which support data entry and device management. Their emphasis is on data input, with less consideration given to full situational awareness and review capabilities. Regardless, by reviewing the contents of these forms, incident managers can learn what is currently being done to manage the incident scene. Unfortunately, the structure of these forms often makes assessing current conditions an arduous task. Doing after-action review from within the live system is often impossible because the forms only reflect the current conditions. Many systems try to support after-action review by allowing users to print out text-based history logs that list every action that was taken while managing an incident. These logs are often several pages long, and extracting the interesting and meaningful events is tedious.

Before development on TIME began, several incident management systems from the states of Maryland, Virginia, Georgia, and Texas were reviewed, and their strengths and weaknesses were evaluated. The majority of the design decisions made during the development of TIME were influenced in some way by these evaluations.

All of the incident management systems surveyed are comparable in how they allow users to enter and, by extension, view data. Users enter 1-dimensional information (number of vehicles involved, weather conditions, etc.) using standard form controls like drop-downs and check boxes, and they specify geospatial information, through some means, via a map. These controls in and of themselves provide all of the relevant information about their respective fields: Users can see what the weather conditions were at the time of the incident by simply reading the text in the appropriate drop down.

Unfortunately, these systems do not handle temporal data as elegantly as they handle spatial and 1-dimensional data types. Responders, for example, have a notification time, an arrival time, and a departure time. Many systems opt for a tabular layout when displaying this information which makes deciphering when the associated events occurred laborious. During after-action evaluation an incident manager might need to determine which responder was on-scene the longest. In a few of the incident managements systems reviewed, the duration is not made visible, and users would have to tediously subtract the arrival and departure times for each responder.

2. Related Work

The prominent features of a dataset often suggest appropriate visualization techniques. Nearly every piece of information in the incident logs has some sort of temporal data associated with it, so an interface that emphasizes temporal information may be beneficial. Timeline visualizations have been used for centuries to display the progression of time and are a good starting point when considering potential visualizations for temporal data. Although numerous temporal visualizations exist, many follow a common practice: plotting time-oriented data as horizontal lines across a temporal axis. Techniques that use the approach are hence forth referred to as "traditional timeline visualizations."

Careful consideration must be given when determining how to differentiate the various uses of time while still maintaining a consistent presentation. Aigner et al. catalogued several techniques used to visualize data based on how temporal information is used within a dataset, including techniques for visualizing time intervals, discrete events, and cyclic and linear time [1]. The traditional timeline visualization influenced the majority of the applications Aigner et al. surveyed.

Timeline visualizations have been used to successfully convey time-series data in a number of domains. PlanningLines [2] displays the duration of tasks in a project and includes methods for visualizing uncertain timeframes. These techniques are useful when differentiating events that have recently ended from events that are still on-going. ThemeRiver [3] displays temporal data differently; by plotting time along a horizontal axis and numerical values along a vertical axis, it allows for the search of trends in multiple time-series. Another application, TimeSearcher [4], provides an environment for exploring generic time-series data.

Because of their long history and ease of use, traditional timeline visualizations are commonplace outside of academia. The media has long used timelines to convey complex temporal datasets to the public [5, 6] and commercial calendar applications [7, 8, 9] use variations of the classic timeline to show the duration of scheduled events.

Luz and Masoodian [10] observed that traditional timeline visualizations that allocate a horizontal strip for each element in the dataset can rapidly become unwieldy because of their increasing height and wasted space. Their temporal mosaic is an alternative to the traditional timeline that assigns vertical space such that each element is sized proportionally to the total number of active elements at a given time. The temporal mosaic works well with interval data, but it is not clear how it can be adopted to handle instantaneous events. It uses a space-filling algorithm, so a method for allotting a reasonable amount of space for instantaneous events needs to be devised before the mosaic can adequately handle the discrete time points found within the traffic incident dataset.

The LifeLines project [11] displays an individual's medical history using a series of stacked timelines to group related events, such as hospitalizations or the results of blood tests.

Each item in the stack can be collapsed to free up screen real-estate, effectively combating the increasing height that Luz and Masoodian's temporal mosaic addresses. In traditional timeline fashion, each event is plotted as a horizontal bar with length proportional to that event's duration. Controls are provided to allow users to zoom in on a time range of interest. The datasets visualized by LifeLines and TIME are both rich with various forms of temporal information. Because of this similarity, TIME borrows heavily from the lessons learned during the LifeLines project.

The interplay between temporal and spatial data is a key component of the incident database. While focusing primarily on spatial data, commercial GIS software packages [12, 13] address the need to integrate temporal data as well. GeoVISTA [14] uses animations to help users make sense of how data changes over time. Unfortunately, the timelines are rendered separately from the map, giving the spatial and temporal properties of the dataset a disconnected representation.

GeoTime [15] integrates spatial and temporal data with a 3D interface that plots position on the xy plane and uses the z axis to represent the passage of time. By tracing the path of objects in the positive z direction, a user can follow those objects as they move forward in time. This works well for visualizing the changes in position over time but needs to be expanded upon in order to account for changes in other properties, like the messages placed on the VMS.

Despite the effectiveness of existing visualizations, there are no existing solutions that meld temporal and spatial data together in a way that is ideal for the traffic incident dataset.

3. Description of the interface

The TIME visualization tool, shown in Figure 1 and at http://tinyurl.com/bly8k5, derives several of its visualization techniques from the traditional timeline. To separate different temporally-oriented data, TIME employs the stacking technique used by LifeLines. The TIME interface includes six sub-visualizations: Communications, Variable Message Signs, Responders, Lane Status, Traffic Speed, and Traffic Volume.

TIME adds the ability to drag and drop any of these sub-visualizations to rearrange them as needed. Each sub-visualization may also be collapsed by clicking on its header. The collapsing process is animated to prevent users from becoming disoriented by rapid changes in the layout of the interface. The 1-dimensional data associated with the incident can be viewed as a tooltip by rolling the mouse over the blue information icon.

3.1. The Interactive Timescale Control

In each category of data, temporal information underpins the visualization of choice. This is an important property of the dataset, and to make this information apparent to the users, identical interactive timescale controls are placed at the top of each sub-visualization. The layout of the timescale has been designed to convey as much information as possible without cluttering the interface. The start time of the incident is printed on the left of the timescale and the current time is printed on the right. In the event that the incident being viewed has already ended, the "close time" is used in place of the current time. A series of tick marks runs between the two ends at each minute mark, and each tick mark representing and hour is labeled, space permitting.

Like the markings on a yardstick, each tick mark is sized depending on its significance; one minute marks are the shortest, five minute marks are slightly longer, etc. By providing labels and a visual differentiation between the significance of each tick mark, users should be able to find arbitrary times on the timeline with less effort than they would when using a less descriptive timescale.

Tooltips indicating the time represented by each tick mark can be shown by rolling the mouse over any point on the timescale. In addition, a vertical line is drawn across all sub-visualizations of TIME at the mouse's x position. Events that intersect the vertical line are emphasized while events that do not are grayed out. This draws attention to events occurring at the time under the mouse cursor, making it easy for the user to identify everything that occurred at any given time.

By dragging the left and right borders of the tool users can expand the timeline, giving more screen real-estate to each time interval. This has the advantage of keeping the entire history of an incident visible while making more fine-grained details available. Because traffic incidents generally last no more than a few hours, a standard 1024 pixel wide screen can usually accommodate a sufficient level of detail for each event. Expanding a timeline for an incident lasting 120 minutes to 1024 pixels in width will allocate 8 horizontal pixels for each minute.

3.2. Data-Specific Sub-Visualizations

The six categories in the dataset have different properties associated with them, and TIME uses separate sub-visualizations to accommodate these differences. Each is based on the traditional timeline. Instantaneous events are rendered as diamond-shaped markers while time-intervals are rendered as horizontal bars. Several existing temporal visualizations use bars for both instantaneous events and time interval events, but the diamond shape makes it easier to differentiate instantaneous events from relatively brief time intervals.

3.2.1. Communications. Incident managers who send messages during the course of an incident are assigned their own horizontal strip spanning the width of the temporal axis (shown in Figure 1-A).

Figure 1: The Transportation Incident Management Explorer. The sub-visualizations are (from top to bottom) Communications, Responders, Lane Status, VMS messages, Speed Data, and Volume Data.

The tooltips for each marker display the time and text of the relevant message. TIME's communications visualization shows all messages regarding an incident, allowing users who were initially "out of the loop" to review the messages they missed.

3.2.2. Variable Message Signs. The VMS visualization (Figure 1-D) used by TIME allows users to see the full history of the VMS message postings. Each VMS is rendered on its own line, and the messages posted on each sign are displayed as horizontal bars. Each bar is positioned on the temporal axis such that the left end of the bar refers to the posting time and the right end refers to when the message was removed. A rendering of the sign's appearance is displayed when users roll the mouse over each message.

Using the geospatial coordinates associated with each sign, TIME is able to place the signs on an interactive map (Figure 2). The map appears when a user clicks the map icon in the upper-right corner of the application. Like many common mapping tools, TIME allows users to pan and zoom in to a desired location. Clicking on an icon representing a VMS will display a miniature timeline for that sign's posted messages.

Figure 2: The TIME map with a VMS selected. The bull's eye represents the location of the incident.

3.2.3. Responders. The visualization TIME uses for responders combines the techniques used to display VMS and communications (Figure 1-B). The notification time of each responder is displayed as a diamond-shaped marker, and the timeframe that the unit was on-scene is represented as a horizontal bar. Tooltips describing each responder event (e.g. "Local police notified at 9:30:15 pm") are provided to give users details when needed, and color is used to differentiate the various agencies involved in the incident.

3.2.4. Lane Status. Only the current lane status is visible in most existing incident management systems. This is problematic when doing after-action review because the progression of events is impossible to deduce. The visualization used by TIME allows users to view the full history of the incident's lane status. A timeline-style rendering of the highway is used to provide relative spatial information (Figure 1-C). Lanes are rendered in the same relative locations that they are found on the road. Time periods when a given lane is opened or closed are colored black or red, respectively. As with the other visualizations, tool tips reveal detailed information.

3.2.5. Speed and Volume Data Graphs. Detector readings provide incident managers with a way to estimate an accident's impact on nearby traffic. As the queue builds up behind the accident scene, detectors upstream of the accident will report lower speed readings. To display this data while maintaining consistency with the other temporal visualizations, TIME converts a traditional timeline visualization into a 2D temporal-spatial plot (Figure 1-E and 1-F). The readings for each detector are plotted horizontally in accordance with when their readings were taken and vertically with the location of the detector. As speeds range from low to high the color varies between red and green. The inverse relationship is used when graphing volume as a lower number of cars on the road is usually more favorable to traffic. Bilinear interpolation is used to smoothly fill in the areas between detectors (vertically) and between readings (horizontally). The vertical axis is labeled with the mile-markers values, and an arrow indicates the direction of traffic flow. A horizontal line is plotted across the entire graph indicating the location of the incident. Rolling the mouse over the graph displays the mile marker, time, and the value of the reading under the cursor.

None of the incident management systems surveyed provide a way to visualize historical detector data along an entire corridor. In order to view these plots users would have to query the database and enter the results into a graphing application. TIME's detector data graphs update automatically as new data becomes available, providing incident managers with a reliable gauge of how an accident affects traffic through a set of data that was previously unavailable to them.

4. Implementation Details

As incident records are added and modified by the traffic management center, the relevant data is pushed into a PostgreSQL database. TIME's server tier is written in ColdFusion and the front-end is written in Flex. The client application runs on Adobe Flash Player 9.

There are nearly 400,000 recorded incidents dating back to June of 2002 in Maryland's incident database and more than 130 more incidents are being logged on a daily basis.

Because incident managers are often responsible for several incidents at a time, it is useful for them to view multiple incident timelines simultaneously. To simulate this use case, multiple instances of TIME were opened on a 2 GHz machine with 1 GB of RAM. The machine was able to handle thirteen instances before it became too cumbersome to work with. The results of this test are reassuring as incident managers are rarely responsible for more than four or five incidents at a time, and most incidents are cleared in less than two hours.

5. User Evaluation

TIME is currently being used at by traffic management officials in Maryland and Virginia as part of a regional transportation coordination effort. TIME is still in beta release, and a formal study of the benefits of TIME has not yet been conducted, but the users' reactions provide some qualitative information about the usefulness of the system.

The application is accessed an average of 712 times each month by 48 unique users. Of the incidents loaded, each is viewed by an average of 1.5 users. Although the vast majority of incidents are only viewed by a given user a single time, there are instances where a user will load the same incident up to 10 times. This indicates that users are not only using TIME as a system awareness tool, but they're also using it as a reference.

Users have commented that the tool is useful for "correlating the multiple types of events that occur during an incident" and detecting when things are not occurring as they should at any given point in time. In addition to diagnosing large scale problems with incident management, users in supervisory positions have commented that TIME allows them to keep tabs on their staff. One user commented that when "the timeline doesn't make sense, it tells me that someone in the control room needs retraining [on the data entry software.]"

The speed at which information can be gleaned from TIME has also received positive comments. Supervisors have expressed that the system allows them to quickly review how their operations staffs are handling any given incident.

The tool has also been successfully used for after-action reviews and by analysts evaluating operating procedures for incident management centers. Researchers have found TIME to be particularly useful in analyzing both lane closure effects on queues and first-responders effects on lane closures.

6. Future Work

Although incident managers can benefit from using TIME in parallel with their current incident management systems, it would be interesting to extend TIME so it can act as a data entry device.

Given the volume of incidents that occur as a result of existing incidents, it is worthwhile to explore visualizations that combine the data from related incidents. A technique would need to be developed to indicate that these incident pairs share resources because the same group of responders and VMS will often be involved in two related incidents.

Many incident records include photos, video, and radio. These elements along with news clips or articles related to a traffic incident could be valuable additions to TIME, especially for after-action reviews.

7. Conclusions

TIME is a compact visualization of the temporal and spatial data associated with traffic incident management logs. All information is displayed in a compact overview, improving upon existing incident management systems which often spread their data across several screens. Sub-visualizations are displayed beneath unifying timescales representing the duration of the incident. A map allows users to garner spatial significance while still providing temporal information.

The sub-visualizations in TIME make more information readily visible than existing incident management systems, reducing the chance of misinterpreting or overlooking data and expediting after-action analysis. Because incident managers are able to view more data, they are able to make faster, more informed decisions. This in turn can lead to quicker incident clearance times and increased transportation system reliability.

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