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Contact Author	Robert L. Bertini (author 2)
Email	bertini@pdx.edu
Phone	+1-503-725-4249
Fax	+1-503-725-5950

INTEGRATING GEOGRAPHIC INFORMATION SYSTEMS AND INTELLIGENT TRANSPORTATION SYSTEMS TO IMPROVE INCIDENT MANAGEMENT AND LIFE SAFETY

Ahmed El-Geneidy
Graduate Research Assistant
School of Urban Studies and Planning
Portland State University
P.O. Box 751
Portland, OR 97207-0751
Phone: 503-725-5946
Fax: 503-725-8480
Email: elgeneid@pdx.edu

Robert L. Bertini, Assistant Professor
Department of Civil & Environmental Engineering and School of Urban Studies and Planning
Portland State University
P.O. Box 751
Portland, OR 97207-0751
Phone: 503-725-4249
Fax: 503-725-5950
Email: bertini@pdx.edu

Abstract: Intelligent Transportation Systems (ITS) include the applications of information and communication technologies to the planning and operation of transportation systems in order to improve safety and enhance mobility. Recently the convergence of Geographic Information Systems (GIS) and ITS data (real-time and archived) has enabled the development of improved tools for system planning, design and operations. GIS-T data models establish the architecture of archived transportation data and display it geographically in a consistent manner. In this paper we highlight the power of an existing GIS-T data model and integrate new highway incident (e.g., accidents and breakdowns) data model. The model demonstrates how archived data can reveal locations with high incident rates and how recommendations can be derived for transportation planners and operations managers in order to reduce incidents with high injury rates and reduce fatalities on the highways. Many urban areas have developed quick response incident management systems as part of their overall ITS programw. Applying these model results can be used to prioritize the deployment of limited resources when designing and dispatching these incident response vehicles. Finally a case study was developed to show the importance of the integration between the two models and the geographic importance of the new derived variables obtained from the second model.

Keywords: Geographic information systems (GIS), Intelligent Transportation Systems (ITS), Incident, models

1. INTRODUCTION

In 1995 commuters in the United States spent more than 2 billion hours in traffic congestion. Assuming an average hourly rate of $10 US (half the average salary rate) this delay could account for $100 billion US in lost productivity (USDOT, 1998). Incidents (defined as accidents, vehicle breakdowns and other random events on highways) are known to cause more than 50% of urban congestion and lead to economic losses, air pollution and human pain and suffering. In 1996, there were 42,000 fatalities and another 3.5 million injuries associated with automobile related crashes (USDOT, 1998).

Intelligent Transportation Systems (ITS) include the applications of information and communication technologies to the planning and operation of transportation systems in order to improve safety and enhance mobility. ITS are used to monitor the transportation system as well as to control and/or influence driver behavior. Direct system control includes such measures as traffic signal systems, freeway ramp metering and congestion pricing; indirect measures include variable message signage, traveler information system components such as dynamic message signs, Internet-based traffic information and transit trip planning systems as well as private information service providers (Miller *et al.*, 2001). Recently the convergence of Geographic Information Systems (GIS) and ITS data (real-time and archived) has enabled the development of improved tools for system planning, design and operations. Many urban areas have developed quick response Incident Management Systems (IMS), recognizing that congestion can be reduced by minimizing the duration of incidents and that lives can be saved by transporting victims to trauma centers within the golden hour. Further, through coordination among highway operations, law enforcement and emergency personnel, secondary accidents can be prevented and responder safety can be enhanced. IMS are considered as one of the ten main program areas of ITS in the U.S. Recognizing the importance of IMS, the U.S. Department of Transportation (DOT) has developed a database including ITS benefits and unit costs to assist in quantifying the benefits of deployments and investments in ITS (USDOT, 2002).

GIS are valuable aids in transportation planning and operations for both facility and fleet management. GIS are particularly useful in supporting modeling efforts for the analysis of planning options and for real-time vehicle dispatch and traffic control. The visualization tools contained within GIS enable editing and quality control inputs and the display of results that facilitates interpretation and sharing among multiple users. A major challenge for GIS is to build, update and maintain the digital road-map database that is central to transportation analysis, operations, and real-time management and control. Capturing the underlying dynamic geography of the transportation system is crucial to many computer planning and ITS applications. GIS has become a major requirement in any transportation planning process. Current research is investigating the integration of GIS and transportation (GIS-T) in order to develop GIS-T data models (Miller, *et al.*, 2001). In this paper we apply the basic concepts of an enterprise GIS-T data model to develop a GIS-T incident data model, and then test the model by re-archiving existing IMS data based on the proposed model. Several visualization tools are applied to highlight the importance of the proposed archiving system and the new derived variables that were added to the incident model.

The primary contribution of this paper is the application and testing of a real GIS-T model hypothesis. Usually, GIS-T data modeling papers include hypothetical studies and GIS-T data model architecture. Until this point, it has been rare to see an actual application in the form of a case study. It is hoped that the use of real case studies highlights the power and importance of the modeling framework and will encourage planners and operators to adopt similar systems.

2. INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

ITS are defined as the application of information and communication technologies to the planning and operation of transportation systems in order to improve safety and enhance mobility. In this section we introduce the basic concepts of ITS and the types of data that ITS can provide. ITS include a diverse range of technologies and applications, including surveillance, information processing, communications, control, and electronics. ITS have evolved with applications including collision warning systems, ramp metering systems, advanced signal control systems, transit and emergency vehicle management systems and others. The implementation of these systems provides opportunities to archive data that are required for operation in real time. These archived data have the potential to improve traveler safety, traveler mobility and system efficiency. The strain on the transportation system as a whole is thus eased through the application of modern information technology and communications. Some technologies provide more cost-effective benefits than others, and as technology evolves, the choices to deployers are bound to improve. These technologies are often combined into a single integrated system, providing benefits that exceed the benefits of any single technology (Proper *et al.*, 2000). The next sections describe how incident data can be maintained and archived using a proposed GIS-T incident data model. This process will lead to improved graphical displays that can help transportation planners and operations planners assign incident response vehicles to appropriate routes.

3. INCIDENT MANAGEMENT SYSTEMS

Many metropolitan areas have developed incident management programs in order to provide rapid response to motorists and incident clearance. These very popular programs lead to improved safety and reduced congestion. These programs also require heightened coordination among many agencies, including the state Department of Transportation, state police, emergency medical response, local police, fire, and private tow companies. This coordination can result in new synergies and efficiencies that improve the working relationships among all entities. Incident management systems are coordinated preplanned and/or real-time use of human resources to reduce the duration of incidents (Zografos *et al.*, 2001). Incident management systems contain components such as incident detection, incident verification, response to the incidents, clearance of the incidents and traffic management at the incident locations. Incident management typically involves response vehicles and personnel that are dispatched from a centralized traffic management center (TMC). The TMC will typically have operations software that allows a dispatcher to log incident location, type, and all discrete events during the life of an incident. In some cases, detailed incident data are archived on a regular basis. This can help in the identification of locations of high incident frequency. These locations can be used in planning the responders' routes on the highways and for identification of incident causation in an effort to improve existing roadway design characteristics to avoid future incidents at the same locations. Numerous studies have been conducted to evaluate the implementation of incident management programs. Most of these studies came to the conclusion that incident management programs have a substantial effect on reducing vehicular delay.

Consideration of applications of GIS to incident management requires an understanding of the GIS literature. Goodchild (1999) has mentioned several research challenges facing the full development of GIS-T:

- Develop a digital representation process that accommodates the lack of standards in transportation and overcomes the lack of positional accuracy;
- Devise a representation for the full range of information types for a comprehensive approach to GIS-T and ITS;
- Develop methods of inter-computer negotiation that produce communication of location emulating the traditional practice of inter-human negotiation;
- Build an economic models for the development of the GIS-T industry;
- The GIS-T research community so should maintain the flexibility and creativity to take quick advantage of the new technology stream; and
- Find fields that are substantively analogous to GIS-T, and make research advances by taking advantage of a broadly conceived approach that sees the parallel between widely disparate applications.

Consistent with Goodchild (1999), and in the context of incident management, this paper develops tools to help face these challenges in linking GIS-T with ITS.

4. GIS-T DATA MODELS

Modeling is one of the most important parts in a decision making process. Modeling is a way to simplify and abstract data to make the decision process more tractable (Hensher *et al.*, 2000). Transportation problems are becoming more dynamic, consistent with the changes in the complex social, economic, and physical world (Dueker *et al.*, 2000). GIS-T data models are intended to abstract, identify and simplify the relationships and characteristics of the transportation system towards better management and understanding of the existing system. The UNETRANS transportation data model (Curtin *et al.*, 2001) has defined a method for modeling incidents using ArcGIS. This limits the use of such a model and makes it difficult to be generalized. Another comprehensive approach towards a GIS-T framework for transportation data sharing was developed by Dueker and Butler (2000). This framework is more general and can be implemented using different GIS software. The Dueker and Butler (2000) framework is built upon a transportation feature class, which may be a freeway, an arterial, a local street, a path or even a pipeline. The transportation features are used to build the network needed for specific applications. A transportation feature can be a point (intersection), a linear event (road), or an area (railyard or airport). According to the simplified enterprise GIS-T data model, an incident can be presented as an event. An event can either be a point, line, or area. In the case of an incident we recommend classification as a point event. The location of an incident is identified on the transportation feature using the event points defined in the enterprise data model. Recently there have been some efforts to introduce the ideas contained in Dueker and Butler (2000) to the UNETRANS model. These efforts have been pursued by one of the UNETRANS developers (Grise, 2002) in coordination with Dueker and Butler. Grise described the GIS-T data model as a set of different models integrated to form the overall GIS-T model. This model included routes, address ranges, cartographic, and reference network models as a common base. This base is integrated with a set of assets, incidents, navigation, traffic modeling, and transit models. Recently, Dueker and Butler (2001) developed a comprehensive physical database model for archiving the transportation features. This physical model is where incident data can be linked and spatial incident data model can be presented to benefit from the concepts introduced in the enterprise GIS-T data model.

5. INCIDENT DATA MODEL

In order to model the incidents more accurately, a flow chart of the incident time line is presented in Figure 1. This figure shows the different periods of the incident and when the service patrol vehicles and different agencies are involved in the incident. Figure 2 shows a traffic flow diagram during the incident and recovery phases to show the effect of incident duration on highway congestion. Both figures can help in understanding when the incident occurs and which agency should be involved at different stages.

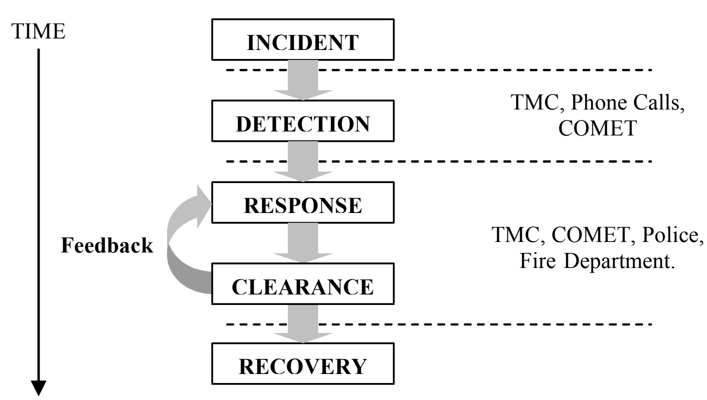


Figure 1 Incident Flowchart

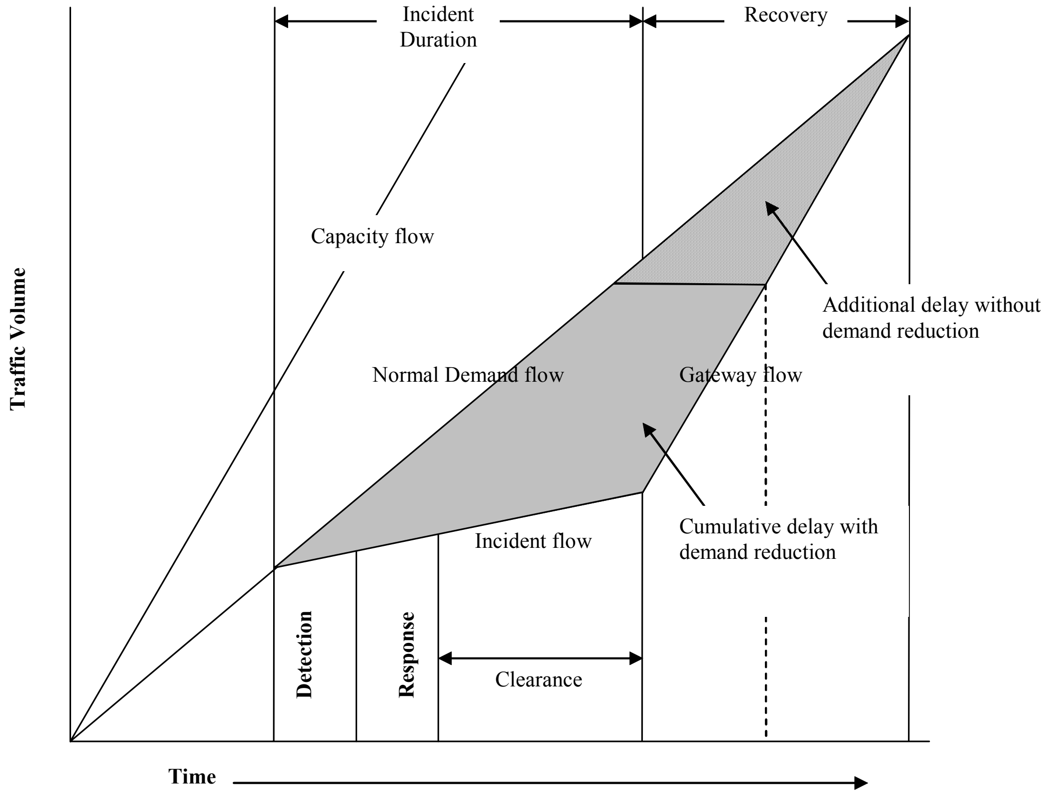
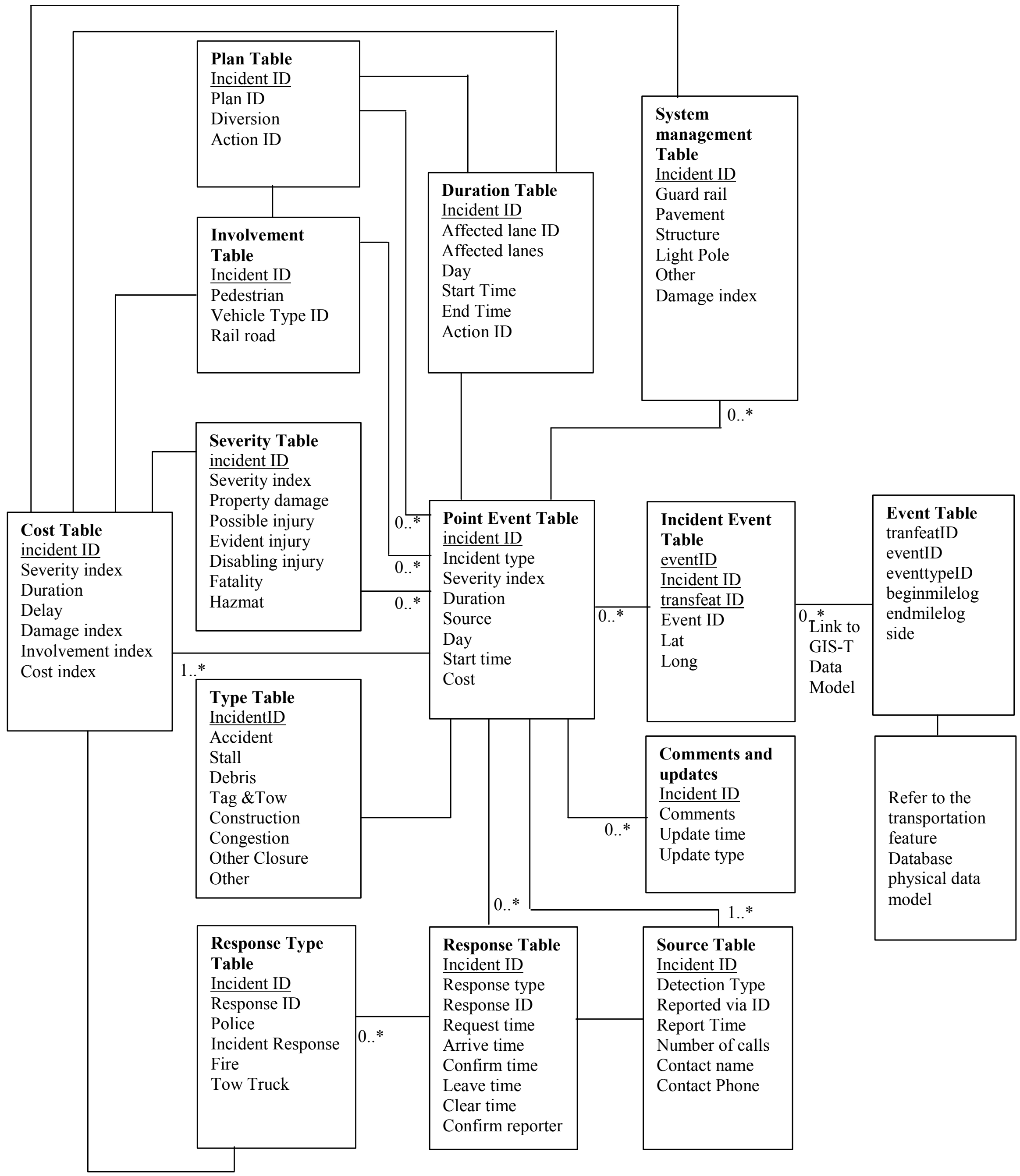


Figure 2 Traffic Flow Reduction During Incident Duration and Recovery Phases

Understanding the flowchart of an incident and the consequences of an incident on the highway enables us to understand the importance of archiving the incident data in a way that can be more easily integrated with other data models.

The power in the GIS-T data model is that it provides a framework for satisfying the need of the transportation community to integrate multidimensional data (Koncz *et al.,* 2002). The strategy for developing this incident data model is to use components of existing data models and apply them to a logical GIS-T incident data model.

Figure 3 shows a proposed IMS data archiving system model. This model is based upon the concepts of the GIS-T data enterprise model because the sharing of the archived incident data between different agencies is critical. The figure shows a set of database tables where the incidents are archived and linked to the different feature classes through the characteristics of the event point. As shown in the figure the amount of information archived in the incident tables is minimized by the GIS-T data model that enables the referencing. According to the described archiving system, different entities could receive information about the incident, and appropriate agencies could respond to the incident and use the part that is useful for them for future planning purposes. The absence of duplication is one of the most important characteristics of this model as will be seen in the implementation section. The IMS database model is integrated with the transportation features database physical data model that was developed by Dueker and Butler (2000) at the event table level with a relation of zero to one. If an incident occurs it will be presented in GIS as a point event. The event point will be used to display the incident geographically. According to the GIS-T model tree, there will be no need to archive any transportation feature related data associated with the incident. The event table will be used as the link to locate incidents on different transportation features. Inconsistencies in entering street and highways names, intersections, etc., will no longer exist, which is a common complaint from planners when using secondary data sources.



—— One is a must *...1 one or many 0...* Zero or many 1...0 One or zero

Figure 3 Integrated IMS Archiving Database Model

The isolation between the incident-related information and geographic location, while having one link to the GIS-T physical model, will lead to better consistency in the data and efficiency in storage. At this level, the planner's role will be mainly directed towards improving the efficiency of the existing transportation system rather than searching for ways to avoid inconsistencies in data which might lead to poor decision-making. In the following sections we will demonstrate how better decision-making is possible when re-archiving the incident and transportation data according to the previous models.

6. SEVERITY INDEX

New derived variables are readily included in the IMS. These variables were not present in the archived data. The variables can be used to assign a cost to the incident and accordingly allocate more resources where incidents occur to avoid delay or save lives. In this section we describe two of the variables used in the application section. A severity index is a common tool for incident classification. One severity index used in the U.S. is the standard police classification of property damage only, possible injury, evident injury, disabling injury and fatality. These terms are vague but used throughout the U.S. so there is some consistency in using them to derive costs (Mannering, 2002). In these reports the number of occupants is reported so the severity increases according to the number of fatalities or the number of injuries. Another method used for measuring the severity index is by consolidating some of the upper indices into three main levels (Monsere, 2002). This enables planners to highlight locations on the streets and highways of high severity for detailed study. The consolidation method is used by different Departments of Transportation (DOTs) in the US.

No (Fatality + Disabling Injury) * 100

No (Evident Injury + Possible Injury) * 10

No (Property Damage) * 1

Another important index that can be derived from the archived incident data is the duration. Duration measures how long the incident affected the transportation network by blocking a lane or lanes or by causing rubbernecking when located on a shoulder. This index calculates the amount of delay caused by the incident, which is also linked to the fuel consumption and air quality impacts of nonrecurrent congestion. Looking at the existing ITS infrastructure and with an understanding of recurrent traffic patterns and bottlenecks, the number of passengers delayed and the time lost to drivers can be calculated. Assigning a monetary value to incidents is another approach to measure an incident's severity. The USDOT (1994) proposed possible values in its motor vehicle crash cost report. Another method was proposed by Hallmark, Basavaraju, and Pawlovich (2002). They assigned a value to crashes similar to Monsere (2002). In this paper we use the severity index and combine it with duration to highlight locations on the highways where incident responders need to be present. The priority will be proposed according to both the duration and severity. Another approach will include consideration of the time of the day in relation to the type of incident. The time when the incident occurred is another factor when assigning the routes to the incident responders.

7. APPLICATION

The Oregon Department of Transportation (ODOT) has implemented a comprehensive incident management program in the Portland metropolitan region. This system includes a traffic management center, communications system, surveillance (loop detectors and closed circuit video detection) and the COMET system of continuously patrolling vehicles that respond to incidents during peak periods. This paper demonstrates a model for integrating the archived incident data reported by the COMET system and other reporting entities (including law enforcement and the 911 system). In this application we demonstrate how the use of the re-archived data can be beneficial in highlighting locations with high incident rates and how recommendations can be derived for transportation planners in order to reduce incidents with high injury rates. The model can also be used to identify high priority locations that should be protected from the delay impacts of incidents. These results can be used to prioritize use of limited resources when deploying and dispatching the COMET vehicles and in choosing when to dispatch private tow vehicles.

7.1 Data

During the year 2001 the incident management center archived 70,974 incident records. Duplication was present in these data since dispatchers often enter new information for ongoing incidents as new records. Some incidents were reported three or more times. According to the incident database model each incident should be defined with one record in the data set. So a re-archiving process was developed to remove the duplication from the data. This process took into consideration that none of the data is to be lost during the process. Several new fields were added to capture the changes between the records that point to the same incident. The new data set included 21,293 records (70% of the incident data consisted of duplications with new information in separate records). A total of 2,796 incidents (13%) were geo-coded with latitude and longitude. The geographical attributes enable decision makers and planners to visualize incidents geographically. All other incidents included an intersection location or a mile post. In the existing system, locating these incidents is difficult, since an enterprise GIS-T data model is not available. Geographic coordinates help remove inconsistencies in defining the location of the incident.

As a preliminary study on incident database modeling, we concentrate on the 2,796 incidents with geographic attributes. The incidents reported were from all over the Portland Metropolitan area. Figure 4 shows the type of incident distribution. Approximately 1,066 of the incidents were reported as accidents and these are the incidents where both the severity index and the duration can be measured. The remaining incidents can not be measured except by the duration and delay caused by the presence of the incident on the highway. Thus, applying both measures to the reported incidents is important.

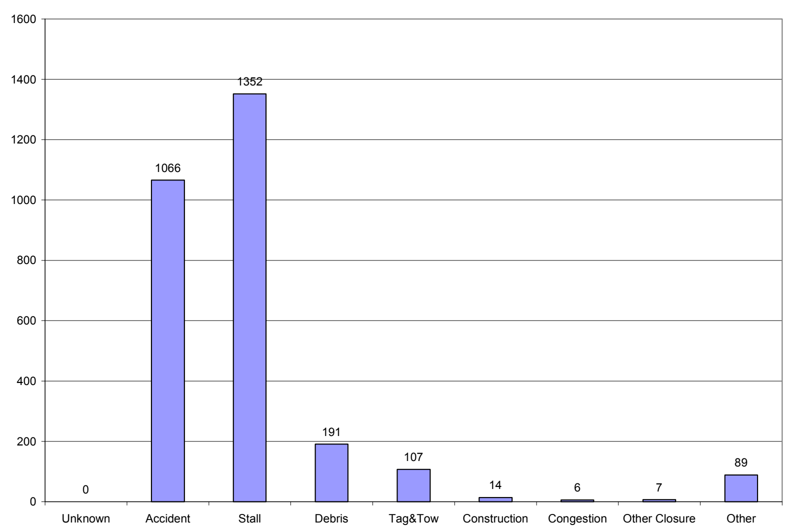


Figure 4 Distribution of Incidents by Type

Figure 5 shows the time of day when incidents occurred. Studying the time of incident occurrence will help in managing the COMET vehicles on the highways. Further research is recommended in relating the incident type, location and time. The figure indicates that most of the incidents occurred in the morning peak period.

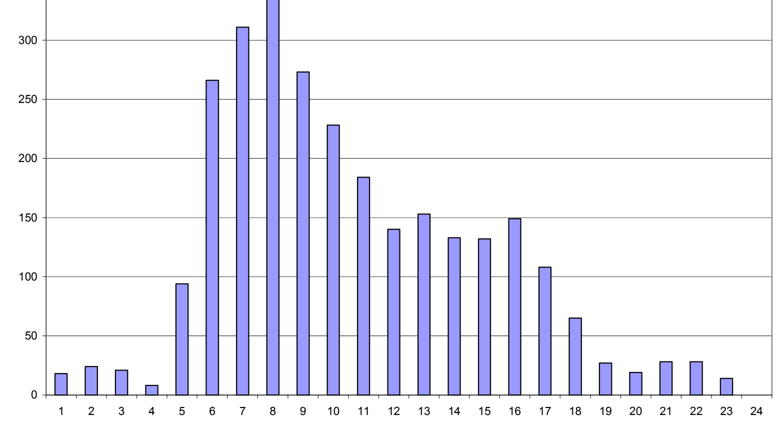


Figure 5 Incident Occurrence Time of Day

In this application we consider how to optimally dispatch the COMET vehicles. COMET vehicles operate on the freeways in the Portland region. Of the 2,796 incidents considered here, 2,029 occurred on freeways. The data included 16 fatalities and 908 injuries during the year 2001. None of the fatalities occurred on the highways during this period so as will be seen in the analysis the severity index did not exceed the value of 40. The raw data recorded by ODOT includes a row for each recorded incident where 72 different variables are assigned to each row. Each variable indicates a particular piece of information describing the incident. During one year's worth of data many of the 72 columns indicated a value of zero. This is due to comments which need more consistency in archiving. Table 1 shows the 72 archived columns in the ODOT incident management system. According to this archived data, field revisions were made to the incident data model to capture most of the events that were not recorded in this data set and were only mentioned in the comments column. The comments field was reviewed and different variables were added to the model. The proposed data model has tried to address this issue in a way to reduce the comments and keep them in a separate data table.

Table 1 ODOT list of Incidents Attributes

ATMSROWID	LOCATEDFLAG	MOTORCYCLECOUNT	RADIOUNITNUMBER
INCIDENTID	FIREPRESENCE	PICKUPVANCOUNT	SCHEDULEDSTART
INCIDENTTYPEID	HAZMATPRESENCE	DOTVEHICLECOUNT	SCHEDULEDEND
DETECTIONTYPEID	INJURYCOUNT	CONSTVEHICLECOUNT	ACTUALSTART
COUNTYCODEID	FATALCOUNT	MOTORHOMEBUSCOUNT	ACTUALEND
CITYCODEID	NEEDPOLICEFLAG	LIGHTTRUCKCOUNT	CONFIRMFLAG
PRIMARYROUTE	NEEDCOMETFLAG	TRACTORTRAILERCOUNT	CONFIRMTIME
SECONDARYROUTE	NEEDAUTOWRECKERFLAG	OTHERVEHICLECOUNT	CONFIRMOPERATOR
LOCATIONTYPEID	NEEDTRUCKWRECKERFLAG	HAZARDFLAG	LASTUPDATETIME
LOCATIONTEXT	GUARDRAILDAMAGE	OFFICERNAME	LASTUPDATEOPERATOR
DIRECTION	PAVEMENTDAMAGE	OFFICERBADGENUM	ACTIONPENDING
AFFECTEDLANETYPEID	SIGNALDAMAGE	ESTIMATEDEND	PLANFLAG
NUMLANESAFFECTED	LIGHTPOLEDAMAGE	IMPACTTYPEID	DIVERSIONFLAG
STATIONID	STRUCTUREDAMAGE	NUMBERCALLS	XPOSITION
SEGMENTID	OTHERDAMAGE	REPORTEDVIAID	YPOSITION
NAVLINKSTARTID	PEDESTRIANCOUNT	REPORTEDBYNAME	ALARMINTERVAL
NAVLINKENDID	RAILROADCOUNT	CONTACTNAME	INCIDENTLEVEL
JURISDICTIONID	AUTOMOBILECOUNT	CONTACTPHONE	COMMENTS

7.2 Visualization

Three-dimensional (3D) visualization can play an effective role in summarizing data. The geovisualization tools serve the collaboration and exploration process in the planning support system (Jiang *et al.,* 2003). Figure 6 shows a 3D interpolated surface where the color represents the incident duration index and the height represents the severity index. The statistical method kriging was used to interpolate the surface. Kriging is the estimation procedure used in geostatistics using known values and a semivariogram to determine unknown values. The procedures involved in kriging incorporate measures of error and uncertainty when determining estimations. Based on the semivariogram used, optimal weights are assigned to unknown values in order to calculate unknown ones. Since the variogram changes with distance, the weights depend on the known sample distribution (Longley *et al.*, 2001). This kind of figure can be used as part of public participation to simplify the data, since it highlights locations with both high incident severity and duration.

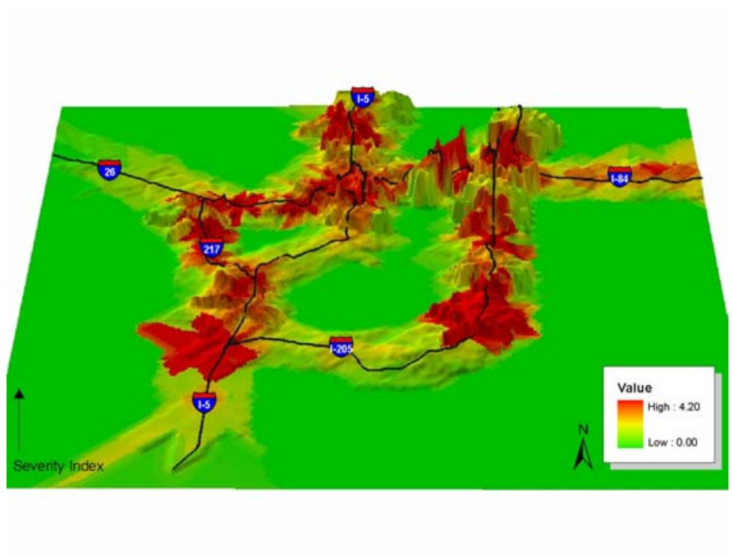


Figure 6 3D Interpolated Incident Surface

Figure 7 shows the subtraction of the two surfaces together to locate the incidents with both high severity and longer duration. This figure is used to highlight the variance in the relation between duration and severity index. If the color distribution is equivalent to zero then the middle color will be dominant. If there is a variation between the severity index and the duration then the color will be either darker or lighter than the zero value. When a lighter color is present this indicates a high duration and low severity. On the other hand the darker the color the more severe the incident is and the duration was low at these locations. The figure highlights that there is a variance between duration and severity index.

The relation between the two measures is not clear enough, so when assigning the routes for the COMET vehicles both variables need to be taken in consideration. Applying the GIS-T enterprise data model results in the presentation of point events along the transportation features which enabled the segmentation of the highways. The segmentation was performed according to the location of the point event on the transportation feature (highway). Displaying the severity on the highway segment was possible as shown in Figure 8. Displaying the duration in Figure 9 shows different segments that will have high priority because of the delay incidents there might cause. The GIS tool enables the display of various queries on the data once it is in the right format. As shown in Figure 10, the locations that have both high duration and high severity indices are clearly represented. Using dynamic segmentation these locations can be identified by mile post for optimizing the design of future incident management strategies.

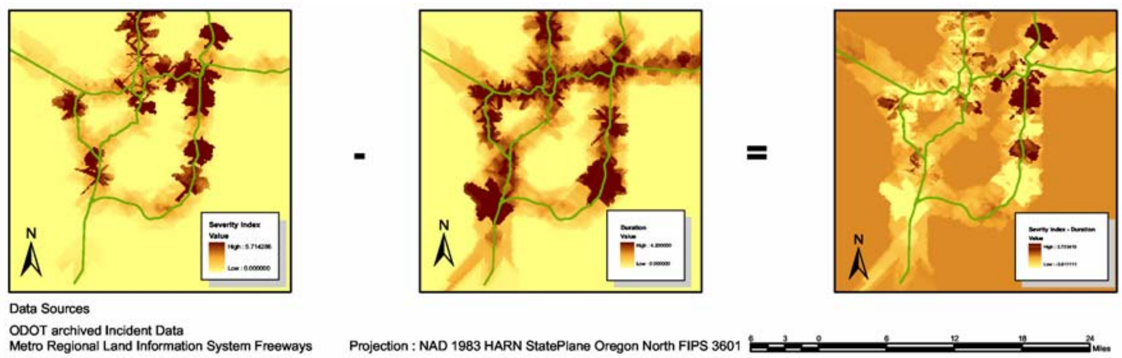


Figure 7 Subtraction of Two Interpolated Surfaces

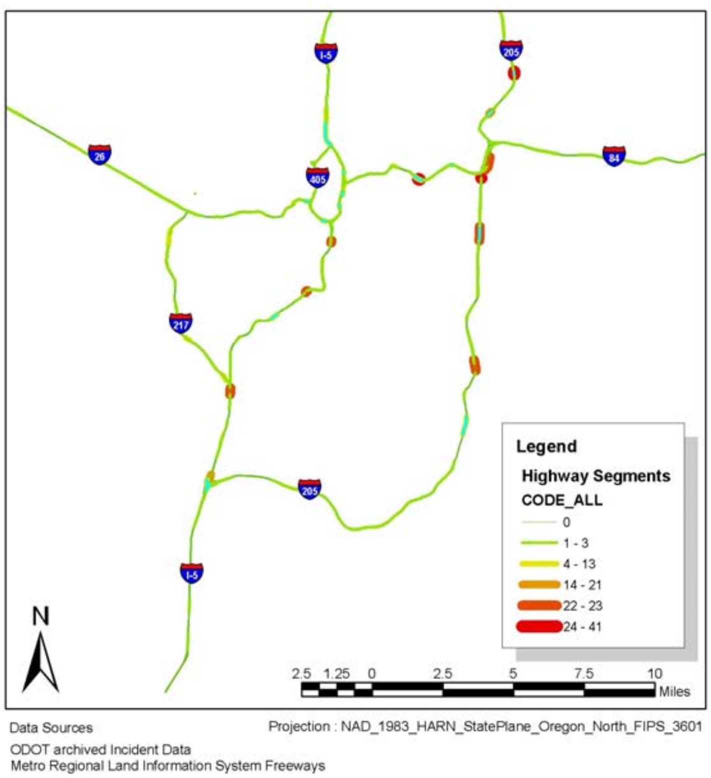
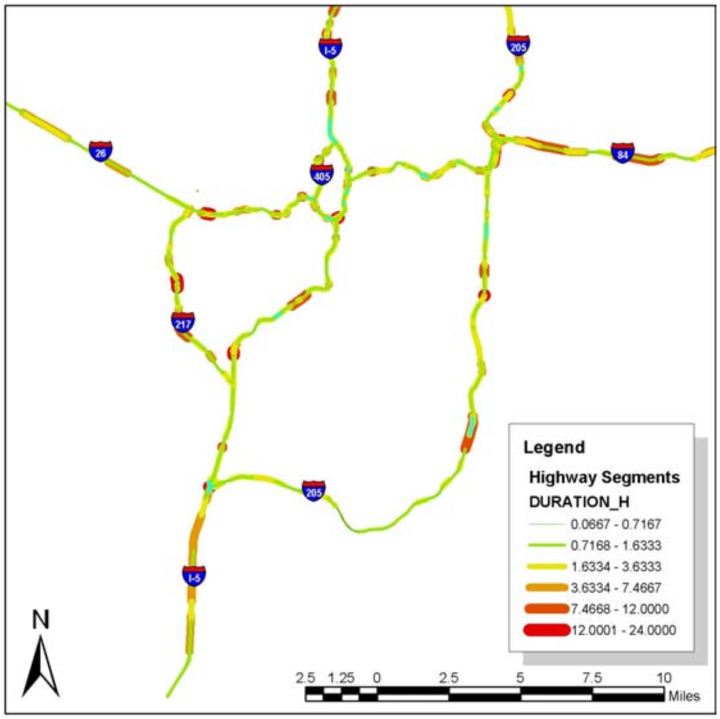


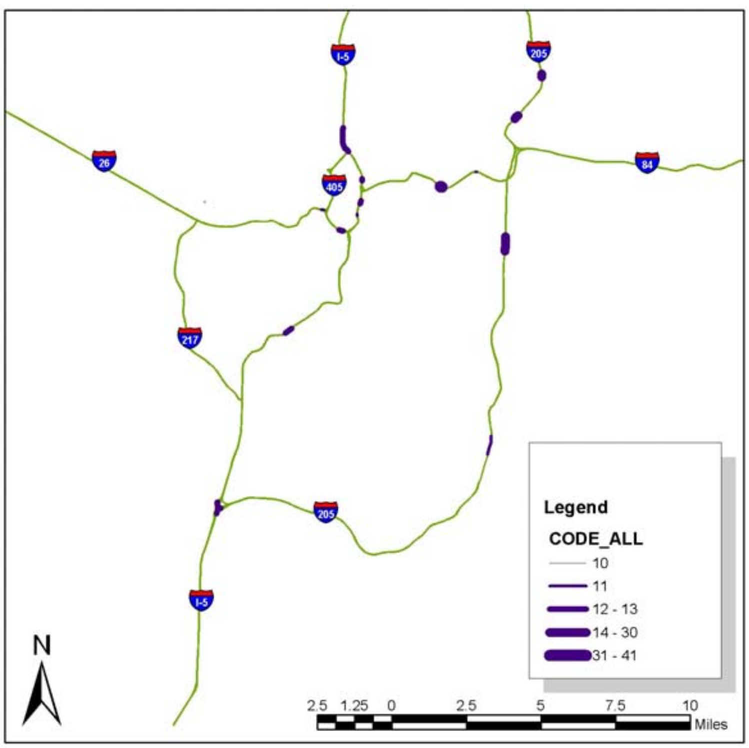
Figure 8 High Severity Index Segments



Data Sources
ODOT archived Incident Data
Metro Regional Land Information System Freeways

Projection : NAD_1983_HARN_StatePlane_Oregon_North_FIPS_3601

Figure 9 High Duration Segments



Data Sources
ODOT archived Incident Data
Metro Regional Land Information System Freeways

Projection : NAD_1983_HARN_StatePlane_Oregon_North_FIPS_3601

Figure 10 High Severity and Duration Segments

The highlighted locations are recommended to be monitored by the incident response (COMET) vehicles more frequently during their operating periods. Further research is ongoing where different incident response scenarios are being investigated.

8. CONCLUSION

The presentation of incidents as event points on transportation features led to the definition of high incident severity and duration highway segments. These segments should be highlighted as high priority locations for the incident response program in Portland, Oregon. The 3D visualization and the raster modeling were not sufficient for this application yet they are a good way to explore the data before starting detailed analysis. The use of GIS-T and ITS data has shown that if the transportation data is archived properly, GIS can be a useful tool. Without archiving the data in a better format and applying the incident data model, it would be difficult to develop this kind of analysis. Future research is needed to apply findings of the study on assigning the COMET incident response vehicles to different routes during the day time according to the findings and the time of day where the incidents occur. Due to the complexity of incident dynamics, a decision support system can be developed based upon this model. This will help in finding the best routes for the incident response vehicles on the highways. In addition it can use more archived data. The more archived data we have the more accurate the study can be. Further research is recommended to try to link incident occurrence to the road characteristics such as road structure, alignment, guidance system and so on.

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