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DISCRETE EVENT SIMULATION EXPERIMENTS AND GEOGRAPHIC INFORMATION SYSTEMS IN CONGESTION MANAGEMENT PLANNING

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ABSTRACT

A regional transportation system and the movement of large traffic volumes through it, are characteristic of stochastic systems. The standard traffic management or transportation planning approach uses a *slice in time* view of the system. Static, mean values of system variables are used for the basis of incident-caused, congestion management decisions. By reason of the highly variable nature of transportation systems, discrete event simulation is used in the planning process. The simulation model is highly dependent on the spatial accuracy of real world coordinates of nodes and the lengths of the roadway network links. Link travel times, queue spill back and turn lane queue size are directly related to the magnitude of incident-caused congestion, and the roadway system's ability to recover from it. The incorporation of accurate Geographic Information System (GIS) data with a powerful transportation simulation software package and properly designed data collection and analysis techniques are invaluable in support of transportation incident management decisions.

1 INTRODUCTION

Numerous traffic studies exist for large metropolitan regions that utilize simulation and include congestion analysis (Craig and Demetsky, 1995, Shepard, 1988 Southworth, 1995). These are the foundation for traffic incident and congestion management planning efforts for those areas. While such an incident management plan also exists for the Interstate 25 highway corridor through Pueblo, Colorado, the supporting studies do not.

The accuracy of a roadway network's spatial component is of critical importance to simulation-based transportation studies (Wiley, 1998). When modeling intersections (nodes) and road sections (links), vehicle travel times and potential queue sizes are directly dependent on accurate node locations and link lengths. A typical data source for road network or map data is the US Census Bureau's TIGER (Topologically Integrated Geo-referencing and Encoding Record) Line files. This data generally serves the purpose for which it is developed but node locations and link lengths are inaccurate. The spatial data accuracy is within ± 10 meters in some areas but is offset by over 200 meters for a roadway section only a block away (Wiley, 1996).

Conducting a study of congestion potential for the Pueblo area is simply a matter of prioritization and resource allocation. In determining the consequence of transportation modeling with variably inaccurate spatial data, prior studies have not been found. Conversely, the value of more accurate spatial data to a traffic model's reliability is unidentified.

Geographic Information System managers, analysts and technicians have dealt with this issue for decades. Data conversion issues involving data sources of differing levels of accuracy are well known in the GIS industry. Determining accuracy and reliability requirements of GIS data in support of planning and decision-making functions is a day-to-day activity. The justification of new data acquisition based on these requirements or making compromises at the level of quality of GIS products versus their timely delivery is part of the GIS profession.

By using GIS data and concentrating on the traffic incident-caused congestion problem, it is now possible to answer questions on the importance of accurate spatial data in transportation modeling. This effort supplements the Pueblo Area: I-25 Corridor, Incident Management Plan (IMP) (MK Centennial, 1996). Particular attention is paid to queuing and spill-back from incident-caused congestion and the impact on access to alternate routes. The incident severity-level criteria are improved by including consideration for variation in traffic flow-rate.

2 METHODOLOGY

With the extent of the general study area in mind, appropriate traffic modeling software is selected to accomplish the goals of the project. The subset of the transportation network to simulate is selected to take advantage of the model strengths. This is accomplished while testing a representative cross-section of characteristics of the local network and its traffic conditions. Consideration is given for the nature of spatial inaccuracies contained in the TIGER line data for the target area.

2.1 Traffic Model

INTEGRATION release 2.00r is the mesoscopic traffic model used to simulate a portion of the Pueblo roadway transportation system. The software tracks individual vehicles and their movement. This level of granularity, along with the discrete yet dynamic traffic assignment components of the model, give the model its microscopic traffic modeling characteristics. At the same time, the model produces accurate traffic speed-flow relationships consistent with macroscopic traffic flow theory. The realms of application are typically differentiated with microscopic models serving signalized roadway links and macroscopic models used in freeway or transit corridor modeling (Van Aerde, 1995, Wunderlich, 1996).

The package is similar to general discrete simulation software in that entities or vehicles are generated randomly and routes are dynamically assigned. The generated entity inter-arrival rate is limited to using an exponential distribution. While this is most typical, actual data does not always fit this distribution over another, such as Weibull or gamma. These were found to be more typical under the relatively moderate traffic flow-rates of the Pueblo area.

Baseline simulations are run using existing traffic count, turn movement and volume data. Lane blockage levels by type of incident are based on the IMP incident definition criteria.

Model calibration is based on Federal Highway Administration (FHWA) standards for allowable deviation from observed traffic volume by link. Demand load, by origin-destination (O-D) pair, is adjusted during model calibration to achieve link volumes and turn movement volumes approaching observed levels. For the volume group (> 25,000 vehicles/day), the FHWA standard requires deviation to be less than 22%, (Pueblo Department of Transportation, 1994). Calibration of the model is terminated at a deviation of < 17%. While meeting FHWA standards, insufficient O-D demand data and traffic volume data prohibit further improvement of the calibrated deviation level.

2.2 Study Area

The area selected for simulation and analysis is described as the northern portion of the I-25 corridor in Pueblo, CO, as seen in Figure 1, Pueblo IMP Study Sub-Area. The northern extent is near the north city limit line, running in a north-south direction. The other major features are the crossing intersection of US Hwy 50/Colo. St. Hwy 47 in the northern part of the area, 29th St. in the south and the parallel arterial, Elizabeth St. to the west.

Special characteristics of the area include the roadway sections with the highest average annual daily traffic (AADT) (CDOT, 1996) and the most complex, six-way intersection in the city.

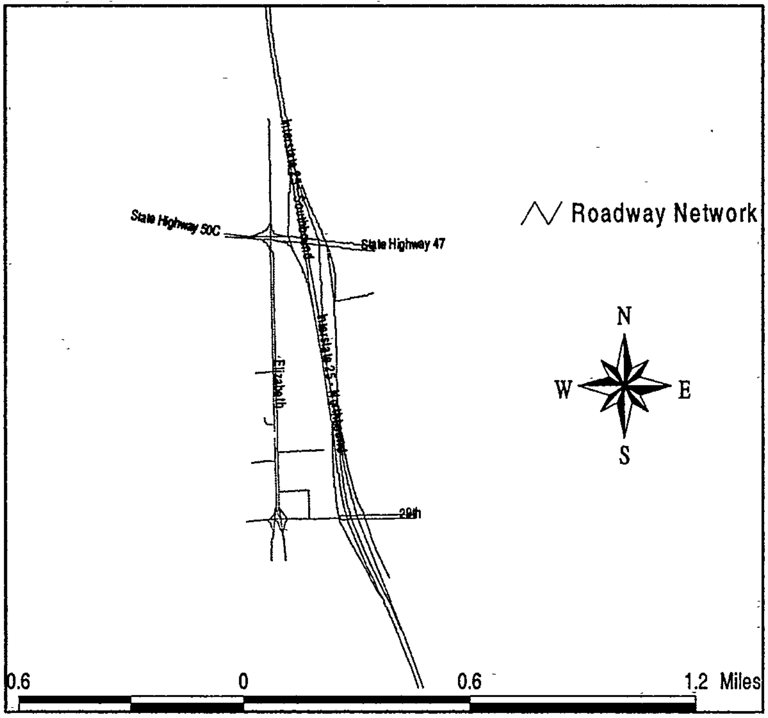


Figure 1: Pueblo IMP Study Sub-Area

2.3 Data

2.3.1 Spatial Data

Data supplied by Pueblo County's GIS Program is converted and processed as the primary roadway network structure. The data is based on aerial photogrammetry, obtained during October 1991. The data capture is spatially controlled using Global Positioning System (GPS) based, North American Digital Datum (NADD) 1983, State Plane, Colorado South Zone coordinates. The GIS road data are maintained as ± 1-1.5 meter and ± 2.5-3 meter relative accuracy landbases, in units of State Plane feet. The GIS engine/database used is ARC/Info®. The x and y coordinates of nodes and the lengths of links are converted from feet to meters for simulation. Both node and link index numbering (record ids) are systematically converted to conform to allowed number ranges of the modeling software.

The TIGER line data is extracted from the Pueblo County TIGER line file (1995 version), for the project sub-area. This data is originally in a Geographic coordinate system in longitude-latitude decimal degree units.

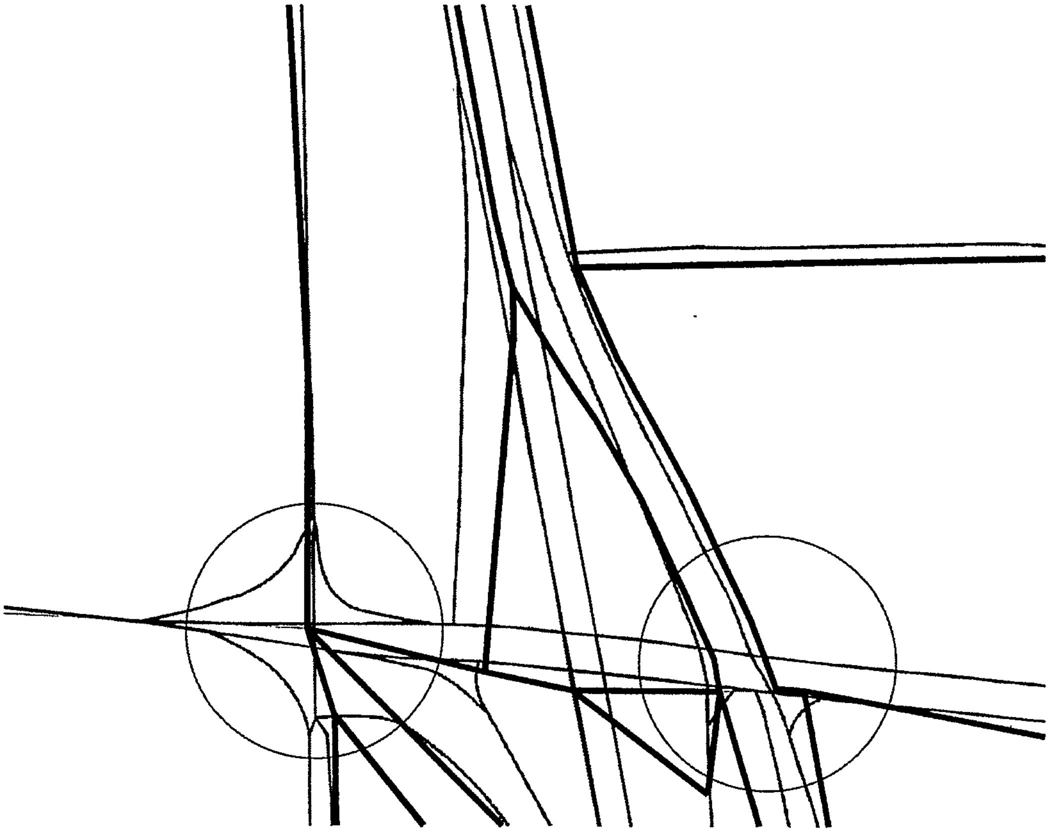


Figure 2: Pueblo Area TIGER Data Distortion

For the analyzed highway links, lengths from the corresponding TIGER links are converted and substituted during simulation. The TIGER line network is too severely distorted to be used directly. This is shown below in Figure 2, Pueblo Area TIGER Data Distortion. The heavy black lines represent TIGER lines in contrast to the lighter, road-symbol-formatted GIS road data. The interstate intersections with US Hwy 50/Colo St Hwy 47 are particularly confusing (circled).

2.3.2 Traffic Data

Traffic counts for the interstate are conducted continually by the Colorado Department of Transportation. These counts are compiled on an hourly basis, 24 hours per day. Data for 1996 is available (CDOT, 1996). The City of Pueblo collects turn-movement counts approximately twice yearly on major intersections (Centa, 1996). For the study area, the most recent sampling is during September, 1997 through December, 1997, (Pueblo Department of Transportation, 1997a, 1997b). The counter's collection periods are only active during the assumed peak traffic volume periods. These are the anticipated morning (AM), noon, and evening (PM) rush-hours (approximately 8:00am-9:00am, 12:00n-1:00pm, and 5:00pm-6:00pm). The time-periods are not consistent between daily samplings.

Limited O-D data is available (Pueblo Department of Transportation, 1995). For all primary origin points in the study sub-area, total demand load is derived from the existing count data during the calibration process.

Signal timing plans for the five signal groups are supplied by the City of Pueblo (Pueblo Department of Transportation, 1997c).

3 RESULTS

The first four southbound links on the interstate are the focus of analysis. The links numbered 1, 13, 47, 165, from north to south have detailed statistics captured during simulation. Incidents are simulated as occurring on link 165 and a secondary incident occurs on link 13.

3.1 Congestion Variations and Measures of Performance

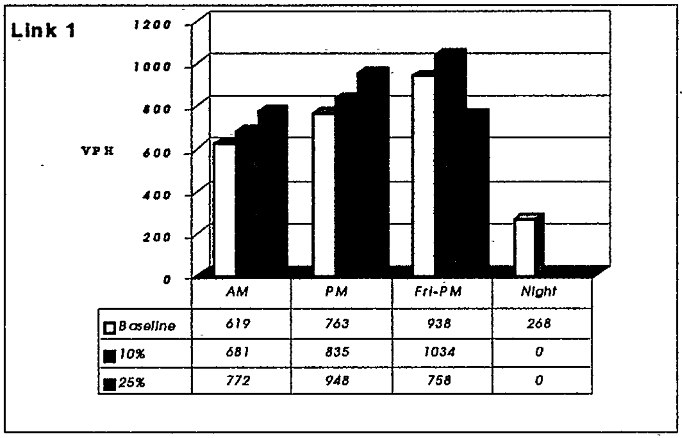
As O-D demand load is increased, congestion increases as expected. Traffic flow-rate, the standard measure of performance, (MOP) in vehicles-per-hour (vph), indicates congestion occurring only at the highest demand scenario, as shown in Figure 3, Congestion Effects on Traffic Flow-Rate. As demand is increased by scenario, (from left to right in the graphic), traffic flow-rate also increases. Traffic flow-rate is reduced at the O-D demand load simulated for the Friday-PM + 25% scenario.

In contrast, the newly derived MOPs, Queued Vehicle Ratio and Free-Flow Travel Time Proportion, reveal that congestion exists during four of the nine main scenarios. All demand levels of the Friday-PM scenarios, as well as during the PM+25% scenario reflect noticeable congestion. (see Figure 4, Queued Vehicle Ratio and Free-Flow Travel Time Proportion).

3.2 Link Length Impacts on Congestion

Links 13 and 47 are approximately 60 % short in their TIGER representations versus the accurate GIS data. Link 165 is approximately 25 % longer.

As link length varies, MOPs vary inconsistently. Travel time related MOPs vary directly with link length. For a TIGER link that is shorter than its GIS representation, fuel consumption, travel time and link travel cost are shorter, with the opposite being true for longer links. Queued Vehicle Ratio initially appears to indicate that shorter GIS links have larger queues. However, the same situation occurs for the longer TIGER link, 165. (see Figure 5, Link Length Variation: Queued Vehicle Ratio, below).



	AM	PM	Fri-PM	Night
☐ Baseline	619	763	938	268
■ 10%	681	835	1034	0
■ 25%	772	948	758	0

Figure 3: Congestion Effects on Traffic Flow-Rate

3.3 Incident-Caused Congestion Impacts

Incident location has greater overall congestion impact than does incident type, for the analyzed links. Figure 6, Two-Lane, South Incident Location vs. One Lane Middle Incident Location, reflects greater upstream congestion. A shift of the incident location, upstream, by approximately 200 meters, causes greater queuing on links more than 1000 meters upstream.

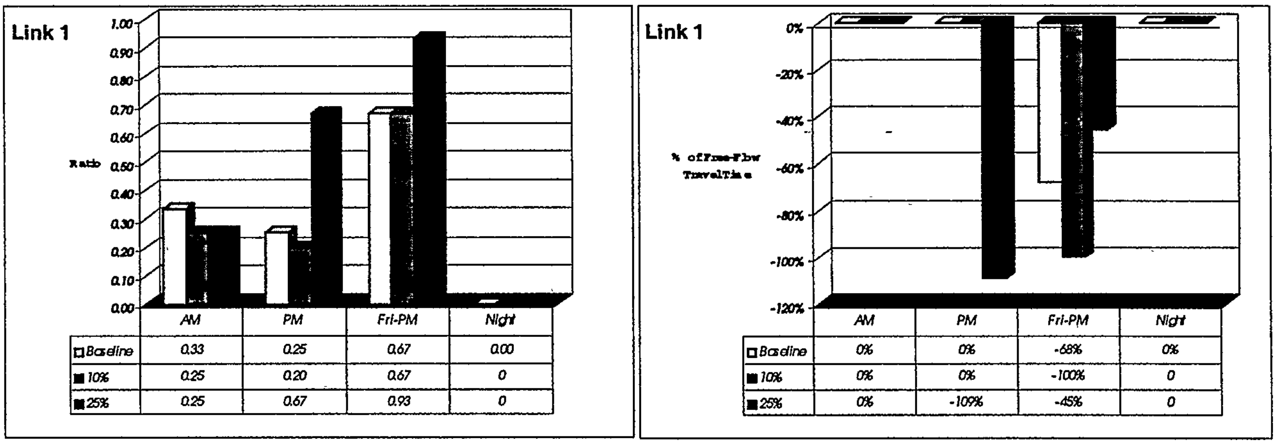


Figure 4: Queued Vehicle Ratio and Free-Flow Travel Time Proportion

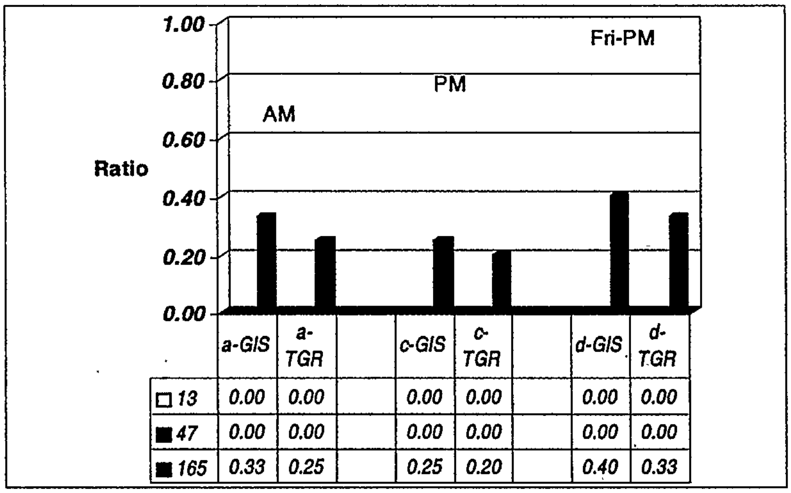


Figure 5: Link Length Variation: Queued Vehicle Ratio

The reduced queuing on links 47 and 165 (right chart) is due to reduced traffic flow-rate resulting from upstream congestion.

4 CONCLUSIONS AND SUMMARY

The unique roadway configuration and traffic conditions contribute to the nature of the simulation and analysis results. Similar circumstances in other metropolitan regions may produce different results.

4.1 Congestion Impacts

Weaving sections exhibit the most congestion impact in the shortest time following incidents. Inherent congestion problems in weaving sections compound incident-caused congestion, as traffic flow-rate increases. This congestion is greater than that occurring on downstream links that are closer to the incident.

Incident location causes greater impact than does incident type. Queuing and spill-back affect upstream links sooner and to a greater degree for a one lane incident located in the middle of link 165 than does a two lane blockage at the southern end.

The highest severity level definitions should include one-lane-closed incidents during the PM and Friday-PM peak demand periods. Minor incidents, located in weaving sections, can also be classified at a higher severity level.

On a per incident basis, travel delay costs are projected to be 44% greater than estimated in the IMP. This is considered to be a low estimate given that simulated congestion reached the limits of the project sub-area and total congestion impact is not measured.

4.2 Measures of Performance

The standard measure of performance, (MOP) of traffic flow-rate (vph) is not sensitive enough to consistently identify the occurrence of congestion. Average speed, link travel cost and fuel consumption are impacted more readily as queuing begins to develop. As link lengths vary with inaccurate spatial data, These MOPs produce inconsistent results or are directly affected by link length differences.

Newly derived MOPs based on this work provide overall system performance metrics more clearly. These are the ratio of queuing vehicles to total vehicles on the link and the simulated travel time as a percentage of free-flow travel time. These are only useful for evaluating unsignalized links, however, they are more sensitive and consistently indicate relative congestion where traffic flow-rate does not. They are not impacted by link length variations as are direct travel time dependent MOP's.

4.3 Future Research

Simulation experiments must be expanded to include detailed monitoring and analysis of alternate routes and the urban network. The impacts of the rerouted traffic from the interstate on the urban network are unknown but are expected to be significant (Centa, 1996).

Simulated queues spill-back and impact upstream links in under 5 minutes. This congestion blocks two upstream alternate route accesses. Furthermore, emergency managers estimate that it takes a minimum of 14 minutes to respond (MK Centennial, 1996). By the time responders are on the scene, their primary resources for rerouting traffic, the two closest alternate routes, are already blocked.

Simulation must be conducted with more comprehensive data. Existing data is insufficient for clearly identifying probability distribution parameters of vehicle inter-arrival rates. Data collection programs must be improved and expanded. Data collection periods should be standardized for collection times and periods of data collection. Daily variation in traffic flow-rates are not currently known, however, existing data indicates up to 100 % variability between Monday and Friday traffic flow-rates. Data collection periods at intersections are not sampling entire 24-hour periods. The traffic volumes and flow-rate variability outside the peak periods are currently just estimates.

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