

Quick-Response Bypass Forecasting for Small Urban Communities Using an Economic Gravity Model for External Trip Analysis

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The Iowa Department of Transportation routinely assesses the potential traffic impact of highway bypasses on small cities in the State. For a given city, this labor-intensive process may take from one-to-three person months to complete. With the implementation of Iowa's Commercial and Industrial Network, bypass analyses are becoming more frequent, and are now required for six-to-eight cities per year, placing a strain on limited planning staff resources. This paper describes a GIS-based modeling approach which can streamline and automate the process, thereby reducing resource requirements or increasing the number of studies that can be completed within a given time. The automated process also serves to promote consistency across projects. This paper also validates the new approach by comparing manual-based estimates of impact to those predicted by the new methodology. Key words: bypass planning, traffic forecasting, GIS.

INTRODUCTION

The National Highway Cooperative Research Program (NCHRP) defines a highway bypass as an existing roadway that previously passed through town which is realigned through rural land outside the city limits, see Figure 1 (1). The Iowa DOT five year transportation improvement program includes 34 bypass locations and ten more are under consideration (2). The bypass planning technique currently employed by planning staff includes a somewhat subjective and labor intensive spreadsheet-based assessment of historical traffic trends sometimes based on 30 year old origin-destination studies. The studies result in hand-generated traffic flow maps and associated tables and reports. As each bypass plan may require one to three (or more) person-months to complete, staff resources are becoming strained.

To assist the Iowa DOT in meeting the needs of an increasing number of bypass studies, the Center for Transportation Research at Iowa State University has developed a geographic information system (GIS) based methodology for bypass analysis. The methodology uses datasets maintained by various government organizations and other commercially available sources. The GIS-based methodology provides a series of interactive steps that develop a "quick-response" travel demand model which forecasts traffic volumes and turning movement counts. The methodology reduces the subjectivity associated with the existing process by employing a

conventional urban-modeling approach to determine travel patterns in a matter of days. This paper describes and tests the methodology in a case study of one Iowa community where a highway bypass plan was recently completed. The results of the case study demonstrate the GIS-based methodology can provide similar traffic assignments in a fraction of the time.

MODEL DEVELOPMENT

There are six steps involved in the GIS-based quick response model development methodology. They follow the similar structure used to develop travel models using traditional strategies. The steps include: data collection, defining model structure, digitizing the attributed network, calculating productions and attractions, validation of the base model and developing alternative bypass scenarios, and forecasting future traffic volumes. These steps are demonstrated in the following section.

Step 1: Data Collection

The initial step required for model development involves collecting appropriate datasets. The ability to store, query, manipulate and perform calculations on the datasets in a GIS environment affords several time-saving and quality control advantages. For the

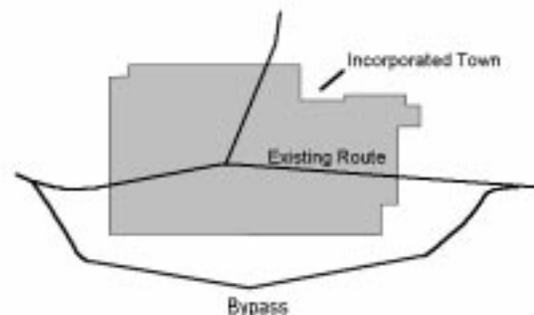


FIGURE 1 Typical bypass configuration.



FIGURE 2 Roadway data for an Iowa community.

current study, all data sets were incorporated into the MapInfo GIS program (MapInfo Corp., Troy, NY).

Street Data

Roadway network data are available from a number of sources:

- TIGER street files
- local government agencies
- State DOT
- other commercially available sources.

TIGER street files include street names and address ranges for roadway segments. This information can be used to geocode address specific data. Iowa DOT street and highway maps contain geometric and operational data for all roadways for the state (speed limits, roadway volumes, and available lanes). An example Iowa DOT map is shown in Figure 2.

Socio-Economic Data

Socio-economic data to support travel modeling are available from several sources:

- employment data from state agencies monitoring workforce statistics
- census data
- white pages databases available at most software outlets.

Employment data from government agencies are typically considered private and are protected from dissemination, at least in their most disaggregate form, by law. Many public planning agencies can obtain permission to use these data, however, provided they do not disclose the identity and characteristics of individual employers. Data containing business addresses, number of employees and business function (through the use of a industrial codes) can easily be geocoded and used to calculate zonal attractions. Census data, available at block and block-group levels, include population, household occupancy and income levels. "White-pages" data generally contain addresses for all households and businesses in the study area which can be geocoded in the same manner as the

employment data and aggregated to a traffic analysis zone level. An example of a popular package geocoded to the TIGER street network is shown in Figure 3 (circles indicate businesses and stars represent households).

Step 2: Define Model Structure

After collecting roadway and socio-economic data, the next step involves defining the travel demand model network through the establishment of traffic analysis zones and travel model streets. This process requires personal judgment and experience to define the appropriate model structure and selecting the location, number, size and shape of the traffic analysis zones will not be addressed in this paper. Census block-groups can provide a suitable structure for zones in some of the larger communities, however, for most smaller communities, block-groups will be too aggregated to be effective zones. In these areas, using high volume roadways as zonal edges represents another alternative. The user should develop a new GIS table for the zones with columns for zone number and all the variables required to perform the trip generation calculations.

After developing the GIS table structure, the user needs to digitize polygons to define the traffic analysis zones. Note that it is important to locate the zones and number the zones in the same fashion as the centroids (which will be placed later). An example table showing traffic analysis zones is provided as Figure 4.

While the traffic analysis zones are being defined, the user needs to select the major streets in the network included in the travel model. This information can be determined from traffic count maps or queried within the GIS if the data are available. As mentioned, the Iowa DOT roadway database is one potential dataset containing traffic volumes, which can be accessed through various query statements. It is recommended that the network roadways are selected



FIGURE 3 White pages software geocoded to the TIGER Network.

and stored as a new table or a sketch is made on a paper map to assist in digitizing the network.

Step 3: Digitizing the Attributed Network

Following the initial network definition, the next step digitizes the attributed link-node network. To automate this step, a MapBasic program was written that “walks” the user through a series of steps and enters default data values (note that any values entered can be manually changed by the user). For agencies without MapInfo, the network can be digitized within the GIS of choice attributing the node and link tables with the appropriate information. This requires digitizing points at all centroid and intersection locations and lines for each roadway in the model with the attribute information following the travel model structure.

Step 4: Calculate Productions and Attractions

With the zone table and socio-economic data stored in the GIS, the user can calculate zonal productions and attractions for the community. We begin by outlining two methods to perform the internal-internal calculation. First, if the user has census and employment data and has developed zones closely following block groups, then the user should follow the NCHRP 187 methodology to calculate production and attractions based on the given equations. Second, if the zones were not developed to follow the block-groups and either the census and employment data are not available, the user should begin by aggregating the number of households and businesses from the “white pages” software to the zonal level. These zonal totals can then be used to calculate the number of productions as the number of households multiplied by a factor representing total trips per household (9.2 trips per household is the national average) and calculate the attractions as a ratio of the zonal businesses to total businesses multiplied with total number of attractions.



FIGURE 4 Traffic analysis zones developed for Waverly, Iowa.

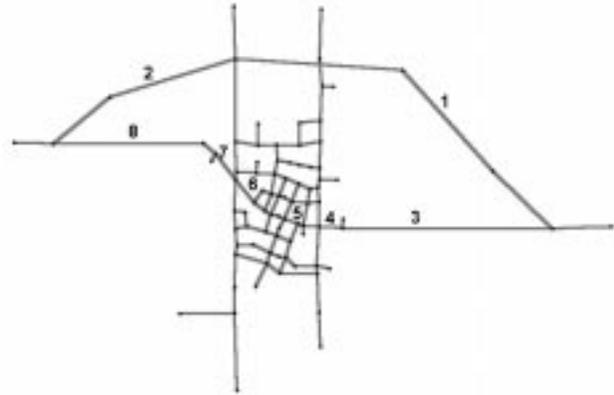


FIGURE 5 Location of Carroll traffic counts.

After the internal-internal calculation, the model requires external-external and external-internal data. The main requirement for the external trips is defining the percentages of vehicles which will stop in the study area versus the vehicles passing through to an ultimate destination. A novel methodology for determining the percentage of vehicles into or through town uses an economic gravity model of community attractiveness. The economic model defines the relationship between the attractiveness of the study community versus surrounding communities. This model is defined by the following equation (3):

$$PROB_{ax} = \frac{\left(\frac{POP_x}{D_{ax}}\right)}{\left(\sum \frac{POP_x}{D_{ax}}\right)}$$

where,

$PROB_{ax}$ = the probability that a customer located at a, which is D_{ax} miles from x, will patronize x,

POP_a = population of city a,

D_{xa} = distance from city a to city x.

The fundamental application of this model is based on the central place hierarchy stating that towns of comparable size should have similar business functions with larger towns possessing more amenities to compete for resident’s business. Incorporating this principle into the project requires examining the communities in surrounding the study area to identify towns matching the study area’s socio-economic characteristics. Entering probability that a customer from one town will patronize another into a spreadsheet program allows the user to develop the appropriate splits for external traffic.

Step 5: Validate Base Model and Develop New Scenarios

The initial model should be run through the travel demand software and the assigned volumes should validate the model using traffic counts. Some manipulation of network attributes might be required to improve validation. After validating the base model, the model should be altered to include the highway bypass and the travel model used to assign traffic. To assist the users, another

TABLE 1 Differences between DOT and GIS Methodologies for Carroll

Location	DOT volume	GIS-based volume	Difference
On northern bypass			
1 east bypass	2,900	2,846	-54
2 west bypass	2,100	2,500	400
On residual roadway			
3 east of Carroll to Monterey Drive	4,800	5,245	445
4 Monterey Drive to Grant Road	6,950	8,197	1,247
5 Grant Road to Main Street	10,800	9,021	-1,779
6 Main Street to US 71	11,100	12,682	1,582
7 US 71 to Burgess Avenue	5,700	5,645	-55
8 Burgess Avenue to west of Carroll	3,500	3,175	-325

MapBasic program was written to automate the development of new model scenarios.

Step 6: Forecast Future Traffic Volumes

The final step is to develop forecasts for future traffic in the area. To perform this step, traffic expansion factors normally used should be applied to the assigned volumes on the network links.

CASE STUDIES

The GIS-based bypass development methodology case study was performed for the community of Carroll, Iowa. Projected traffic volumes resulting from the GIS-based methodology were compared to the results of the existing forecasting method used by the Iowa DOT (4). Forecasted volumes for both the bypass and residual roadway were similar using the GIS-based methodology to the existing DOT procedure. The differences, which generally range from less than ten to twenty percent are outlined in Table 1 with Figure 5 showing the traffic count locations. These differences generally do not have serious implications for roadway design, but may have a limited effect on estimates of economic impact performed after the traffic study.

CONCLUSIONS

The proposed methodology for developing highway bypass plans within a geographic information system (GIS) environment seems

promising, as it provides consistent, reproducible results with fewer staff resources. Using the GIS-based modeling approach, bypass traffic forecasts were obtained in less than one week (the original forecasts took three months). As the new model and data are maintained in a GIS, analysis and display of data are greatly enhanced. In addition, an analyst using the methodology is able to quickly analyze traffic conditions for many different alignment and access scenarios.

ACKNOWLEDGMENTS

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