When is work zone ITS deployment worth it?

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Abstract

The objective of this research is to develop an evaluation methodology to test whether intelligent transportation systems (ITS) investment is a valid solution for work zone traffic mitigation. The methodology considers what performance is required of the proposed ITS deployment to balance the cost of the deployment. The evaluation process uses micro-simulation to analyze the network-wide effects caused by the construction work zone via defined relevant performance measures.

The network-wide performance is analyzed statistically and economically for varying diversion rates. The performance of diversion rates causing net benefits is compared to the cost of the proposed ITS deployment. The research completed provides an evaluation tool for transportation planners to determine when ITS deployment is beneficial and when other traffic mitigation strategies should be considered.

A case study is evaluated to test the proposed micro-simulation evaluation methodology. The case study is the Glenmore Trail/Elbow Drive/5th Street S.W. interchange project in the City of Calgary. The analysis indicates that the City of Calgary requires an ITS-induced diversion rate of the PM peak hour traffic volume of between approximately 1.5% and 13.5% to offset the costs of ITS deployment. This required effectiveness is within the range of diversion that has been achieved by other similar ITS deployments throughout the world. More research is required to be able to determine how to encourage a particular rate of diversion to ensure that potential network disbenefits are avoided due to overreaction to the provided ITS roadway information.

Introduction

The use of Intelligent Transportation Systems (ITS) in construction work zones is intended to disseminate information to the travelling public about roadway conditions. If routes exist to bypass the construction area, the provided information may be intended to divert traffic to routes that are relatively unaffected by the construction activities. However, reaction to the provided information cannot be accurately predicted prior to ITS deployment.

Studies have been completed to evaluate the diversion rates for Variable Message Signs (VMS) using various methods of evaluation over a range of geographic locations. Table 1 summarizes the results from these studies and indicates that diversion rates for VMS deployments are extremely variable. Further compounding this issue is that transportation planners and professionals make decisions to deploy ITS based on forecasts/estimates for anticipated effectiveness. Fortunately, funding exists at the moment to deploy pilot projects in attempts to reduce the speculation regarding VMS and ITS effectiveness. Unfortunately, the amount of data is still limited.

The research documented here offers an alternative planning approach for proposed ITS deployments. A micro-simulation-based planning approach is presented and tested to determine what diversion rate is required of work zone ITS deployments to warrant their use. This approach changes the planning strategy – instead of attempting to predict what diversion rate will occur, the required diversion rate is found and evaluated to determine if this diversion rate can be attained. The approach takes into account the local and area-wide effects that diversion from a specific route can cause by measuring total travel time and several environmental measures.

Approach and Methodology

Many methodologies exist to analyze ITS deployments from aggregate analysis of traffic flows using spreadsheets to more sophisticated modelling. After comparing various methodologies to evaluate planned ITS deployments, a micro-simulation-based performance measurement and planning approach was selected. Of the various forms of modelling (macro-, meso-, and micro-scopic) and aggregate flow analysis, micro-simulation is the only method that accounts for traffic interactions at the individual level. Individually modelled vehicles allow for the simulation of "real-world" decisions that individuals may make based on ITS-provided information. In addition, the numerous route choices available to drivers in an urban environment are easily incorporated in micro-simulation models. The more established micro-simulators have the capacity to model large networks with little to no constraints on number of links, nodes, or vehicles. Summed concisely by Oketch and Carrick, the key advantage of micro-simulation models is "their ability to model relatively large networks to sufficient detail to enable operational outputs at the link or intersection level while correctly accounting for area wide impacts of localized activities."(6)

The evaluation of ITS deployments requires the definition of performance measures. Table 2 summarizes the results of a literature review to provide a "toolbox" of relevant ITS performance measures.(7) Unfortunately, micro-simulation cannot be used to assess all the performance measures identified in Table 2. Safety and customer satisfaction cannot be measured with simulation. Incidents can be incorporated in some simulations to test the network effects of a collision or incident, however, the severity and frequency of incidents cannot be stochastically evaluated through simulation. As with safety, customer satisfaction for ITS deployments cannot be evaluated in micro-simulation. Safety and customer satisfaction have to be evaluated with separate tools and are not included in this research.

The micro-simulation-based methodology is used to complete the following steps in order to evaluate an ITS deployment. The research completed here uses a work zone as the case study and basis for evaluating the methodology. The proposed methodology builds on work completed by Chu et al (8) but extends it to include a completely urban environment. More importantly, the change in planning philosophy proposed by this research is through model 3.

1. Model the existing conditions prior to any change to the roadway network to calibrate the model routing and behaviour parameters.
2. Model the geometric, traffic signal timing, and all other non-ITS changes to the roadway network associated with the roadway construction project using the calibrated vehicle behaviour and routing from model 1.
3. Model the VMS effectiveness by varying the potential diversion rates that are directly related to the ITS deployment based on the simulated network in model 2. The outputs are used to calculate the diversion scenario performance. The performance measures are monetized based on cost of time and emissions. The performance of the diversion scenarios is compared to the performance of model 2 to determine if benefits are attainable from diversion of traffic. If benefits are attainable, the monetized benefits are then compared to the ITS deployment costs to assess if ITS deployment will provide a social benefit and what range of diversion rates produce beneficial network performance.

Due to time constraints and lack of 24 hour data, the case study evaluation only considers the PM peak hour. More discussion on analysis time period for this research can be found in reference (7). It is believed that the results obtained from only analyzing the PM peak hour provides adequate evidence for testing the proposed micro-simulation methodology.

Review of Paramics

The micro-simulation software used in this research is Paramics. Paramics is a commercially available traffic micro-simulation software package. Paramics is governed by three primary algorithms: vehicle following, gap acceptance, and lane change. These algorithms are controlled by a combination of vehicle behaviour characteristics and vehicle dynamics. The vehicle behaviour characteristics are described by randomly allocated aggression and awareness parameters which control gap acceptance, top speed, headway, and the propensity to lane change. In addition, mean headway and minimum gap parameters also affect vehicle behaviour. The vehicle dynamics component is a combination of behaviour characteristics (minimum gap, mean headway) and vehicle limitations based on a vehicles' physical type and kinematics (size, acceleration and deceleration). The three algorithms are applied simultaneously at the individual level.

Assignment in Paramics is user-defined as all-or-nothing, stochastic, or dynamic. Paramics recalculates assignment for the next two turns every time a vehicle enters a link (except for all-or-nothing assignment). Route choice is based on selecting the route with the minimum value for the generalized cost function (GCF). The GCF is outlined below and considers travel time, travel distance, and tolls.

$$GCF = aT + bD + cP, \text{ where}$$

a = time coefficient	T = travel time in minutes
b = distance coefficient	D = length of link in miles
c = toll cost coefficient	P = price of toll in monetary cost units

In addition, Paramics, via its *Matrix Estimator* component, can be used to estimate origin-destination (O/D) matrices. The matrix estimator is further discussed below.

Table 3 summarizes the data requirements for Paramics. From the table, the output data clearly satisfies most of the performance measure classes defined in Table 2 – accessibility, mobility, operating efficiency, quality of life, and environmental. In addition, the outputs can be included in the economic measures class. The only measures not evaluated by Paramics are safety and customer satisfaction.

Case Study Description

The selected case study used to test the micro-simulation evaluation methodology had to exhibit three characteristics – urban environment, available diversion routes, and intended ITS deployment. The selected case study is the Glenmore Trail/Elbow Drive/5th Street S.W. (GE5) interchange project in Calgary, Alberta. The project consists of the construction of two interchanges as well as roadway widening along the major east/west arterial, Glenmore Trail. Also, the Glenmore Causeway over the Glenmore Reservoir will be reconstructed. To accomplish this project, a four-stage detour plan has been implemented (pre-stage 1, stage 1, stage 2, stage 3). The staging of the project allows for complete transfer of Glenmore Trail traffic to a newly constructed detour road while allowing the widening and interchange construction activities to occur. For the research completed, only the stage 1 detour scenario is evaluated.

At present, City of Calgary traffic data indicates Glenmore Trail carries approximately 78,000 AADT near Elbow Drive and 120,000 AADT over the Glenmore Causeway. Due to the high traffic volumes, the traffic mitigation objectives were to reduce the impacts of the construction on the traveling public.(9, 10) These objectives are consistent with the ITS objectives of Transport Canada used in formulating the relevant ITS performance measures summarized in Table 2 (see reference 7 for detailed discussion). The traffic mitigation strategy includes:

- The construction of a staged detour road slightly north of Glenmore Trail;
- ITS application deployment including video monitoring of the area, VMS for information dissemination, and internet-based ATIS; and,
- Traffic signal timing optimizations.(9, 10)

The case study area is illustrated in Figure 1. The construction activities occur in the boxed area. The network defined for analysis in the case study encompasses an area bounded by 58th Avenue, Heritage Drive, the Bow River, and Crowchild Trail. Figure 2 illustrates the constructed stage 1 detour alignment to be incorporated in the "after construction" models.

Model Development

Existing Conditions Model

The existing conditions model represents the roadway network, and associated road and traffic data, prior to the commencement of the GE5 construction project representing a geographic area of approximately 6.3 km by 3.2 km. The existing conditions model has a total of 51 zones, 725 nodes, and 1671 one-way links. The modelled network is illustrated in Figure 3. Within the study area, links have posted speed limits ranging from 30 kph to 80 kph. Of the 176 coded intersections, there are 44 signalized intersections. The defined network illustrated in Figure 3 is generally the same as that defined for the after construction models, with minor modifications discussed in the subsequent sections. This existing conditions model is used to calibrate the vehicle behaviour and routing as defined in the model.

Calibration and Validation

Micro-simulation Calibration Overview

In practice, calibration and validation is an iterative process. Initially, calibration assigns values to certain parameters under controlled conditions such that traffic theory and local design criteria can be replicated (e.g. saturation flow). Once these parameters are assigned values, validation compares the results of the model to observed traffic data (volumes, speed, travel time, etc.). Should the modelled characteristics vary from the observed characteristics, more calibration is required. The calibration and validation procedure consists of three primary elements.

1. Debugging the model for any coding errors such as traffic signal timings, number of lanes, and speed.
2. Adjusting the O/D demand matrix to better replicate the volumes observed by turning movement count surveys.
3. Refining the default global and local model parameters to improve the consistency between modelled characteristics and observed characteristics including traffic volumes, travel times, and travel speeds.

For calibration, there must be a defined convergence criterion (or criteria) that signifies when a process or method adequately represents the system that it is intended to define. The GEH statistic is the goodness of fit criterion used in this research. The use of the GEH statistic "stems from the inability of either the absolute difference or relative difference statistics to cope with flows over a wide range" of values.(13) The GEH statistic, mathematically summarized below, is a modified Chi-squared statistic that incorporates both relative and absolute differences to compare modelled and observed characteristics. The form of the GEH statistic allows for greater absolute differences for low volumes while requiring lower relative differences for large volumes.

$$GEH = \sqrt{\frac{2(E-V)^2}{(E+V)}}\text{, where}$$

E = model estimated characteristic
V = observed characteristic

The outcomes of the GEH statistic can be grouped for defining goodness of fit. Scottish Transport Appraisal Guidance (STAG) defines acceptable fit to have a GEH ≤ 5 for 85% or more of all cases.(13) For the research documented here, this criterion was slightly relaxed as was done in other studies due to the size of the modelled network.(6, 14) The goodness of fit criteria used in this research for traffic flows is summarized in Table 4.

Calibration Results

Calibration of the existing conditions model was completed by a trial-and-error procedure. The calibration procedure commenced by calibrating saturation flow to the City of Calgary design value of 1850 veh/hr. This was accomplished by adjusting the aggression, mean headway, awareness, and minimum gap. Next, any remaining debugging was addressed, though further debugging arose when calibrating routing parameters. Following debugging, the demands provided by the City of Calgary from the EMME/2 regional transportation model were calibrated using the Paramics feature *Matrix Estimator* (ME). The ME adjusts a given prior matrix based on traffic movement counts and a routing file from a full run of the coded network. The ME procedure uses a matrix refinement algorithm similar to that used in the SATURN traffic modelling package known as matrix estimation from maximum entropy.(15) Finally, parameters controlling routing and behaviour were adjusted to replicate observed traffic counts. The iterative process started by adjusting all parameters listed below without an asterisk individually and in combination. When the calibration of these parameters was optimized, the parameters with asterisks were adjusted to fine-tune the model.

- Feedback coefficient (0.25, 0.5, 0.75)
- Route cost coefficients (time 0.5, 1.0, 2.0, 3.0)
- Link restriction (varies upon location)
- Link headway factor (0.5, 1.0)
- Mean headway* (1.0, 2.0 sec.)
- Aggression* (amp. x1, x2, x3, x4)
- Perturbation algorithm* (square root, percentage)
- Feedback period (1, 5 min.)
- Minor road cost factor (1.0, 1.2, 1.5, 1.7, 2.0)
- Release rate (varies upon location)
- Link cost factor (1.0, 2.0, 3.0)
- Minimum gap* (1.0, 1.7, 2.0 m)
- Awareness* (amp. x1, x2, x3, x4)
- Random seed* (500, 509, 490, 709, 973, 78, 244)

After hundreds of calibration/validation iterations, the existing conditions model met the goodness of fit criterion defined in Table 4. Figure 4 illustrates the GEH statistic for all movements and important movements (defined as intersections between selected major arterials). When all movements are considered, 87% have a GEH ≤ 10 while 61% exhibit a GEH ≤ 5. Reviewing the important intersections, 87% of these movements have a GEH ≤ 10, with 57% having a GEH ≤ 5. Figure 5 further illustrates the percent difference between observed volumes and modelled volumes for the important intersections while also illustrating how the GEH statistic varies with traffic volume.

After Network Without ITS

The after network without ITS represents all changes to the network due to the construction except for the deployed ITS applications. Five major intersections had signal timing revisions: Elbow Drive and Glenmore Trail, Macleod Trail and Glenmore Trail, 58th Avenue S.W. and Elbow Drive, 61st Avenue S.W. and Centre Street, and 60th Avenue and Macleod Trail. The speed limit along Glenmore Trail was reduced from 70 and 80 kph to 50 kph from the Glenmore Causeway to approximately Centre Street. In addition, the roadway alignment of Glenmore Trail from 14th Street S.W. to the Macleod Trail on- and off-ramps was changed from the pre-construction alignment, including the Elbow Drive and 5th Street S.W. intersections with Glenmore Trail. Also, the number of lanes was changed within the affected construction area. The after construction model without ITS is illustrated in Figure 6.

The simulation of this network uses the calibrated behaviour and routing algorithms from the existing conditions model. In addition, the after construction model without ITS is run for each random seed (490, 500, 509, 709, 973) used in calibration plus additional random seeds to increase the number of observations for each test scenario. The output statistics for total network travel time and emissions is averaged over all runs and is used as the baseline performance for the construction network.

After Network With ITS

The construction network after ITS deployment builds off the construction model without ITS. The same alignment, signal timings, number of lanes, behaviour/routing parameters, and random seeds are used. The only difference is the addition of ITS Controllers in the model network. The ITS Controllers change the behaviour of the simulated vehicles by instructing the affected vehicles to make a defined response. Figure 7 illustrates the location of the ITS Controllers. The ITS Controllers located at the extreme west and east sides of Glenmore Trail represent the VMS deployed at these locations by the City of Calgary. Total travel time and emissions output statistics are collected for the after construction with ITS models for each diversion scenario tested.

The after construction with ITS model uses the ITS Controllers to change the behaviour of selected vehicles passing the ITS Controller. For example, vehicles travelling eastbound along Glenmore Trail pass the first ITS Controller west of 14th Street S.W. This ITS Controller instructs vehicles with destination zones as illustrated in Figure 8 that Glenmore Trail has major congestion (by defining the travelling speed as 0 kph) and that they should reroute along 14th Street S.W. The proportion of vehicles heeding the message on the VMS is controlled by the researcher and is set to the diversion scenario being tested.

Continuing on for the diversion of eastbound Glenmore Trail traffic, the diverted traffic passes the north ITS Controller along 14th Street S.W. This ITS Controller instructs all vehicles with destination zones south and east of 75th Avenue that travel along eastbound 75th Avenue S.W. is congested and that they should continue to Heritage Drive. This was done because it was assumed that diverted traffic would use Heritage Drive and not the residential 75th Avenue.

Next, the diverted eastbound Glenmore Trail traffic passes the south ITS Controller along 14th Street S.W. This ITS Controller instructs vehicles with destination zones east of Elbow Drive that travel along Elbow Drive is congested and to continue on to Macleod Trail. This was done because the researcher wanted to ensure that the diverted traffic would not reenter Glenmore Trail until after the construction zone, which is to the east of Macleod Trail. Likewise, similar routing was done for westbound traffic along Glenmore Trail prior to Blackfoot Trail. Figure 8 and Figure 9 illustrate the destination zones used for ITS controlled eastbound and westbound diversion, respectively.

From Figure 8 and Figure 9, the selection of the traffic that would elect to divert routes was completed on an ad hoc basis. It was assumed that traffic would not divert if destined to zones with relatively direct access to Glenmore Trail. When testing a certain diversion percentage, the percentage is only pertaining to the trips destined to the defined diversion destination zones and not the total percentage of trips using Glenmore Trail. Therefore, the revised definition of the diversion rate is the rate of diversion from Glenmore Trail for those vehicles with alternative routes.

Unfortunately, inclusion of ITS Controllers in Paramics is not as straight-forward as initially hoped. To include ITS Controllers in Paramics, visual basic programming must be done using the Paramics simple network management protocol (SNMP) agent via the Active-X plug-in called *PController*. In the visual basic code, the process described above had to be defined for each diversion rate tested. For the research completed, diversion rates were tested as summarized in Table 5. The high percentage diversion scenarios were run to test the potential impacts of overreaction to the ITS provided information. The low diversion rates are defined as such because past research has shown these diversion rates are attainable (see Table 1).

Model Results and Analysis

Results and Statistical Analysis

The model output statistics for total travel time, carbon monoxide, carbon dioxide, total hydrocarbons, oxides of nitrogen, and particulate matter were produced by the Paramics model for each scenario tested. Due to the project timing, only total travel time was evaluated statistically and included in this paper. The mean total travel time for each scenario is summarized in Table 6.

The statistical analysis used two nonparametric statistical tests. Nonparametric statistics were selected to analyze the outputs because: (i) normality is not a required assumption of the data, and (ii) fewer than 30 samples for each scenario were run. The nonparametric statistics were completed to test the null hypothesis that the total travel time means between scenarios are equal.

The first statistical test completed was a Kruskal-Wallis test with a null hypothesis that all scenario total travel time means are equal. From Table 7, since the significance is less than 0.05, the null hypothesis is rejected indicating that the total travel times for at least two scenarios are not equal at the 95% confidence level. However, Kruskal-Wallis does not define which scenarios are not equal.

To determine which scenarios exhibit statistically different travel times, Mann-Whitney tests were completed comparing each pair of scenarios. The results are summarized in Table 8 and indicate whether each scenario is significantly different from every other scenario. The results from Table 8 can be further summarized to allow for grouping of scenarios into homogeneous sets. The grouped table states for which groups of scenarios the null hypothesis cannot be rejected. At the 90% confidence level, six homogeneous sets can be defined as is presented in Table 9. It should be noted that the statistical analysis did not incorporate increases in Type I error that occur when completing multiple Mann-Whitney or student t-tests.

From Table 9, the construction work zone negatively affects the overall network and is statistically different from all other scenarios. The after network with no ITS and 10%, 15%, and 20% diversion are statistically the same. Another group includes 5% and 10% diversion. Finally, the high diversion rates can be considered as three groups: 40%, 60% and 80%, and 100% diversion. The total travel times pertaining to each group are averaged (see final row of Table 9) and used in the economic analysis.

Benefits are calculated by comparing the total travel time of the diversion scenarios to the total travel time for the network without ITS (0% diversion). Benefits caused via diversion occur nominally from diversion rates of 5% and 10%. The statistical analysis provides evidence that the mean total travel time for 5% diversion and 10% diversion are the same – the averaged total travel time from these two scenarios is used in the economic analysis. For diversion rates of 10%, 15%, and 20%, the overall performance of the network is statistically equivalent to the case with no ITS deployed. Interestingly, the overall network performance is worse than the no ITS case for all diversion rates greater than 20%. This suggests that overreaction to the ITS-provided information can cause network disbenefits and that the diversion range exhibiting potential benefits is quite narrow.

Economic Analysis

The subset groups defined through the statistical analysis (Table 9) are used in the economic analysis. The economic analysis compares the monetary benefits of the ITS diversion scenarios exhibiting network-wide benefits to the cost of the ITS deployment. There are a number of parameter values that must be defined in order to complete an economic evaluation. As the cost and benefit streams occur over a period of three years, the future costs and benefits must be discounted using a present value approach. The analysis completed here is a cost benefit analysis including all ITS deployment costs (agency, maintenance, etc.) and the societal benefit of total travel time savings. The method neglect other intangible costs/benefits including reductions in driver frustration. Various parameters required to complete the economic evaluation are defined below based on a literature review of relevant practices and research.(17- 22) In addition, effort was made to incorporate values used by the City of Calgary for economic evaluation in this research to ensure consistency with potential analysis already completed by the City of Calgary.

- Discount rate of 5% is used with sensitivity analysis completed at 3% and 10%.
- Assumed life cycle cost of the ITS deployment to be $650,000 (2006 CDN dollars).
- Assumed project time period starting in January 2006 and ending in December 2008.
- The average aggregate value of time is $17.25/hr for peak hour periods (2004 CDN dollars).

Because only one detour scenario was analyzed, the economic evaluation assumes that the overall network performance of the stage 1 detour is also representative of the performance for all other detour stages. Because only the PM peak hour was modelled, the results are solely based on the network performance during this hour which has been shown to exhibit the greatest hourly proportion of the daily delay.(7) In addition, it was assumed that there were five weekdays per week over 52 weeks in a year for a total of 260 PM peak hours per year.

Table 10 summarizes the present value cost for the total travel time for each scenario subset. Converting these costs into relative costs/benefits by subtracting the "No ITS" total travel time cost from each scenario (see Table 11), only the 5% and 10% diversion subset produce a net societal benefit. For all other diversion scenarios, the diversion imposes a societal cost. Therefore, the diversion rate required to offset the costs of the ITS deployment must occur within a general range of +/- 5% to 10%. Also, due to the short analysis time period of three years, the variations in benefits/costs due to the discount rate are relatively negligible (less than 10% difference).

Figure 10 illustrates the ITS-based societal benefits as compared to the ITS deployment costs. The diversion scenarios depicted in Figure 10 were defined as the average diversion rate for each diversion subset. For subset 2, the monetary performance is plotted at 0% diversion and at 15% diversion (the average of 10%, 15%, and 20%). Likewise, subset 3's monetary performance is plotted at 7.5% diversion.

From Figure 10, the diversion rate attributed to the ITS deployment must be between a range of +/- 1.5% to +/- 13.5% in order for the ITS-related diversion benefits to offset the ITS deployment costs. For any other diversion rate, the ITS-related diversion benefits do not offset the cost of the ITS deployment. Comparing these results to those stated in Table 1, the required performance of the ITS deployment for the GE5 project is within the range of diversion performance exhibited by other documented deployments around the world.

Conclusions

The research and case study indicates that the proposed micro-simulation-based evaluation methodology is applicable for evaluating proposed work zone ITS deployments. This research suggests that the methodology is time and data intensive, however, the results allow for improved planning to determine the required diversion effectiveness of work zone ITS deployments to offset the ITS deployment costs. The research completed provides an evaluation tool for transportation planners to determine when ITS deployment is beneficial and when other traffic mitigation strategies should be considered.

In regards to the evaluated case study, the analysis indicates that the City of Calgary requires an ITS-induced diversion rate for the PM peak hour of between approximately 1.5% and 13.5% to offset the costs of ITS deployment. Based on a review of diversion effectiveness from other ITS deployments, the required diversion range is attainable. Interestingly, diversion of greater than 20% was found to be a disbenefit for the overall network. More research is required to be able to determine how to encourage a particular range of diversion rates ensuring that potential network disbenefits can be avoided from overreaction to the provided ITS information.

Continuing Efforts

The continuing research will focus on completing more model runs to increase the sample size of the diversion scenarios to increase the strength of the statistical arguments. In addition, emissions performance will be included in the final statistical and economic evaluation of the diversion scenarios.

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Tables

Table 1: Documented effectiveness of VMS strategies

Location of Study	Method of Evaluation	Results
Milwaukee, United States	Revealed preference survey	66% of respondents diverted at least once per month.(1)
Omaha, United States	Network monitoring	No significant diversion. Believed to be attributed to low traffic volumes during evaluation.(2)
Glasgow, Scotland	Revealed preference survey	40% of respondents changed routes as recommended.(3)
Forth Estuary, Scotland	Revealed preference survey	16% diversion when message indicates problems on route.(4)
Birmingham, England	Network monitoring	27-40% diversion when collision and route instruction included, 2-5% without route instructions.(4)
London, England	Stated preference survey / revealed preference survey	24% of drivers indicated they would divert. Revealed preference indicated only a 3% diversion.(4)
Europe	Network monitoring	Average diversion of 11%.(5)

Table 2: Relevant ITS performance measures (7)

	Performance Measure Classes							
Performance Measure	**Accessibility**	**Mobility**	**Operating Efficiency**	**Economic**	**Quality of Life**	**Customer Satisfaction**	**Environmental**	**Safety**
Vehicle-kilometres travelled (VKT)		x						
Total delay		x	x		x			
Incident rate by severity/type per VKT								x
Origin-destination travel time	x	x	x		x			
Tonnes of pollution					x		x	
Fuel consumption per VKT					x		x	
Customer satisfaction (from surveys)						x		
Average speed		x	x					
Speed variance		x	x					x
Travel costs (driver's time, VOC, etc.)				x				
Social costs (pollution, crashes, etc.)				x				

Table 3: Paramics data – inputs, calibration/validation, and outputs

Input Data	Calibration/Validation Data	Output Data
Traffic intersection counts	Route or link travel times	Travel time
Origin-destination matrices	Queue lengths	Travel delay
Vehicle types	Traffic volumes	Speed
Roadway alignment	Saturation Flow	Emissions
Traffic signal timing		Fuel consumption

Table 4: Goodness of fit criteria

GEH Range	Goodness of Fit Definition	Goodness of Fit Criteria
GEH ≤ 5	Flows are a good fit.	• 85% with GEH ≤ 10; and, • 50% with GEH ≤ 5.
5 < GEH ≤ 10	Flows are an acceptable fit.	
10 < GEH	Flows are a poor fit.	

Table 5: Diversion scenarios tested

Low Diversion Rates	High Diversion Rates
5 %	40 %
10 %	60 %
15 %	80 %
20 %	100 %

Table 6: Total travel time output

Scenario	Sample Size	Average Total Travel Time (sec)
Existing Conditions	10	21,401,152
No ITS (0% diversion)	11	26,315,733
5% Diversion	11	25,400,524
10% Diversion	11	25,935,839
15% Diversion	11	26,633,782
20% Diversion	11	26,497,089
40% Diversion	5	29,615,886
60% Diversion	5	32,19,2014
80% Diversion	5	33,367,832
100% Diversion	5	33,969,546

Table 7: Kruskal-Wallis results

Scenario	Sample Size	Mean Rank
Existing Conditions	10	5.70
No ITS (0% diversion)	11	39.45
5% Diversion	11	30.45
10% Diversion	11	36.55
15% Diversion	11	43.00
20% Diversion	11	41.91
40% Diversion	5	64.80
60% Diversion	5	74.80
80% Diversion	5	77.20
100% Diversion	5	81.80
Chi-Square	60.840	
Degrees of freedom	9	
Asymp. significance	0.000	

Table 8: Results for Mann-Whitney tests

Scenario I	Scenario J	Significance
Existing Conditions	No ITS	0.00
	5% Diversion	0.00
	15% Diversion	0.00
	10% Diversion	0.00
	20% Diversion	0.00
	40% Diversion	0.00
	60% Diversion	0.00
	80% Diversion	0.00
	100% Diversion	0.00
No ITS	Existing Conditions	0.00
	5% Diversion	0.07
	10% Diversion	0.53
	15% Diversion	0.41
	20% Diversion	0.53
	40% Diversion	0.00
	60% Diversion	0.00
	80% Diversion	0.00
	100% Diversion	0.00
5% Diversion	Existing Conditions	0.00
	No ITS	0.07
	10% Diversion	0.67
	15% Diversion	0.10
	20% Diversion	0.09
	40% Diversion	0.00
	60% Diversion	0.00
	80% Diversion	0.00
	100% Diversion	0.00
10% Diversion	Existing Conditions	0.00
	No ITS	0.53
	5% Diversion	0.67
	15% Diversion	0.77
	20% Diversion	0.38
	40% Diversion	0.02
	60% Diversion	0.00
	80% Diversion	0.00
	100% Diversion	0.00
15% Diversion	Existing Conditions	0.00
	No ITS	0.41
	5% Diversion	0.10
	10% Diversion	0.77
	20% Diversion	0.58
	40% Diversion	0.01
	60% Diversion	0.00
	80% Diversion	0.00
	100% Diversion	0.00
20% Diversion	Existing Conditions	0.00
	No ITS	0.53
	5% Diversion	0.09
	10% Diversion	0.38
	15% Diversion	0.58
	40% Diversion	0.01
	60% Diversion	0.00
	80% Diversion	0.00
	100% Diversion	0.00
40% Diversion	Existing Conditions	0.00
	No ITS	0.00
	5% Diversion	0.00
	10% Diversion	0.02
	15% Diversion	0.01
	20% Diversion	0.01
	60% Diversion	0.02
	80% Diversion	0.01
	100% Diversion	0.01
60% Diversion	Existing Conditions	0.00
	No ITS	0.00
	5% Diversion	0.00
	10% Diversion	0.00
	15% Diversion	0.00
	20% Diversion	0.00
	40% Diversion	0.02
	80% Diversion	0.35
	100% Diversion	0.03
80% Diversion	Existing Conditions	0.00
	No ITS	0.00
	5% Diversion	0.00
	10% Diversion	0.00
	15% Diversion	0.00
	20% Diversion	0.00
	40% Diversion	0.01
	60% Diversion	0.35
	100% Diversion	0.08
100% Diversion	Existing Conditions	0.00
	No ITS	0.00
	5% Diversion	0.00
	10% Diversion	0.00
	15% Diversion	0.00
	20% Diversion	0.00
	40% Diversion	0.01
	60% Diversion	0.03
	80% Diversion	0.08

Table 9: Homogeneous defined subsets at the 90% confidence level

Scenario	Subset 1	Subset 2	Subset 3	Subset 4	Subset 5	Subset 6
Existing Conditions	21,401,152					
No ITS		26,315,733				
15% Diversion		26,633,782				
20% Diversion		26,497,089				
10% Diversion		25,935,839	25,935,839			
5% Diversion			25,400,524			
40% Diversion				29,615,886		
60% Diversion					32,192,014	
80% Diversion					33,367,832	
100% Diversion						33,969,546
Average (sec)	21,400,152	26,345,611	25,668,182	29,615,886	32,779,923	33,969,546

Table 10: Total travel time costs (in $millions)

Diversion	i = 10%	i = 5%	i = 3%
0%, 10%, 15%, and 20%	$118.87	$108.32	$105.01
5% and 10%	$115.93	$105.59	$102.35
40%	$132.98	$121.46	$117.82
60% and 80%	$146.44	$134.08	$130.15
100%	$151.39	$138.78	$134.75

Table 11: Total travel time relative benefits/costs (in $millions)

Diversion	i = 10%	i = 5%	i = 3%
0%, 10%, 15%, and 20%	$0.00	$0.00	$0.00
5% and 10%	-$2.94	-$2.73	-$2.66
40%	$14.11	$13.14	$12.81
60% and 80%	$27.57	$25.76	$25.14
100%	$32.53	$30.46	$29.74

Figures

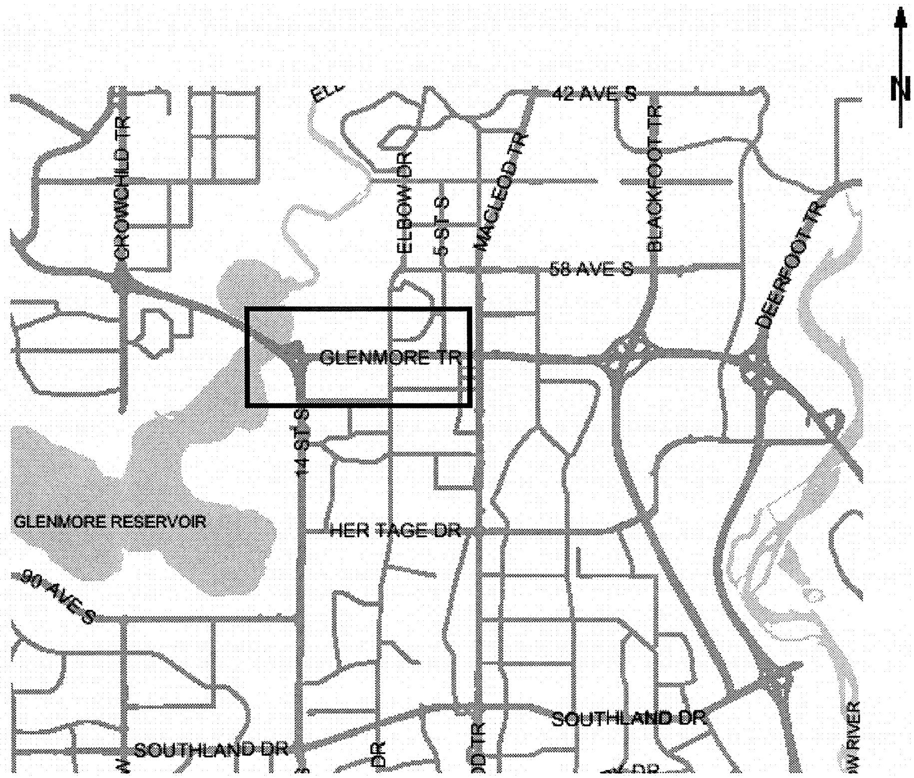

Figure 1: Location of GE5 project (11)

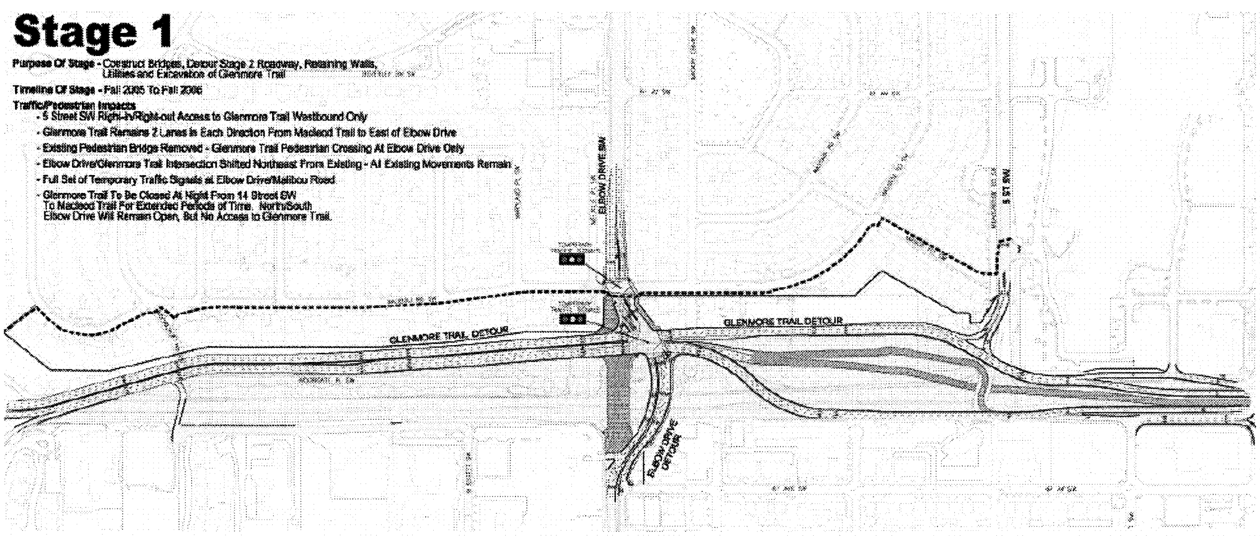

Figure 2: Stage 1 detour alignment (12)

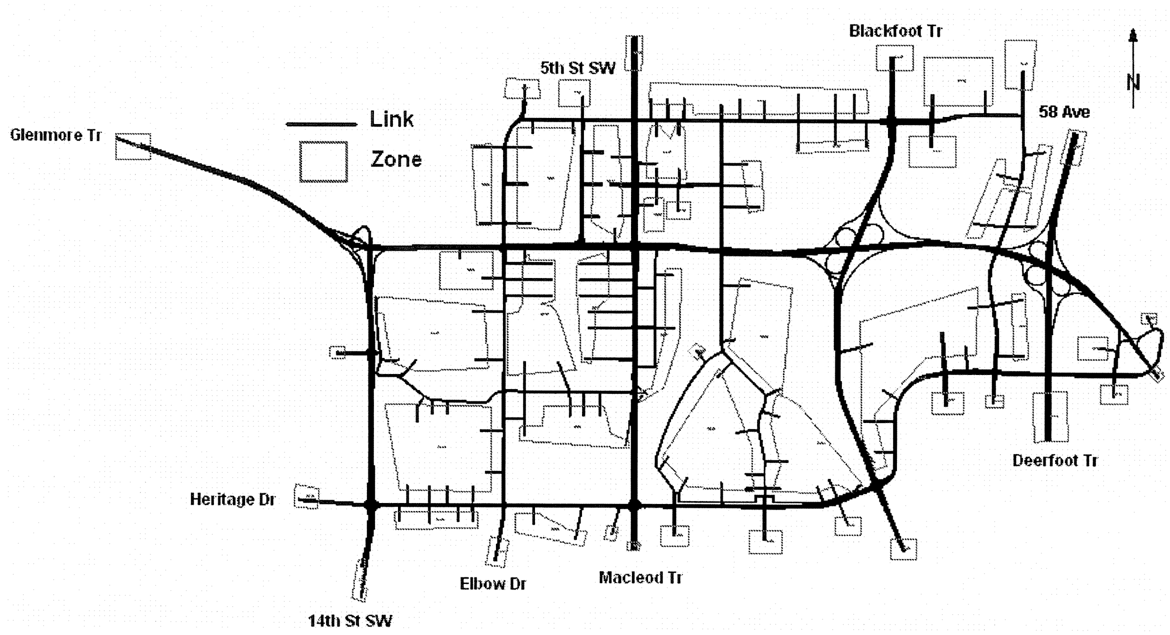

Figure 3: Existing conditions network

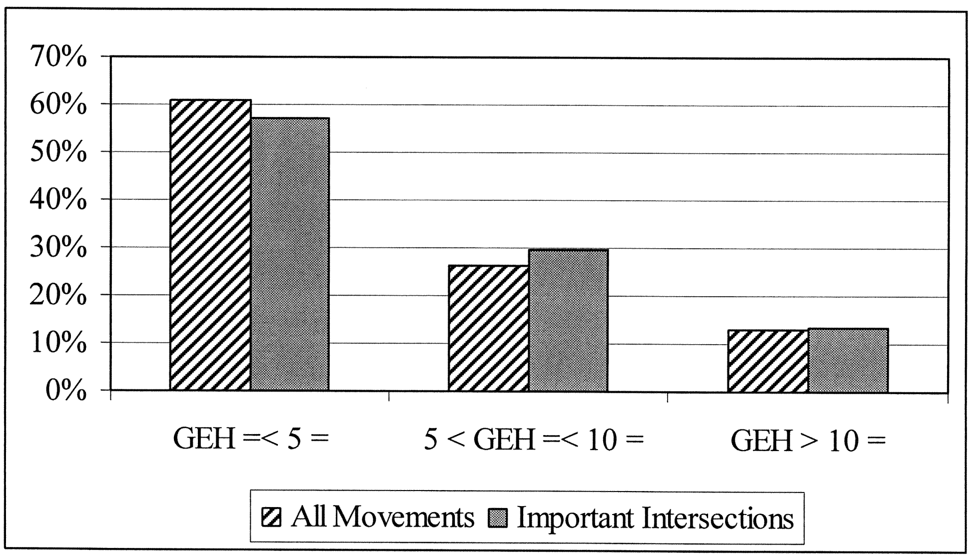

Figure 4: Goodness of fit for PM peak period

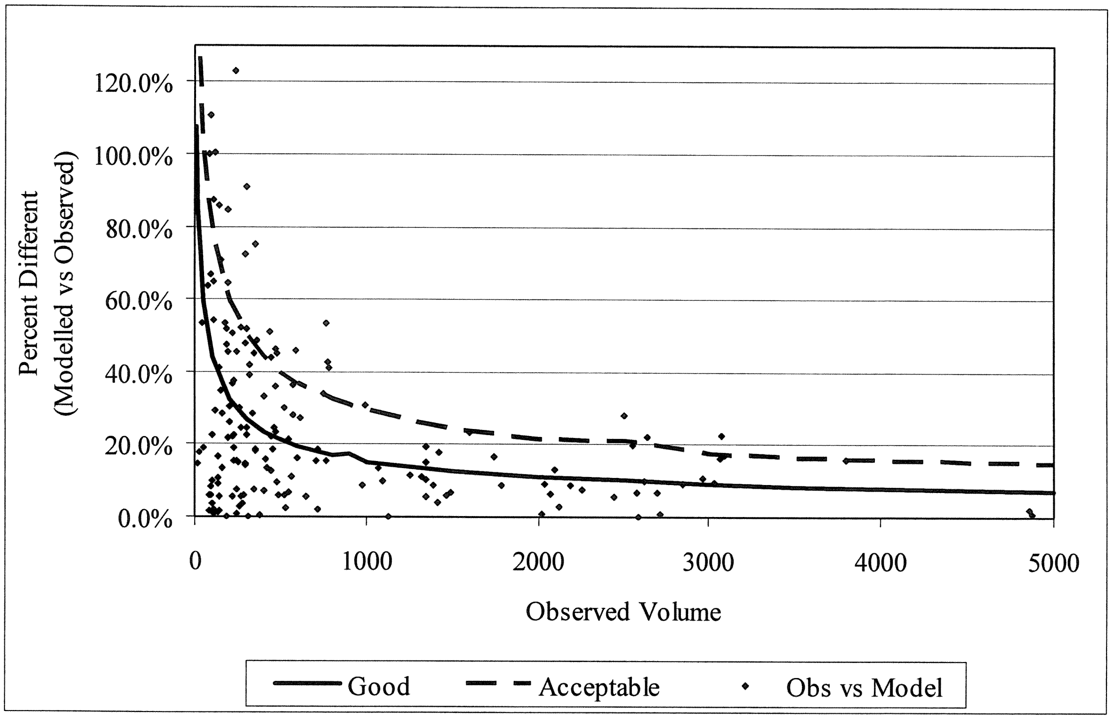

Figure 5: Goodness of fit for PM peak period – illustration of GEH

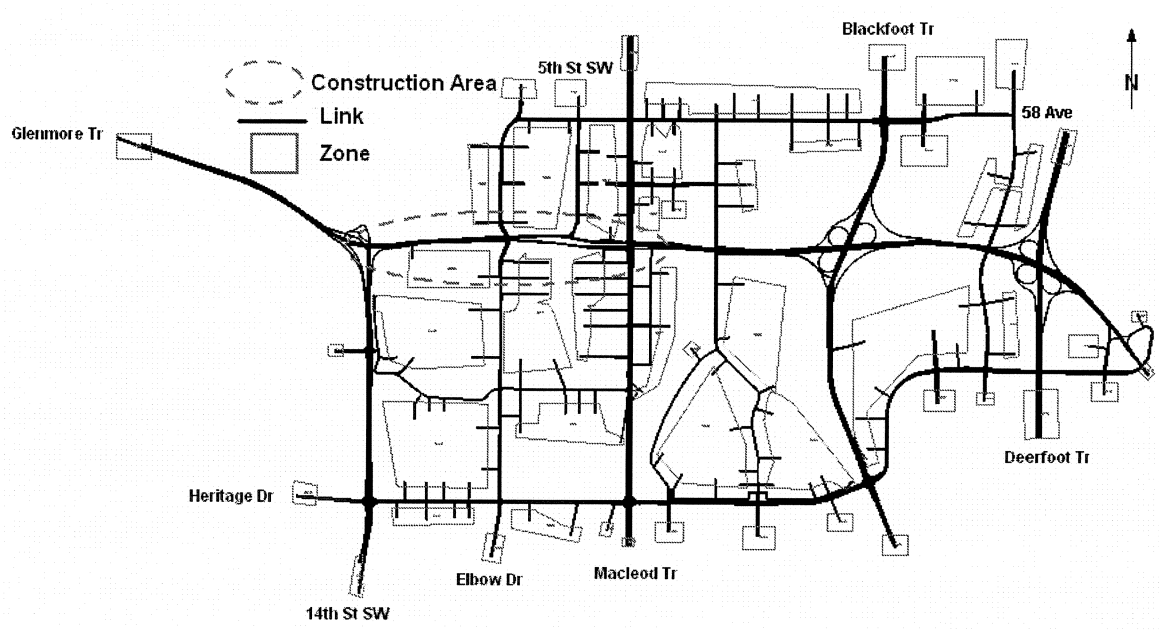

Figure 6: After model alignment without ITS deployment

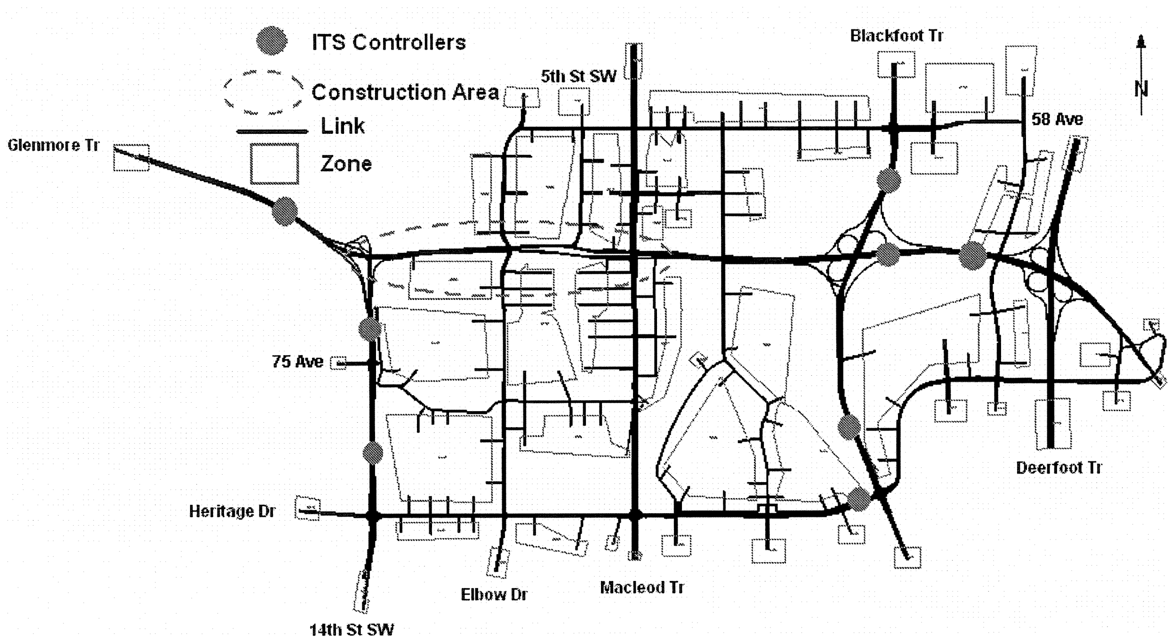

Figure 7: After model alignment with ITS deployment

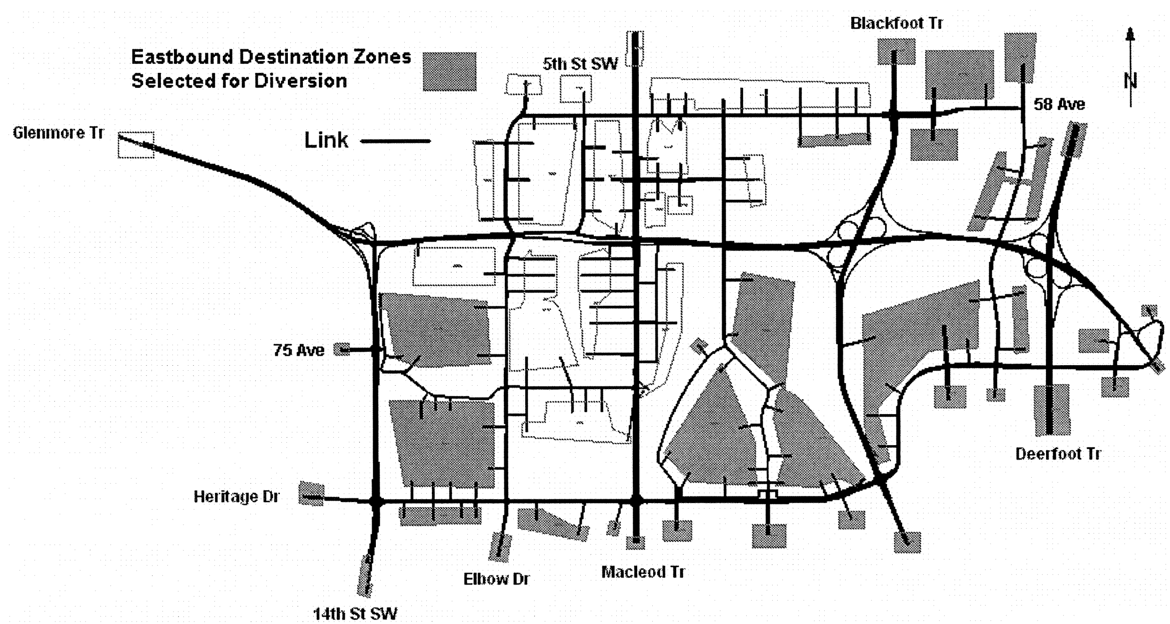

Figure 8: Eastbound traffic destination zones selected for diversion

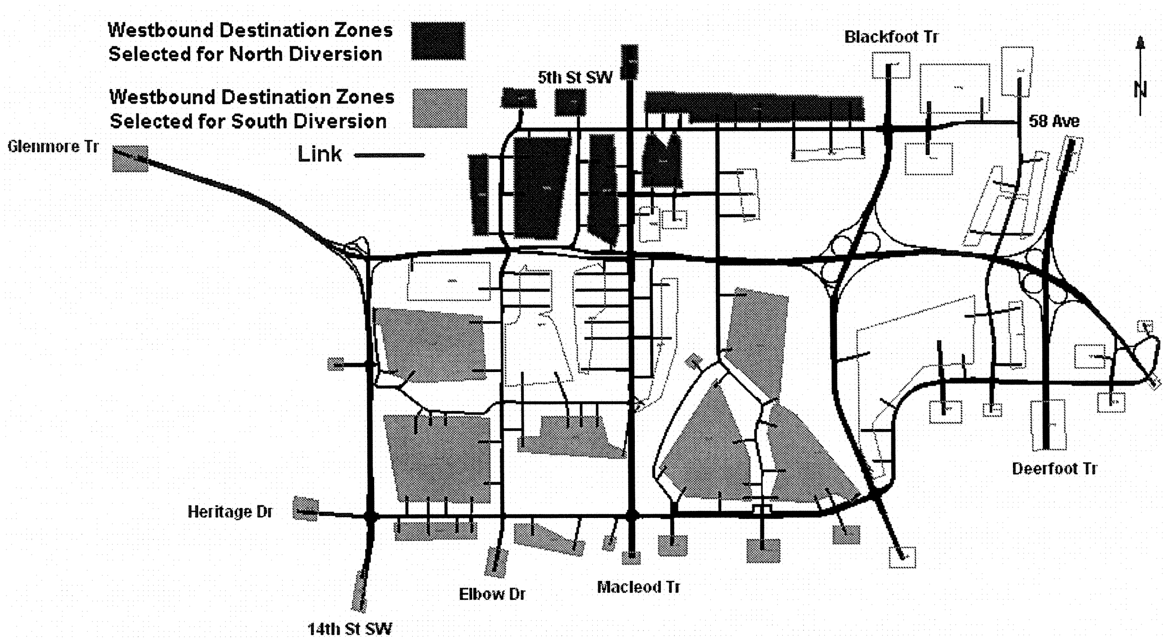

Figure 9: Westbound traffic destination zones selected for diversion

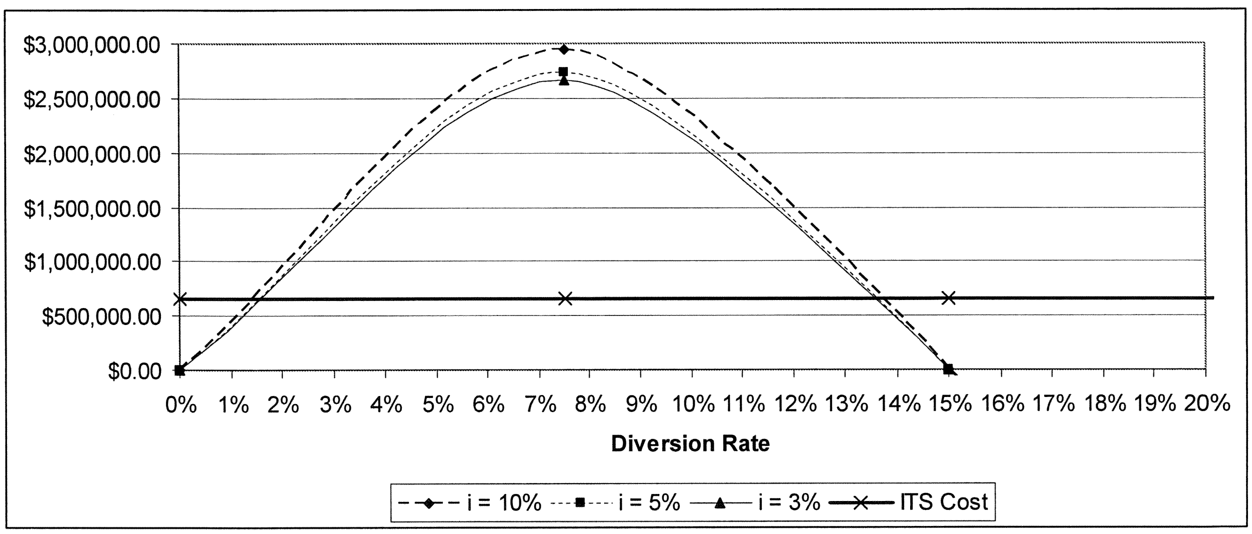

Figure 10: ITS related societal benefits versus ITS deployment costs