FINAL REPORT
to

THE FLORIDA DEPARTMENT OF TRANSPORTATION
ROADWAY DESIGN OFFICE

on Project

"Impact of Lane Closures on Roadway Capacity"

FDOT Contract BD-545, RPWO #61 (UF Project 00059056)

Part C: Modeling Diversion Propensity at Work Zones

January 31, 2008

Transportation Research Center
The University of Florida

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METRIC CONVERSION CHART

U.S. UNITS TO METRIC (SI) UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

METRIC (SI) UNITS TO U.S. UNITS

LENGTH

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

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16. Abstract

Chapter 10 of the FDOT Plans Preparation Manual titled “Work Zone Traffic Control” contains a lane closure analysis procedure, in which a "Remaining Traffic Factor" (RTF) is used to account for possible traffic diversion during a lane closure. However, no guidance has been offered on how to obtain the value of the RTF. The purposes of this study are twofold. First, diversion behaviors at work zones were modeled in a discrete choice modeling framework. We conducted a stated preference survey to collect data on drivers' diversion propensity and then calibrated a binary logit model. The model provides a better understanding of drivers’ diversion behaviors at work zones, and can be used to forecast diversion rates in a work zone traffic analysis. Second, we proposed two procedures, namely open-loop and closed-loop, to apply the calibrated binary logit model to compute the RTF. An Excel tool was developed to facilitate the computation.

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EXECUTIVE SUMMARY

Chapter 10 of the current FDOT Plans Preparation Manual titled "Work Zone Traffic Control" contains a lane closure analysis procedure that calculates the restricted capacity for roadway segments with a lane closure. The calculated capacity will then be compared with an estimate of hourly traffic demand to determine the time of day/night that the lane can be closed. To estimate the hourly traffic demand, the procedure applies a "Remaining Traffic Factor" (RTF) to the observed hourly traffic demand without the lane closure. The RTF accounts for possible traffic diversion during the lane closure. However, no guidance has been offered on how to obtain the value of the RTF in the manual.

The purposes of this study are twofold. First, diversion behaviors at work zones were modeled in a discrete choice modeling framework. A stated preference survey was carried out to obtain the data on drivers' diversion propensity from work zones. By calibrating a logit model with the data, we identified three major factors that influence drivers' diversion decisions, namely, travel time, work zone location and weather condition. For other factors, such as trip purpose and drivers' social economic characteristics, we found no evidence that they are important in drivers' decision making of diversion at work zones. The calibrated model provides us more insights on drivers' work zone diversion behaviors and may be used to forecast diversion rates or be incorporated into a work zone traffic analysis tool.

Second, we proposed two procedures, namely open-loop and closed-loop, to apply the calibrated binary logit model to estimate the RTF. The former directly applies the choice model without considering the feedback of remaining and diverted flows on travel times. It may be more appropriate to be used for a short-term work zone lane closure. The latter applies the notion of equilibrium to maintain the consistency between travel times and flows at different routes. Therefore, it may better replicate the situation at a long-term work zone. Based on the combinations of the weather condition and work zone location, four Fisk's stochastic user equilibrium models have been formulated, which can be solved by the Excel solver to compute the RTF. An Excel tool was developed to facilitate the computation.

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1 INTRODUCTION

Chapter 10 of the FDOT Plans Preparation Manual (PPM) titled “Work Zone Traffic Control” contains a lane closure analysis procedure (pp. 10-30 - 10-43) that calculates the restricted capacity for roadway segments with a lane closure. The calculated capacity will then be compared with an estimate of hourly traffic demand to determine the time of day/night that the lane can be closed. To estimate the hourly traffic demand, the procedure applies a “Remaining Traffic Factor” (RTF) to the observed hourly traffic demand without the lane closure. The RTF accounts for possible traffic diversion during the lane closure. However, no guidance is currently offered on how to obtain the value of the RTF in the PPM. In this study, we first model drivers’ diversion behaviors at work zones in a discrete choice modeling framework and calibrate a binary choice model for drivers’ diversion propensity from work zones. We then propose two procedures, namely open-loop and closed-loop, to apply the calibrated binary logit model to compute the RTF.

The remaining of this report is organized as follows. Section 2 reviews empirical diversion rates reported in the literature and existing approaches to modeling diversion behaviors at work zones. Section 3 describes a stated preference (SP) survey, including survey design and implementation and then discusses the subsequent data analysis and model calibration. Section 4 introduces two procedures of applying the calibrated model to compute the RTF. Concluding remarks are provided in the last section.

2 LITERATURE REVIEW

2.1 Empirical Diversion Rates

There are only a limited number of empirical diversion rates at work zones reported in the open literature. These field data show that natural diversion does occur and the diversion rate varies substantially under different circumstances.

In the rural areas, reported diversion rates are usually low, varying from 0% to 37.5%. Directly measuring diversion rates at work zones may be difficult. It is a general practice to use loop detectors to measure traffic volumes on the original and alternative routes or ramps before and after the work zone is placed, and then apply the volume data to compute the diversion rate. McCoy and Pesti (2001) evaluated the impacts of changeable message sign (CMS) at work zones on I-80 during a 49-day period in the summer of 1999. When the CMS was blank, the diversion rate was 8%. It increased to 11% when CMS was active. Horowitz et al. (2003) did a real-world experiment on a rural highway with a 12-mile work zone in Wisconsin. By setting up CMS along the highway displaying delays caused by the work zone, they observed that the diversion rate was around 10%. Bushman et al. (2004) conducted a study of a Smart Work Zone System deployment on I-95 in North Carolina and found that diversion rates were 10.9% and 20.2% in uncongested and congested situations respectively. Chu et al. (2005) did a similar experiment in California. The traffic information was collected and distributed to drivers via a Computerized Highway Information Processing System. Not surprisingly, the diversion rate varied a lot at different time of day. For the off ramp immediate before the work zone, diversion rate could reach as high as 37.5% in peak hours. They also indicated that the diversion rate pattern was consistent with the congestion level on the highway mainline. Lee and Kim (2006) did another experiment on I-15 in California. The procedures they used were similar to those of Chu et al. (2005). The diversion rate was found to be around 17 to 18% in the peak hours. A summary of actually-incurred diversion rates are given in Table 1.

For the urban areas, we did not find any empirical data on work zone diversion rates, perhaps due to the complexity of urban road networks. The method used to estimate diversion rates in rural areas is difficult to implement for urban areas. However, some previous studies have been carried out to examine diversion tendencies when drivers are confronted with recurrent delays. Since those studies are closely related to this research, a summary of the results is given below.

Mannering et al. (1994) analyzed a survey of commuters using I-5 to downtown Seattle, conducted in September, 1988. They observed that 5.8% of drivers surveyed diverted frequently on home-to-work trips and 13.7% on work-to-home trips. Khattak (1998) analyzed another two sets of survey data from Chicago and San Francisco, which were collected in 1990 and 1993 respectively. These data showed that 42.5% of respondents in Chicago and 16.3% in San Francisco diverted when they experienced unexpected delays. During the summer of 2001, Texas Department of Transportation (2002) made a survey regarding the TransGuide system and its use in San Antonio. 55% of drivers claimed that they would get off the freeway and take another route other than the frontage road and 18% of drivers stated that they would take the frontage road when they encountered significant traffic congestion on the freeway. If we also consider using a frontage road as diversion, then the total diversion rate could be as high as 73%. However, the results were subject to the presence of TransGuide system, the city's ATIS system including radio, CMS, and informational website. In London, Chatterjee et al. (2002) studied drivers' responses to CMS. Based on their survey, 24% drivers indicated that they would divert when they met delays.

The above field observations and survey results confirm that diversion rates may vary remarkably at different locations. Even for the same location, it changes with times of day. The rate is directly dependent on the congestion level at the work zone area and the alternative routes. Many other factors could affect the rates as well, such as trip purpose and traffic information provision etc.

TABLE 1 Summary of Actually-Incurred Diversion Rates in Rural Areas

Location	Facility	Work zone	Diversion ratio	Information	Diverted route	Source
Nebraska	I-80	Two lanes closed; Two-lane, two-way operation on the other side	8-11% (peak period)	CMS	One alternative route	McCoy and Pesti (2001)
Racine, Wisconsin	I-94	12miles One lane closure on two lanes each direction	10% (peak period)	CMS with travel time estimation	Yes, known to all regular drivers; runs in parallel	Horowitz et al. (2003)
Rocky Mount, North Carolina	I-95	1.25-2.5 miles	10.9-20.2% (peak period)	Smart Work Zone system	One alternative route	Bushman, et al. (2004)
Santa Clarita, California	I-5	1.3 miles, one lane closure on three lanes each direction	3-20% (average)	Automated work zone information system (AWIS)	One alternative route	Chu et al. (2005)
San Bernardino, California	I-15	4.5 km, closed half of eight lanes; two by three lane configuration on the left half	17-18% (peak hour)	AWIS coupled with multi-faceted proactive public outreach	I-10 and I-215	Lee and Kim (2006)

2.2 Existing Approaches to Estimating Work Zone Diversion

It is resource consuming to observe diversion behaviors at a particular work zone in reality. Therefore, for actual applications, estimates of diversion rates often come from engineering judgment. Apart from pure engineering judgment, some quantitative methods have been developed to help engineers to determine diversion rates at work zones.

2.2.1 Diversion Modules in QUEWZ

Queue and User Cost Evaluation of Work Zones (QUEWZ) is an analysis tool developed by the Texas Transportation Institute for estimating the traffic impacts of work zone lane closures (Copeland, 1999; Krammes et al., 1987). QUEWZ-98 incorporates a diversion algorithm to account for the natural diversion of vehicles away from the freeway work zone to unspecified alternative routes. In the analysis, the queue length is calculated and compared with a critical queue length (with a default value of two miles). If this queue length does not exceed the critical one, no traffic diversion occurs. Otherwise, certain amount of traffic will be diverted so as to keep the queue length less than the critical value.

The following assumptions are used for diversion calculation:

- The length of the alternate route equals the length of the work zone plus the critical length of queue;
- The travel time for diverting vehicles is equal to the time required for a vehicle at the end of the queue to travel through the queue and work zone;
- Diverting traffic maintains a uniform speed equal to the length of the alternative route divided by the travel time, and
- Trucks do not divert.

It can be seen that this diversion algorithm is simple and easy to implement. However, it does not necessarily produce accurate estimates. The algorithm was developed based on observations of work zones on urban freeways in Texas where parallel frontage roads are available, which, however, are not common in other states. Moreover, the critical queue length plays an important role in estimating diversion rates, but again engineering judgment has to be applied to specify its value.

2.2.2 Diversion Module in Quickzone

Quickzone was developed by Mitretek Systems with support from the federal highway administration to quantify work zone delays and queue lengths given work zone capacity, traffic demand and work phasing (Miterek Systems, 2005). Different from QUEWZ, Quickzone is a network-based tool in which networks can include up to two alternative routes (one inbound, one outbound). The diversion is considered with the following heuristic rules:

In an urban application:

- Diversion to the alternative routes will not occur until the tail of the queue reaches back to the diversion point. After that, additional volume will divert onto the alternative routes up to 90 % of the spare capacity on the alternative route;
- If a CMS is deployed, then traffic will divert to the alternative routes up to 100 % of the capacity.

In a rural application:

- If the travel time of the original route is less than the alternative-route travel time, then there will be no diversion;
- If the original-route travel time is greater than the alternative-route travel time, some traffic will divert onto the alternative route. The amount of diverted traffic will depend upon the percentage of the total demand as specified by the user (% Local Traffic Traveling on Alternative Routes) and the spare capacity of the alternative route.

2.2.3 Permeable Pipe Analogy Approach

Ullman and Dudek (2003) proposed a theoretical approach to consider natural diversion at short-term work zones on high-volume roadways in urban areas. The essential idea is to use an analogy between flow through a permeable pipe and traffic on roadway with lane closures and perceive the flow across the permeable medium as diverted traffic. Assume the initial condition of a permeable pipe is that the pressure inside the pipe equals the outside pressure. When a temporal bottleneck is placed in the pipe, fluid state would change, resulting in lower flow rate, higher density, lower speed, and, more importantly, higher fluid pressure. The change would propagate upstream from the bottleneck. The increased pressure generates a pressure differential across the walls that forces the flow out through the walls of the pipe. Mathematically, we have the following equation:

$$Q = KiA$$

where Q is the flow rate through the permeable medium; K is coefficient of permeability to be calibrated; i is the pressure gradient across the permeable medium and A is the area through which flow is occurring. Ullman and Dudek further proposed a mathematical representation of a pressure gradient between the roadway with the work zone and the rest of the travel corridor using another energy analogy. When the traffic speed is less than a critical speed, the internal energy will increase as the speed decreases, leading to an increase of the traffic stream pressure. A closed-form formulation was derived to represent the relationship. With the calculated the pressure gradient and a calibrated permeability coefficient, the above equation is ready to use to produce an estimate of diverted flows.

This approach represents an interesting attempt, but unfortunately seems another forced analogy between social systems and physical systems. The transferability of the model may be questionable, e.g., it may not be appropriate to use the permeability coefficient calibrated at one location for another location.

In summary, there is still a lack of sensible and practical approaches to addressing diversion in the work zone analysis, which should be built upon a good understanding with travelers' diversion behaviors. Unfortunately, perhaps due to the difficulty of obtaining empirical data, such a behavioral analysis has not yet been conducted. In this study, we designed and performed a SP survey to obtain drivers' diversion propensity and then used the data to calibrate a binary logit model. The model shall serve as a reference for engineers to consider diversions in their work zone analyses.

3 MODELING DIVERSION BEHAVIORS

3.1 Stated Preference Survey

SP survey is an important technique to measure people's preferences when a conventional revealed preference (RP) survey is not feasible or appropriate. There are mainly three types of SP data collection methods, namely, ranking-, rating- and choice-based. In the ranking-based method, respondents are asked to give a relative ranking of different scenarios; the rating-based method normally uses a semantic scale for respondents to indicate their preferences and the choice-based method presents respondents with different choice scenarios and allows them to make a single choice for each scenario. Ortzar and Garrido (1994) compared these three methods in terms of the length and degree of difficulty of the interview and the subsequent data analysis, and concluded that the ranking method is inferior to the other two approaches. The rating-based method may provide more information, but the data are harder to collect and analyze. More importantly, the results are sensitive to the semantic scale provided to the respondents. In contrast, the choice-based method stands out as "the easiest, quicker and more natural task, and can be used for situations involving many real options." Moreover, the data collected can be easily combined with some RP survey data, if available, to do a combinatorial analysis. Therefore, this study adopted the choice-based method. Note that since travelers only have two options to choose from, the original and alternative routes, the choice-based method is actually the same as the ranking-based method in this study.

3.1.1 Potential Attributes

We consider the following factors or attributes that may potentially affect drivers' diversion decisions and select some of them to incorporate into the survey questionnaire. We note that diversion at work zones is closely related to other route choice problems. Therefore, in determining the potential attributes, the literature on general route choices was reviewed.

Travel time. Travel time may be one of the most important factors that travelers consider in their route choices. The reason why travelers divert is that they expect or are informed of delay on their original routes and try to avoid it. Therefore, travel times on the original as well as the alternative routes become critical attributes in the survey;

Location. Roughly speaking, a work zone can be either in a rural or an urban location. In an urban area, there are likely more alternative routes. Therefore when travelers encounter the work zone, they may be more inclined to divert. However, in a rural area, fewer alternative routes would be available. At the same time, it may be more difficult for travelers to obtain the information on those alternative routes;

Traffic information provision. Many studies (Uno et al., 2000; Khattak et al., 1993) have demonstrated that travel time information provision is critical for travelers' route choices especially in non-recurrent situations. In Florida, CMS near a work zone often displays some general information about the work zone, and no detailed traffic information is provided. Therefore, traffic information provision is not included in the survey;

Purpose of trip. Previous research (Khattak et al., 1993) shows that travelers may be more willing to divert in home-to-work trips than work-to-home, likely because the former have a greater time pressure. However, the research by Mannering et al. (1994) seems suggest otherwise. In any event, trip purpose may be an important factor and is then included in the questionnaire;

Type of vehicle. Generally, heavy vehicles such as trucks and buses are not supposed to divert. Since the focus of this study is on passenger vehicles only, this attribute is not selected for the SP survey;

Route attributes. Travelers may also take into account some other attributes such as the neighborhood along the route, number of traffic stops and safety etc. (Stinson and Bhat.,2003; Khattak et al., 1993). Nonetheless these attributes are highly conceptual and difficult to capture. Thus route attributes are excluded in the survey;

Weather conditions. Weather conditions may directly influence divers' diversion behaviors.

Intuitively, in bad weather conditions travel time reliability decreases and safety becomes one of the prominent concerns;

Traveler attributes. Socioeconomic characteristics and personality may affect travelers' decisions on diversion. For example, younger people may be more likely to divert.

Based on the above pre-screening, we consider travel time, work zone location, trip purpose, weather condition and socioeconomic characteristics of drivers in the survey questionnaire.

3.1.2 Survey Design

Survey design should be treated with extreme caution, since ill-defined survey questionnaire may lead to inaccurate or even biased results. One of the advantages of SP survey is that more than one scenario can be asked for each respondent. The most general way to design scenarios is full factorial design, which considers all possible combinations among attributes. In our case, if we specify three attribute levels for travel times on the original and alternative routes, three trip purposes and two work zone locations and weather conditions respectively, the full factorial design is $3\times3\times3\times2\times2=108$ scenarios. The number is simply too large to implement in practice. In order to keep the questionnaire in a meaningful and manageable length, we can consider only a fraction of all possible combinations, called fractional factorial design. When selecting the fraction, orthogonality of different attributes should be guaranteed. In other words, different attributes in the design must have no correlation. One of the common ways to achieve this is the main-effects-only design, which considers all independent effects of each attribute on the choice and ignores interaction effects among two or more attributes. In this study, since no clear evidence exists to show that there are certain interaction effects on route choices at work zone, the main-effects-only design is adopted.

Hensher et al. (2005) suggested that the minimum number of combinations for the main-effects-only fractional design is the number of coefficients to be estimated. In this problem, if we include the coefficients of socioeconomic attributes in the estimation, the minimum combination requirement is 12 scenarios. To guarantee the orthogonality, we employed SPSS to generate a minimum orthogonal design that consists of 16 scenarios. Considering that a respondent may not be patient enough to answer all those 16 scenarios in one telephone interview, we further divide the scenarios into four blocks. The orthogonality within each block is also maintained and our pilot experiments suggest that respondents are able to make rational choices when only given four scenarios.

The resulting 16 scenarios included in the survey are shown in Table 2. Note that only two types of weather condition, normal and bad, are specified, which we believe are enough in Florida. In the survey, a respondent will be asked questions associated with the four scenarios in one block. The interview time is estimated to be less than 15 minutes. One example script used in the telephone interview is given as follows: "Let's suppose you are driving HOME. The work zone location is an URBAN area and the weather is NORMAL. If you take your regular route through the work zone location it might take 10 minutes. If you take an alternative route without a road work zone it might take 25 minutes. Which one would you choose? Your regular route through a road work zone or would you choose an alternative route without a road work zone to get home?" The full script for Block 1 (See Table 2) is attached as an appendix to this report.

3.2 Data Analysis and Model Calibration

3.2.1 Data description

The telephone interview was carried out by the Independent Data Collection Center, Gainesville, FL in April 2007. Interviewees were randomly selected from a phone book database across the State of Florida. In order to maintain the orthogonality of the design, the frequency of using each of those four blocks was kept the same. Totally 800 samples were collected. Eliminating those with missing socioeconomic information or incomplete choices, 436 valid samples were obtained and then used to calibrate a binary logit model via NLOGIT.

TABLE 2 Hypothetical Scenarios in SP Survey

Scenario	Travel Time Regular	Travel Time Alternative	Purpose	Location	Weather	Block
1	10	25	HOME	URBAN	NORMAL	1
2	30	15	WORK	URBAN	BAD	1
3	20	5	LEISURE	RURAL	BAD	1
4	10	5	WORK	RURAL	NORMAL	1
5	10	5	WORK	RURAL	BAD	2
6	20	15	WORK	URBAN	NORMAL	2
7	30	5	HOME	RURAL	NORMAL	2
8	10	25	LEISURE	URBAN	BAD	2
9	10	15	LEISURE	RURAL	NORMAL	3
10	20	5	HOME	URBAN	BAD	3
11	30	25	WORK	RURAL	BAD	3
12	10	5	WORK	URBAN	NORMAL	3
13	20	25	WORK	RURAL	NORMAL	4
14	10	15	HOME	RURAL	BAD	4
15	10	5	WORK	URBAN	BAD	4
16	30	5	LEISURE	URBAN	NORMAL	4

Table 3 summarizes the socioeconomic characteristics of the respondents in the valid samples. There are slightly more female respondents (see Figure 1). A large portion of respondents is married (see Figure 2. In the survey, those who are separated, divorced and widowed were classified as “others”), and comes from middle-income households (see Figure 3). It is also shown that more than 60% of the respondents are older than 50, indicating that the survey samples may over-represent the elder population (see Figure 4). As we have considered socioeconomic factors including income and age as independent variables in the calibration process, such a sample distribution will not bias the model calibration.

3.2.2 Model calibration

In the initial model, only one variable, time, serves as generic variable. All binary variables and alternative specific constant are associated with the utility of the original route. For the location variable, 1 indicates rural and 0 urban area. Similarly, 1 indicates normal weather and male, and

0 bad weather and female. From Table 4, it can be observed that only three coefficients are statistically significant at the 90% confidence level (threshold = 1.645). In other words, we can only conclude that coefficients associated with time, location and weather variables are not zero at a 90% confidence level. There is no statistic evidence that the rest eight coefficients are not zero. Based on the observation, we may eliminate those insignificant variables one at a step form the initial model without influencing the accuracy of the model. At each step, *t*-test was performed in determining whether a specific variable should be eliminated from the model or not. After several rounds of calibration, the final model specification is shown in Table 5.

TABLE 3 Sample Socioeconomic Distributions

		Frequency	Percent	Cumulative Percent
Gender	Male	50	45.9	45.9
	Female	59	54.1	100.0
	Total	109	100.0	
Marital Status	Single	23	21.1	21.1
	Married	71	65.1	86.2
	Others	15	13.8	100.0
	Total	109	100.0	
Household Income	Less than $30,000	19	17.4	17.4
	$30,000 to $70,000	54	49.5	67.0
	More than $70,000	36	33.0	100.0
	Total	109	100.0	
Age	Less than 20	2	1.8	1.8
	21 to 30	7	6.4	8.3
	31 to 40	12	11.0	19.3
	41 to 50	17	15.6	34.9
	51 to 60	31	28.4	63.3
	61 to 70	23	21.1	84.4
	71 to 80	14	12.8	97.2
	Older than 80	3	2.8	100.0
	Total	109	100.0	

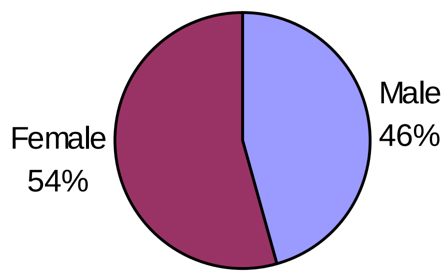

FIGURE 1 Sample Gender Distribution

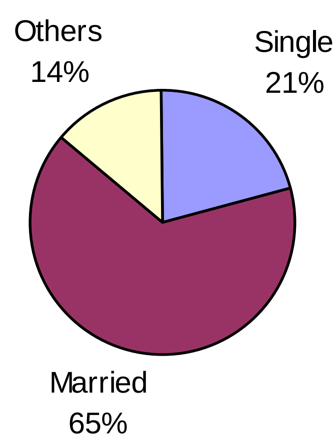

FIGURE 2 Sample Marital Status Distribution

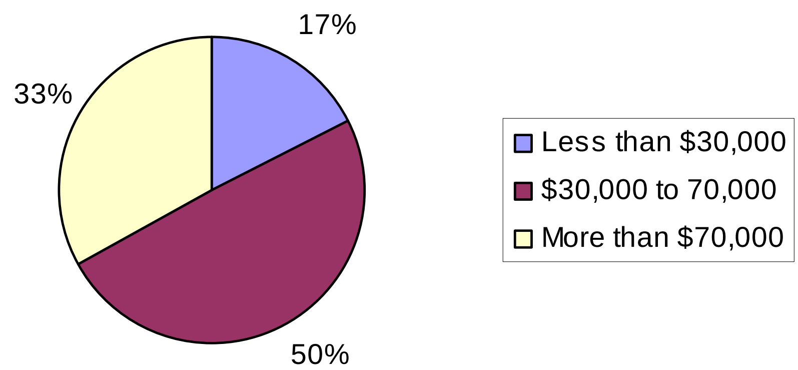

FIGURE 3 Sample Household Income Distribution

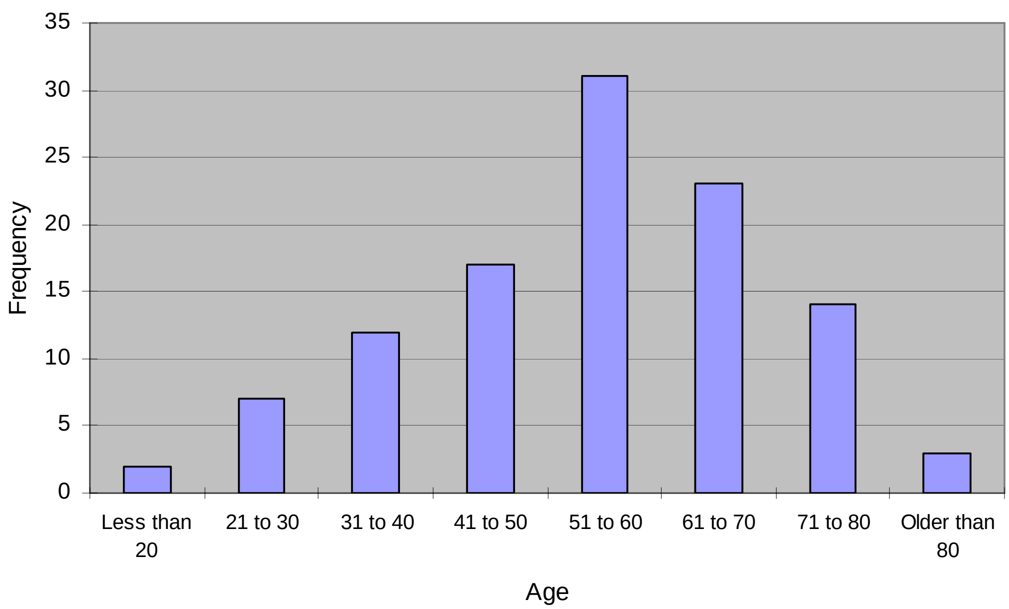

FIGURE 4 Sample Age Distribution

TABLE 4 Initial Model Specification

Explanatory Variables	Original		Alternative	
	Param.	*t* stat	Param.	*t* stat
Constant	-0.5705	-0.7690	--	--
Travel time	-0.1398	-9.7710	-0.1398	-9.7710
Location	0.7171	2.8010	--	--
Weather conditions	0.4249	1.6590	--	--
Trip purpose-work	-0.1594	-0.4720	--	--
Trip purpose-home	0.0827	0.1990	--	--
Middle income	-0.2521	-0.8710	--	--
Low income	-0.4013	-0.9990	--	--
Married	-0.0203	-0.0500	--	--
Single	-0.1272	-0.2820	--	--
Age	0.0062	0.7410	--	--
Gender	0.0766	0.2615	--	--
Number of cases	436			
Log likelihood at convergence	-199.7370			
LL for no coefficient model	-302.2122			
Rho^2	0.3391			
Adjusted rho^2	0.3204			

TABLE 5 Final Model Specification

Explanatory Variables	Original		Alternative	
	Param.	*t* stat	Param.	*t* stat
Constant	-0.5013	-2.0800	--	--
Travel time	-0.1416	-10.1580	-0.1416	-10.1580
Location	0.7220	2.8440	--	--
Weather conditions	0.3959	1.5840	--	--
Number of cases	436			
Log likelihood at convergence	-201.3115			
LL for no coefficient model	-302.2122			
Rho^2	0.3339			
Adjusted rho^2	0.3277			

The negative sign of time coefficient shows that the longer time the route is, the less attractive it is. The positive sign of the location coefficient indicates that travelers tend to stay on the original route in the rural area. As previously stated, in rural areas there are fewer alternative routes than in urban areas and travelers may be less familiar with the routes, which may explain this behavior. The sign of weather coefficient is also positive (note that *t*-statistics of weather coefficient is slightly lower than the 90% threshold). It can be interpreted that people are more likely to divert in a bad weather. In a bad weather, traffic conditions in work zone become more unpredictable and the conditions of the alternative routes may be perceived better, and thus become more attractive. This result is consistent with the finding by Khattak et al. (1994), where more diversions were observed in bad weather conditions. In summary, all the above findings are not only consistent with our perceptions but also with previous studies.

As for the goodness of fit of the model, the pseudo-R^2 (Rho^2) of a choice model is not exactly the same as R^2 in a linear regression model. A pseudo-R^2 of 0.3 represents a decent model fit for a discrete choice model. In the final model specification, the pseudo-R^2 is 0.33 is approximately equivalent to a R^2 of 0.7 for a linear regression model (Hensher et al., 2005).

4 ESTIMATING RTF

We propose two procedures, namely open-loop and closed-loop, to apply the calibrated binary logit model to estimate the RTF. The former directly applies the model without considering the feedback of remaining and diverted flows on travel times while the latter applies the notion of equilibrium and attempts to maintain the consistency between travel times and flows on different routes. As traffic equilibrium may not be achieved in a short time, the “open-loop” estimate may be more appropriate for short-term work zones while the “closed-loop” estimates may be closer to actual diversion rates at long-term work zones.

4.1 Open-Loop Implementation

For the short-term work zone analysis, a direct application of the calibrated binary logit model can generate the value of the RTF as follows:

$$RTF = \frac{1}{1 + \exp[0.1416(t_{org} - t_{alt}) + \rho]}$$

where t_{org} and t_{alt} are travel times of the original and alternative routes respectively, to be input by the users. ρ is a parameter derived from the calibrated model as listed in Table 6. When there are multiple alternatives available, t_{alt} is the average travel time of all alternatives, as discussed in Section 4.4.

TABLE 6 Value of Parameter ρ

		Work Zone Location	
		Rural	Urban
Weather Condition	Normal	-0.6166	0.1054
	Bad	-0.2207	0.5013

4.2 Closed-Loop Implementation

For a long-term work zone, travelers may learn and adjust their route choices over time and traffic equilibrium may better replicate the actual situation. To consider the equilibrium in the closed-loop implementation, we incorporate the calibrated logit model into the stochastic user equilibrium (SUE) assignment to calculate the RTF.

In the SUE assignment, travelers are assumed to choose the route with the minimum perceived travel cost (disutility) and at the equilibrium condition no travelers can reduce his or her perceived travel cost by unilaterally changing routes (Daganzo and Sheffi, 1977). There are several SUE formulations and we solve Fisk's formulation (Fisk, 1980) after incorporating the calibrated logit model as follows:

$$\min Z = \int_0^{x_{org}} \left(t_{org}(\varpi) + \alpha \right) d\varpi + \int_0^{x_{alt}} t_{alt}(\varpi) d\varpi$$
$$+ \frac{1}{0.1416} \left(x_{org} \ln x_{org} + x_{alt} \ln x_{alt} \right)$$

s.t.

$$x_{org} + x_{alt} = q$$
$$x_{org} \geq 0$$
$$x_{alt} \geq 0$$

where x_{org} and x_{alt} are the remaining traffic on the original route and the diverted traffic on the alternative routes; q is the traffic flow on the original route previously observed without the work zone; t_{org} and t_{alt} are travel times on these two routes, estimated by the following BPR functions:

$$t_a = t_a^0 \cdot \left(1 + 0.15 \cdot \left(\frac{x_a}{c_a} \right)^4 \right), a = org, alt$$

where t_a^0 is the free-flow travel time and c_a is the capacity of the original route or spare capacity of the alternative route. These values will be input by the users. For different combinations of the weather condition and work zone location, the value of parameter α is given in Table 7, which is derived from the calibrated model.

TABLE 7 Value of Parameter α

		Work Zone Location	
		Rural	Urban
Weather Condition	Normal	-4.3545	0.7443
	Bad	-1.5586	3.5402

By solving the above minimization problem, we obtain the equilibrium flows x_{org}^* and x_{alt}^*, and the RTF is simply x_{org}^* / q. If there are multiple alternatives available, t_{alt}^0 needs to be substituted with the average travel time across the alternatives and c_a is the combined spare capacity of all alternative routes, which will be further elaborated in Section 4.4.

In summary, to calculate the RTF, the users need to specify the location of work zone and weather condition, and then provide their best estimates on free-flow travel times and capacities of both the original and alternative routes and the total incoming traffic. We then solve the corresponding minimization problem to obtain the optimal solution x^*_{org} and x^*_{alt}, which is the new flow distribution. Consequently, by definition the RTF is computed using the following equation:

$$RTF = \frac{x^*_{org}}{q}$$

4.3 Excel Tool for Closed-Loop Implementation

To facilitate the closed-loop implementation, we developed a tool using Microsoft Visual Basic for Applications. The tool is a macro built in an Excel file. To use, one may open the Excel file and enable macros. If Solver Add-In has not been installed, click Tool → Add-Ins and then check Solver Add-In. In the Excel spreadsheet, clicking "INPUT" button, as shown in Figure 5, a popup menu will appear, requesting the user to input the data needed to compute the RTF, as shown in Figure 6. All the sections must be filled before clicking the "OK" button. Otherwise an error message will appear to remind the user to finish the input form. The user will then be brought back to the Excel spreadsheet and will find that all information has been filled in the sheet. After that, once the user clicks the "RTF" button, the Excel solver will be called to solve the corresponding Fisk's formulation, and the RTF will then be computed and displayed, as in Figure 7.

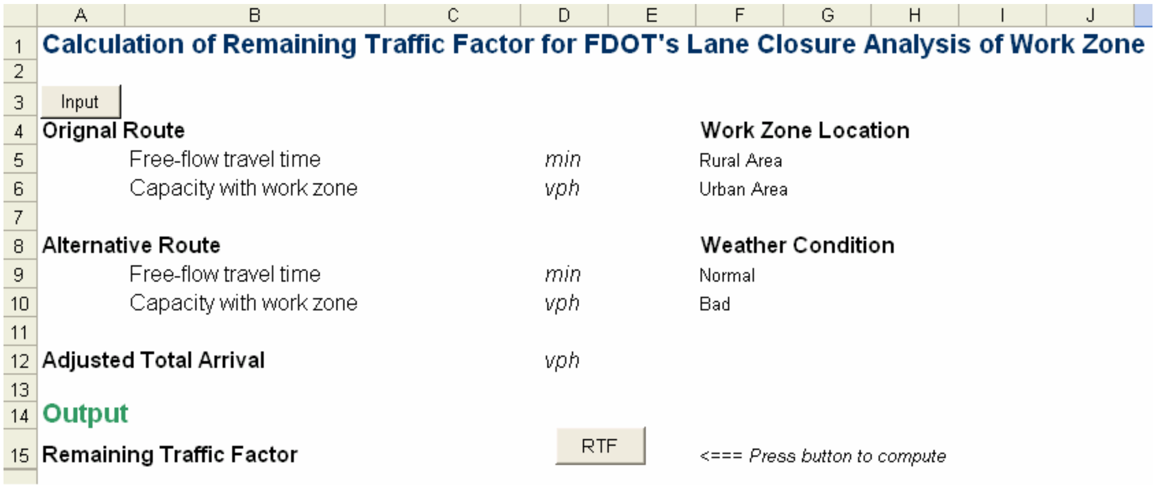

FIGURE 5 Excel Work Sheet without Input

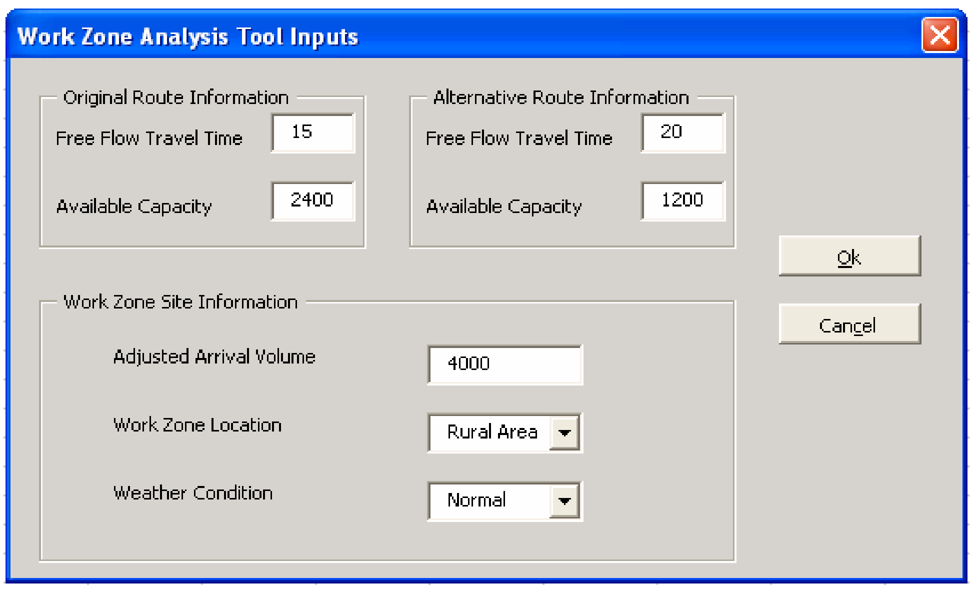

FIGURE 6 Work Zone Analysis Tool Input Window

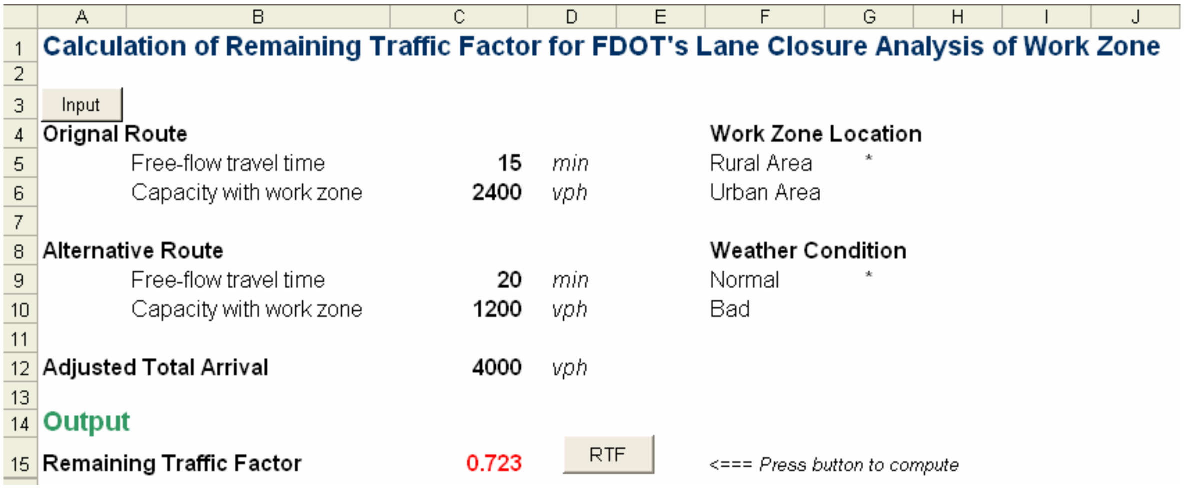

FIGURE 7 Excel Work Sheet with Inputs and Output

4.4 Dealing with Multiple Alternatives

The above RTF calculation assumes there is only one alternative route available. If there are more than one, the user needs to combine those multiple routes into a composite route with average travel time and combined spare capacity.

The combined spare capacity is simply the sum of the spare capacity of each alternative route. To calculate the average free-flow travel time, t^0_{alt}, algorithmic average of free-flow travel times across all alternative routes may be used, i.e.,

$$c_{alt} = \sum_{i \in J} c_i$$

$$t^0_{alt} = \frac{\sum_{i \in J} t^0_i}{N}$$

where J is the set of all alternative routes and N is the number of available alternative routes.

A numerical example is given here to illustrate how to calculate RTF with multiple routes. Assume in an urban area there is a work zone with two parallel alternative routes and the free-flow travel time and capacity/ spare capacity are shown in Figure 8. The total incoming traffic is 5000 vph and the weather condition is normal.

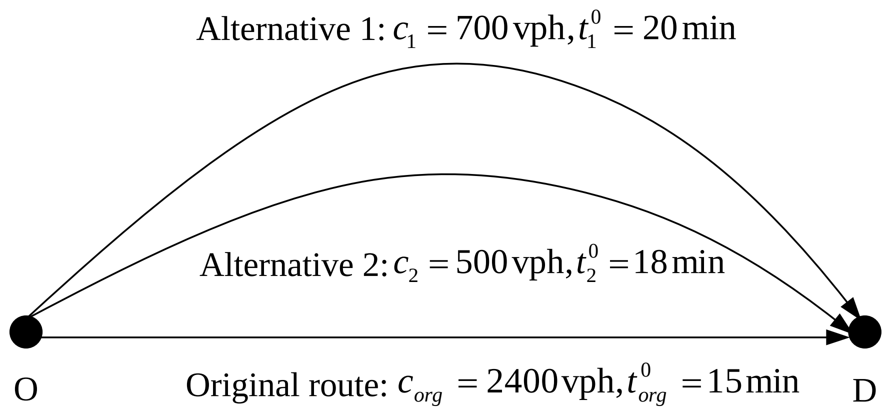

Figure 8 Two Parallel Alternative Routes Example

Using the equations of calculating combined capacity and average free-flow travel time, we have:

$$c_{alt} = c_1 + c_2 = 700 + 500 = 1200\ \text{vph}$$

$$t_{alt}^0 = \frac{t_1^0 + t_2^0}{2} = \frac{20+18}{2} = 19\ \text{mins}$$

In the Excel tool, input the above as the “Alternative Route Information”, and follow the procedure described in the last section. After clicking the “RTF” button, the tool will generate a RTF value of 0.67.

Since algorithmic average is based on the assumption that all alternative routes carry the same portion of diverted traffic, which may not be accurate, a more realistic assumption is that the split among those alternative routes is based on another logit model. The equations are as follows:

$$t_{alt}^0 = \sum_{i \in J} P_i \times t_i^0$$

$$P_i = \frac{\exp(-\beta \times t_i^0)}{\sum_{j \in J} (-\beta \times t_j^0)}$$

where β is a positive parameter indicating the degree of perception variance of travelers, reflecting the information level of the travelers on alternative routes. J is the set of all alternative routes. The more familiar travelers are with the alternative routes, the larger value of β will be.

Leurent (1995) did a case study in the Paris metropolitan area and calibrated the value of β to be 0.2. Certainly β may vary from place to place and the value provided here only serves as a reference. If a route choice model has been calibrated in a similar area, the value may be directly used in view of the good transferability of discrete choice models.

The above discussion assumes parallel alternative routes in the network. When alternative routes are overlapping, the above equations may be invalid since the basic assumption of the multinomial logit model (MNL), i.e., independence of irrelevant alternatives, is violated. Figure 8 shows two different specifications of alternative routes.

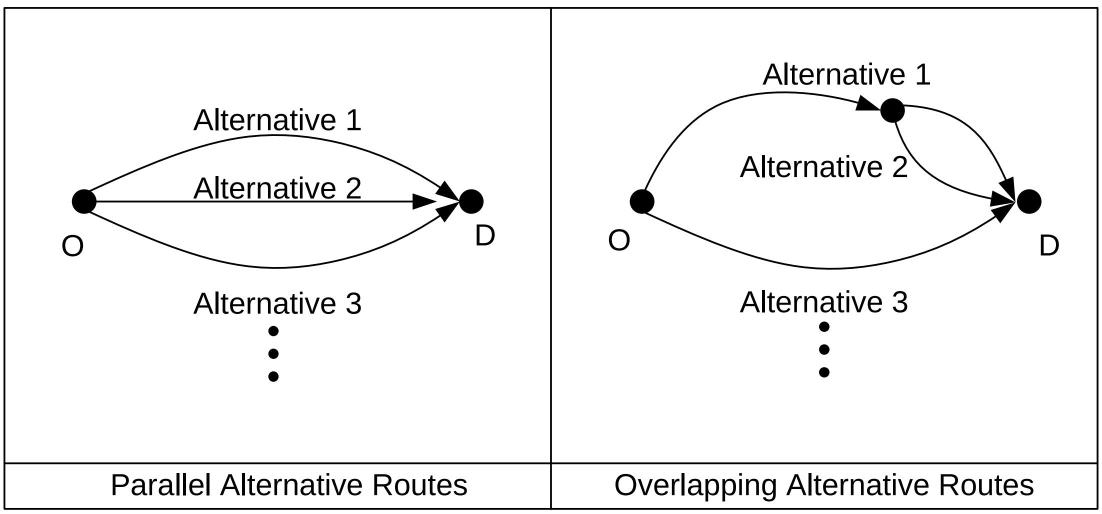

Figure 9 Alternative Route Specifications

To overcome the issue of overlapping alternative routes, C-Logit (Cascetta et al., 1996) can be employed. The basic idea of C-Logit is to introduce a commonality factor to account for the similarity among overlapping routes. The C-Logit model retains the close-form structure of the MNL model with a modified utility function:

$$P_i = \frac{\exp(-\beta t_i^0 - CF_i)}{\sum_{j \in J} (-\beta t_j^0 - CF_j)}$$

where CF_i is the commonality factor of route *i*, which may be estimated as follows (Cascetta et al., 1996):

$$CF_i = \beta_{CF} \ln \sum_{j \in J} \left(\frac{L_{ij}}{\sqrt{L_i L_j}} \right)^{\gamma}$$

where L_{ij} is the length of links common to route *i* and *j*, and L_i and L_j are the overall length of route *i* and *j*. β_{CF} is a coefficient to be estimated. Cascetta et al. (1996) suggested the theoretical value of β_{CF} is 1, obtained through a behavioral interpretation. However, Russo and Vitetta (2003) claimed that other values of β_{CF} may provide a better fit to empirical data. Parameter γ is normally set to a convenient value, often 1 or 2.

5 CONCLUSIONS

This chapter focuses on exploring drivers' diversion behaviors at work zones using a discrete choice model. A stated preference survey was carried out to obtain the data on drivers' diversion propensity from work zones. By calibrating a logit model, we identified three major factors that influence drivers' diversion decisions, namely, travel time, work zone location and weather condition. For other factors, such as trip purpose and drivers' social economic characteristics, we found no evidence that they are important factors in drivers' diversion decision making at work zones. The calibrated model provides us more insights on work zone diversion behaviors and may be used to forecast diversion rates or be incorporated to a work zone traffic analysis tool.

We then proposed two procedures, namely open-loop and closed-loop, to apply the calibrated binary logit model to estimate the RTF. The former directly applies the choice model without considering the feedback of remaining and diverted flows on travel times. It may be more appropriate to use for a short-term work zone lane closure. The latter applies the notion of equilibrium to maintain the consistency between travel times and flows of different routes. Therefore, it may better replicate the situation at long-term work zones. Based on the combinations of the weather condition and work zone location, four Fisk's SUE models have been formulated, which can be solved by the Excel solver to compute the RTF. We note that the resulting RTF estimate is based on sound behavioral modeling and network equilibrium analysis, which we believe should be more accurate than the engineering judgment.

Finally, it should be pointed out that the calibrated choice model is solely based on the SP survey data. It is widely known that in the SP survey, the respondents frequently overpredict their responses. As a result the calibrated model may overestimate the diversion rate and underestimate the RTF. Although this issue has been addressed in this study through carefully-designed questionnaires, it can not be eliminated. One indication is that in Table 5, the sign of the constant associated with the original route is negative (-0.5013). This implies that even when the travel times are equal, drivers are inclined to divert, which may not be necessarily consistent with actual behaviors observed at work zones. Therefore, a future study may be needed to combine the SP data with some RP data on actual behaviors to further refine the choice model.

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APPENDIX: TELEPHONE INTERVIEW SCRIPT

1: **INTRO**

simple

min = 1 max = 1 l = 2

INTRO

2007/03/20 09:54

Hello, my name is _______. I'm calling from Perceptive Market Research in Gainesville, Florida on behalf of the University of Florida Transportation Research Center. We are conducting a survey of people with driver's licenses to understand under what conditions a driver might choose to use an alternative route other than their regular route to avoid road work zones.

The information collected will be used to develop guidelines for the Florida Department of Transportation regarding lane closure traffic patterns for road work zones. This survey is a good opportunity for citizens like you to help the Florida Department of Transportation provide a better transportation system for all of us.

This survey should take less than 15 minutes. Your cooperation is voluntary and we'd greatly appreciate your help. There are no known risks or benefits to you for participating in this survey, and you will not receive compensation. All of your responses will be held in complete confidence and will be exempt from public disclosure by law. There will be no reference to your identification at any point in the research.

INTERVIEWER: ENTER F1 FOR CHOICE LIST@INTRO

ENTER TO CONTINUE.. 01 D

«INTRO »

2: **INTR1**

simple

min = 1 max = 1 l = 2

INTR1

2007/03/21 09:22

If you have any additional questions about this survey or the research project, please contact the project supervisor Scott Washburn, with the Transportation Research Center at the University of Florida. The phone number is (352-392-7575 x1453). If you have questions regarding your rights as a participant please contact the UFIRB office, at the University of Florida, PO BOX 112250, Gainesville, FL 32611. The phone number is 352-392-0433.

INTERVIEWER: ENTER TO CONTINUE@INTR1

ENTER TO CONTINUE... 01 D
«INTR1 »

3: **Q1**

simple
min = 1 max = 1 l = 2

2007/03/22 11:12
Do you have a currently valid Florida driver's license?
Yes... 01
No-Thank and terminate... 02 => INT
«Q1 »

4: **Q2**

simple
min = 1 max = 1 l = 2

2007/03/21 08:10
Have you entered a work zone on the road when driving during the past two years?
Yes... 01
No-Thank and Terminate... 02 => INT
«Q2 »

5: **HYPSC**

simple
min = 1 max = 1 l = 2

HYPSC
2007/03/21 08:22

Now I am going to ask you several questions about driving and road work zones. For these questions I want you to imagine that you are driving and see a sign saying "Road Work Ahead" and that you know at least one alternative route to where you are heading. In each of the questions you will be given different information on your trip purpose, the weather condition at the time of the trip and a location of where the road zone work is located.

And for each question you will be given the travel time it will take to get to your destination by either your regular route or the alternative route. You will be asked to choose either your regular route or the alternative route to make the trip described in the question. So let's start with the first question:

INTERVIEWER: ENTER F1 FOR CHOICE LIST@HYPSC

ENTER TO CONTINUE... 01 D
«HYPSC »

6: **SCEN1**

simple
min = 1 max = 1 l = 2

SCEN1
2007/03/23 00:55

Let's suppose you are driving HOME. The work zone location is an URBAN area and the weather is NORMAL. If you take your regular route through the work zone location it might take 10 minutes to get home. If you take an alternative route without a road work zone it might take 25 minutes to get home. Which one would you choose? Your regular route through a road work zone that likely takes 10 minutes to get home or would you choose an alternative route without a road work zone that likely takes 25 minutes to get home?

INTERVIEWERS: ENTER F1 FOR CHOICE LIST@SCEN1

Regular route with road work zone taking 10 minutes 01
Alternative route without road work zone taking 25 minutes............... 02
DON'T KNOW (DO NOT READ).. 88 I
REFUSED (DO NOT READ)... 99 I
«SCEN1 »

7: **SCEN2**

simple
min = 1 max = 1 l = 2

SCEN2

2007/03/23 01:01

In this next question suppose you are driving to WORK. The work zone location is an URBAN area and the weather is BAD. If you take your regular route through the work zone location it might take 30 minutes to get to work. If you take an alternative route without a road work zone it might take 15 minutes to get to work. Which one would you choose? Your regular route through a road work zone that likely takes 30 minutes to get to work or would you choose an alternative route without a road work zone that likely takes 15 minutes to get to work?

INTERVIEWER: ENTER F1 FOR CHOICE LIST@SCEN2

Regular route with road work zone taking 30 minutes 01
Alternative route without road work zone taking 15 minutes............... 02
DON'T KNOW (DO NOT READ).. 88 I
REFUSED (DO NOT READ).. 99 I
«SCEN2 »

8: **SCEN3**

simple
min = 1 max = 1 l = 2

SCEN3

2007/03/23 01:02

In this next question suppose you are driving for LEISURE. The work zone location is a RURAL area and the weather is BAD. If you take your regular route through the work zone location it might take you 20 minutes to get to your destination. If you take an alternative route without a road work zone it might take you 5 minutes to get to your destination. Which one would you choose? Your regular route through a road work zone that likely takes 20 minutes to get to your destination or would you choose an alternative route without a road work zone that likely takes you 5 minutes to get to your destination?

INTERVIEWER: ENTER F1 FOR CHOICE LIST@SCEN3

Regular route with road work zone taking 20 minutes 01
Alternative route without road work zone taking 5 minutes................. 02
DON'T KNOW (DO NOT READ)... 88 I
REFUSED (DO NOT READ).. 99 I
«SCEN3 »

9: **SCEN4**

simple
min = 1 max = 1 l = 2

SCEN4
2007/03/23 01:03

In this next question suppose you are driving to WORK. The work zone location is a RURAL area and the weather is NORMAL. If you take your regular route through the work zone location it might take 10 minutes to get to work. If you take an alternative route without a road work zone it might take 5 minutes to get to work. Which one would you choose? Your regular route through a road work zone that likely takes 10 minutes to get to work or would you choose an alternative route without a road work zone that likely takes 5 minutes to get to work?

INTERVIEWER: ENTER F1 FOR CHOICE LIST@SCEN4

Regular route with road work zone taking 10 minutes 01
Alternative route without road work zone taking 5 minutes................. 02
DON'T KNOW (DO NOT READ)... 88 I
REFUSED (DO NOT READ).. 99 I
«SCEN4 »

10: **GEND**

simple
min = 1 max = 1 l = 2

2007/03/21 08:51

INTERVIEWER: RECORD THE GENDER OF THE RESPONDENT

Male.. 01

Female 02

«GEND »

11: **AGE**

simple, ouverte

min = 1 max = 1 l = 2

2007/03/21 08:54

What is your age?

Record Respondent's age 01   DO

REFUSED (DO NOT READ) 99

«AGE »

«O_AGE »

12: **MSTAT**

simple

min = 1 max = 1 l = 2

2007/03/21 08:58

Are you:

READ LIST!!!

Single.. 01

Married 02

Others (separated, divorced or widowed) 03

REFUSED (DO NOT READ) 99

«MSTAT »

13: **INCOM**

simple

min = 1 max = 1 l = 2

2007/03/21 09:28

What is your annual household income? Is it:

READ LIST!!!

Less than $30,000 01

From $30,000 to $70,000 02

More than $70,000... 03

REFUSED (DO NOT READ) 99

«INCOM »

14: **NAME**

simple, ouverte

min = 1 max = 1 l = 2

2007/03/21 09:00

For verification purposes only can I have name?

ENTER RESPONDENT'S NAME... 01 DO

«NAME »

«O_NAME »

15: **THANK**

simple

min = 1 max = 1 l = 2

2007/03/21 09:03

Those are all the questions I have for you. Thank you for participating in this survey.

INTERVIEWER: ENTER TO CONTINUE

ENTER TO CONTINUE.. 01 D

«THANK »

16: **INT99**

simple

min = 1 max = 1 l = 2

INTERVIEWER ENTER THROUGH THIS!!!!

COMPLETE.. 01 D => END

«INT99 »

17: **INT**

simple

min = 1 max = 1 l = 2

Enter the call result

COMPLETE	01	N	=> END
REFUSAL	02		=> END
NO ANSWER	03		=> END
BUSY	04		=> END
ANSWERING MACHINE	05		=> END
INTERRUPTED	06		=> CB
WRONG NUMBER/MOVED/DECEASED	07		=> END
DISCONNECTED NUMBER	08		=> END
DUPLICATE NUMBER	09		=> END
FAX	10		=> END
GOVERNMENT/BUSINESS	11		=> END
CALLBACK	12		=> CB
REFUSAL CALLBACK	13		=> CB
LANGUAGE BARRIER	14		=> END
MACHINE GENERATED REFUSAL	15		=> END

«INT »

18: **CB**

simple

min = 1 max = 1 l = 12

When would be a good time to call you back?

$CHS

«CB »
