Traffic Operational Impacts of Contemporary Multi-Pump Island Fueling Centers

by

Christopher M. Cunningham, P.E.,

Daniel J. Findley, E.I.,

Bastian Schroeder, E.I.,

and

Robert S. Foyle, P.E.

at the:

Institute for Transportation Research and Education
North Carolina State University

Raleigh, North Carolina

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Abstract

NCDOT has relied on trip estimates based on the ITE *Trip Generation Handbook* for years; however, the number of fueling positions at contemporary fueling centers typically exceeds the range presented by ITE. This project aimed to quantify the effects of contemporary fueling stations by looking into other previous literature and investigating various analysis methods, such as linear and multi-variable linear regression models, on actual trip count data.

The fueling center is known to be one of the most difficult land uses to quantify trip ends because many site characteristics affect whether or not a fueling center is chosen by a consumer. The research team conducted an extensive literature review and thorough email surveys prior to conducting data collection at thirty case sites. Most states use traditional methods based on the ITE *Trip Generation Handbook* for predicting trip demand. However, a couple of states employ multi-linear regression models with limited success. The results from these models were either flawed or had low R^2 values, and therefore were not useful.

The project team conducted a two-fold analysis of the data collected at each of the sites. The first analysis used traditional methods such as those employed by ITE. Linear and log-linear plots were generated for a number of various independent variables. The second analysis method looked at the potential for a multi-variable model. The team ran many different models including various combinations of independent variables. Based on our analysis of the data, the proposed recommendation is to use two multi-variable linear regression models for AM and PM peak trip estimations.

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We extend special thanks to the project Steering and Implementation Committee members:

- Anthony Wyatt, P.E., P.T.O.E. (Chair)
- Kent L. Taylor, P.E.
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- Brad Hibbs, P.E. (FHWA)
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Without the help of all of the above individuals, this project could not have been completed in such a successful manner.

EXECUTIVE SUMMARY

As population grows and housing developments spread out away from concentrated cities within North Carolina, developers are constructing multi-pump island fueling centers. These fueling centers have more pump islands and provide more services than traditional gas stations. In addition, many stations are now introducing fast food facilities to improve convenience to the consumer. NCDOT has relied on trip estimates based on the ITE *Trip Generation Handbook* for years; however, the number of fueling positions at contemporary fueling centers typically exceeds the range presented by ITE. This project aimed to quantify the effects of contemporary fueling stations by looking into other previous literature and investigating various analysis methods, such as linear and multi-linear regression models, on actual trip count data.

In general, fueling centers are known to be one of the most difficult land uses to quantify trip ends because many site characteristics affect whether or not a fueling center is chosen by a consumer. The research team conducted an extensive literature review and thorough email surveys prior to conducting surveys at thirty case sites. Most states use traditional methods based on the ITE *Trip Generation Handbook* for predicting trip demand. However, a couple of states employ multi-linear regression models with limited success. The results from these models were either flawed or had low R^2 values, and therefore were not useful. From the data collection, the team observed peak hour volumes ranging from 15 vehicles per hour to 472 vehicles per hour. These vehicles represent turning movements into and out of driveways. The high volumes that some fuel centers experience during the peak hour can lead to spillback into adjacent roadways and increase the potential for collisions. Detailed review of driveway access permits can identify potential access issues prior to construction.

Sites chosen for analysis were distributed based on several characteristics including: their location across North Carolina, urban or rural setting, proximity to interstate facilities, and services offered. The project team conducted a two-fold analysis of the data collected at each of the sites. The first analysis used traditional methods such as those employed by ITE. Linear and log-linear plots were generated for a number of various independent variables. The findings indicated that these models were not

particularly useful because they had very low correlation based on R^2 values. The second analysis method looked at the potential for a multi-variable model. The team ran many different models including various combinations of independent variables. The findings were much more significant, with adjusted R^2 values in the range of 0.5 to 0.7 for models that seemed to show promise.

Based on our analysis of the data, the proposed recommendation is to use two multi-regression models for AM and PM peak trip estimations, with adjusted R^2 values of 0.591 and 0.558, respectively. The equations are:

AM Trips = (0.625 * ADT) + (128 * Hybrid) + (136 * Drive Through) + 116
PM Trips = (0.654 * ADT) + (130 * Hybrid) + (119 * Drive Through) + 153

In addition to the recommended models, the team highly recommends that NCDOT invest in more data collection to improve calibration and reliability in the models. The final models categorize the data by the type of site: non-fast food (n=11), fast-food (n=15), and "hybrid" (n=4). A hybrid site would have characteristics somewhere between a non-fast food and fast food site. The primary drawback with any of these models is the limited data sets in each of the categories of sites. To conform to ITE standards, the recommendation is to collect and analyze data at a total of twenty sites for each category. Thus, thirty *additional* sites are needed for data collection and analysis in conjunction with the data already collected.

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INTRODUCTION

The NCDOT has made significant strides in its efforts to increase capacity while decreasing collisions along many of its key highway corridors across the state. Of special interest are high speed corridors where limited driveway access is essential for longer trip mobility. In efforts to continue making decisions which would benefit users of all types along these corridors, the Traffic Safety Unit staff, Congestion Management and Signing Unit staff, and Division staff need additional tools to help determine trip generation rates at newer types of facilities. One such facility is the contemporary, multi-pump island fueling center.

Newer, contemporary fueling centers have many commodities that traditional fueling centers did not offer. Pay at the pump, increased numbers of fueling islands, car wash facilities, convenience markets, and fast food restaurants at these updated gas station facilities have brought increased numbers of trips as fueling and dining becomes more 'convenient'. However, methods based on outdated data on more traditional types of fueling centers may not be good indicators of trips generated at more contemporary types of facilities, and therefore underestimate actual trips. In addition, methods used in the ITE *Trip Generation Handbook*, 7th *Edition*, for Land Uses 945 and 946, do not provide trip generation equations because of the scatter plot of information (*1*). Only averages are given for trip generation. Based on observations from NCDOT staff at many of these fueling centers, these averages may not represent recent North Carolina installations.

Engineers providing traffic impact assessments for developers are at best using the average trip generation rate to determine the additional traffic for these contemporary fueling centers. Significantly lower traffic estimates will under-predict the severity of additional traffic turning into and out of these fueling centers. NCDOT then ends up correcting the problems which should be the developer's responsibility to safely accommodate site traffic at the time of construction. If the magnitude of the trips generated at these newer facilities were more accurately predicted, determining the placement of access points and installation of roadway treatments could be accounted for during the initial review phase. Through traffic can be impacted if entering vehicles are frequently slowing down in the through lanes, creating a higher potential for rear-end and side swipe collisions. However, proper design treatments could significantly reduce this potential.

The opportunity to collect and evaluate North Carolina specific data will provide insight into how these larger, non-traditional fueling centers operate. This information will allow NCDOT to better predict traffic demand, thus making improved recommendations for driveway access permits and design decisions related to safety and capacity (auxiliary lanes, signal warrants, stacking issues at pumps spilling over into the roadway, etc).

LITERATURE REVIEW

INTRODUCTION

Since the inception of the gasoline powered automobile, along with the ability to mass produce and sell them throughout the United States, gasoline has become a highly demanded natural resource. Due to the rise of automobile ownership and use throughout the 20th century, the fueling station became an ideal location for transferring fuel to vehicles on a large scale. In the latter part of the 20th century, as vehicles were changing and evolving, stations also evolved to serve the needs of the consumer. Unfortunately, this increased use of the automobile along with the services it required brought with it more demand to the surrounding roadway networks.

Currently, the primary resource for determining the expected impact of various facilities on the roadway network is the Institute of Transportation Engineers (ITE) *Trip Generation Handbook*, 7th *Edition*. This handbook is a standard resource to traffic engineers conducting traffic impact analyses (TIA's). However, this handbook is only meant to be used as a resource. The data used in the analyses for many of these facilities was collected in the 1980's. Due to the rapid evolution of the fueling center and the addition of supplementary facilities such as the car wash, convenience mart, larger numbers of pumps, fast food, etc., there is concern in the profession that the traffic impacts of these facilities may be severely underestimated. Even more controversy arises from debates that traffic impacts could be overestimated by not accounting for the potentially large amount of pass-by trips.

To help aid this analysis effort of conventional multi-pump island fueling centers, the research team needed to understand the current state of the practice. This review is summarized in the following three areas: state of the industry, ITE approach, and other state's approaches and research efforts.

STATE OF THE INDUSTRY

The gasoline industry is a market of supply and demand. In the past century, fueling stations have continued to evolve by adding additional facilities to serve the needs of customers and increase profits. In a 1991 paper, Firtel noted "The rapidly changing technology in many industries has out-dated some traditional trip generation definitions and rates. Gas stations are one industry that has seen a significant shift in services and technology that has changed the way trips are generated." (*2*)

In the history of the fueling station, trends have changed from a small full service station, to a combination self/full service station, to the more popular self service station. Recent additions have included increased numbers of fueling positions, 24-hour operation, fuel type options, a convenience market, a car wash, and the newly evolving fueling station with convenience market and fast food. Even with all of those changes, industry standards are expected to continue to change drastically in the coming years with possible additions such as diagnostic checks of your vehicle for maintenance needs, placing food and beverage orders from the pump, internet capability for directions to destinations, or even a robot filling your car for you (*3*).

There is no question that the market for gasoline stations is one of the most unpredictable markets in terms of services offered and their impact on traffic. A few statistics are given to better understand the market in terms of the everyday commuter and the industry. In a 1998 customer profile by the National Petroleum News (*4*), of total fuel consumption, cars and trucks accounted for 47% and 53%, respectively. The main route of travel for motorists was urban streets (60.6%), followed by main rural roads (24.9%), and lastly local roads (14.4%). The average number of miles traveled annually during 1998 was 11,725 miles per passenger car, using 548 gallons of gas at an efficiency of 21.4 miles per gallon.

A 1997 Economic Census report (Table 1) shows revenue sales from three co-related facilities (*5*). Without more data, it is not feasible to rank these sites by profitability. However, the number of establishments indicates that gasoline service stations with convenience stores have a stronghold on the overall market share.

Table 1. Economic Census Summary

United States	*Establishments*	*Sales*	*Payroll*
Gasoline Stations	42,405	$70,556,669,000	$4,253,505,000
Gasoline Stations w/ Convenience Store	81,684	$127,609,117,000	$7,228,587,000
Convenience Store	27,081	$16,847,766,000	$1,598,361,000

In 2000, approximately 200,000 facilities sold retail gasoline in the United States (*5*). Making comparisons on a regional perspective, Table 2 shows that 35% of the expenditures for gasoline products sold in the United States were in the South, (*6*). In Table 3, based on the market profile, roughly 70% of fuel purchases were done by commuters ranging in age from 25 to 54 years old (*6*). Statistics such as these indicate marketing towards middle-aged drivers with new schemes and conveniences likely to develop heavily in the South where fuel is in high demand.

Table 2. Gasoline Sales by Region

Region	
Northeast	17.9%
Midwest	24.2%
South	35.2%
West	22.7%

Table 3. Gasoline Purchases by Age

Age within Household	
Under Age 25	4.5%
25 to 34	19.3%
35 to 44	27.5%
45 to 54	23.8%
55 to 64	12.6%
65 to 74	8.4%
Age 75 and Over	3.9%

Statistics from various sources appear to identify target populations across the U.S. with the largest demand for gasoline and other additional services. An emerging software tool that many fuel industry providers are likely taking advantage of is Geographical Information Systems, or GIS. GIS is a very powerful tool designed for storing, manipulating, analyzing, and displaying data in a geographical context (*7*). ESRI (Environmental Systems Research Institute, Inc.), which is the developer of one GIS-based program, states that many companies developing fueling centers "Use GIS to analyze demographic and transportation information to effectively choose retail sites." (*8*) Characteristic data could include traffic, land use (retail, industry, and dwellings), streams and rivers, topography, and other features. GIS allows users to manipulate many different data sets to make informed decisions, such as where to place a gasoline station with convenience mart and fast food to maximize exposure to traveling motorists.

THE ITE APPROACH

Over the years, traffic engineers, planners, and analysts have become increasingly aware of the intricacies involved in conducting trip generation studies. As land uses become more elaborate in design, the analysis of the site's impact on the adjacent roadways becomes much more complex. In an effort to aid the user, the *ITE Trip Generation Handbook – An ITE Recommended Practice – 2nd Ed.* and *ITE Trip Generation User Guide* (*1,9*) provides instruction and guidance on using analyses of various land uses and offers guidance related to other issues of importance, such as the pass-by trip phenomenon and trip generation at multi-use developments. This section will primarily focus on summarizing information from these two resources to gain an enhanced perspective on the guidelines for using various land uses, their variables, analysis procedures, and potential pitfalls. It is important to note that *Trip Generation* is a report, and not a manual, and is published to aid the analyst; however, it is not intended to replace engineering judgment or local data (*10*).

In using *Trip Generation*, the challenge to the analyst is making reasonable estimates of trip ends for a particular development. The report consists of data from many sources across the U.S. and Canada since the 1960's, with significant data from Florida, Arizona, and California (*10*). It is primarily made up of suburban locations with little or no transit and may not be applicable in a central business district (CBD). The tools used in predicting these trips are data plots of a dependent variable (generated trips) versus any number of independent variables, a weighted average trip generation rate, and a regression equation relating the dependent variable to the independent variable. Guidance is given in the *Trip Generation Handbook* for how to use these predictive tools in an appropriate manner.

Selection of the independent variable is one of the most important decisions in calculating trip generation. Different independent variables are used to calculate trip generation for various land uses. The selection of the independent variable requires that the data is available from existing and proposed sites. This is usually in the form of plan sheets or other applicable materials. Trips should be logically influenced by the independent variable. In many cases, *one* land use could be evaluated using *two or more* different variables. This depends on whether there is a better data set (and thus less variance) to describe trips during that classification for a variable. Preferred variables for trip generation should:

- "appear to be a 'cause' for the variation in trip ends generated by a land use;
- be reliably forecast for applications;
- produce a rate/equation with the 'best fit' of data;
- be related to the land use type and not solely to the characteristics of the site tenants (values and measurements attributable to an independent variable should not change dramatically with changes in building tenants. Physical site characteristics such as Gross Floor Area (GFA) or number of dwelling units are preferable); and
- be obtained through a primary measurement and not derived from secondary data (i.e. calculation for number of employees in an office building from GFA). Instead use the primary measurement such as GFA or dwelling units." (*1*)

Trip data is collected for a site with many potential independent variables and data analyses are completed for each possible combination using two methods: weighted average trip generation rates and regression equations. The weighted average trip generation rate represents the number of trip ends per unit of the independent variable (*9*). Graphically, the rate is represented as the slope of a line with a y-intercept passing through the origin. Weighted average simply means that trips are weighted by the units of the independent variable. Standard deviations are given with this average rate to describe the dispersion of the data about the mean.

The second analysis method used for trip generation is a regression equation. Regression methods are used in an attempt to better describe the data set; however, the equation *does not* pass through the origin. Regression equations used in *Trip Generation* can be represented in the following forms:

- $T = aX + B$ (linear) and
- $Ln(T)= aLn(X) + b$ (logarithmic)

Although regression equations better represent the data set, they can be misinterpreted at very small values located outside the range of the independent variable when the equation has a large y-intercept, and therefore caution should be used. For instance, an analyst would expect very small numbers of trips with smaller values of the independent variable (i.e. zero trips when the independent variable is not there).

The choice of independent variable (fueling positions, square footage, etc.) and linear regression plot for a classification (i.e. AM, PM, Daily Trips, etc.) is determined by which regression line and equation 'best fits' the data plot. This 'best fit' is determined by a coefficient of determination which is related to the equation representing the data plot. The coefficient of determination, many times referred to as the R^2 value, is defined as the percent of variance in the dependent variable (number of trips) that can be explained by the independent variable. This value is always between 0 and 1.0. The closer the value is to 1.0, the less variance in the data set, and thus the better the fit of the regression line. Plots with less than five data points or having an equation with a R^2 value less than 0.5 (considered weak) do not show a regression equation or R^2 value. When an equation and R^2 value are given, values greater than or equal to 0.75 are considered strong.

Understanding when to use regression equations and weighted average trip generation rates can be difficult. The *ITE Trip Generation Handbook* gives guidance on how to use the plots, equations, and rates for each of the various land uses. Figure 1 from the *Trip Generation Handbook* shows a flow chart for selecting between an average trip rate and an equation.

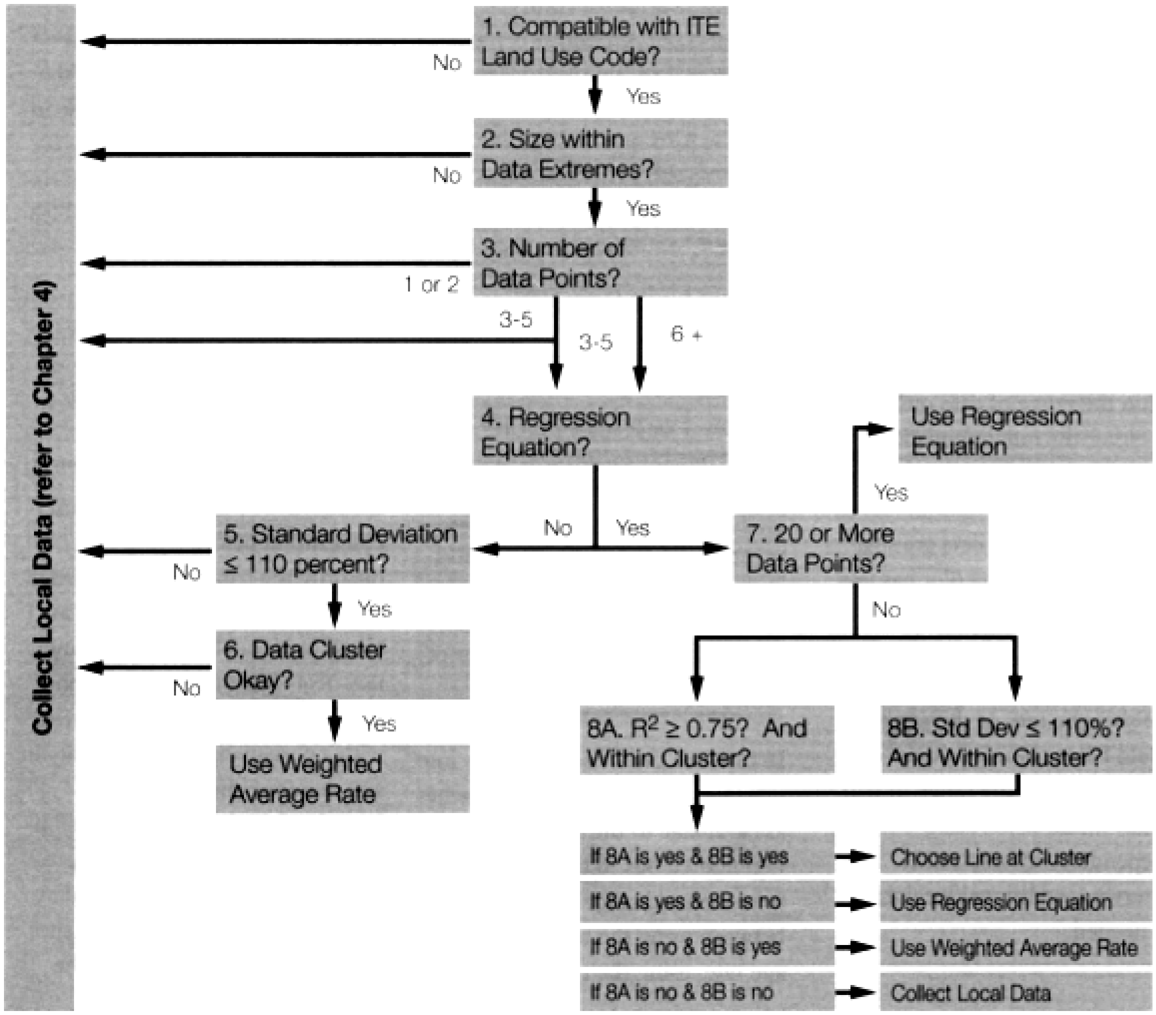

Figure 1. Recommended Procedure for Selecting Between Trip Generation Average Rates and Equation 1 (page 30 this report). ***Note that in Steps 5 and 8B, the calculation is as follows: standard deviation divided by the weighted average rate is less than or equal to 1.1.***

When testing local sites of a similar land use code to verify ITE trip generation rates or to add data to a limited sample, the choice of the sites for data collection is a vital step. Sites should match the ITE Land Use Code to allow for proper comparisons and/or include additional data. The development must be established and located in a mature area (>2 years) to accurately represent the development. As noted earlier, data that will be used to describe the independent variable must be readily available to an analyst or engineer. The sites should be typical to others in the region and no unusual activities should be occurring at or near the location. In addition, accurate and feasible collection of the trip generation data and other characteristics should be considered.

Various land use codes cover a wide array of gasoline facilities and/or convenience markets. The data was collected sporadically over four decades across the United States, starting in the 1970s. These land use codes are noted in Table 4 with ITE descriptions.

Table 4. Land Use Codes and Descriptions

Land Use	R^2 > 0.50 / # Categories	Description
853: Convenience Market with Gasoline Pump	0/14	"Sell gasoline, convenience foods, newspapers, magazines, and often beer and wine. The primary business is the selling convenience items, not the fueling of motor vehicles"
944: Gasoline/ Service Station	5/7	"Includes gasoline/service stations where the primary business is the fueling of motor vehicles. Service stations may also have ancillary facilities for servicing and repairing motor vehicles."
945: Gasoline/ Service Station with Convenience Market	0/11	"Includes gasoline service stations with convenience markets where the primary business is the fueling of motor vehicles. Service stations may also have ancillary facilities for servicing and repairing motor vehicles. Commonly sold convenience items are newspapers, coffee or other beverages and snack items consumed in the car."
946: Gasoline/ Service Station with Convenience Market and Car Wash	0/5	"Includes gasoline service stations with convenience markets and car washes where the primary business is the fueling of motor vehicles. Service stations may also have ancillary facilities for servicing and repairing motor vehicles."

One major problem associated with the various types of fueling centers is the large amount of variance in the data sets. The column "R^2 > 0.50 / # Categories" indicates that of the four various types of land uses including fueling of vehicles, the only one with linear regression equations included for a classification type was Land Use 944: Gasoline/Service Station. This facility has seven possible descriptive combinations (i.e. Weekday AM or PM peak hour of adjacent street traffic, etc.) that were analyzed of which five were found to have R^2 values greater than 0.5. Only one of these five has a strong correlation ($R^2 = 0.74$), with the other four having R^2 ranging from 0.53-0.60. Although the reason for this phenomenon is not entirely clear, it is fairly obvious that the primary independent variable, the vehicle fueling position, is not describing the sites very well. In fact, of the four land use types noted above, the only one that has regression equations shown with the data plot is a gasoline/service station facility in which there is no other combined land use. Figure 2 shows a plot of Land Use 945, which shows some of the common mishaps, such as no fitted curve equation and a dispersed data set, with other related plots in similar land uses.

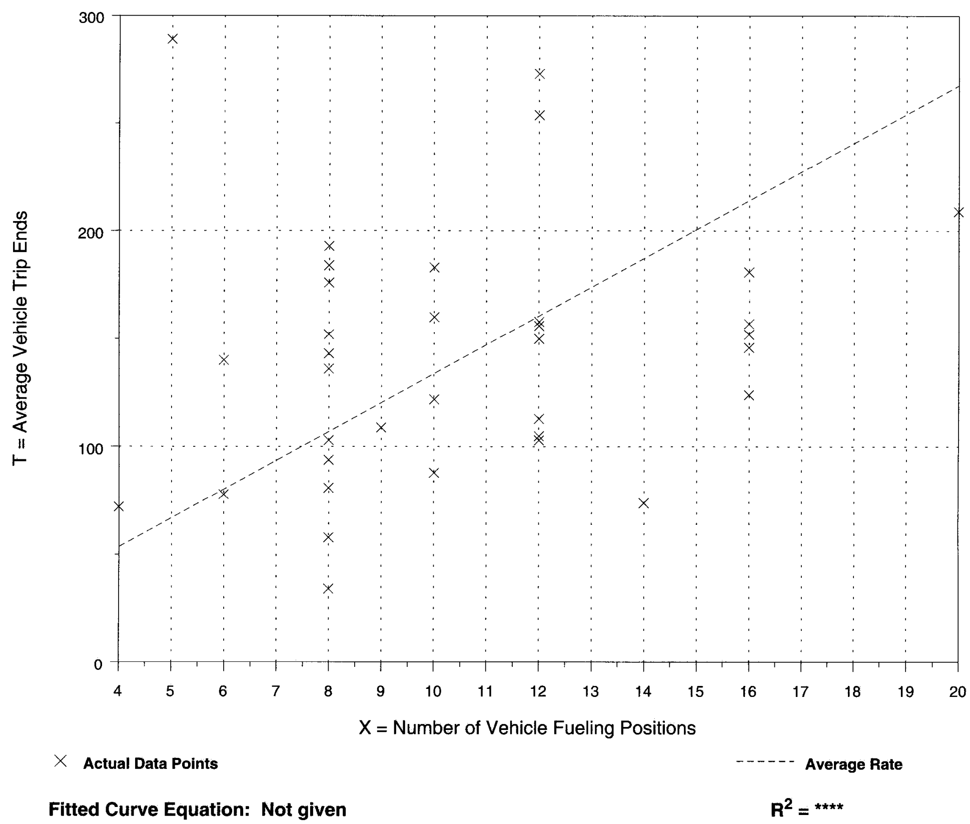

Figure 2. Land Use 945 Plot

This plot was derived from trip generation data in the PM peak hour of a typical weekday. The primary problem seems to be that the number of fueling positions is not adequately describing the trips generated by the facility. For instance, a site with eight fueling positions could be located on a heavily traveled arterial. The high volume of traffic, along with the number of fueling positions or some other information, could help describe the site more clearly. A further look at this idea will be considered during the analysis.

Another pitfall in the data presented in *Trip Generation* is the lack of significant data describing pass-by trips. Pass-by trips are defined as trips that are made on the way from an origin to a destination without changing your intended route. These trips should be recognized because their impact on the current through traffic is less in comparison to primary trips which add new traffic as commuters trying to access the facility turn off of their originally planned route, thus impacting the adjacent roadway traffic at the facility. The *Trip Generation Handbook* notes "The pass-by trip making phenomenon, if estimated to be significant, should be recognized when examining the traffic impact of a development on the adjacent street system." These are especially significant with the fast-food and fueling center developments, which are estimated to have pass-by trips of approximately 45% and 60%, respectively (*11*). Users of such estimates are cautioned by ITE because they are based on limited samples and are generally not as accurate as estimates of trip ends. Whenever, possible, local data should be collected. The *Trip Generation Handbook* notes pass-by trips "are closely linked to the size of the development and the volume of traffic on the adjacent street that can deliver the pass-by trips. However, predictive mathematical relationships have been elusive."

STATE SURVEYS, RESEARCH, AND ALTERNATE APPROACHES

A select number of states and municipalities have made attempts to figure out the complex nature of multi-use fueling stations because of their observations and experience that indicate they may be underestimating trips. In an attempt to gather information from other states, the research team worked by email and phone to survey each of the state DOT's and various municipalities across the country. Through email and phone communication with state and municipal groups, we determined that a large number of analysts use ITE rates produced in *Trip Generation.* Of fifty-one agencies (including the fifty states and the District of Colombia) surveyed, forty-one responded. Of the forty-one respondents, all but five (88%) use ITE rates exclusively (Table 5). The five states (Florida, New Jersey, New Hampshire, New Mexico, Virginia) that differed either used their own rates or developed rates or additional information in addition to that of ITE. Florida was the only state that was able to provide information about other municipalities. This section will summarize findings from the survey, various state methodologies, their findings, and alternative approaches that other states and municipalities have used to evaluate current ITE rates versus their own, as well as new methods for evaluating trip ends.

Table 5. States Using ITE Rates Exclusively

Alaska	Delaware	Kansas	Mississippi	North Dakota	Tennessee
Arizona	Georgia	Kentucky	Missouri	Ohio	Texas
Arkansas	Idaho	Louisiana	Montana	Oklahoma	Utah
California	Illinois	Massachusetts	Nebraska	Oregon	West Virginia
Colorado	Indiana	Michigan	Nevada	Rhode Island	Wisconsin
Connecticut	Iowa	Minnesota	New York	South Dakota	Wyoming

The Southern New Hampshire Planning Commission started a long range plan in October 2005 to study land uses that were in need of further analysis because of the lack of available ITE data (*12*). Eighteen land use types were chosen for this study, of which four did not exist in the ITE *Trip Generation Handbook* at that time. A list of the land use types is shown in Table 6.

Table 6. Southern New Hampshire Planning Commission Land Use Types

ITE Code	Land Use
251/252	Senior Adult Housing Detached/Attached
253/620	Congregate Care Facility/Nursing Home
494	Bowling Alley
565	Day Care Center
630	Clinic
710	General Office Building, 50,000 sq. ft.
732	United Sates Post Office
820	Shopping Center ,50,000 sq. ft.
833/834	Fast Food Restaurant (Dunkin Donuts) w-out/with Drive Through
845	Gasoline/Service Station with Convenience Market
881	Pharmacy/Drugstore with Drive Through Window
-	Large Bookstore
-	Gas Station with Convenience Market and Quick Food
-	Drive Through Only Coffee Restaurant (Quickava)
-	Recreation Ball/Soccer Field Complexes

Due to limited availability of time and resources, Land Uses 845 and 945 were not studied by them at the time of this report. However, their planning commission mentions the inherent need for data collection and analysis of ITE 845: Service Station with Convenience Market and Service Station with Convenience Market and Quick Food.

In a 1992 University of Florida study, research focused on the combination of a convenience store and fueling station (*13*). At that time, the combination of land uses was relatively new and no ITE code existed for convenience stores with gas pumps. The report is a synthesis of four previously conducted trip generation studies that were carried out in Montana and Florida.

One of the studies reviewed by Florida in their research effort was a 1991 document by Greg Luttrel (*13*). This document separated trip types during their data collection effort in 1989. Luttrell and various field personnel attempted to classify trips based on one of three possibilities: a gasoline-only, convenience-only, or a combination trip. Field personnel defined each by observing motorists entering the facility. If a car pulled up to a pump and no one from the car entered the building, it was considered a gasoline-only trip. If anyone from the vehicle went inside while the car was fueling, and returned with some form of groceries, it was considered a combination trip. A vehicle pulling up to the convenience area and not fueling and only entering the store was a convenience-only trip. In this way, the total number of trips could be proportioned out by facility type, with the combination trips proportioned separately. Consider a sample of 100 trips. Assume 50 were for gasoline-only, 40 were convenience-only, and 10 were combination trips. The analysts would calculate a trip generation rate separately for the gasoline-only and convenience-only using the ITE *Trip Generation Handbook*. The proportion of the gasoline trips would be [50+0.50(10)] = 55 trips. The proportion of convenience trips would be [40+0.40(10)] = 44 trips. The "leftover" trip would go the gasoline trip ends due to the larger proportion being in this category, making a total of 56 trips for the gasoline stations and 44 trips to the convenience store.

In addition, surveys were conducted to determine percentages of pass-by, primary, and diverted link trips. This helped determine a more accurate interpretation of the number of new, or non-pass-by, trips added to the roadway network. Independent variables included: GFA (Gross Floor Area) of the building, number of gas pumps, total traffic adjacent to site, and distance to the central business district (CBD). Linear regression was used to aid in correlating the choice variables to trips. In this case, the distance to the CBD was the only variable with strong correlation. However, the study recommended that distance to CBD not be used as an estimator of trip generation because it is site specific.

Looking at data from the previous efforts of Luttrell, as well as three other cited references, Florida's end result was the development of a model that was based on two variables: gross floor area and gas pumps. These variables should be easily accessible to an engineer when a traffic impact study is conducted. A continuous model was created which eliminated discontinuities between ranges of the dependent variable when different rates are employed for different ranges. A multiple linear regression analysis was used to generate the following model:

Site trips during P.M. Peak hour of adjacent street = 0.0382 * GFA + 16 * Pumps

The primary flaw of this model is that there is no intercept value. This means that the model was forced through the origin, which in turn makes the model have an increased R^2 value (reported as $R^2 = 0.904$) because the model is treating the origin as an actual data point with no variance.

Table 7. Average Daily Trips of Convenience Markets with Gas Pumps (*13*)

Gross Square Feet	Number of Pumps • 2	3	4	5	6	7	8	9	10	11	12
700	877	1,116	1,354	1,593	1,832	2,071	2,310	2,548	2,787	3,026	3,265
750	905	1,144	1,383	1,622	1,860	2,099	2,338	2,577	2,816	3,054	3,293
800	934	1,173	1,411	1,650	1,889	2,128	2,367	2,605	2,844	3,083	3,322
850	962	1,201	1,440	1,679	1,917	2,156	2,395	2,634	2,873	3,111	3,350
900	991	1,230	1,468	1,707	1,946	2,185	2,424	2,662	2,901	3,140	3,379
950	1,019	1,258	1,497	1,736	1,974	2,213	2,452	2,691	2,930	3,169	3,407
1,000	1,048	1,287	1,525	1,764	2,003	2,242	2,481	2,719	2,958	3,197	3,436
1,050	1,076	1,315	1,554	1,793	2,031	2,270	2,509	2,748	2,987	3,226	3,464
1,100	1,105	1,344	1,582	1,821	2,060	2,299	2,538	2,776	3,015	3,254	3,493
1,150	1,133	1,372	1,611	1,850	2,089	2,327	2,566	2,805	3,044	3,283	3,521
1,200	1,162	1,401	1,639	1,878	2,117	2,356	2,595	2,833	3,072	3,311	3,550
1,250	1,190	1,429	1,668	1,907	2,146	2,384	2,623	2,862	3,101	3,340	3,578
1,300	1,219	1,458	1,696	1,935	2,174	2,413	2,652	2,890	3,129	3,368	3,607
1,350	1,247	1,486	1,725	1,964	2,203	2,441	2,680	2,919	3,158	3,397	3,635
1,400	1,276	1,515	1,753	1,992	2,231	2,470	2,709	2,947	3,186	3,425	3,664
1,450	1,304	1,543	1,782	2,021	2,260	2,498	2,737	2,976	3,215	3,454	3,692
1,500	1,333	1,572	1,810	2,049	2,288	2,527	2,766	3,004	3,243	3,482	3,721
1,550	1,361	1,600	1,839	2,078	2,317	2,555	2,794	3,033	3,272	3,511	3,749
1,600	1,390	1,629	1,867	2,106	2,345	2,584	2,823	3,061	3,300	3,539	3,778
1,650	1,418	1,657	1,896	2,135	2,374	2,612	2,851	3,090	3,329	3,568	3,806
1,700	1,447	1,686	1,924	2,163	2,402	2,641	2,880	3,119	3,357	3,596	3,835
1,750	1,475	1,714	1,953	2,192	2,431	2,669	2,908	3,147	3,386	3,625	3,863
1,850	1,532	1,771	2,010	2,249	2,488	2,726	2,965	3,204	3,443	3,682	3,920
1,950	1,589	1,828	2,067	2,306	2,545	2,783	3,022	3,261	3,500	3,739	3,977
2,050	1,646	1,885	2,124	2,363	2,602	2,840	3,079	3,318	3,557	3,796	4,034
2,150	1,703	1,942	2,181	2,420	2,659	2,897	3,136	3,375	3,614	3,853	4,091
2,250	1,760	1,999	2,238	2,477	2,716	2,954	3,193	3,432	3,671	3,910	4,149
2,350	1,817	2,056	2,295	2,534	2,773	3,011	3,250	3,489	3,728	3,967	4,206
2,450	1,874	2,113	2,352	2,591	2,830	3,069	3,307	3,546	3,785	4,024	4,263
2,550	1,931	2,170	2,409	2,648	2,887	3,126	3,364	3,603	3,842	4,081	4,320
2,650	1,989	2,227	2,466	2,705	2,944	3,183	3,421	3,660	3,899	4,138	4,377
2,750	2,046	2,284	2,523	2,762	3,001	3,240	3,478	3,717	3,956	4,195	4,434
2,850	2,103	2,341	2,580	2,819	3,058	3,297	3,535	3,774	4,013	4,252	4,491
3,000	2,188	2,427	2,666	2,904	3,143	3,382	3,621	3,860	4,099	4,337	4,576
3,150	2,274	2,512	2,751	2,990	3,229	3,468	3,706	3,945	4,184	4,423	4,662
3,300	2,359	2,598	2,837	3,076	3,314	3,553	3,792	4,031	4,270	4,508	4,747
3,450	2,445	2,683	2,922	3,161	3,400	3,639	3,877	4,116	4,355	4,594	4,833
3,600	2,530	2,769	3,008	3,247	3,485	3,724	3,963	4,202	4,441	4,679	4,918

For calculating the average daily site trips for the Florida data, the percentage of P.M. peak hour trips to average daily trips was found to be 6.7%. The P.M. peak hour trips should be divided by this percentage to find the average daily site trips. A matrix is shown in Table 7 for values of gross floor area every fifty square feet. Last, the Florida report emphasizes the importance of terminology, particularly in the various definitions of "fueling positions" or "pumps." A fueling position, or pump, is defined as the number of available positions for vehicles to fuel simultaneously at a given gasoline facility.

A 2001 study conducted by the Evansville Urban Transportation Study (EUTS) in Evansville, Indiana focused on the comparison of local trip generation rates to ITE Trip Generation Rates for five land use types (*14*). As a part of this effort, five gas station locations where studied. Each location contained gasoline pumps, a convenience store, and a fast-food restaurant. ITE Land Use 945: Gasoline/Service Station with Convenience Market experienced the largest difference in trip ends when compared with five gas stations with convenience market and fast food. Direct comparison showed that when using this ITE land use code to evaluate these facilities, EUTS rates were found to be 57% to 70% lower (see Tables 8 and 9).

Table 8. EUTS Analysis Results

Land Use	Independent Variable	Weekday	Generator		Adjacent Street	
			AM Peak	PM Peak	AM Peak	PM Peak
Gas Station w/ Convenience Store & Fast Food Restaurant	Thousand Sq. Ft.	416.79	33.84	35.97	26.33	28.52

Table 9. Comparison of ITE and EUTS Rates

Land Use	Time Frame	ITE Rate	EUTS Rate	Difference
Gas Station w/ Convenience Store & Fast Food Restaurant	Weekday	N/A	416.79	N/A
	AM Peak Hour Generator	78.06	33.84	-57%
	PM Peak Hour Generator	97.14	35.97	-63%
	AM Peak of Adjacent St.	77.68	26.33	-66%
	PM Peak of Adjacent St.	96.37	28.52	-70%

EUTS stated the differences could be attributable to the small sample size or the fact that the locations were not near interchanges of highways and interstates as in the ITE *Trip Generation Handbook*. Further, since Land Use 945 provides average trip rates and no fitted curve equation (and thus no R^2 value), a difference in rates from EUTS and ITE is very likely. In summary, EUTS concluded that ITE rates serve as a conservative estimate of rates in the Evansville area. The study concluded that the results can be assumed to verify that national rates are representative of local conditions, but more studies are needed to completely verify this conclusion.

The City of San Diego developed trip generation rates specific to their region (*15*). Table 10 shows trip generation rates San Diego uses for fueling stations with various combinations of facilities. These are average rates based on the number of vehicle fueling positions.

Table 10. San Diego Trip Generation Rate Summary

Land Use	Driveway Vehicle Trip Rate	Cumulative Vehicle Trip Rate	Peak Hour In/Out Ratio	
			AM (In:Out)	PM (In:Out)
Gasoline Station	130 trips/vehicle fueling space; 750 trips/station	26 trips/vehicle fueling space; 150 trips/station	7% (5:5)	11% (5:5)
Gasoline Station with Food Mart	150 trips/vehicle fueling space	30 trips/vehicle fueling space	8% (5:5)	8% (5:5)
Gasoline Station with Fully Automated Carwash	135 trips/vehicle fueling space	27 trips/vehicle fueling space	- -	- -
Gasoline Station with Food Mart & Fully Automated Carwash	155 trips/vehicle fueling space	31 trips/vehicle fueling space	8% (5:5)	9% (5:5)

Note: Driveway trips refer to the number of total trips to the site, while cumulative trips refer to new vehicle trips to the community (i.e. diverted trips). Total trips equal the sum of cumulative and pass-by trips.

The Virginia DOT primarily uses *Trip Generation* to evaluate impacts of various land uses on roadways. In email communications with VDOT staff, the only variation from ITE rates were under rare or extenuating circumstances (*16*). The only variation for fueling facilities noted during the survey was a weighted average trip rate of 850 vehicles/day for Land Use 853: Convenience Market with Gasoline Pumps.

The New Mexico DOT primarily relies on the registered professional engineer that prepares the study for traffic impacts of facilities (*17*). Those traffic impact studies typically follow ITE rates for various land uses. However, a recent study the NMDOT reviewed did utilize traffic counts from existing facilities. No information was given regarding whether those numbers reflected similar rates to that of ITE. Suggestions were also given to the research team about considering actual fuel sales at existing facilities. This data could be summarized by various time periods and average fuel purchases could be determined. No suggestions for how to deal with fast-food at these fueling facilities were given.

New Jersey DOT is similar to other states in that they do not have any information on how to deal with fueling centers with convenience markets and fast food. However, during the survey, NJDOT personnel noted that the department stopped using ITE rates in 1992. They adopted their own rates for gasoline stations depending on whether they had fuel only, a convenience market, service bays, or a car wash. It was noted that "The change was triggered because gasoline companies believed that the ITE rates varied too much for each independent variable and they were not appropriate for NJ stations." It was noted that these rates were developed prior to the mega-pump developments with large convenience markets and/or fast food. The rates being used at this time in NJ are presented in Table 11.

Table 11. New Jersey DOT Trip Generation Rates

Facility	AM Peak	PM Peak	Daily Volume
Gasoline Only	71	92	1012
Gasoline/Service Station	81	86	781
Gasoline Station with Convenience Market (<2000 sf)	128	129	1224
Gasoline Station with Convenience Market (>2000 sf)	Use ITE Land Use Code 853		
Gasoline Station with Car Wash	108	94	1174
Gasoline Station with Convenience Market (< 2000 sf) and Car Wash	110	151	1288

SUMMARY

The literature review and email requests to state and municipal agencies confirm that minimal research has been conducted to improve upon ITE trip generation methods at fueling centers, especially newer facilities including additional pumps, convenience, and even fast food in many cases. Those states that have collected additional data have found that it is very hard to accurately predict trip demand at fueling centers, with local data still falling back to average rates because significance testing of linear models shows little to no strong correlation. Florida is the only state noted to use an alternative analysis method. Multi-linear regression was used; however, the results were significantly flawed because the R^2 value was highly overestimated by forcing the trend line through the origin. Last, the pass-by trip phenomenon seems to be very high at fueling centers, with estimates ranging from 45% to over 80%.

SITE SELECTION AND FACTORS

Site selection was an integral component in determining the outcome of the trip generation model for fueling centers studied. In initial meetings with NCDOT, an agreement was reached that the thirty sites would be chosen based on a wide range of different factors, while understanding that we had a limited sample of sites to include such factors. Figure 3 shows a flowchart outlining the site selection process based on limited, but important factors. These factors were determined by the research team based on past literature and input from NCDOT during the kickoff meeting. The number of ***desired*** sites is noted at various points in the chart in parentheses.

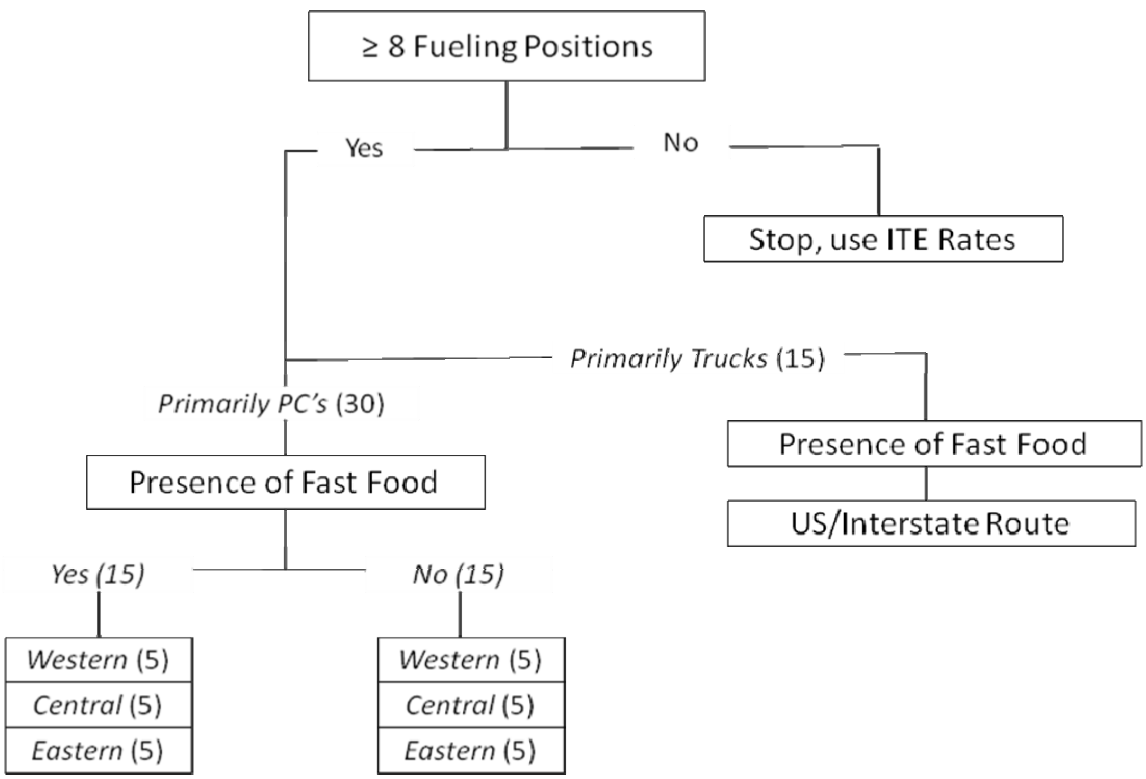

FIGURE 3. Site Selection Flow Chart (Number of <u>Desired</u> Sites)

During site selection stage of this research effort, the research team along with NCDOT Regional and Division Traffic Engineers gathered a list of potential sites together with known characteristics, fitting the criteria in the flow chart. A total of seventy sites were obtained, with forty-five sites falling in the ‘primarily passenger car’ criteria. The sites were distributed as follows across the State:

Table 12. Actual Site Distribution for “Primarily Vehicle” Sites Submitted by NCDOT Personnel

	East	Central	West	Total
No Fast Food	5	15	7	27
Fast Food	6	7	5	18
Total	11	22	12	45

The primary ‘factors’ the team looked for in the site selection process were:

- **Vehicle Type.** This research effort specifically focuses on sites consisting of ‘primarily’ vehicular traffic, and not heavy vehicles. It is important to note that many sites selected for the study do include fueling positions for heavy vehicles. In addition to this research effort, the research team assisted NCDOT in selecting fifteen primarily heavy vehicle sites for a separate research effort to be conducted by NCDOT.
- **Fueling Positions.** Each site contained a minimum of eight fueling positions. The number of fueling positions at a site is defined as the maximum number of vehicles that can be fueled at once. The ITE *Trip Generation Handbook* has limited data for fueling positions, which was discussed by all present during the kickoff meeting. A model was needed that more accurately portrayed how many trips were generated by larger gas stations. The final selection featured sites with a range of eight to twenty-four fueling positions.
- **Fast Food.** Another very important factor was the presence of fast food at a gas station. Of the thirty total sites chosen, the presence of fast food was chosen at half the sites. Two reasons exist for this split in the distribution of sites. First, ITE has limited reliable or updated information relating to the fueling center with a convenience store. NCDOT wanted to gather specific data in the state in hopes of alleviating this problem. Second, fast food is becoming very popular at many of the larger fuel centers. However, there is

no land use in the ITE *Trip Generation Handbook* for sites that include fueling stations and fast food. Currently, NCDOT makes decisions based on the addition of the trips for each land use analyzed separately. It is important to note that eight of the fifteen fast food sites chosen for study included a drive-through facility.

- **Area.** North Carolina is known to have varying traffic and geographical characteristics from east to west. To help eliminate any bias in the data, the team decided that, to the extent possible, data collection would equally cover three zones – Western, Central, and Eastern. The Western boundary was the I-77 corridor and the Eastern boundary was the I-95 corridor. A site located on one of these two interstates was considered either Western or Eastern for sample distribution considerations.

In addition to the flow chart in Figure 3, the team also attempted to distribute sites based on the following secondary factors thought to be influential:

- **Traffic Volume.** ADT's were collected from NCDOT's website along any major roadways. Traffic volumes are indicative of the vehicular exposure a facility receives. For instance, a site within one mile of an interstate, and at an intersection, would include the sum of ADT's from all of the adjacent roadways plus the interstate. ADT exposures ranged anywhere from about 13,000 to 205,000 vehicles per day (vpd).
- **Bordering Roadway Facility Type.** Traffic volume could be accounted for in another variable, roadway facility type. This factor was based on the presence of an interstate facility within one mile of the site. Traffic volumes are typically much higher along interstate facilities, in addition to the fact that trips along an interstate are longer on average.

Each site was mapped so the team could see site dispersion throughout the state. Mapping also allowed the team to 'color code' sites by presence of fast food. Sites were then chosen in a manner that was consistent with the methodology selection. The final site distribution is shown in Figure 4.

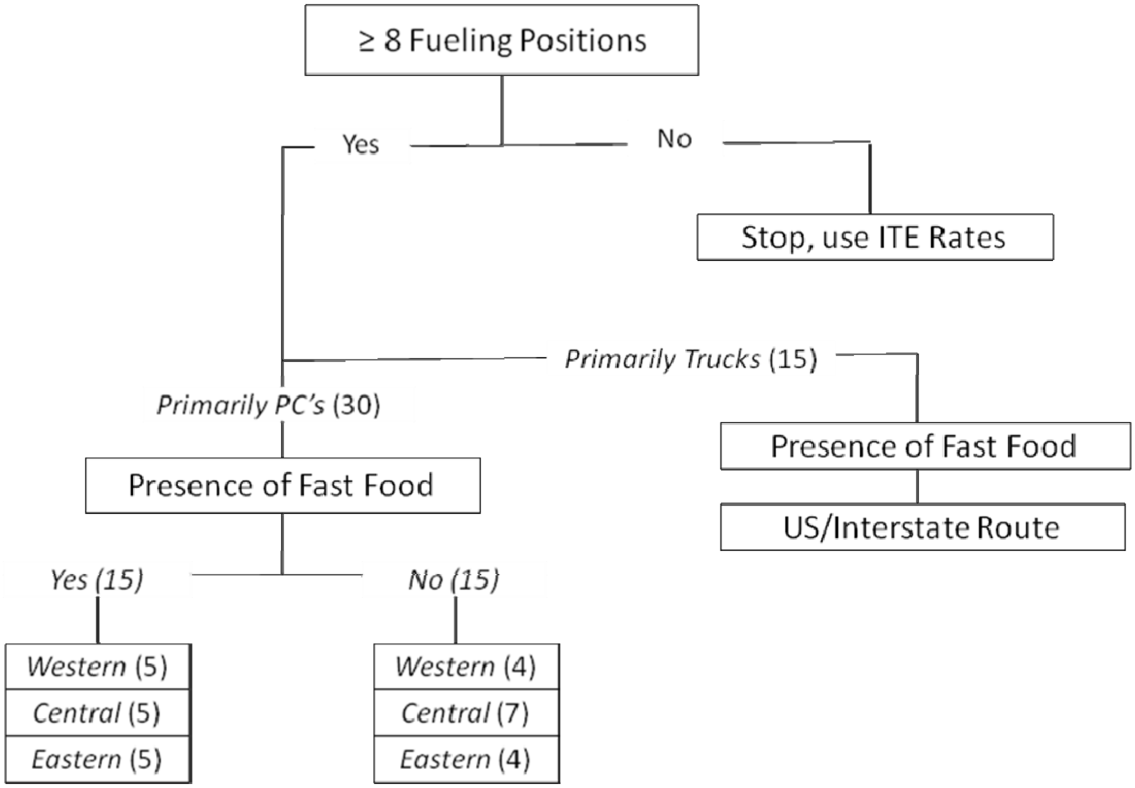

FIGURE 4. Site Selection Flow Chart (Number of Actual Sites)

DATA COLLECTION

Data was collected from February 6 to April 25, 2007. This time frame allowed us to collect data around extraneous weather events and school breaks or holidays. In addition, the spring is typically considered to have a slightly lower number of non-typical traffic events than the fall months due to the number and types of holidays.

With a secondary goal of submitting the data to ITE for the upcoming ITE Trip Generation update, the team made every effort to follow ITE guidelines during data collection. When conducting a trip generation study, the time period that should be analyzed is when the combination of the trip generated traffic and adjacent street traffic is at a maximum *(9).* Two pilot data collections were done to determine the peaking characteristics of these types of sites. ITE asks that a minimum of two hours of data collection during the peak periods be collected. At two randomly chosen sites, the team determined that peaking occurred during the AM and PM from 7:00 - 9:00 and 4:30 - 6:30, respectively. Because these times concur with typical peak times on adjacent roadways during the week, the team selected this to be the correct data collection time period for fuel center sites in North Carolina. The data collection summary can be found in Appendix A.

Directional traffic volume counts (entering and exiting) were manually recorded in fifteen minute increments during each two hour window. An array of various data was recorded at each site for further analyses. An example of a completed data sheet is shown in Figure 5. Most data are sufficiently described in the previous section; however, there are a couple of categories not previously described which should be explained. These are:

- **Square Footage.** ITE uses fueling positions and square footage as independent variables for the fueling center with convenience store. However, fueling positions are not a good descriptor for sites including fast food, and it is highly likely that another variable is needed such as square footage. Square footage is a rough field estimate based on assumed parking lane widths in front of the store or 'stepping off' the area using a rough 1 step equals 3 feet estimate.

- **Pass-by Trips.** One of the key arguments during the site impact analysis is the percentage of pass-by trips. Of all the various types of sites analyzed, the fast food restaurant and the fueling center with convenience store likely have the highest percentage of pass-by trips. Literature suggest that pass-by trips for fueling centers typically fall somewhere in the range of 45-80% *(10, 11, and 18)*, with fast food restaurants slightly lower.
- **Intersection.** One of the key variables hypothesized as being important was the adjacent traffic flow. This was a "yes/no" variable. Exposure of traffic from two roadways, such as at a signalized intersection, would be important information to gather in the field to account for vehicular exposure at the site.
- **Adjacent Traffic Flow.** NCDOT's Traffic Surveys Unit gathered updated field traffic counts using tubes at adjacent roadways near the sites of interest. If the site was not at a signalized intersection, only one tube count was obtained; if it was, two tube counts were taken (one along both roadways). If the site was within one mile of an interstate, traffic counts for the interstate were obtained from NCDOT's website. The total 'exposure', or traffic flow of all relevant ADTs combined, was used in the analysis portion of this project.
- **Heavy Vehicle Information.** Although this specific research effort only dealt with sites primarily used by passenger cars, many sites had trucking facilities. Most of the larger facility types this research effort focused on were newer, more contemporary sites which accommodated varying vehicular traffic. The goal was not to exclude those types of facilities, but to make sure the excluded sites catered to heavy vehicles (typically referred to as a truck stop). Diesel fueling positions, trips, and truck parking were collected for further analysis.

Candidate Site Information			
Fueling Center Name:	Wilco Travel Plaza		Site #: 4
Fast Food Restaurant Name:	Dairy Queen, Wendy's		
Convenience Square Footage:			8100
Fast Food Square Footage: DQ (30X75) + Wendys (40X75)			5250
DQ # Seats = 16		Wendys # Seats = 96	
# Gasoline Fueling Positions:	10	Vehicle Spaces:	80
# Diesel Fueling Positions:	12	Truck Parking Spaces:	150
● Car Wash Present			
Location			
County:			○ Urban
Municipality:			● Rural
Location:			○ Suburban
Adjacent Traffic Flow	**Survey Results**		**Intersection**
Primary Roadway:	% Pass-by (AM):	20	○ Yes
Secondary Roadway:	% Pass-by (PM):	33.3	● No
● Adjacent Freeway within 1 mile of Fueling Station			
Notes: Driveway entrance for Trucks causing problems on three lane adjacent to site, especially exiting truck traffic.			

Driveway Counts

Note: Mark Driveway Numbers on Diagram Below

	Driveway #	Gas	Fast Food	Both	Trucks
AM	7:00 - 7:15	20	1	0	9
AM	7:15 - 7:30	26	0	1	6
AM	7:30 -7:45	17	1	0	6
AM	7:45 - 8:00	23	3	0	7
AM	8:00 - 8:15	21	5	0	6
AM	8:15 - 8:30	14	2	0	14
AM	8:30 - 8:45	16	4	0	5
AM	8:45 - 9:00	17	7	1	12
PM	16:30 - 16:45	41	7	0	9
PM	16:45 - 17:00	41	6	0	11
PM	17:00 - 17:15	38	4	1	9
PM	17:15 - 17:30	33	8	0	8
PM	17:30 - 17:45	26	5	0	5
PM	17:45 - 18:00	29	2	2	12
PM	18:00 - 18:15	39	6	0	5
PM	18:15 - 18:30	29	8	1	8

Site Picture

Site Layout (Plan View)

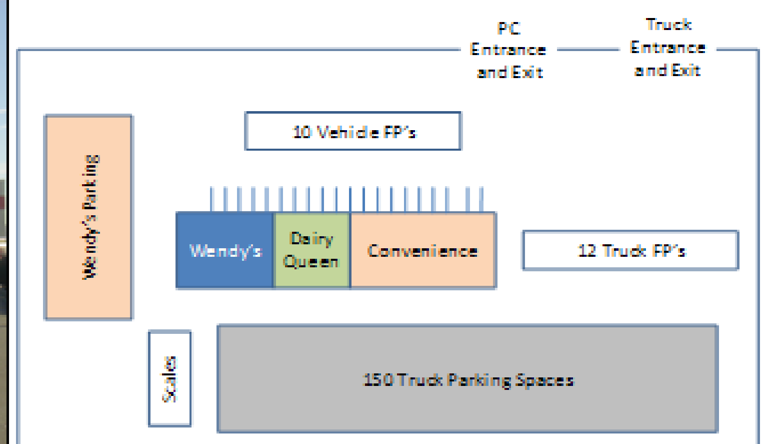

Figure 5. An Example of a Data Collection Sheet

PASS-BY TRIPS AND SPECIFIC DRIVEWAY ACCESS ISSUES

Accounting for Pass-by Trips

The fueling center and fast-food restaurant facilities are two of the most controversial generators of traffic. Traffic engineers are aware that these two types of facilities inherently have a large percentage of "pass-by" traffic. However, there is no good data to support that hypothesis, and thus the reason ITE does not report this type of information in the ITE *Trip Generation Handbook*.

The team ***attempted*** to classify pass-by and diverted trips at each of the facilities using a surrogate method while manually counting inbound and outbound traffic. A diverted trip was classified as a vehicle entering from one direction, and subsequently exiting in the opposite direction of travel. This type of trip was considered to be a fair and accurate representation of a diverted trip. A pass-by trip was one where a vehicle entered and exited in the same direction of travel. The data collection team believes that these data were collected accurately, although the method was not perfect. Table 13 shows the percent of pass-by trips at each facility type as collected by the team.

Table 13. Pass-by Trips

Average Trips		
Site Type	Time	Pass-by
All (30)	AM	63%
	PM	61%
Non FF (15)	AM	65%
	PM	68%
FF (15)	AM	61%
	PM	54%

However, attempts at collecting this type of data inherently have some problems. For instance, access management techniques, such as median U-turns, may have forced the driver to right in/right out which would cause a diverted driver to U-turn prior to, or after, entering the site to go back in the direction they came. Without some specific questions and responses from drivers during these time periods, it is difficult to be certain about these findings.

Although error certainly exists in the data collection methodology for pass-by trips, the data does align with other information collected by Florida DOT and IBI Group. In the literature review, it was noted that Florida DOT reports that pass-by trips ranged from 45%-80% during their data collection. IBI reported that 60% or more of the trips at a fueling station are typical and that fast food restaurants have slightly lower percentages of 45% pass-by trips. Sites containing no fast food during this data collection had a larger proportion of pass-by trips on average than those that contained a fast food restaurant. Based on these comparisons, it can be stated that these findings are generally consistent with that of Florida DOT and IBI Group, but the methods for collecting this data could be overstating the significance of the pass-by trip phenomenon.

Access Issues Noted in the Field

In addition to collecting pass-by trip data, the team recorded any visible traffic operational and safety issues at the fuel centers studied. The idea was that specific problem areas observed in the field could be noted in the report for future reference by the appropriate NCDOT personnel. Pictures were obtained, when possible. In some instances, aerial photographs were used from the internet. The images and descriptions can be found in Appendix B.

ANALYSIS

INTRODUCTION

The analysis began with a compilation of the data from the field data collection. The research team determined that a multi-faceted approach to the analysis would provide the most comprehensive results. The two approaches included analyzing the data in 1) the typical ITE formats and 2) a multi-variable regression equation format. The ITE formats include an average rate and a single-variable regression equation. The average rate is the most simplistic and basic format of the three types. According to ITE guidelines, this approach is used when the R^2 value does not meet minimum requirements for the regression equation. Likewise, when an equation has an appropriate R^2 value or large data set, the equation should be utilized. Although not considered in the ITE *Trip Generation Handbook*, based on the literature review, the team decided to consider a multivariable equation approach in the event that a more precise model based on multiple variables could be determined.

SINGLE-VARIABLE LINEAR REGRESSION ANALYSIS

Background

Regression analysis using a single independent variable is the method used by ITE in predicting traffic demand at a facility. This method is simple in nature, and thus practical for use by engineers trying to forecast demand based on limited site factors. The basic methodology for single regression analysis is a trend line fit to a specific data set. ITE selects the type of trend line (linear or log-linear) that best represents the data based on the R^2 value. In many cases, a weighted average is used. Reasons could include a limited data set, poor R^2 value for the trend line, or too much variance in the data. Figure 1, presented in the Literature Review, lays out the framework for when to use average rates versus the regression equation.

The weighted average rate calculations are based on standard ITE guidelines. The equations for weighted average rate and the standard deviation are shown below.

$$\text{Weighted Average Rate} = \frac{\sum \textit{Vehicle Trips}}{\sum \textit{Independent Variables}} \quad \textbf{(Equation 1)}$$

$$\text{Standard Deviation} = \sqrt{\frac{1}{(N-1)}\sum_{i=1}^{N}(x_i - \bar{x})^2} \quad \textbf{(Equation 2)}$$

Results

From the data collection effort, the team was able to obtain data on many of the attributes related to fueling facilities. For fueling center and fast food facilities, NCDOT recommends the use of ITE rates with independent variables of fueling positions (FP) and gross floor area (GFA) (*19*). Based on the site selection criteria, critical categories were developed for analysis. Figure 6 shows a flow chart of how the thirty sites were categorized for the ***analysis***, along with the available sample sizes for each category. *It is important to note that although the team analyzed all categories, the sample sizes were very limited outside of the presence of a fast food restaurant.*

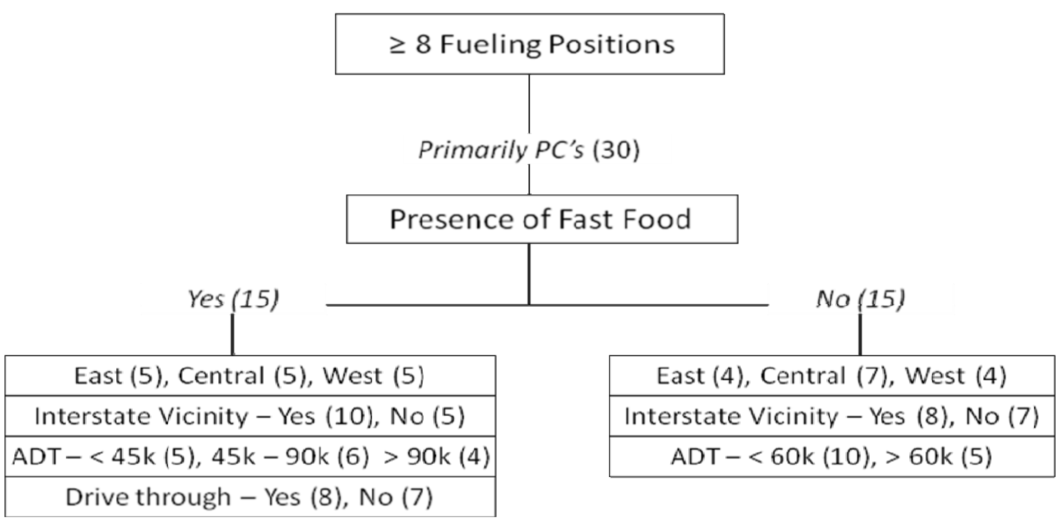

Figure 6. Analysis Categorization Flowchart

Next, a linear or log-linear trend line was superimposed over the scatter plot of data for each independent variable in all of the categories. The plots can be viewed separately in Appendices C, D, and E. The results from these plots are summarized in

Table 14, below. Forty different categories are shown. ITE guidelines suggest using the regression equation when a category contains more than twenty data points, provided the regression equation is given ($R^2 > 0.5$).

Table 14. Descriptive Statistics of Various Categories of Data Using Linear Regression Models

Site Description		Sample Size	Peak Hour	R^2 - FP	R^2 - GFA	Page #
All Sites	All Sites	30	AM	0.033	0.000	A - 2
			PM	0.018	0.094	A - 3
Fast Food	All Sites	15	AM	0.000	0.193	B - 2
			PM	0.024	0.057	B - 3
	ADT < 45,000	5	AM	0.027	0.235	B - 4
			PM	0.086	0.072	B - 5
	45,000 ≤ ADT < 90,000	6	AM	0.094	0.037	B - 6
			PM	0.283	0.013	B - 7
	ADT ≥ 90,000	4	AM	0.365	0.366	B - 8
			PM	0.927	0.012	B - 9
	Without Drivethrough	7	AM	0.005	0.017	B - 10
			PM	0.005	0.390	B - 11
	With Drivethrough	8	AM	0.012	0.435	B - 12
			PM	0.092	0.056	B - 13
	Non-Interstate Location	5	AM	0.096	0.056	B - 14
			PM	0.624	0.446	B - 15
	Interstate Location	10	AM	0.060	0.179	B - 16
			PM	0.150	0.052	B - 17
	Western NC Location	5	AM	0.015	0.218	B - 18
			PM	0.005	0.002	B - 19
	Central NC Location	5	AM	0.152	0.360	B - 20
			PM	0.747	0.015	B - 21
	Eastern NC Location	5	AM	0.006	0.062	B - 22
			PM	0.664	0.034	B - 23
Non-Fast Food	All Sites	15	AM	0.001	0.118	C - 2
			PM	0.002	0.020	C - 3
	< 60,000 ADT	10	AM	0.108	0.168	C - 4
			PM	0.129	0.008	C - 5
	≥ 60,000 ADT	5	AM	0.074	0.254	C - 6
			PM	0.092	0.001	C - 7
	Non-Interstate Location	7	AM	0.084	0.311	C - 8
			PM	0.003	0.096	C - 9
	Interstate Location	8	AM	0.062	0.052	C - 10
			PM	0.001	0.000	C - 11
	Western NC Location	4	AM	0.218	0.292	C - 12
			PM	0.161	0.000	C - 13
	Central NC Location	7	AM	0.101	0.097	C - 14
			PM	0.005	0.000	C - 15
	Eastern NC Location	4	AM	0.455	0.939	C - 16
			PM	0.201	0.532	C - 17

The only data set meeting the sample size requirement was "All Sites" containing thirty data points. However, this data set had an $R^2 = 0.1$, indicating a poor fit. Thus, the regression equation would not be included with this data plot because a minimum $R^2 \geq 0.5$ is needed to show the equation. However, this is to be expected since two very different groups of fueling centers (with and without fast food) are being categorized.

Second, there were only two categories of data that met the $R^2 \geq 0.75$ criteria with samples between six and twenty data points. In this case, ITE suggests using the regression equation. However, even these two categories fall short because the second requirement states that a minimum sample size of twenty sites is needed to use the regression equation, with recommendations to collect local data for smaller data sets.

This detailed linear analysis of all the different categories did not produce any conclusive results, although this was not totally unexpected. It is fairly well documented by trip generation experts that many various factors contribute to the use of a fueling station, of which a significant amount cannot be measured or understood (i.e. fuel price, vicinity to other fueling sites, etc). Therefore, average rates would need to be used ***if*** single-variable regression analysis was the method of choice.

If linear analysis is the preferred analysis method, the preferred independent variable for both non-fast food and fast food categories would be gross floor area. Gross floor area is preferred because the R^2 values are typically higher than those using fueling positions at non-fast food sites, and fast food sites cannot use fueling positions because they are not correlated (i.e. fueling positions cannot describe a dining establishment). In meetings with NCDOT, they also asked the team to look at a separate category of sites. These were termed "Hybrid" sites, and were described as non-fast food sites with added convenience such as order at the pump (i.e. there were food items that could be ordered such as sandwiches or coffee), larger convenience and fueling facilities, etc. Tables 15 and 16 show average rates presented in terms of fueling positions and 1,000 square feet of gross floor area, respectively. Appendix F contains detailed information on average rates.

Table 15. Average Rate Data by Fueling Positions

Site	Peak Hour	Average Independent Variable	Sample Size	Average Rate	Range of Rates (Trips per FP)	Standard Deviation
Fast Food	AM	12 FP's	15	19.13	8.30 - 39.33	9.81
	PM			21.78	9.20 - 43.20	9.35
Non-Fast Food	AM	16 FP's	11	9.26	4.67 - 22.67	6.23
	PM			11.59	6.42 - 27.00	6.33
Hybrid	AM	15 FP's	4	20.40	15.75 - 24.43	3.60
	PM			23.23	19.88 - 25.63	2.66

Table 16. Average Rate Data by 1,000 Sq. Ft. Gross Floor Area

Site	Peak Hour	Average Independent Variable	Sample Size	Average Rate	Range of Rates (Trips per 1,000 Sq. Ft. GFA)	Standard Deviation
Fast Food	AM	8,000 Sq. Ft. GFA	15	28.90	7.24 - 214.55	56.09
	PM			32.91	12.72 - 179.09	44.04
Non-Fast Food	AM	4,000 Sq. Ft. GFA	11	37.11	18.67 - 75.56	15.50
	PM			46.48	23.21 - 90.00	17.85
Hybrid	AM	6,000 Sq. Ft. GFA	4	53.13	46.67 - 67.86	9.91
	PM			60.50	45.43 - 75.93	13.81

MULTI-VARIABLE REGRESSION ANALYSIS

Background

While not the typical method for determining trip generation for new developments, the research team hypothesized that the classic variables used by ITE to analyze these newer fueling centers might not be appropriate. Therefore, the team attempted to model fueling centers based on all the representative data collected for each site. Although not commonly used in traffic impact studies, a multi-variable linear regression model could provide the correlation needed to predict trips for these newer fueling centers.

In statistics, a multi-linear regression model looks at the relationship between a dependent variable Y (trips) and multiple independent variables X_i, i = *1*,..., *p*, and a random term *ε*. The model can be written as

$$Y = \beta o + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_p X_p + \varepsilon \quad \textbf{(Equation 3)}$$

where β_o is the intercept ("constant" term), the β_i's are the respective coefficients, or multipliers, of independent variables, and *p* is the number of parameters to be estimated in the linear regression. The method is called “linear” because the relation of the response (the dependent variable, trips) to the independent variables is assumed to be a linear function of the coefficients.

Results

A statistical analysis was performed using SAS. The results can be viewed in Appendices G and H. Consistent with ITE, the dependent variables analyzed were trip ends, and the log of trip ends. Each of the independent variables explained previously in the Site Selection and Data Collection sections were analyzed. The variables were:

- **FF:** This variable accounted for three different facilities (non-fast food, fast-food, and “hybrid”), each containing a gas and convenience component. A fast food facility would be defined as being able to “stand alone”, while a hybrid would be a site somewhere between a non-fast food and fast food. Such characteristics could include pay at the pump, order at the pump, indoor seating, and a wide array of convenience items not typically seen in more typical fueling facilities.
- **DRIVE:** Was a drive-through present? This variable would help distinguish between many of the fast food facilities.
- **FUEL:** The number of available “primarily vehicle” fueling positions.
- **DIESEL:** The number of available “primarily heavy vehicle” fueling positions. These would be “stand alone” diesel fueling positions, and not those used in conjunction with the vehicle pump.
- **SQFT:** The gross square footage of the convenience store.
- **FF_SQFT:** The gross square footage of the fast food facility.
- **TOT_SQFT:** Sum of the convenience and fast food square footage.
- **SEATS:** Number of available seats in the fast food facility.
- **INT:** Was the facility within one mile of an interstate? This only applies to freeways and not beltlines.
- **INT_ADT:** If within one mile of an interstate (not a beltline), what is the nearest ADT count on that freeway, projected to the future year?

- **TOT_ADT:** This variable represents the total vehicular exposure the site received. For instance, a site within one mile of an interstate, and at an intersection, would include the sum of ADT's from all of the adjacent roadways plus the interstate, projected to the future year.
- **Int_ADT_1000:** In order to have a positive intercept value (β_o), the team divided "INT_ADT" by 1000. Starting with a positive intercept was intuitive because a facility being built with no other variable present should have some trip ends.
- **Tot_ADT_1000:** In order to have a positive intercept value (β_o), the team divided "TOT_ADT" by 1000. Starting with a positive intercept was intuitive because a facility being built with no other variable present should have some trip ends.
- **V_PARK:** The total number of vehicular parking positions at the site?
- **T_PARK:** The total number of heavy vehicle parking positions at the site?
- **WASH:** Was there a car wash present at the facility? Y/N

Six categories were analyzed with each of the above independent variables during the AM and PM peak periods. The groupings chosen looked at the categories that could potentially define the varying sites. The categories included: All sites (n=30), fast food only (n=15), non-fast food (n=11), hybrid (n=4), fast food plus hybrid (n=16), and non-fast food plus hybrid (n=15). It is important to note that these categories were merely explored during this phase of the project. Recommendations were made on which to use following discussions with key NCDOT personnel.

A "correlation analysis" was performed using the PROC CORR method in SAS for each of the categories (Appendix G). The purpose of this analysis was to look at the relationship between the dependent and independent variables. A perfect correlation would be given as a +1, and a negative correlation would be given as a –1. In addition, a p-value is given to show the significance of a particular independent variable in predicting the dependent variable. Last, if two or more *independent* variables are correlated with each other, a determination was made prior to running the model as to which variable should be used.

Table 17 shows each of the above categories along with independent variables that show promise (correlation ≥ 0.4, p-value ≤ 0.1). Variables showing promise for a particular category are indicated with a check mark.

Table 17. Summary of Relevant Independent Variables Based on Correlation Analysis for Six Different Categories

AM PEAK HOUR	Tot_ADT_1000	Int_ADT_1000	Type*	DRIVE	WASH	V_PARK
All Data	√	√	√	√		
FF	√			√	√	
Non-FF						√
HYBRID **	√	√				
FF + HYBRID	√	√	√	√	√	
Non-FF + HYBRID	√	√	√			√
PM PEAK HOUR	Tot_ADT_1000	Int_ADT_1000	Type*	DRIVE	WASH	V_PARK
All Data	√		√	√		√
FF	√	√		√		
Non-FF	√					√
HYBRID **	√	√				
FF + HYBRID	√	√	√	√		√
Non-FF + HYBRID	√		√			√

**Type is one of three variables: non-FF, FF, or Hybrid. This variable looks at whether the type of facility (non-FF, FF, or hybrid) is significant. In the model, the types were analyzed individually.*
*** The number of fueling positions (FUEL), convenience square footage (SQFT and TOT_SQFT), and relation to interchange (INT) are all highly correlated to Hybrid sites. However, because of the small sample size (n = 4), we elected not to include this variable and analyze using only variables from the larger samples in the other five categories.*

Overall, trips seem to be correlated to the total vehicular exposure (tot_ADT_1000). This variable shows up more consistently than "Int_ADT" and it was therefore used in further analysis. Additional correlation is evident from the presence of a non-fast food / fast food / hybrid facility (FF), presence of a drive-through (DRIVE), number of vehicular parking spaces (V_Park), and the presence of a car wash (WASH). The correlation is positive in almost all cases, indicating that a presence of these features results in an increase in traffic generated at the facility.

After conducting a correlation analysis, each of the six categories was analyzed with the five variables mentioned above using the PROC GEN method in SAS. The initial model for each category used five variables (tot_ADT_1000, Fast Food, Hybrid, Drive, Wash, V_Park). In many instances, one or more variables did not require analysis in the first model (i.e. the Fast Food Only category would not include the Hybrid or Fast Food variable because no hybrids are in the data set, and every site is a fast food site). One or more variables were removed at a time while running models in SAS, and the associated adjusted R^2 values for each model under each category were recorded. Adjusted R^2 means that for every additional independent variable used, the precision of the model is penalized by some fraction less than the R^2 value. (Note: For models containing one independent variable, the R^2 and Adjusted R^2 values are equal). The purpose was to have a range of potential models for each category so that a determination could be made as to which model(s) would be appropriate.

Each of the six categories are evaluated for each of the potential variables for the AM and PM peak hours in Tables 18-23 and Tables 24-29, respectively. Following the analysis, the team presented the findings to members of the NCDOT steering and implementation committee who would use the findings of this research project. The goal was three-fold: 1) discuss whether vehicular fueling positions (FP) should be included in the models (discussed below), 2) determine the appropriate independent variables to use in the models, and 3) based on these discussions, determine the appropriate models to recommend.

Although not shown in the Tables 18-29, it is important to note that interactions were tested for all independent variables in the models. For instance, instead of the independent variables analyzed by themselves, a variable interaction such as "tot_ADT_1000" * "Drive" could lead to more significant models because the two variables may "interact" with one another (i.e. a higher traffic volume site with the presence of a drive-through window could have more trip ends than a low traffic site). The team found that there were no interaction terms that increased the statistical significance of any of the models; therefore, the decision was made to eliminate any interaction terms.

Tables 18-29 are shown in the same basic format. For instance, Table 18 looks at **all** sites (Fast Food, Hybrid, and Non-Fast Food) during the AM peak hour. Rows A-1 to A-6 represent six potential models with the dependent variable as trips. Rows B-1 to B-6 represent the exact same models; however, the difference is the dependent variable is now "normalized" by vehicular fueling positions. Although the correlation analysis indicates that vehicular fueling positions were not well correlated, certain members of the team thought it would be reasonable to try and include the number of vehicular fueling positions in the model and look at the effect on the model precision if the decision was made for keeping this variable. Therefore, the research team decided to normalize trips by number of vehicular fueling positions, or "pumps" (trips/pump). In looking at Table 18, the result can be seen by comparing A-1 to B-1, A-2 to B-2, and so on. The same applies to Tables 19-29. In the discussions during a team meeting with the committee, NCDOT concurred that the team should **not** normalize trip ends by fueling positions because the effect was too great on the adjusted R^2 values.

Next, the team discussed which variables were appropriate. Unanimously, it was decided that vehicle parking spaces (V_Park) and the presence of a car wash (Wash) should not be included. In most site plans, the number of parking spaces is not known during the traffic impact assessment phase. In many cases, it was thought that the addition of a car wash might be known; however, the fact that 60-80 trips were added if a car wash was present didn't make sense based on data collected in the field. In addition, based on this fact, NCDOT decided not to use this for their impact assessments because the number of trips in the peak hour was not credible. Each of the other independent variables was reasonable and in the majority of cases could be collected during the traffic impact assessment phase.

Table 18. AM - All Data

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
A-1	AM_Trips	All-Data	103.624***	0.626*	23.438	137.133***	123.461***	8.282	-0.018	30	0.626	0.549
A-2	AM_Trips	All-Data	108.836***	0.621**	18.66	135.683***	124.488***	.	.	30	0.625	0.582
A-3+	AM_Trips	All-Data	96.432***	0.835**	57.612*		82.902**	.	.	30	0.509	0.473
A-4	AM_Trips	All-Data	115.825***	0.625**	.	128.243***	135.841***	.	.	30	0.620	0.591
A-5	AM_Trips	All-Data	118.817***	0.932***	.	.	111.331***	.	.	30	0.446	0.426
A-6	AM_Trips	All-Data	145.399***	0.979**	.	.	.	.	.	30	0.187	0.187
B-1	AM_Trips_Pump	All-Data	3.812	0.052	6.361	9.875**	12.273***	4.94	-0.004	30	0.580	0.493
B-2	AM_Trips_Pump	All-Data	7.002**	0.050	3.773	9.172*	12.843***	.	.	30	0.533	0.479
B-3+	AM_Trips_Pump	All-Data	6.429**	0.060*	5.570		0.005***	.	.	30	0.511	0.474
B-4	AM_Trips_Pump	All-Data	8.415***	0.051	.	7.668*	15.139***	.	.	30	0.513	0.477
B-5	AM_Trips_Pump	All-Data	8.594***	0.069**	.	.	13.673***	.	.	30	0.457	0.437
B-6	AM_Trips_Pump	All-Data	11.858***	0.075*	.	.	.	.	.	30	0.100	0.100

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level
+ - this scenario combined 'FastFood' and 'Hybrid' into one binary variable 'FF_Hybrid'

Table 19. AM - FF Only

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT_1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
C-1	AM_Trips	FF_only	112.511**	0.782	.	.	114.613**	73.772	-0.092	15	0.653	0.559
C-2	AM_Trips	FF_only	111.927**	0.696	.	.	115.508***	77.207	.	15	0.652	0.594
C-3	AM_Trips	FF_only	98.667*	1.096	.	.	119.994***	.	.	15	0.567	0.533
C-4	AM_Trips	FF_only	142.205**	1.408	.	.	.	.	.	15	0.192	0.192
D-1	AM_Trips_Pump	FF_only	9.027	0.055	.	.	11.540*	11.488	-0.004	15	0.556	0.435
D-2	AM_Trips_Pump	FF_only	9.002	0.052	.	.	11.579**	11.638*	.	15	0.556	0.482
D-3	AM_Trips_Pump	FF_only	7.003	0.112	.	.	12.255**	.	.	15	0.419	0.374
D-4	AM_Trips_Pump	FF_only	11.45	0.144	.	.	.	.	.	15	0.142	0.142

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 20. AM - Non-FF Only

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT_1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
E-1	AM_Trips	nonFF_only	36.008	0.44	.	.	.	-69.45*	6.462**	11	0.617	0.522
E-2	AM_Trips	nonFF_only	16.037	0.396	.	.	.	.	5.364	11	0.343	0.270
E-3	AM_Trips	nonFF_only	117.325***	0.474	.	.	.	.	.	11	0.103	0.103
F-1	AM_Trips_Pump	nonFF_only	4.445	0.048	.	.	.	-1.909	0.197	11	0.272	0.091
F-2	AM_Trips_Pump	nonFF_only	3.896	0.047	.	.	.	.	0.167	11	0.236	0.151
F-3	AM_Trips_Pump	nonFF_only	7.048**	0.049	.	.	.	.	.	11	0.195	0.195

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 21. AM – Non-FF + Hybrid

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT_1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
G-1	AM_Trips	nonFF + Hybrid	76.748	0.608*	.	20.585	.	-64.238**	3.661*	15	0.811	0.760
G-2	AM_Trips	nonFF + Hybrid	55.998	0.661*		59.082			2.56	15	0.718	0.671
G-3	AM_Trips	nonFF + Hybrid	66.760*	0.657**		.	.	-64.238**	4.152***	15	0.811	0.780
G-4	AM_Trips	nonFF + Hybrid	22.804	0.817**	.	.	.	.	3.947***	15	0.701	0.678
G-5	AM_Trips	nonFF + Hybrid	128.180***	0.865*	.	.	.	.	.	15	0.249	0.249
H-1	AM_Trips_Pump	nonFF + Hybrid	4.300	0.041	.	3.73	.	-0.965	0.194	15	0.694	0.611
H-2	AM_Trips_Pump	nonFF + Hybrid	3.977	0.042	.	4.33	.	.	0.177	15	0.690	0.638
H-3	AM_Trips_Pump	nonFF + Hybrid	2.49	0.050**	.	.	.	-1.383	0.283***	15	0.682	0.629
H-4	AM_Trips_Pump	nonFF + Hybrid	1.544	0.053**	.	.	.	.	0.278***	15	0.671	0.646
H-5	AM_Trips_Pump	nonFF + Hybrid	8.974**	0.057*	.	.	.	.	.	15	0.217	0.217

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 22. AM - FF + Hybrid

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
I-1	AM_Trips	FF + Hybrid	113.560***	0.802*	.	88.364*	116.065***	58.338	-0.093	19	0.662	0.565
I-2	AM_Trips	FF + Hybrid	124.741***	1.073**	.	.	85.493**	79.635**	-0.186	19	0.565	0.477
I-3	AM_Trips	FF + Hybrid	116.685***	1.042**	.	.	85.662**	80.454**	.	19	0.557	0.502
I-4	AM_Trips	FF + Hybrid	138.337***	1.046**	.	.	83.851**	.	.	19	0.409	0.374
I-5	AM_Trips	FF + Hybrid	177.411***	0.994*	.	.	.	.	.	19	0.207	0.207
J-1	AM_Trips_Pump	FF + Hybrid	8.924*	0.063	.	1.317	11.632**	9.901*	-0.006	19	0.539	0.407
J-2	AM_Trips_Pump	FF + Hybrid	9.091*	0.067	.	.	11.177**	10.219**	-0.007	19	0.537	0.444
J-3	AM_Trips_Pump	FF + Hybrid	8.775**	0.065	.	.	11.183**	10.251**	.	19	0.536	0.478
J-4	AM_Trips_Pump	FF + Hybrid	11.534**	0.066	.	.	10.953**	.	.	19	0.340	0.301
J-5	AM_Trips_Pump	FF + Hybrid	16.638***	0.059	.	.	.	.	.	19	0.060	0.060

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 23. AM - Hybrid Only (LOW SAMPLE SIZE)

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
K-1	AM_Trips	Hybrid only	156.531	0.730	.	.	.	.	1.576	4	0.627	0.441
K-2	AM_Trips	Hybrid only	316.854	0.128	.	.	.	-46.976	.	4	0.767	0.651
K-3	AM_Trips	Hybrid only	264.868**	0.415	.	.	.	.	.	4	0.596	0.596
L-1	AM_Trips_Pump	Hybrid only	26.484***	-0.015**	.	.	.	.	-0.080**	4	0.999	0.998
L-2	AM_Trips_Pump	Hybrid only	19.967**	0.007	.	.	.	0.917	.	4	0.816	0.724
L-3	AM_Trips_Pump	Hybrid only	20.982***	0.001	.	.	.	.	.	4	0.064	0.064

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 24. PM - All Data

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
A-1	PM_Trips	All-Data	132.007***	0.550*	1.092	124.296***	107.137***	5.234	0.716**	30	0.666	0.596
A-2	PM_Trips	All-Data	135.436***	0.548*	-1.489	123.651***	107.714***	.	0.716**	30	0.665	0.612
A-3	PM_Trips	All-Data	135.033***	0.549*	.	124.295***	106.909***	.	0.710**	30	0.665	0.626
A-4+	PM_Trips	All-Data	123.798***	0.792**	44.242		63.112*	.	0.594	30	0.529	0.474
A-5	PM_Trips	All-Data	153.470***	0.654**	.	130.260***	118.937***	.	.	30	0.589	0.558
A-6	PM_Trips	All-Data	156.509***	0.966***	.	.	94.041***	.	.	30	0.401	0.380
A-7	PM_Trips	All-Data	145.399***	0.979**	.	.	.	.	.	30	0.148	0.148
B-1	PM_Trips_Pump	All-Data	5.782*	0.048	4.737	9.065**	10.234***	4.120	0.060	30	0.607	0.525
B-2	PM_Trips_Pump	All-Data	8.474***	0.047	2.710	8.559*	10.687***	.	0.060	30	0.571	0.502
B-3	PM_Trips_Pump	All-Data	9.208***	0.046	.	7.387*	12.152***	.	0.070	30	0.561	0.511
B-4+	PM_Trips_Pump	All-Data	7.930***	0.058*	4.847		8.603**	.	0.054	30	0.542	0.489
B-5	PM_Trips_Pump	All-Data	11.035***	0.057	.	7.979*	13.345***	.	.	30	0.489	0.451
B-6	PM_Trips_Pump	All-Data	11.222***	0.076**	.	.	11.820***	.	.	30	0.422	0.401
B-7	PM_Trips_Pump	All-Data	11.858**	0.075*	.	.	.	.	.	30	0.009	0.009

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level
+ - this scenario combined 'FastFood' and 'Hybrid' into one binary variable 'FF_Hybrid'

Table 25. PM - FF Only

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
C-1	PM_Trips	FF_only	96.090**	1.693**	.	.	98.761**	-37.996	0.267	15	0.697	0.614
C-2	PM_Trips	FF_only	97.794**	1.944***	.	.	96.153**	*48.007	.	15	0.683	0.630
C-3	PM_Trips	FF_only	106.038**	1.696***	.	. .	93.363**	.	.	15	0.647	0.620
C-4	PM_Trips	FF_only	139.934**	1.938**	.	.	.	.	.	15	0.399	0.399
D-1	PM_Trips_Pump	FF_only	6.718	0.16	.	.	9.432*	-0.052	0.019	15	0.558	0.437
D-2	PM_Trips_Pump	FF_only	6.841	0.178**	.	.	9.244**	-0.773	.	15	0.552	0.477
D-3	PM_Trips_Pump	FF_only	6.974	0.174**	.	.	9.199**	.	.	15	0.551	0.516
D-4	PM_Trips_Pump	FF_only	10.311**	0.198**	.	.	.	.	.	15	0.349	0.349

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 26. PM – Non-FF Only

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
E-1	PM_Trips	nonFF_only	56.809	0.486	.	.	.	-27.207	5.763*	11	0.459	0.324
E-2	PM_Trips	nonFF_only	48.985	0.468	.	.	.	.	5.333*	11	0.413	0.347
E-3	PM_Trips	nonFF_only	149.688***	0.546	.	.	.	.	.	11	0.151	0.151
F-1	PM_Trips_Pump	nonFF_only	5.93	0.053	.	.	.	1.567	0.12	11	0.289	0.111
F-2	PM_Trips_Pump	nonFF_only	6.38	0.054	.	.	.	.	0.145	11	0.266	0.185
F-3	PM_Trips_Pump	nonFF_only	9.121***	0.056	.	.	.	.	.	11	0.237	0.237

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 27. PM – Non-FF + Hybrid

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
G-1	PM_Trips	nonFF + Hybrid	78.525	0.566	.	28.701	.	-10.431	3.887*	15	0.759	0.694
G-2	PM_Trips	nonFF + Hybrid	64.599	0.633**	.	.	.	-13.645	4.571***	15	0.756	0.715
G-3	PM_Trips	nonFF + Hybrid	55.262	0.668**	.	.	.	.	4.528***	15	0.751	0.732
G-4	PM_Trips	nonFF + Hybrid	176.140***	0.723	.	.	.	.	.	15	0.170	0.170
H-1	PM_Trips_Pump	nonFF + Hybrid	3.914	0.038	.	4.868	.	3.236	0.214	15	0.652	0.557
H-2	PM_Trips_Pump	nonFF + Hybrid	1.553	0.049*	.	.	.	2.671	0.330***	15	0.636	0.575
H-3	PM_Trips_Pump	nonFF + Hybrid	3.394	0.042	.	.	.	.	0.339**	15	0.607	0.577
H-4	PM_Trips_Pump	nonFF + Hybrid	12.436**	0.047	.	.	.	.	.	15	0.108	0.108

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 28. PM - FF + Hybrid

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
I-1	PM_Trips	FF + Hybrid	131.179**	0.592	.	115.310**	104.746**	21.5724	0.665*	19	0.628	0.522
I-2	PM_Trips	FF + Hybrid	165.546***	0.714*	.	112.221**	102.641**	.	.	19	0.522	0.463
I-3	PM_Trips	FF + Hybrid	212.425***	0.834	.	53.487	.	.	.	19	0.271	0.228
I-4	PM_Trips	FF + Hybrid	182.062***	1.040**	.	.	63.301	.	.	19	0.338	0.299
I-5	PM_Trips	FF + Hybrid	211.559***	1.001**	.	.	.	.	.	19	0.219	0.219
J-1	PM_Trips_Pump	FF + Hybrid	10.266*	0.048	.	3.699	10.045**	5.905	0.06	19	0.465	0.313
J-2	PM_Trips_Pump	FF + Hybrid	14.183***	0.055	.	5.001	10.323**	.	.	19	0.928	0.919
J-3	PM_Trips_Pump	FF + Hybrid	18.898***	0.067	.	-0.898	.	.	.	19	0.085	0.031
J-4	PM_Trips_Pump	FF + Hybrid	14.920**	0.069	.	.	8.567**	.	.	19	0.289	0.247
J-5	PM_Trips_Pump	FF + Hybrid	18.912***	0.064	.	.	.	.	.	19	0.084	0.084

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Table 29. PM - Hybrid Only <u>(LOW SAMPLE SIZE)</u>

			INDEPENDENT VARIABLES PARAMETERS							MODEL FIT STATISTICS		
Model #	Dep. Varialbe	Data Used	Intercept	tot_AADT _1000	FastFood	Hybrid	Drive	Wash	V_Park	Sample Size (n)	R-Square	Adj. R2
K-1	PM_Trips	Hybrid only	368.411	-0.105	.	.	.	.	-0.193	4	0.013	-0.481
K-2	PM_Trips	Hybrid only	295.488	0.263	.	.	.	53.877	.	4	0.196	-0.205
K-3	PM_Trips	Hybrid only	355.11**	-0.067	.	.	.	.	.	4	0.013	0.013
L-1	PM_Trips_Pump	Hybrid only	41.234	-0.077	.	.	.	.	-0.184	4	0.228	-0.159
L-2	PM_Trips_Pump	Hybrid only	18.832	0.014	.	.	.	8.792	.	4	0.442	0.163
L-3	PM_Trips_Pump	Hybrid only	28.562**	-0.040	.	.	.	.	.	4	0.211	0.211

NOTES:
* - significant at 90% confidence level, ** - significant at 95% confidence level, *** - significant at 99% confidence level

Last, based on the discussion and answers to the first two questions, the team had to determine which models made sense to recommend. The team eliminated all "normalized" models (rows containing B, D, F, H, J, and L for AM and PM) along with those containing vehicle parking spaces (V_Park) and the presence of a car wash (Wash). Table 30 shows the model chosen for each category based on the highest adjusted R^2 value after eliminating the models described above. This elimination left two possible scenarios: 1) choose equations for appropriate categories (not all five, but those that make sense based on adjusted R^2 values and non-overlapping categories) or 2) use equations for all thirty sites combined for both AM and PM from Tables 18 and 24.

The "Hybrid Only" category had a very low sample size of four sites. As a result, this category will not be considered by itself. In order to accommodate a hybrid site, it would need to be included with either fast food or non-fast food sites. The major issue with using models for specific categories is there is not a good model for non-fast food sites (by itself, or with hybrids included) in the AM or PM peak hour. Therefore, in answering the third question on which models to use if multi-variable regression models

Table 30. Potential Equations for AM and PM Peak Hour Trips

	Category	Model # *	Equation	Adjusted R^2
AM	All Sites	A-4	116 + (0.625 * ADT) + (128 * Hybrid) + (136 * Drive Through)	0.591
	FF Only	C-3	99 + (1.096 * ADT) + (120 * Drive Through)	0.533
	Non-FF Only	E-3	118 + (0.474 * ADT)	0.103
	FF + Hybrid	I-4	139 + (1.046 * ADT) + (84 * Drive Through)	0.374
	Non-FF + Hybrid	G-5	129 + (0.865 * ADT)	0.249
	Hybrid Only *	K-3	265 + (0.415 * ADT)	0.596
PM	All Sites	A-5	153 + (0.654 * ADT) + (130 * Hybrid) + (119 * Drive Through)	0.558
	FF Only	C-3	106 + (1.696 * ADT) + (94 * Drive Through)	0.620
	Non-FF Only	E-3	150 + (0.546 * ADT)	0.151
	FF + Hybrid	I-2	166 + (0.714 * ADT) + (113 * Hybrid) + (103 * Drive Through)	0.463
	Non-FF + Hybrid	G-4	177 + (0.723 * ADT)	0.170
	Hybrid Only	K-3	356 - (0.067 * ADT)	0.013

* These models were chosen based on the highest Adjusted R^2 value in each category after eliminating models that could not be used based on independent variables that were not attainable at the traffic impact assessment level.

were to be the suggested method of analysis, the team recommends using Model A-4 and A-5 for AM and PM Trips, respectively. This recommendation is made on the basis that "All Sites" categories have a much larger sample (n=30) and the shortcomings mentioned above of trying to use specific models for all categories is eliminated.

COMPARISON OF DIFFERENT METHODS OF TRIP GENERATION

One of the primary concerns regarding trip generation at fueling centers was the accuracy of the current technique of prediction for trips. Therefore, the team decided that the extent of the current problem should be documented by conducting a trip generation study at each of the sites using the ITE *Trip Generation Handbook*, average rates based on the linear regression models, and multi-linear models against actual trip ends collected in the data collection phase of the project. The idea was to use the results of these analysis methods, in conjunction with the significance test in each of the categories presented earlier using R^2 and adjusted R^2 values, to make a final recommendation for which model should be recommended for use by NCDOT.

The current method NCDOT uses for determining trip generation is based on the ITE *Trip Generation Handbook*. For a typical fueling station and convenience store, Land Use 945/946 is used to predict the demand. This method, although accepted by the vast majority of transportation professionals, is a poor indicator of traffic demand at this type of facility. NCDOT personnel are specifically concerned with the newly emerging fueling stations with convenience and fast food because there is limited trip data at these types of sites. The current method NCDOT recommends for this type of facility is a combined trip generation technique which looks at the fueling station (Land Uses 945/946) and the fast food (Land Uses 931-935) site separately to determine demand. The primary objective of this research was to use North Carolina specific data at both of these types of sites to determine if there is a better method for determining trip generation at these sites.

Next, the team evaluated which method of analysis was the most precise for trip generation analysis. Tables 32 and 34 compares each of the three methods with the actual trip ends during the AM and PM peak periods, respectively. Tables 33 and 35 show the ranges for the thirty sites summed together for the AM and PM peak periods, respectively. The ranges in these two tables represent the difference between the actual trips from the data collection and the three trip generation methods. At every range, the multi-variable equation estimate is more accurate than the ITE and average rate estimates, which correlates well with R^2 values for each of the three analysis methods. For the multi-variable equation estimate, 28 sites in the AM peak hour and all 30 sites in the PM peak hour were within ±75% difference from the actual trips generated by the site. Note that the multi-variable equation was also a better predictor of trips for all percent difference categories, including where 17/30 sites in the AM and 20/30 sites in the PM are within ±25% difference, which is a good result considering the limited number of sites available for this study.

Table 31. AM Comparison Between Various Trip Generation Methods

	AM Trips						
Site	Actual Trips	ITE Estimate	% Diff	Average Rate Estimate	% Diff	Multi-Variable Equation Estimate	% Diff
4	248	379	53%	386	56%	324	31%
5	232	141	-39%	130	-44%	138	-40%
6	330	161	-51%	326	-1%	303	-8%
7	166	314	89%	185	11%	176	6%
9	156	170	9%	148	-5%	129	-17%
24	198	213	7%	185	-7%	151	-24%
26	314	320	2%	173	-45%	306	-3%
27	162	294	81%	217	34%	272	68%
29	252	128	-49%	245	-3%	272	8%
30	122	170	40%	148	21%	141	16%
33	140	128	-9%	111	-21%	124	-11%
34	58	255	340%	222	283%	137	137%
35	310	453	46%	477	54%	296	-5%
37	276	195	-29%	64	-77%	270	-2%
40	472	162	-66%	145	-69%	311	-34%
42	200	106	-47%	93	-54%	212	6%
44	90	271	201%	117	30%	129	44%
45	94	128	36%	111	18%	141	50%
46	122	201	65%	185	52%	136	12%
47	342	161	-53%	326	-5%	373	9%
52	272	241	-11%	222	-18%	173	-37%
53	112	170	52%	148	32%	191	70%
56	348	146	-58%	260	-25%	302	-13%
60	246	271	10%	97	-61%	167	-32%
61	172	406	136%	686	299%	180	4%
62	100	254	154%	257	157%	147	47%
63	300	149	-50%	286	-5%	276	-8%
67	234	224	-4%	156	-33%	286	22%
70	84	101	20%	93	10%	151	80%
72	184	187	1%	116	-37%	128	-31%

Table 32. Summary of AM Comparison Between Various Methods

	Number of Sites within % Difference Range		
% Difference from Observed Data (±)	ITE Estimate	Average Rate Estimate	Multi-Variable Equation Estimate
25%	9	12	17
50%	16	20	25
75%	24	23	28
100%	26	27	29

Table 33. PM Comparison Between Various Trip Generation Methods

	PM Trips						
Site	Actual Trips	ITE Estimate	% Diff	Average Rate Estimate	% Diff	Multi-Variable Equation Estimate	% Diff
4	432	316	-27%	439	2%	347	-20%
5	130	187	44%	162	25%	176	35%
6	318	214	-33%	372	17%	345	8%
7	184	327	78%	211	14%	215	17%
9	188	213	13%	185	-1%	167	-11%
24	308	215	-30%	211	-32%	190	-38%
26	384	318	-17%	197	-49%	329	-14%
27	280	301	7%	247	-12%	293	5%
29	410	160	-61%	279	-32%	313	-24%
30	174	213	23%	185	7%	179	3%
33	158	160	1%	139	-12%	162	2%
34	104	320	208%	278	167%	175	69%
35	264	405	53%	543	106%	318	20%
37	308	204	-34%	72	-76%	290	-6%
40	394	170	-57%	165	-58%	333	-15%
42	228	133	-42%	116	-49%	253	11%
44	124	253	104%	133	7%	167	35%
45	236	160	-32%	139	-41%	180	-24%
46	174	268	54%	232	33%	174	0%
47	352	214	-39%	372	6%	418	19%
52	324	321	-1%	278	-14%	212	-34%
53	154	213	38%	185	20%	231	50%
56	288	146	-49%	296	3%	325	13%
60	268	245	-9%	110	-59%	207	-23%
61	302	331	9%	782	159%	220	-27%
62	142	225	59%	293	106%	185	30%
63	314	187	-41%	325	4%	316	1%
67	196	201	2%	178	-9%	308	57%
70	124	134	8%	116	-7%	189	53%
72	134	200	49%	132	-2%	165	23%

Table 34. Summary of PM Comparison Between Various Methods

	Number of Sites within % Difference Range		
% Difference from Observed Data (±)	ITE Estimate	Average Rate Estimate	Multi-Variable Equation Estimate
25%	10	17	20
50%	22	23	26
75%	27	25	30
100%	28	26	30

SUMMARY OF FINDINGS

This research effort aimed to quantify the effects of contemporary fueling centers on adjacent roadway facilities. Current methods used by the ITE *Trip Generation Handbook* fall short of ideal methods used in other land uses, with only average rates to be used at best. Based on the literature review, the fueling center is known to be one of the most difficult land uses to quantify trip ends because many site characteristics play into whether or not a fueling center is chosen. The research focused on trying to quantify the effects through traditional methods (linear regression) such as those used by ITE, and investigated the use of non-traditional methods (multi-linear regression).

CONCLUSIONS

Overall, the linear regression models were plagued by low R^2 values which led to the use of average rates for the single variable model. The multi-variable equation was able to represent the fuel centers more precisely than traditional single variable methods. The contemporary fuel centers are more complex and offer more services than traditional fuel centers which might provide an explanation for the relative success of utilizing multiple variables. For the multi-variable equation estimate, 28 sites in the AM peak hour and all 30 sites in the PM peak hour were within ±75% of the actual trips generated by the site. When compared to the multi-variable equation results, the ITE and average rate estimates have fewer sites within the ±75% difference range.

RECOMMENDATIONS TO NCDOT AND OTHER STATES

The analysis of actual trips from the data collection with characteristic variables that define the sites led to three potential models for estimation of trips generated by fuel centers. The models that were investigated included linear regression, average rate, and multi-variable regression. These models were compared against the current method suggested by NCDOT of utilizing the ITE *Trip Generation Handbook*. When evaluating the models in terms of their fit of the actual data, the multi-variable regression model provides a better estimation of the trips generated by a fuel center. Therefore, the team recommends the multi-variable model for estimating the trips generated by a fuel center with ≥10 fueling positions. The R^2 values for the AM Trips and PM Trips equations are 0.591 and 0.558, respectively.

Recommended Trip Generation Models

AM Trips = (0.625 * ADT) + (128 * Hybrid) + (136 * Drive Through) + 116

PM Trips = (0.654 * ADT) + (130 * Hybrid) + (119 * Drive Through) + 153

where:

ADT, Average Daily Traffic (in thousands of vehicles per day). The ADT represents traffic "exposure" at a given site and should be composed of a maximum of three volumes, including the primary street ADT, side street ADT (utilized for a fuel center located at an intersection), and full access control facility ADT (utilized for a fuel center located within one mile of a freeway interchange), divided by 1,000.

Hybrid. Yes = 1, No = 0. Hybrid sites *typically* offer the following services: convenience market, fast food (store brand which are not found at stand-alone facilities), indoor and outdoor seating, pay at the pump, order at the pump, and car wash. For the calculation of trips, a hybrid site cannot have the presence of a drive through window.

Drive Through. Yes = 1, No = 0. At a fast food restaurant, is there a drive through window present?

A user's guide is provided in Appendix I for supplementing the ITE *Trip Generation Handbook*.

RECOMMENDATIONS FOR FUTURE RESEARCH

This research effort collected data from 30 sites across the state. After evaluating the data and the relationships between independent variables and trips, three distinct types of fuel centers emerged: fast food with gas and convenience (n=15), gas and convenience only (n=11), and hybrid (n=4). The original thirty sites exceeded the ITE *Trip Generation Handbook* recommendation of twenty sites for data collection; however, the three final categories of fuel centers do not include twenty sites each. Therefore, the team **highly** recommends a future data collection effort to increase the number of sites in each category to 20 sites each, yielding an additional 30 sites (5+9+16) total.

In visiting various fueling centers, it was obvious to the team that large trucking facilities were also becoming increasing popular. On many occasions, members of the NCDOT technical committee mentioned the need to study these sites in addition to the more contemporary fuel centers. To facilitate any future research, the research team identified sites that were "primarily truck" facilities during the site selection process. NCDOT has expressed interest in looking at these sites in the near future.

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