NORTH CAROLINA FORECASTS FOR TRUCK TRAFFIC

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16. Abstract

North Carolina has experienced significant increases in truck traffic on many of its highways. Yet, current NCDOT project-level highway traffic forecasts do not appropriately capture anticipated truck traffic growth. NCDOT methods forecast total traffic AADT based on historical trends and assume base year and future year truck percentages are the same. Also, NCDOT determines the growth factor of historical AADT traffic data by looking only at the first year and the last year ignoring intermediate year traffic data. This research recommends that traffic for dual axle (Dual) trucks and tractor trailer (TTST) trucks be separately forecast using an average growth factor (AGF) method that uses all available data and calculates growth factors year by year and averages them for the historical trend. The results of this research propose statistical methods to separately estimate growth factors for light vehicles (Cars), Duals and TTSTs. In this study Cars represent FHWA vehicle classes 1-3, Duals 4-7 and TTSTs 8-13. The methods have modest data requirements based on NCDOT traffic counts and VTRIS on-line traffic data. Statistical guidelines including mean AGFs and confidence intervals to help refine the estimates for growth factors by vehicle class and highway type. Case study examples demonstrate the methods and guidelines for Interstate, US, and NC highways. Other issues are explored including the effects of increased truck traffic on highway level of service and pavement design.

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TABLE OF CONTENTS

List of Figures

List of Tables

Executive Summary

Introduction

North Carolina has experienced a significant increase in truck traffic along many of its highways. This results from economic trends such as the large increase in freight movement for rising imports, growth and development, and freight logistics that use just-in-time delivery strategies. The challenge for this research project is to statistically confirm the increase in truck traffic and forecast truck traffic growth for new highway projects in North Carolina. This requires careful assessment of truck traffic using a variety of data sources. It is critical that good truck traffic forecasts be prepared so NCDOT roadway and pavement designs and highway improvements can be cost effective.

A primary question frames the research:

- What analytical procedures are available to forecast truck traffic, and how can they be integrated with available data and expert judgment to produce acceptable estimates of truck traffic for a highway project?

Several secondary questions are also pertinent:

- Is truck traffic growing faster than general traffic?
- How are truck traffic growth rates affected by highway type (Interstate, US, NC), geographic location (eastern, central, and western North Carolina), urban or rural area, proximity to truck generators, and factors such as regional population and economic development?
- As highway projects develop, should new truck counts be taken or can default values be used for some minor facilities with limited truck traffic?
- How does truck traffic affect highway and pavement design?

Scope and Objectives

The scope of the project is limited to rural highway segments, not networks, within North Carolina including Interstate, US, and NC routes. The project objective is to develop and demonstrate truck forecasting methods that have modest data requirements and use available data. Data sources available from NCDOT and FHWA support this project.

Research Approach

Heavy truck volumes are critical factors in the design and maintenance of bridge structures, pavements, and highway lanes. NCDOT uses several approaches to estimate future traffic. They range from simple trend line analysis for project-level traffic forecasts to more complicated network-based methods for regional and statewide traffic forecasts. For project-level traffic forecasts NCDOT relies on the Traffic Forecasting Utility and the Trend Program spreadsheets. These software tools apply linear, exponential and polynomial models to the first and last values of an historical traffic trend to calculate a growth factor for total traffic for a highway project. However, NCDOT does not explicitly calculate a truck traffic growth factor for the highway project. Rather, NCDOT assumes that the base year percentages of dual axle trucks and tractor trailer trucks remain the same in the future year. NCDOT applies those truck percentages to the total traffic forecast for the highway segment to determine truck volumes. The NCDOT approach ignores important trends that show that truck traffic increases differently from total traffic that primarily includes light vehicles like passenger cars. If the highway project is part of an urban network TransCAD is likely used, however, network traffic forecasting methods are not within the scope of this research. Thus, this research builds upon existing NCDOT project-level traffic forecasting methods, uses available data sources, and includes explicit estimation of truck traffic growth factors.

Data Sources and Statistical Analysis

The research examined available traffic data and applied statistical methods to compare traffic growth for total traffic, passenger vehicles (cars), and trucks at WIM station locations on Interstate, US and NC routes in North Carolina. The primary data source was FHWA on-line VTRIS data that summarizes WIM station traffic counts. Potential causal factors underlying the growth were evaluated. Statistically based guidelines for choosing truck growth rates are proposed as substitutes for the current NCDOT judgmental approach of assuming a constant truck percentage throughout the forecast period. In this study Passenger Vehicles (Cars) represent FHWA vehicle classes 1-3, Duals represent FHWA vehicle classes 4-7 and TTSTs represent FHWA vehicle classes 8-13.

Traffic Data

The two main data sources for this research are NCDOT vehicle classification counts and the online FHWA Vehicle Travel Information System (VTRIS) Weigh in Motion (WIM) counts. NCDOT data come from continuous monitoring stations, short-term count stations, and turning movement count stations. NCDOT data sets include classified traffic counts, station numbers, and detailed descriptions of station locations. In these data sets, traffic volumes are counted on typical days as Average Daily Traffic (ADT), and they are clean, factored, and annualized to Average Annual Daily Traffic (AADT) to be used for trend analysis.

VTRIS summarizes and generates reports on annual vehicle counts and classifications across the U.S, including North Carolina. In North Carolina there are about 60 WIM (VTRIS) stations on Interstates, US routes, and NC routes. VTRIS maintains a permanent database of the WIM station description, vehicle classification counts, and truck weight measurements. WIM stations usually count traffic 365 days a year. This allows repetitive data averaging and other analysis without the need for time consuming data cleaning, factoring and averaging. Some WIM data reported by NCDOT to VTRIS are estimates because of less than year-long collection and equipment failure.

The online dataset for the Highway Pavement and Monitoring System (HPMS) was a third source considered for this research. However, the available online HPMS data archive consisted of total AADT data and did not include classified counts or any truck data. Truck percents are available in some versions of HPMS. Thus, HPMS was not used for this research.

In order to apply the VTRIS data to the NCDOT truck traffic forecasting problem, some minimal conversions for vehicle classes were necessary. FHWA classifies vehicles as thirteen types. NCDOT and VTRIS use different truck classifications - VTRIS excludes FHWA class 4 (buses) from the truck category. In order for this research to be consistent with the NCDOT classifications, VTRIS buses are included with trucks. This means that the calculated VTRIS truck traffic is the sum of displayed truck volumes and buses. Buses, however, are a very small percentage of the traffic.

VTRIS provides 365-day continuous, classified AADT and truck counts (or estimates) from 1997 to 2004 (the years for this research.) Thus, each WIM (VTRIS) station provides reliable growth factors for Dual and TTST trucks and general traffic. For the 60 NC VTRIS stations, only 51 have data recorded in the VTRIS online database. These 51 stations consist of 19 stations on Interstates and 32 stations on US and NC arterials. Some of these stations have data only for a single year, and they are not included in the statistical analysis and tests. All stations which have at least two years of data are used for developing the research results. The research database thus includes 18 stations along Interstates and 27 stations along US and NC arterials. SomeWIM (VTRIS) stations have missing data between 1997 and 2004, and the analysis assumes that the vehicle class growth rates remain constant between the missing years. Outlier data adjustments were made. A larger data base is desirable and will be available as NCDOT expands its traffic count program. Thus, the results of this research should be updated occasionally.

Statistical Analysis

After establishing the 1997-2004 VTRIS (WIM) database for the research, yearly growth factors for AADT (total traffic), Cars, total trucks, and Duals and TTSTs were calculated at each VTRIS station. (In this study Cars represent FHWA vehicle classes 1-3, Duals 4-7 and TTSTs 8-13.) The yearly growth factors were averaged over 1997-2004 to determine an average growth factor for each traffic category – AADT, Cars, total trucks, Duals and TTSTs - and each VTRIS facility type – rural principal arterial Interstate (Interstates only) and rural principal arterial other (US routes and some NC and SR routes). QQ plots identified outlier average growth factors, which were eliminated, and together with a comparison of data means and medians determined that the average growth factors were normally distributed. T-tests examined the hypothesis that truck traffic is growing faster than other traffic. The statistical analysis included multiple linear regression models to determine how highway type, geographic location (eastern, central, and western North Carolina), proximity to truck generators (warehouses), and factors such as regional population and economic development affect truck traffic growth rates.

Research Findings

The research results are presented as answers to the original questions that motivated the research.

What analytical procedures are available to forecast truck traffic, and how can they be integrated with available data and expert judgment to produce acceptable estimates of truck traffic for a highway project?

NCDOT currently uses the Traffic Forecasting Utility (Trend Program) to calculate growth factors based on the first and last year traffic volumes (AADT) in an historical trend. This approach to growth factors ignores important growth factor changes within the overall trend. Also, Dual and TTST truck volumes are not separately forecast, rather the future year truck percentages are assumed equal to the base year percentages. If the highway project is on an Interstate or other major highway, NCDOT often and appropriately uses a linear model to forecast total AADT. On minor highways that may attract economic growth and traffic, NCDOT appropriately uses exponential models and growth factors to estimate future AADT.

To accommodate alternative models, the Traffic Forecasting Utility and Trend Program allow some degree of user choice and flexibility in terms of models types including linear, exponential, and regression models. The user may accept calculated growth factors based on first and last traffic counts or choose a growth factor based on professional judgment.

Average Growth Factor

To accommodate different growth rates in AADT, passenger vehicles (Cars), Duals and TTSTs and to account for different annual growth rates in historical data, this research developed average growth factors (AGF) for the period 1997-2004 for each vehicle category (Cars, Duals, TTSTs) and WIM (VTRIS) highway types (rural Interstate and rural principal arterial other). The AGF is defined by

$$AGF = \Sigma\ GF / N$$

where:

T = traffic = AADT
GF = annual growth factor
AGF = average annual growth factor
t = year, t-1 = previous year
N = the number of growth factors
fy = future year of a historic or future time period
by = base year of a historic or future time period

This research uses the average growth factor (AGF) and separately forecasts the vehicle classes Cars, Duals, and TTSTs. Future AADT is the sum of the individual traffic forecasts by vehicle class. Percents of Cars, Duals and TTSTs are based on their individual forecasts and the total AADT calculated. Additional details for this recommendation follow.

Principal Arterials: Interstates and Other Major Highways ~ Linear AGF Model

Major highways are not likely to experience rapid traffic growth and a linear model is often appropriate.

$$T_{fy} = T_{by} + AGF\ (fy - by) = AADT_{fy}\ ,\ AGF = \text{annual traffic increment per year}$$

Here, T_{fy} is the vehicle class of interest; Cars, Duals, or TTSTs. Add the vehicle class forecasts to estimate future AADT.

Principal Arterials Other: Minor Highways ~ Exponential AGF Model

If the traffic forecast follows an exponential model, which NCDOT often assumes for minor roads that may experience significant traffic growth, exponential model with the AGF is often appropriate.

$$T_{fy} = T_{by}\ (1 + AGF)^{(fy - by)} = AADT_{fy}\ ,\ AGF = \text{average annual growth rate, e.g., } 0.03 = 3\%$$

Truck Traffic Forecasts

Similar forecasting equations as those above represent future values of Passenger Vehicles (Cars), Duals, and TTSTs. Thus, for a linear model for a major highway:

$$Cars_{fy} = Cars_{by} + AGF\ (fy - by)$$
$$DUAL_{fy} = DUAL_{by} + AGF\ (fy - by)$$
$$TTST_{fy} = TTST_{by} + AGF\ (fy - by)$$
$$AADT_{fy} = Cars_{fy} + DUAL_{fy} + TTST_{fy}$$

and for an exponential model for a minor highway:

$$Cars_{fy} = Cars_{by}\ (1 + AGF)^{(fy - by)}$$
$$DUAL_{fy} = DUAL_{by}\ (1 + AGF)^{(fy - by)}$$
$$TTST_{fy} = TTST_{by}\ (1 + AGF)^{(fy - by)}$$
$$AADT_{fy} = Cars_{fy} + DUAL_{fy} + TTST_{fy}$$

The previous truck traffic forecasting equations emphasize that truck traffic should be forecast separately from AADT before the percentages by truck category are determined.

%Passenger Vehicles = (Cars/AADT) x 100

%DUALs = (DUAL/AADT) x 100

%TTSTs = (TTST/AADT) x 100

Statistical Checks on the Average Growth Factor

The statistical analysis of the VTRIS traffic data for 1997-2004 established mean AGFs for AADT, Passenger Vehicles (Cars), Duals, and TTSTs. The analysis also identified the 95% confidence levels for expected average growth factors of cars and trucks by facility type. The ranges of AGFs in the 95% confidence interval for a particular combination of vehicle class and highway type can guide and check the estimate of AGF for the forecast (Tables ES-1 and ES-2).

Table ES-1: Rural Interstates – VTRIS Data 1997-2004

	Duals	TTSTs	Cars
Mean AGF	0.59%	1.72%	-0.69%
Lower 95% CL AGF	-1.82%	-0.98%	-3.29%
Upper 95% CL AGF	2.99%	4.43%	1.90%
Mean % Vehicles	3.85%	15.77%	80.38%

Cars represent FHWA vehicle classes 1-3, Duals 4-7 and TTSTs 8-13.

Table ES-2: Rural Principal Arterials – VTRIS Data 1997-2004

	Duals	TTSTs	Cars
Mean AGF	1.13%	1.75%	1.32%
Lower 95% CL AGF	-2.08%	-0.32%	-0.36%
Upper 95% CL AGF	4.34%	3.81%	3.01%
Mean % Vehicles	4.12%	7.59%	88.29%

To apply these results consider the following guidelines:

- If the estimated growth factor for the traffic forecast of a proposed highway project is between the lower and upper values in the confidence interval, the value obtained from the forecast is used.
- If the estimated growth factor is lower than the range of the confidence interval it should be set to the lower value of the confidence interval. However, if the lower rate is negative the prudent annual growth rate for the forecast should be set to zero or the usual small value (1% or 2%) that NCDOT often uses for project locations with little anticipated traffic growth.
- If the estimated growth factor is higher than the range of the confidence interval it should be set to the upper value of the interval.
- The mean and median are close for normal data.
- If the data set is small and includes outliers the median may be chosen as a measure of central tendency instead of the mean.

A statistical technique called Q-Q plots can determine any non-normal outliers in the VTRIS data for rural Interstates and rural principal arterials. When applied to the VTRIS data that formed Tables ES-1 and ES-2, the Q-Q plot technique found three outliers for Duals and one for TTSTs for the Interstates and one outlier for TTSTs for rural principal arterials. The adjusted results without outliers appear in Table ES-3 and Table ES-4. Comparing the tables with and without outliers removed indicates that:

- The sample sizes are small and should be increased as more WIM station data become available in North Carolina.
- Interstate mean AGF and confidence interval results for the tables with and without outliers removed are similar for Duals and TTSTs.
- Principal arterial AGF and confidence interval results with and without the outliers removed differ for Duals and are similar for TTSTs. This suggests that the mean AGF is low for Duals in Table ES-2.
- Cars and % vehicles were not evaluated by the Q-Q plots, but AADT was.

The Q-Q plot adjustments are presented for future research and consideration; however, the case studies in this research are based on AGFs that include data outliers.

Table ES-3: Rural Interstates – VTRIS Data 1997-2004 with Outliers Removed

	Duals	TTSTs	Cars	AADT
Mean AGF	0.79%	1.87%	~	-0.40
Lower 95% CL AGF	-1.70%	-0.80%	~	-2.80
Upper 95% CL AGF	3.25%	4.56%	~	2.06
Mean % Vehicles	~	~	~	~
Sample Size	16	18	~	19

Table ES-4: Rural Principal Arterials – VTRIS Data 1997-2004 with Outliers Removed

	Duals	TTSTs	Cars	AADT
Mean AGF	3.34%	1.65%	~	1.41%
Lower 95% CL AGF	-0.80%	-0.30%	~	-0.20%
Upper 95% CL AGF	7.52%	3.66%	~	3.02%
Mean % Vehicles	~	~	~	~
Sample Size	27	26	~	27

The Growth Factor Ratio Method

The Growth Factor Ratio (GFR) method is an alternative to the Average Growth Factor method. Its premise is stated below.

> For a pair of NC and VTRIS (WIM) stations with similar locations (which means they are adjacent to each other, or they are located in areas with the same route type, similar demographic and economic conditions, etc.), the ratios growth factors for trucks (Duals and TTSTs) to AADT growth factor will be constant.

This idea can be presented by formulas as below:

$$Ratio_1 = \frac{Duals\_GF_{NC}}{AADT\_GF_{NC}} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}}$$

$$Ratio_2 = \frac{TTST\_GF_{NC}}{AADT\_GF_{NC}} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}}$$

Thus, growth factors of Duals and TTSTs for NC project locations can be calculated by the formulas below:

$$Duals\_GF_{NC} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC} = Ratio_1 \times AADT\_GF_{NC}$$

$$TTST\_GF_{NC} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC} = Ratio_2 \times AADT\_GF_{NC}$$

The resulting growth factors can be checked against the 95% confidence intervals as discussed above.

Comparing Case Study Forecasts for the NCDOT Trend Program (Traffic Forecasting Utility), the Average Growth Factor, and the Growth Factor Ratio

The Average Growth Factor served as the method for case study forecasts for I-95, US 64, US 421 and NC 279. In each case VTRIS on-line data provided the historical data to develop the AGF. For each case NCDOT provided base year 2003 or 2004 traffic data that were cleaned, factored and annualized.

The I-95 case is a comparison case for the average growth factor method, the growth factor ratio method, and the methods of the Trend Program including linear and exponential models with one or two data points, all available data, and user defined growth factor models. When average growth factors were calculated from historic data without the confidence interval adjustment, the corresponding forecasts of 2020 AADT and truck volumes were unreasonable. With adjustment the forecasts were reasonable.

The results of the AGF, GFR and Trend Program User Defined methods were comparable for the I-95 case (Table ES-5). The comparisons indicate:

- Forecasts based on historic data and unadjusted growth factors produce may unreasonable results for other highway project forecasts, as well as the I-95 case.
- The AGF and GFR methods using all available data and growth factor adjustments based on confidence interval guidelines produce reasonable forecasts for individual vehicle classes and AADT for the I-95 case. Similarly reasonable results with the AGF and GFR methods may be expected for other highway project forecasts.
- The Trend Program and its User Defined growth factor may be utilized with a user defined growth factor based on confidence interval guidelines to produce reasonable forecasts for I-95 and other highway projects.

Table ES-5. Comparison of Forecasting Methods for 2020 I-95 Traffic

Method	Cars	Duals	TTST	AADT	Duals%	TTST%
AGF Exp Model (Historic GF) (AGF not adjusted)	78447	18551	56821	153848	12.06%	36.93%
AGF Exp. Model (AGFs adjusted by CIs)	64666	3254	16813	84733	3.84%	19.84%
GFR Method, no outliers (AGFs adjusted by CIs)	~	3390	17171	80579	4.21%	21.31%
Trend Program (User Defined Rate)	64667	3253	16730	86693	3.75%	19.30%

Is truck traffic growing faster than general traffic?

Growth factors derived from the VTRIS data for 1997-2004 (Tables ES-1 to and ES-4) address this question. The difference in means may be examined directly and a t-test may be evaluated.

From Table ES-3 for rural Interstates there is a 95% probability that the range of AADT AGFs (2.8% to 2.06%) has a mean of -0.4%. On the other hand, Duals have a mean of 0.79% and TTSTs have a mean of 1.87%. Thus, based on means it may be concluded that truck traffic is growing faster than general traffic on NC rural Interstates.

From Table ES-4 for rural principal arterials AADT AGF has a mean of 1.41% while Duals and TTSTs have mean AGFs of 3.34% and 1.65%, respectively. Thus, based on means it may be concluded that truck traffic is growing faster on NC rural principal arterials than is general traffic measured by AADT.

Similarly inspection of the VTRIS truck data (Table ES-1) for North Carolina Interstates shows that the mean growth rates of Duals and TTSTs are greater than those for passenger vehicles (Cars) for the years 1997-2004. It can also been seen that the mean growth rate for light vehicles (classes 1-3) shows a decline for the same years. However, mean values do not confirm that trucks are growing faster than cars. In order to substantiate the analysis, a t-test must be conducted to test the hypothesis that trucks are growing faster than cars. The t-test results show that at 95% confidence level, there is not enough evidence to state that average truck growth rates for Duals and TTSTs differ from general traffic growth rates (classes 1-3). However, t-test results for 90% confidence do indicate an increase in truck growth rates compared to light vehicles.

VTRIS truck data (Table ES-2) for North Carolina arterials (other) indicate that the mean growth rate of TTSTs (FHWA classes 8-13) is greater than the mean growth rates of Duals (classes 4-7) and Cars (classes 1-3), and that the mean growth rate of Cars is greater than that of Duals. Statistical tests, however, show that at 95% confidence level, there is not enough evidence to state that truck growth rates are higher than general traffic growth rates on North Carolina US and NC highways.

How are truck traffic growth rates affected by facility type (Interstate, US, and NC route), geographic location (eastern, central, and western North Carolina), urban or rural region, proximity to truck generators, and factors such as regional population and economic development?

Regression analysis with available VTRIS data for North Carolina Interstates considered some of the causal factors of truck traffic growth. Factors not considered were urban or rural classification (all data were rural), proximity of VTRIS location to other major routes, and economic development. Results show that truck growth rates for NC rural Interstates have no dependence on population, geographic region, warehouses, or facility type. Additional data may be helpful to find such relations if they exist. These results suggest that the increase in NC rural Interstate truck traffic is caused by out-of-state influences such as hauling imported freight, general economic conditions for the U.S., and efficient freight shipment technology and logistics. In-state effects such as truck generator locations and sizes, construction sites, commodity distribution locations, were not considered. Similarly using VTRIS data for rural NC arterials (other), regression analysis did not show a causal relationship of truck traffic growth to NC geographic regions, population distribution, number of transportation warehouse for each county, and highway type.

As highway projects develop for minor facilities with limited truck traffic, should new truck counts be taken or can default values be used?

Some highway project locations, especially minor highways, have little or no historical data. Short term traffic counts can provide ADT and current percentages for Duals and TTSTs, but they cannot provide a basis for a traffic forecast. In such cases NCDOT staff often use their expert judgment and select a nominal growth rate of one or two percent per year for minor facilities. Alternatively, growth rates for segments without annualized traffic counts may be approximated by the means of the VTRIS vehicle class by facility type lacking other information. However, VTRIS locations are on major routes that have a different character of traffic than minor highways. Ad hoc engineering judgment can be strengthened by the VTRIS 95% confidence intervals of the AGFs.

How does truck traffic affect highway and pavement design?

The research included two sensitivity studies to examine the effects of truck traffic on highway design (number of lanes and level of service) and pavement design (cost per linear foot). Both studies used the I-95 case study as a basis.

Highway Design

As demonstrated previously the volume of vehicles, especially trucks, is rising on North Carolina highways. Trucks travel at slower speeds than passenger vehicles and occupy more space on the highway. Thus, trucks have a greater influence on the number of lanes than passenger vehicles. To explore the impacts of trucks on highway design, the Highway Capacity Software was used to test I-95 for alternative combinations of truck volumes, number of lanes and level of service.

Near Smithville in Johnston County I-95 is a four lane facility. In 2003 I-95 ADT was about 57,000 with 3.5% Duals and 14% TTSTs. The sensitivity study found that the four lanes are adequate for LOS B for ADTs of 25,000 and 35,000 for any percent trucks. Similarly a six lane highway is adequate for LOS B for ADTs ranging from 45,000 to 65,000 for any percent trucks. When ADT is 75,000 vehicles per day, six lanes are sufficient for 2% to 10% trucks, but eight lanes are required when the percent trucks is greater than 10% percent.

Pavement Design

The focus of the case study was the effect of truck traffic volumes in pavement design for I-95 and US-64 routes located in Nash County. The analysis was carried out for only three types of flexible pavement constructions (all with soil stabilization): full depth asphalt pavement, flexible pavement with aggregate base course (ABC), and flexible pavement with cement treated aggregate base course (CTABC). The unit costs and design length were based on 10 miles. Using the NCDOT Pavement Design spreadsheet a repetitive analysis for different percentages of Duals and TTSTs gave cost/linear foot. Corresponding ESALs (Equivalent Single Axle Load) for each variation were recorded because they directly relate to percentage truck traffic.

Results indicated three distinct ranges of ESAL values. The mid range was of particular interest because it corresponded to mid ranges of truck volumes such as occur on US routes. Over that range pavement cost/linear foot increased dramatically compared to the other two ranges. Thus, pavement engineers should be particularly concerned about designs in the mid range of ESALs on NC principal arterial routes.

Recommendations

The recommendations follow from the findings in this research.

- Traffic forecasts should not be based on trends that consider only the first and last years in a sequence of historical traffic data. Rather, each year's historical traffic data should be included in the calculation of the growth factor.
- Dual and TTST truck volumes should be forecast independently of AADT for highway projects. Truck percentages should not be assumed equal at the base and future years for the forecast, rather vehicle volumes by class should be calculated or estimated using available data and valid statistical guidelines. Truck percentages should be determined after the total AADT by adding the individual vehicle volume forecasts.
- Statistically based guidelines (confidence interval tables) should guide the calculation and selection of growth factors.
- The results of this study, in particular the historical vehicle class data and confidence interval tables, should be updated as more WIM stations are installed throughout North Carolina and as more VTRIS data become available.
- The NCDOT Traffic Forecasting Utility (Trend Program) should be expanded to include the Average Growth Factor and Growth Factor Ratio methods from this research.
- The prototype GIS methodology for processing VTRIS vehicle class data, calculating vehicle class growth rates, and displaying the results with land use and other map images should be more fully developed and demonstrated operationally.
- Extend the research and proposed AGF methodology to include Interstate and Principal Arterials in fringe areas not covered network-based travel demand models.
- In order to develop default traffic growth factors for minor highway facilities in rural and fringe areas, apply the research approach to such traffic data when new traffic count programs are completed in 2006 and 2007.

Products

As a result of the methodology and data used for the project, the following products are available for use at NCDOT.

- Two new traffic forecasting methods (AGF and GFR).
- Statistical tests (QQ plots, t-tests and confidences intervals) and test results to check growth factors for traffic by class on NC rural Interstates, US and NC routes.
- Guidelines for default traffic growth factors based on VTRIS to use where data is sparse.
- A GIS shapefile for Statewide VTRIS (WIM) stations (51 WIM and LTPP stations).
- A statewide 1997-2004 spreadsheet and database for the VTRIS archive including classified counts for Passenger Vehicles (Cars), Duals and TTSTs.
- A methodology for integrating spreadsheet tools and data for traffic forecasts.
- A GIS methodology for integrating growth factor methods and data from VTRIS, land use files, the Census and other sources that describe economic trends for traffic forecasts.
- Four case study demonstrations of the growth factor methods: I-95, US 64, US 421, and NC 279.
- A sensitivity study based on I-95 highway design for number of lanes and level of service versus truck volumes.
- A pavement design sensitivity study based on I-95 for cost per linear foot versus truck volumes.

- An application of GIS and average growth factor methods to locate an electrified truck stop near an Interstate, e.g. I-95.

Implementation and Technology Transfer Plan

Truck traffic is significantly growing year by year because of the dynamics of the U.S. economy. Increased truck traffic, however, increases traffic congestion and impacts on pavement and bridge structures. Good forecasts of truck traffic are critical to the design procedures of NCDOT. Thus, the results of this research must be transferred to appropriate NCDOT users.

The research products can be used by the Transportation Planning Branch to forecast truck volumes to support a variety of transportation improvements including highway widening, pavement and bridge design, and identification of future network deficiencies. The research products include new traffic forecasting applications of standard statistical methods that are adaptable to the current NCDOT Traffic Forecasting Utility (Trend Program) and GIS implementations. Thus, NCDOT staff should be able to apply the research products directly with little or no training. The extensive documentation, spreadsheets and data related to this technical report will facilitate the transfer the technology to the users. However, in-house or external training are options.

Transportation Planning Branch staff are preparing *Best Practice Guidelines for Traffic Forecasting*. The *Guidelines* will be based on NCDOT practice, peer DOT practice, and a research project report *Guidelines for NCDOT Project-Level Traffic Forecasting* (Stone 2002). The results of this important truck traffic research, *North Carolina Forecasts for Truck Traffic*, should also be included in the TPB *Guidelines* effort. Thus, TPB should coordinate its efforts with the traffic forecasting needs of other NCDOT units including Traffic Surveys, Pavement Management, and Bridge Maintenance.

Specific NCDOT implementation tasks include:

- Modify the existing NCDOT Traffic Forecasting Utility (Trend Program) to incorporate the confidence intervals to help users select reasonable traffic and truck growth factors.
- Modify the Traffic Forecasting Utility to include the Average Growth Factor and Growth Factor Ratio methods developed in this research.
- Modify the Traffic Forecasting Utility with Q-Q plots or similar statistical methods to test for normal distributions and outliers of traffic data that should be removed before a forecast is prepared.
- Modify the Traffic Forecasting Utility to:
  - Individually forecast Passenger Vehicles, Duals and TTSTs.
  - Sum the results for AADT.
  - Separately calculate future values of percent Passenger Vehicles, Duals, and TTSTs based on individual forecasts for Passenger Vehicles, Duals, TTSTs, and calculated AADT.
- Update the current VTRIS database for to include traffic data beyond 2004 and recalculate confidence intervals.
- Provide the products of this research to the Traffic Surveys Unit and discuss data upgrade opportunities based on new traffic count programs.
- Provide the results of this research to the Traffic Forecasting Unit.
- Discuss training requirements with the authors and ITRE.

CHAPTER 1: INTRODUCTION

Background

North Carolina has experienced a significant increase in truck traffic along many of its highways. Much of this increase results from the large increase in freight movement for rising imports and freight logistics that use just-in-time delivery strategies. The challenge for this research project is to forecast such truck traffic growth for new highway projects in North Carolina. This requires careful assessment of truck traffic using a variety of data sources.

This project expands truck traffic forecasting methods by building upon recently completed NCDOT traffic forecasting research. *Guidelines for NCDOT Project-Level Traffic Forecasting*, prepared by NC State University, developed a systematic methodology of manual calculations, computer methods, analytical tasks, and documentation requirements. The guidelines resulting from the research reflect current NCDOT practice and include computer-based approaches for estimating future year total vehicle traffic. This project uses enhanced statistical methods and data sources for estimating future truck traffic separately from future automobile traffic to help NCDOT prepare highway and pavement designs that greatly depend on the number of trucks in the traffic stream.

Depending on the urban or rural location of the highway, total traffic growth rates vary from near zero to several percent per year. The volume of trucks increases with total traffic growth, and NCDOT usually assumes that the percentage of trucks remains constant between counting cycles - a time period of up to three to five years. National and state data suggest that trucks are becoming an increasingly larger fraction of total highway traffic due to the relatively low cost and convenience of shipping packages and freight by truck. Furthermore, North Carolina truck traffic is increasing faster than general traffic according to some forecasters because of the state's economic development in the past decade. Consequently, NCDOT may be underestimating future truck traffic. Underestimates of truck traffic will cause new highway pavements and structures to be under-designed. Similarly, pavement and bridge maintenance schedules may be inadequate. On the other hand, there are anecdotal reports that suggest that NCDOT engineers apply generous adjustments for design that may over compensate for possible underestimates of truck traffic. Such adjustments, however, can lead to over design and unnecessary construction expense. These conflicting reports justify an examination of the NCDOT truck traffic forecasting process.

This project develops procedures for NCDOT truck traffic forecasts and demonstrates their use for pavement and highway design. It uses NCDOT and USDOT sources for truck traffic and other data.

Problem Statement

To help prioritize roadway and bridge projects, engineers in the Traffic Forecasting Unit perform more than 300 project-level traffic forecasts each year. The forecasts support other NCDOT units including Project Development and Environmental Analysis, Roadway Design, Pavement Management, and Feasibility Studies. Engineers in the Traffic Forecasting Unit use data from the Traffic Survey Unit to estimate traffic for periods ranging from five to twenty years. They use historical trend analysis of local traffic data, field reviews, technical expertise, past and present information on local development, state trends, and other information. Their project level traffic forecasts are the basis for environmental documents, feasibility studies, maintenance schedules, and designs for roadways, pavements, and bridges. Virtually all road and bridge improvements in the Transportation Improvement Program (TIP) depend on the results of the Traffic Forecasting Unit. Hence, accurate traffic and truck forecasts at the project level are imperative.

Truck traffic is a main determinant of road and bridge design, maintenance scheduling, and cost. Bridges and pavements must withstand the weight and frequency of truck traffic. In years past North Carolina primary routes carried about 24% trucks including truck tractors and semi-trailers (TTST, FHWA classes 8- 12). Primary routes carried about 8% dual axle trucks (Duals) that must have at least one dual tired axle (FHWA classes 4-7). A typical growth rate was 2.5% according to NCDOT summary data. Now, anecdotal reports indicate that in some locations NC highways carry up to 40% TTST (Truck Tractors with a single Semi-Trailer) and Twin TTST (Truck Tractors with a double Semi-Trailer) as part of total AADT (Average Annual Daily Traffic). Furthermore, some professionals predict that truck traffic will double between 2000 and 2010 as industries and firms ship more freight by trucks. North Carolina traffic also includes automobiles, pick-ups, vans, SUV type trucks and motorcycles (FHWA classes 1-3) which this report does not address. Figure 1-1 illustrates all FHWA classes.

As truck traffic increases, loads on bridges and pavements will increase requiring stronger, more costly designs. Thus, it is critical that good truck traffic forecasts are prepared so NCDOT roadway designs and improvements satisfy the expected demand. Under-estimates of future truck traffic can result in inadequate maintenance schedules as well as under design of pavement thickness and type. On the other hand, over-estimates of truck traffic may result in over design and unnecessary construction expenses.

To address such truck forecasting needs this project focused research on the following questions:

- What data sources and analytical procedures are available, and how can they be integrated with expert judgment to produce the best estimates of truck traffic for a project?
- As highway projects develop, should new truck counts be taken or can default values be used for some minor facilities with limited truck traffic?
- Is truck traffic growing faster than general traffic?
- How are truck traffic growth rates affected by facility type (Interstate, US, NC, SR), by geographic location (eastern, central, and western North Carolina), urban or rural region, proximity to interstates and other truck generators, and factors such as regional population and economic development?
- How can simple changes in the current truck traffic forecasting process lead to better traffic forecasts?

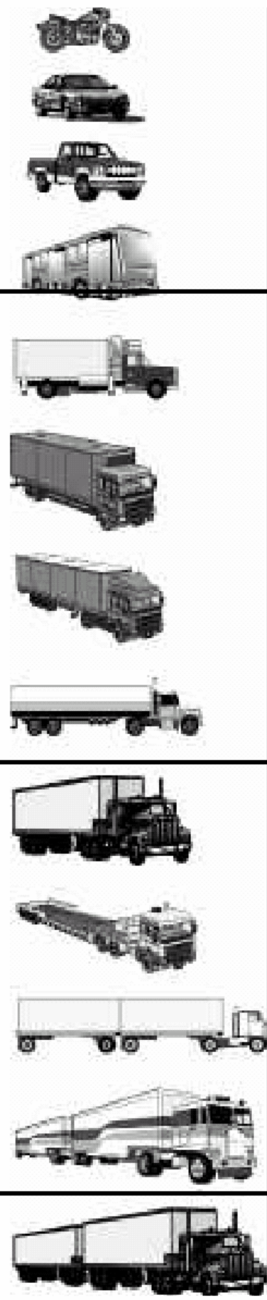
Research Scope and Objectives

The scope of the project is limited to rural highway facilities within North Carolina. Highways within the state include coastal, central, and western areas, and Interstate, US, and NC routes. Data sources available from NCDOT and FHWA support this project. Highway network effects, uncertainty, and exogenous causal factors, such as economic variables, are not considered.

The project goal is to develop truck forecasting methods that have modest data requirements, use fundamental traffic data, and use available data.

Figure 1-1. FHWA Vehicle Classifications

FHWA VEHICLE CLASSIFICATIONS



Axles	Class	Description
1-2 axles	1	Motorcycles
	2	Passenger cars
	3	Two axles and tire single units
	4	Buses
3-5 axles	5	Two axles and tire single units
	6	Three axles single units
	7	Four or more axle singe units
	8	Four or less axle single trailers
6+ axles	9	Five axle single trailers
	10	Six or more axle single trailers
	11	Five or less axle multi-trailers
	12	Six axle multi-trailers
	13	Seven or more axle multi-trailers

Source: Pavement Design Guide 2002-Milestones 2002, TRB, Winter 2001

The specific objectives of the research are to:

- Propose forecasting methods for truck traffic volumes,
- Develop practical alternative methods to forecast truck traffic for NC Highway projects,
- Test NC truck traffic growth with causal factors such as population, employment, geographic region, number of warehouses and facility type, and
- Demonstrate the methods with several case studies.

Chapter Summary and Report Overview

This first chapter introduces the issues related to forecasting truck traffic. Subsequent chapters develop a simplified and systematic methodology. The second chapter reviews current NCDOT methods and software, and those used in other states. Chapter 3 discusses data sources used for the project and provides statistical tests for the growth rate of trucks. Chapter 4 develops the methodology to forecast trucks, and Chapter 5 demonstrates the approach for I-95 case in Johnston County. Chapter 6 draws conclusions and states recommendations based on this research. The report also includes valuable appendices that describe other case studies, shapefile generation for weigh-in-motion stations, statistical tests, regression analyses, and sensitivity studies for the impacts of trucks on bridge and highway designs.

CHAPTER 2: LITERATURE REVIEW

Introduction

This chapter will highlight traffic forecasting procedures and software applications used at NCDOT and elsewhere.

Truck traffic and freight transportation planning have been research topics since the early 1970's (Allen, Baumol and Vinod, Memmott, Slavin). Over the past few decades, various modeling methodologies have been developed and applied to predicting freight movements. Statewide truck network models are utilized in Iowa, Florida, Virginia, Wisconsin, Indiana, California and Louisiana. Other more common forecasting procedures include time series analysis, trend projections, and qualitative methods. This research focuses on "quick-response" quantitative methods using regression and trend projections for long-term truck traffic forecasts.

The following literature review addresses the advantages and disadvantages of traffic forecasting procedures in North Carolina and other states and their data requirements. This literature review lays the foundation for developing a truck traffic forecasting methodology for North Carolina.

Factors Affecting Truck Traffic Demand

Besides highway infrastructure planning and design, forecasting truck traffic is a critical element of the multi-modal freight transportation planning process. It drives many decision-making processes for freight improvements, infrastructure investment, and policies and regulations affecting air, rail and water modes. Truck traffic forecasts are important because trucks carry about 70 percent of the US freight tonnage and 80 percent of the total value of U.S. shipments (FHWA FAF).

In order to ensure that a proposed truck traffic estimation tool is responsive to the overall planning process, the factors that affect truck traffic demand need to be identified and verified. Figure 2-1 constitutes a simplified representation of the direct and indirect factors that affect truck volumes. Due to a lack of good data on these factors, relatively simple statistical models are frequently applied to historical traffic counts.

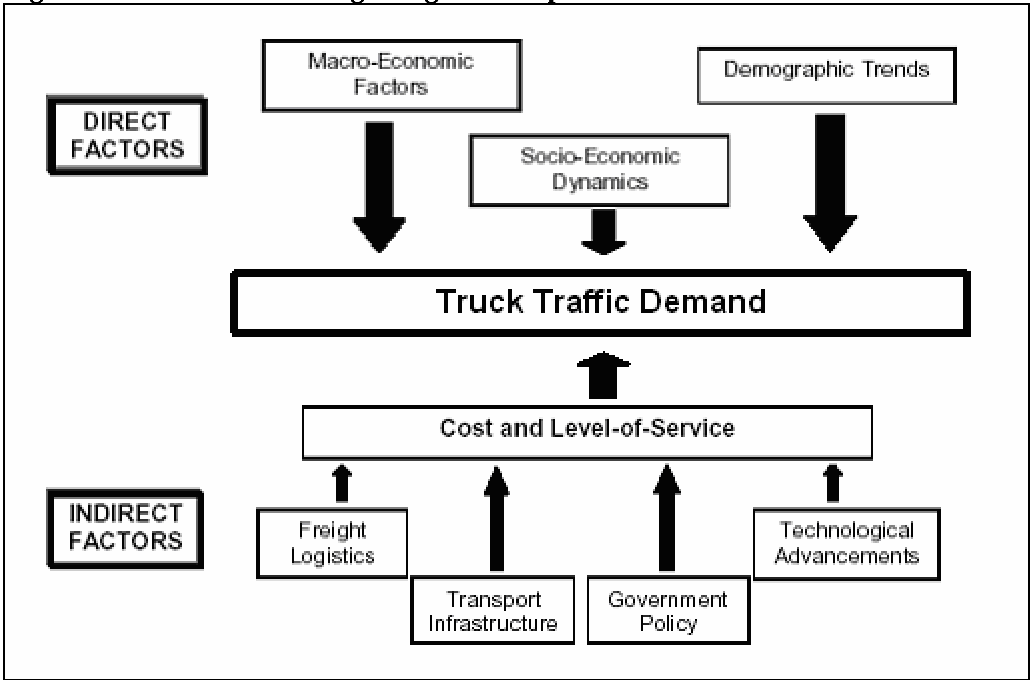
Direct factors are those that contribute to the demand for goods and services and therefore directly lead to the demand for truck traffic as a mode of freight transportation. These factors may be broadly identified as follows:

- *Macroeconomic factors:* the level of economic activity, international trade agreements, and other economic phenomena.
- *Demographic factors:* changes in overall population, age distribution, educational and employment distribution, and spatial location.
- *Socio-economic dynamic factors:* changes in the habits, values, perceptions, and lifestyles of people over time.

Data sources for direct factors are relatively easy to find for cities and counties, but they are hard to incorporate into forecasting models for truck traffic that may vary on highway segments in the same city or county. Furthermore, when highway segments cross county boundaries it is difficult to incorporate statistics for multiple counties.

Unlike direct factors, indirect factors are those that influence truck demand by affecting the cost

Figure 2-1. Factors Affecting Freight Transportation Demand



Source: Guidelines for NCDOT Project Level Traffic Forecasting

and level-of-service of truck transportation services. These factors are generally classified as:

- *Government policy:* user charges and taxes, environmental and safety regulations, subsidies, and other public sector institutional issues.
- *Freight logistics:* just-in-time delivery, centralized warehousing facilities, industry alliances, and demand-responsive scheduling.
- *Transportation infrastructure:* the design, operation, and level-of-service of multimodal and inter-modal transportation facilities.
- *Technological advances:* intelligent transportation systems technologies that greatly aid in the efficient operation of freight transportation systems and logistics communications.

Indirect factors might also include unexpected events – war, natural or man-made disasters, economic upheaval, etc. Information on indirect factors is hard to find and incorporate into simple truck forecasting methods. Such information is usually applied in complex simulation models and probabilistic models.

Truck Traffic Modeling Methods

Various truck traffic simulation and modeling methodologies have been developed and applied. The methodologies differ in the level of complexity, geographic and temporal aggregation scale, and data requirements. Truck models share fundamental planning procedure characteristics with other modes of freight transportation including trip generation, distribution, and assignment. This part of the paper provides a brief overview of the various types of modeling methods. All modeling methods have advantages and disadvantages in different application contexts. The review is limited to models for long term planning and forecasting rather than short-term logistics and operations.

Trend and Time Series Analysis

Trend and time series analysis involve extrapolation of past historical trends in truck activity. The types of models that fall under this category range from simple growth factor models to more complex statistical models. Autoregressive integrated moving average (ARIMA) models are suitable for the analysis of time series data. Trend and time-series models are generally simple to implement, are not data intensive, and build upon historical trends to predict the future. On the other hand, trend and time-series analyses tend to be aggregate in scale and may obscure trends that could be important for truck transportation planning and decision-making. Trend and time series analyses develop the general traffic and truck forecasts that are the focus of this project.

Elasticity Methods

The sensitivity of truck demand to truck transportation costs reflects the price elasticity of demand. Elasticity measures may be short-run or long run in nature. Differences between them can be substantial if considerable adjustments in truck transportation behavior occur long term.

There are several different elasticity measures. The most notable measures include point elasticity, arc elasticity, and shrinkage ratio. Elasticity can be computed or derived in two ways. The first way uses statistical and econometric models based on truck transport demand data to determine elasticity measures. The second way measures elasticity directly from field observations of changes in truck volumes occurring in conjunction with changes in price. Cambridge Systematics, Inc. provides a summary of the issues and limitations associated with elasticity methods. Elasticity measures derived from recent data sources can be very useful, particularly for sketch planning applications. It is not apparent, however, that elasticity measurements are used by state agencies to forecast long-term truck traffic for design purposes.

Network Models of Economics and Logistics

In general, network models assume that shippers and carriers use minimum cost paths on a network where the cost is a combination of price, time, and energy use. The Generalized Spatial Price Equilibrium Model (GSPEM), a comprehensive freight flow model, simultaneously incorporates trip generation and the shipper and carrier decision-making processes (Harker and Friesz). More recently, Friesz proposed a dynamic disequilibria interregional commodity flow model.

Network models of logistics hold promise for modeling intercity truck flows. They are more complex to implement than other methods and have more intensive data requirements. As such, the implementation of network models of truck traffic may be a viable long-term strategy for statewide truck traffic demand forecasting. At the interregional state level the FAF, GeoFreight, and LATTS models have had some success at federal and state agencies.

Direct Demand and Aggregate Flow Models

Aggregate demand models primarily deal with estimating truck volumes using aggregate data that include limited information on the factors affecting truck traffic demand. These models attempt to show the aggregate volume of commodity flow as opposed to the number of individual trips.

Analysts apply different methods to convert aggregate demand flow models to truck volumes. The total flow approach establishes the relationship between total output of the economy and truck traffic demand or establishes a relationship between the output of a selected industry and truck demand for a particular commodity. This approach is a type of forecasting technique and it uses time-series data. Also, regression-based methodologies and simultaneous equations systems have been employed in this context (Abdelwahab and Sargious).

Another major approach involves the generation of synthetic origin-destination matrices for truck traffic. This approach uses limited survey data or truck traffic counts (List and Turnquist), it usually uses iterative algorithms to generate a synthetic origin-destination matrix that best replicates field data. The algorithms are currently well-established and very useful, especially in the presence of limited data.

Economic Input-Output Methods

Young, Zlatoper, and Austrian describe methods for estimating freight transport demand based on economic input-output models that normally utilize econometric techniques. Typical inputs of the production of goods and services may be capital, labor, land, and other such basic input resources that add value through economic activity. These inputs are utilized in an input-output analysis matrix to determine various economic outputs. The outputs may include the quantity of goods and services produced and demanded by type, geographic location, and temporal frame, and other such measures of economic output. The output commodities directly relate to total freight transportation which mode choice models can split into truck traffic.

NCDOT has limited experience with truck simulation and modeling methods except trend analysis and a special freight project that used FAF and LATTS (Patel).

The foregoing modeling methods including time series analysis, elasticity, network models, direct demand aggregate models, and input-output models are complicated and require much data comparable to regional travel demand models. Regression and growth factor procedures require conventional traffic count data and find wider application for traffic forecasts at state agencies. Such regression and growth factor methods will be the basis for the methods in this report.

Truck Traffic Forecasting Procedures

NCDOT Forecasting Procedures

NCDOT engineers often assume that truck traffic is a percentage of overall traffic. For example, in periodic traffic surveys NCDOT engineers estimate truck traffic to be a constant percentage of total traffic for a period of three to five years until the next count cycle. According to Table 2-1, in the 1992-1994 count cycle I-95 near Smithfield carried about 8% trucks with tractors and semi-trailers (TTST, FHWA classes 8-13) and 5% dual axle trucks (Duals must have at least one dual tired axle, FHWA classes 4-7). For the 2003 cycle the percentages are about 15% TTST and 8% Duals. This example illustrates how truck percentages are assumed constant between class count cycles, how they vary over the long term, and that they are generally increasing.

Table 2-1. NCDOT Truck Traffic Near Smithfield, NC. Source: NCDOT Traffic Survey Unit

Station	Route	County	ADT year	ADT	Dual % (classes 4-7)	Dual vol. (classes 4-7)	TTST % (classes 8-12)	TTST vol. (classes 8-12)
215	I 95	JOHNSTON	1992	31100	5%	1555	8%	2488
215	I 95	JOHNSTON	1993	28400	5%	1420	8%	2272
215	I 95	JOHNSTON	1994	27900	5%	1395	8%	2232
215	I 95	JOHNSTON	2003	47046	8%	3764	15%	7057

The use of truck traffic percentages in ADT traffic is traditional yet controversial. While resource constraints may not allow annual vehicle classification counts, transportation engineers would prefer yearly class counts due to the great impact of heavy vehicles on pavement design and maintenance schedules.

Besides assuming constant truck percentages between periodic vehicle classification counts, NCDOT engineers often assume during project-level traffic forecasts that the base year truck percentages are constant for the 20-year to 30-year forecast.

As a foundation for a truck traffic forecasting methodology, NCDOT developed a methodology for project-level traffic forecasting in a report titled Guidelines for NCDOT Project-Level Traffic Forecasting *(*Figure 2-2). This methodology provides a systematic approach for sketch planning and traffic forecasting of individual highway, bridge and other "isolated" projects. The methodology is also suitable for truck traffic forecasting. The method addresses network level projects in urban areas and it provides methods for sketch planning and traffic forecasting.

Fundamental to good NCDOT truck traffic forecasts are the quality of the available traffic counts by vehicle class and "clean" data for a project location that results from a complex procedure of eliminating atypical counts and factoring and annualizing the data. Chapter 3 explains NCDOT traffic counts and discusses data cleansing, factoring, and annualizing. These methods apply to total traffic AADT forecasts and to truck traffic forecasts.

NCDOT generally uses the spreadsheet Traffic Forecasting Utility (TFU), or the related Trend Program, to develop traffic forecasts at project locations. Forecasters use the TFU or Trend Program only for total traffic. They assume percent Duals and TTSTs in the base year carry through to the future year. Rarely will NCDOT forecasters separately consider truck volume forecasts.

Within TFU and Trend Program there are five different models to develop the AADT forecast. The engineer uses experience and engineering judgment to choose the most appropriate forecast.

1. Average Annual Increment
This linear model uses a single past AADT or count for a particular year and a recent AADT or count at the project location to determine the average annual increment in daily traffic.

2. Average Annual Growth Rate
This option uses a single past AADT or count and a recent AADT or count to develop a regression between the two data points using an exponential equation.

3. Regression of Increment
The model uses linear regression with a linear model and multiple available data points for AADT to develop a forecast of the AADT at the project location in a future year.

4. Regression Rate
This option uses an exponential model and available data.

5. User Defined Growth Rate
The user-defined model accounts for engineering judgment, expert opinion or other special factors that could affect forecasts. The engineer can use a growth rate based on experience or

other causal influences at the project location in order to get a reasonable value for future AADT. This model also follows an exponential equation.

The TFU Trend Program use formulas (1) and (2) for linear and exponential models respectively.

$$AADT_{\text{Future Year}} = AADT_{\text{Base Yr}} + \text{AADT Yearly Increment} \times (\text{Future Yr} - \text{Base Yr}) \quad (1)$$

$$AADT_{\text{Future Year}} = AADT_{\text{Base Yr}} (1 + R)^{(\text{Future Yr} - \text{Base Yr})}, \quad R = \text{annual growth rate} \quad (2)$$

Forecasts usually apply a linear model to forecast traffic on high volume roads like Interstate. The exponential model is appropriate for low volume roads, and user-defined growth rates rely on engineering judgment. Possible adjustments to the growth rate depend on local, regional, and national influences on truck traffic. For example, local building permits relate to Dual truck traffic on secondary routes and Gross Domestic Product (GDP) relates to TTST traffic on Interstates. Such economic data are available from state databases (NC links and NC Budget Management Office) and national databases (Bureau of Transportation Statistics, BTS).

Traffic Forecasting Procedures in Other States

State DOTs primarily use two approaches to forecast truck freight traffic: (1) direct analysis of truck traffic counts, and (2) commodity flow models (Guidebook on Statewide Travel Forecasting, Federal Highway Administration).

<u>Direct Truck Traffic Count Technique</u>

The approach directly analyzes truck traffic with two techniques – trend analysis and network models. Trend line analysis is similar to NCDOT methods for AADT forecasting. Usually, truck traffic is calculated by multiplying actual general traffic counts by an assumed truck percentage for each year, rather than taking actual truck counts. Trend line analysis is simple to implement and it is not data intensive. However, trend analysis has no direct link to the regional or national economic activities that may be primary causes of increased truck trips. In addition, trend analysis cannot account for congestion and other network effects.

The second technique, network modeling, includes truck trips as a separate trip purpose in a regional or statewide travel model. It may originate from aggregate commodity flows or from surveys of individual truck trips as discussed previously. Michigan and other states use network models (KJS Associates Inc). A network (flow) model regresses truck trip generation by using employment and tons shipped, and then applies the truck trips to the network structure used by a statewide passenger vehicle model. Such a model exhibits good results for developing a standard network-based truck travel demand model at the state level. More importantly, this model explicitly incorporates explanatory factors that affect truck traffic demand. However, it requires costly origin-destination truck survey data for calibration. Truck network modeling is similar to forecasting person trips in regional models.

Commodity Flow Technique

The forecast approach based on commodity flows also bears a resemblance to regional models for person trips. The commodity flow model uses a "four-step" sequential process that uses a gravity-model distribution, a cursory mode-split step and simple assignment. The only significant difference is that the trip generation step uses freight flow data (usually classified by industry groups), instead of regression equations for employment and population, as with regional models.

A good example of the commodity approach is the Indiana Freight Model (Black). The Indiana model predicts both truck and rail traffic volumes for a network developed from USDOT. For each of 21 commodity groups, trip generation equations are developed based on a regression of data available from 1993 Commodity Flow Survey. Following trip generation, freight shipments are distributed by a gravity model, which is also calibrated using the CFS data. The mode split step also utilizes the 1993 CFS, projecting the 1993 national shares into the future. Next, the model divides the freight tonnages into an equivalent number of vehicles, with tons-per-vehicle rates determined separately for each commodity group. Finally, the traffic is assigned to the network. This approach builds the relationship between commodity flow and truck traffic. It takes economic activities into account using the familiar four-step travel demand methodology to forecast future truck volumes. Generally, results are reasonable. On the other hand, such a model is complicated and requires much survey and quantitative data.

Wisconsin also uses the commodity flow-based technique in its Intermodal Freight Model (Wilbur Smith Associates). California uses it in its Freight Planning Model (AJH Associates). Based on commodity flow forecasts and economic input-output modeling techniques, the procedure for California Freight Planning is notable. It classifies heavy-duty trucks by three gross vehicle weight rating (GVWR) classes: light-heavy (8501 – 14,000 lbs.), medium-heavy (14,001 – 33,000 lbs.), and heavy-heavy (over 33,000 lbs.). Commodity flows are then converted to truck trips using the commodity-specific estimates of the portion of tonnage carried in each truck weight class and the average truck payload for each weight class.

Commodity flow methods are network-based and are beyond the scope of the project oriented methods for this research.

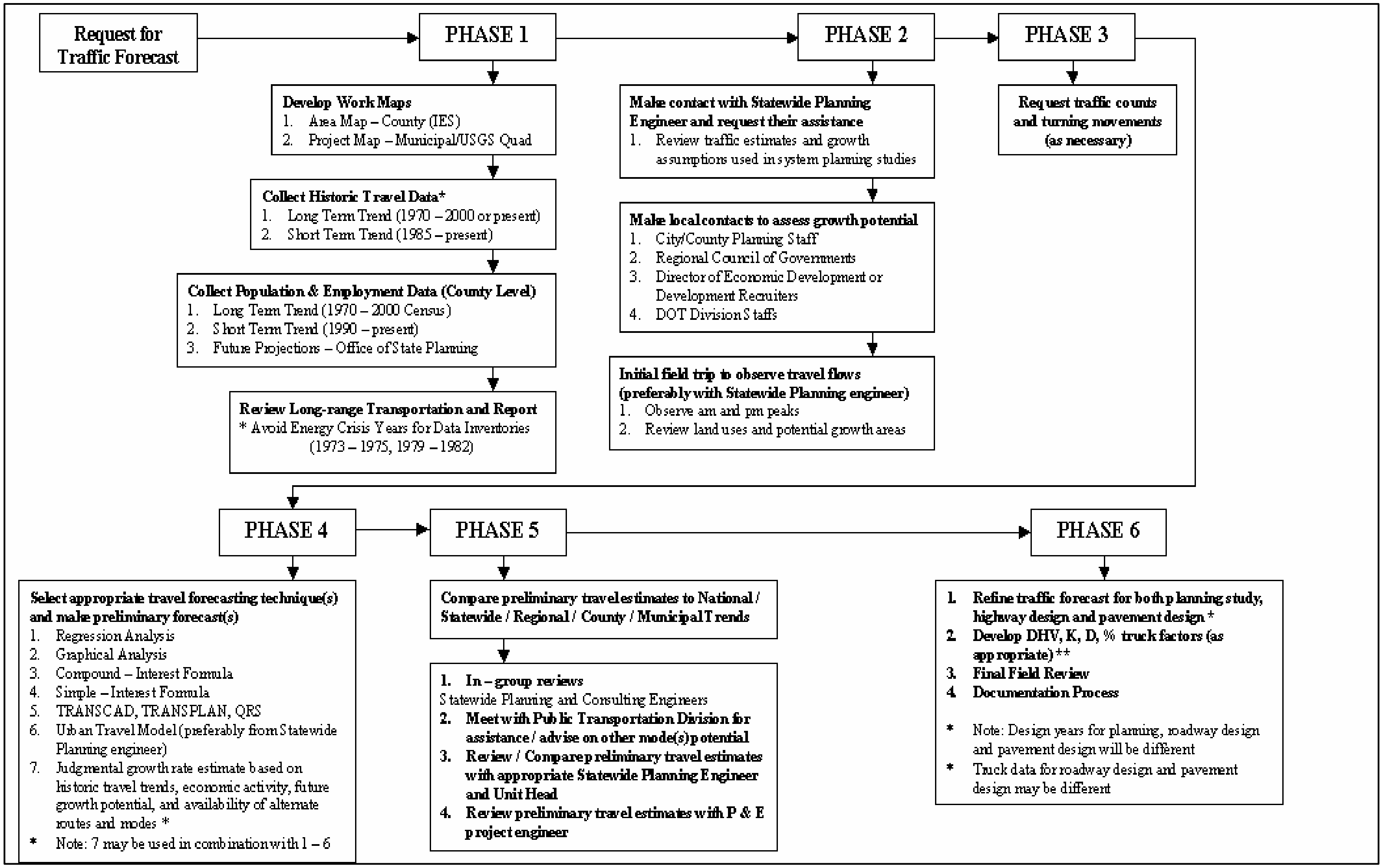
Databases

There are data resources from NCDOT and USDOT for truck data at the state and national levels. The data represent current and past traffic counts and vehicle classifications. However, there is national recognition that traffic data collection is difficult, especially for short duration counts. National research is underway that recognizes the stochastic, uncertain, time varying nature of traffic. The research replaces deterministic annual averages for ADT, TTST and Duals and proposes the alternative use of axle load spectra descriptions of the traffic (VTRIS/WIM). The results of the national research will be particularly important to pavement design engineers, and conversions from the conventional deterministic annual traffic averages to spectra representations of traffic loads will be necessary. This promising, non-deterministic approach to traffic counting, vehicle classification and potentially traffic forecasting, however, is not within the scope of this proposed research project.

Some state DOT's have taken advantage of regional and national databases to build truck traffic models that include information in addition to annual vehicle and truck traffic trends. A good example of data presentation is that used by the Virginia DOT as given by the following link. (http://www.virginiadot.org/projects/resources/AADT_PrimaryInterstate_2002.pdf).

VDOT collects vehicle class counts and presents the data on the Internet in "pdf" file format. It is readily available for use, but forecasters cannot download the file format into software like spreadsheets. Except for pavement performance monitoring using this data, VDOT makes no mention of using this data for traffic or truck forecasts. Virginia DOT is preparing a traffic forecasting manual that will be available in 2005 or 2006.

Figure 2-2 NCDOT Forecasting Flowchart



Source: Guidelines for NCDOT Project-Level Traffic Forecasting Procedures

Similar to the VDOT data the national VTRIS database is available on the Internet, but the data must be painstakingly entered manually item by item into forecasting software. One significant advantage of the VTRIS database compared to VDOT database is that the traffic and truck counts are factored and annualized. Thus, the VTRIS data may be used directly in forecasting procedures without additional data cleansing.

Manuals

Traffic Monitoring Guide

The *Traffic Monitoring Guide* (TMG) is the FHWA standard for highway traffic counts in the states. It describes the different types of counts and how to conduct the counts. A complete document may be found at the Internet site

http://www.fhwa.dot.gov/ohim/tmguide/index.htm

The TMG describes three basic types of traffic counts: continuous, short term and special. It discussed how continuous traffic monitoring is provided by:

- weight in motion (WIM) sites that collect vehicle classification counts and weight data used for damage factors and pavement design;
- classification sites that provide axle and seasonal correction factors and K, D and T factors for highway traffic forecasts and operations analysis;
- total traffic count locations that provide ADT, seasonal correction, K and D factors.

The TMG describes short term counts that are usually 48 hours in length, occur at selected locations for a variety of reasons such as project planning, and use factors calculated at nearby continuous count locations to estimate annual daily traffic. It also describes how to conduct special counts.

Minnesota DOT Traffic Forecasting Manual

Besides the TMC some states have developed their own guides for traffic monitoring. A typical state manual is available in pdf format from the Minnesota DOT website and example spreadsheets can be downloaded. Traffic is forecast for each vehicle class and the total AADT at the project location is obtained as a sum of all class forecast volumes. Raw counts are adjusted for seasonal trends with an adjustment factor and the percent composition of each vehicle class is found. Truck weights obtained from WIM stations also form a significant parameter in the forecasts. Knowledge of the project location and experience with forecasting plays an important role in choosing a final value for the forecast

Quick Response Freight Forecasting Manual

This document constitutes a comprehensive modeling methodology for metropolitan freight planning and forecasting. Even though the Manual is not specifically targeted to statewide truck traffic modeling, it is worthy of consideration due to its methodological merits. The procedure presented in the manual estimates truck trips within urban areas using a traditional four-step modeling process. Trip rates are provided for various truck and industry classifications in order to estimate zonal productions and attractions. These trips are then spatially distributed and assigned to the road network. Modal split is not necessary as the procedure deals exclusively with truck trips. Even though the procedure was developed for urban area freight travel demand modeling, many aspects of the methodology lend themselves to statewide modeling as well.

At the national level there have been numerous NCHRP studies dedicated to multimodal transportation planning, freight transportation planning and forecasting, and multimodal data and information systems. For example, NCHRP project 8-30 resulted in the publication of a "Guidebook for Forecasting Freight Transportation Demand". NCHRP Synthesis Project 230 resulted in the publication of "Freight Transportation Planning Practices in the Public Sector". The methods presented in these references relate to freight planning, not truck forecasting, and they are not generally applicable for project level truck traffic forecasting.

Truck Traffic Forecasting Software

Freight Analysis Framework

To understand freight demands, assess implications for the US surface transportation system, and develop policy and program initiatives to improve freight efficiency, the U.S. Department of Transportation developed the Freight Analysis Framework (FAF). The FAF examines transportation for four key intermodal modes: highway, railroad, water, and air. It relies on a comprehensive database for different modes developed from various government and sector databases. Therefore, truck traffic demand can be obtained and forecast based on the built US network. To evaluate the effect of anticipated truck volumes upon the network, the FAF includes economic forecasts for the years 2010 and 2020.

Regional Travel Modeling Software

For larger scale projects in urban areas, regional transportation software packages like TransCAD are preferred. These integrated transportation software packages estimate link volumes and turning movements for base year networks, and they estimate future year traffic based on land use changes. TransCAD software facilitate freight demand modeling. An innovative Freight Dashboard™ provides an efficient interface for retrieving freight flow data by origin, destination, mode, and commodity. TransCAD offers a complete software for modeling commodity flows and assigning truck movements to the transportation network. NCDOT has experience with TransCAD. Many urban areas in NC have TransCAD models, and some models contain explicit truck submodels.

Sketch Modeling Software

Besides the major regional travel modeling software packages like TransCAD, there are other large and small spreadsheet and software programs available to accomplish traffic forecasts for highway projects. Some are expensive, others not. Some have extensive capabilities for addressing truck forecasting and others are limited.

One simplified approach for forecasting traffic for highway projects is the use of computer "sketch" methods for traffic modeling and traffic impact analysis. Such models like QRSII (AJH Associates) typically evaluate urban and small area travel forecasting problems. They can also use commodity flow data assembled from surveys to assign truck trips to shortest time paths (Reginald, Zachary, and Shirish). Given a network and traffic zone characteristics (typically at the city block or census block levels), sketch methods accomplish the traditional four-step travel forecasting process including trip generation, trip distribution, mode choice, and network assignment. Most sketch methods have graphical network editing features and data import capabilities.

Such network-based software methods are beyond the scope of this research because of their complexity and data requirements.

Chapter Summary

Chapter 2 reviews several categories of truck traffic forecasting methods. They range from simple trend line analysis for project-level traffic forecasts to more complicated network-based methods for regional and statewide traffic forecasts. NCDOT relies on the Traffic Forecasting Utility and the Trend Program spreadsheets for project-level traffic forecasts, especially for isolated highway projects. If the project is part of an urban network TransCAD is likely used. Chapter 2 also reviews data sources for traffic forecasts and various software tools that implement forecasting methodologies. VTRIS is a top data source because it has classified annualized traffic. However, there are only about 60 VTRIS (WIM) sites in North Carolina. This number will double in the future. Traditional NCDOT factored and annualized traffic counts at or near highway project locations are the foundation for NCDOT traffic forecasts.

There are various manuals, spreadsheets and software packages to accomplish truck and total traffic forecasts. These forecasting packages are candidates for NCDOT truck traffic forecasts, but the approach used in this research is to build upon existing NCDOT project-level methods and data sources. Thus, the proposed methods will emphasize trend and regression methods in subsequent chapters.

The next chapter, Chapter 3, evaluates data sources for long-term truck traffic forecasts.

CHAPTER 3: DATA SELECTION AND ANALYSIS

Introduction

This project addresses truck traffic growth and its significance in traffic forecasting. Thus, acquisition of accurate statewide truck traffic counts is important. Accurate estimates of truck traffic volumes are critical to both the reliability of designs for highway, pavement, and bridge projects and to the computation of many other variables such as emissions and patterns of freight movement. Several data sets were considered for developing the methods in this research:

- NCDOT truck traffic counts
- USDOT Vehicle Travel Information System (VTRIS).
- USDOT Highway Pavement Monitoring System (HPMS)

This chapter compares the different data sources and identifies the best one (VTRIS) for the research. Next, the chapter uses the VTRIS database to identify average growth factor statistics for trucks and general traffic. The chapter concludes with general observations about truck traffic growth in North Carolina.

NCDOT Traffic Data

NCDOT has many traffic counters (Figure 3-1). There are two types of count programs of importance to this project – continuous counts and short term coverage counts. The continuous, permanent counters include Automated Traffic Recorder (ATR) stations and Weigh in Motion (WIM) stations and provide AADT and vehicle class data. The short term coverage counts are provided by portable counters throughout the state for many purposes and including sampled data for ADT and vehicle classes.

Approximately 120 ATR permanent, continuous count stations sample traffic on all highway types. About 70% of the ATRs are operational. They provide AADT directly without the need for data cleansing and factoring, however, the ATR data is reviewed and flagged if atypical records occur as from construction detours and extreme weather events. ATRs provide data for factoring and cleaning short term counts from other sites. Permanent ATRs do not provide percent vehicle class.

Permanent WIM stations provide data for FHWA vehicle classes (Figure 2), truck axles, and truck weight to monitor Long Term Pavement Performance (LTPP). There are approximately 60 WIM stations of which 30 are fully operational. 17 WIM stations are partially operational and provide volume count data only. According to the FHWA TMG, NCDOT uses 25 WIM stations each quarter to provide reviewed valid data to the FHWA Long Term Pavement Performance (LTPP) Research Project. The data include seven days of continuous weight data. Additional permanent stations will be built in North Carolina. FHWA VTRIS data are based on WIM data.

Approximately 720 vehicle class count stations are located in North Carolina. Over 300 of the stations provide data for the functional highway classes according to the TMG to be used for the FHWA Highway Pavement Management System (HPMS). A sample of vehicle class data is collected at these stations on a recurring basis – usually every three years. Most stations are automatic 48-hour counters, some are manual. Besides the FHWA data for 13 vehicle classes, the stations identify four NCDOT vehicle classes - passenger vehicles, Duals, TTSTs and other. Short term count programs also include a variety of studies for turning movements, external station counts, travel surveys, before/after impact studies, etc. No weight data are collected.

Figure 3-1a. Traffic Counters in North Carolina

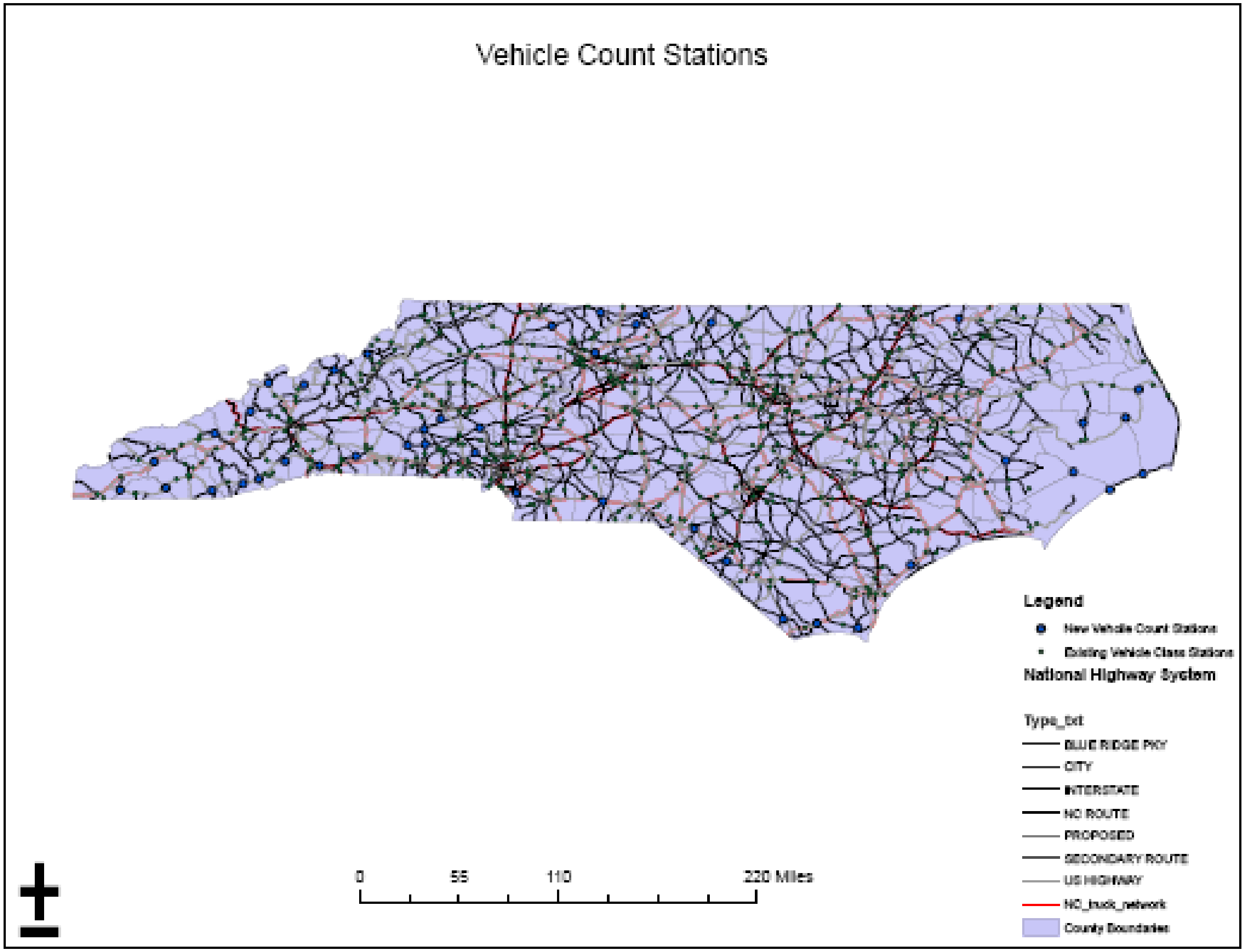


Figure 3-1b. VTRIS (WIM) Stations in North Carolina

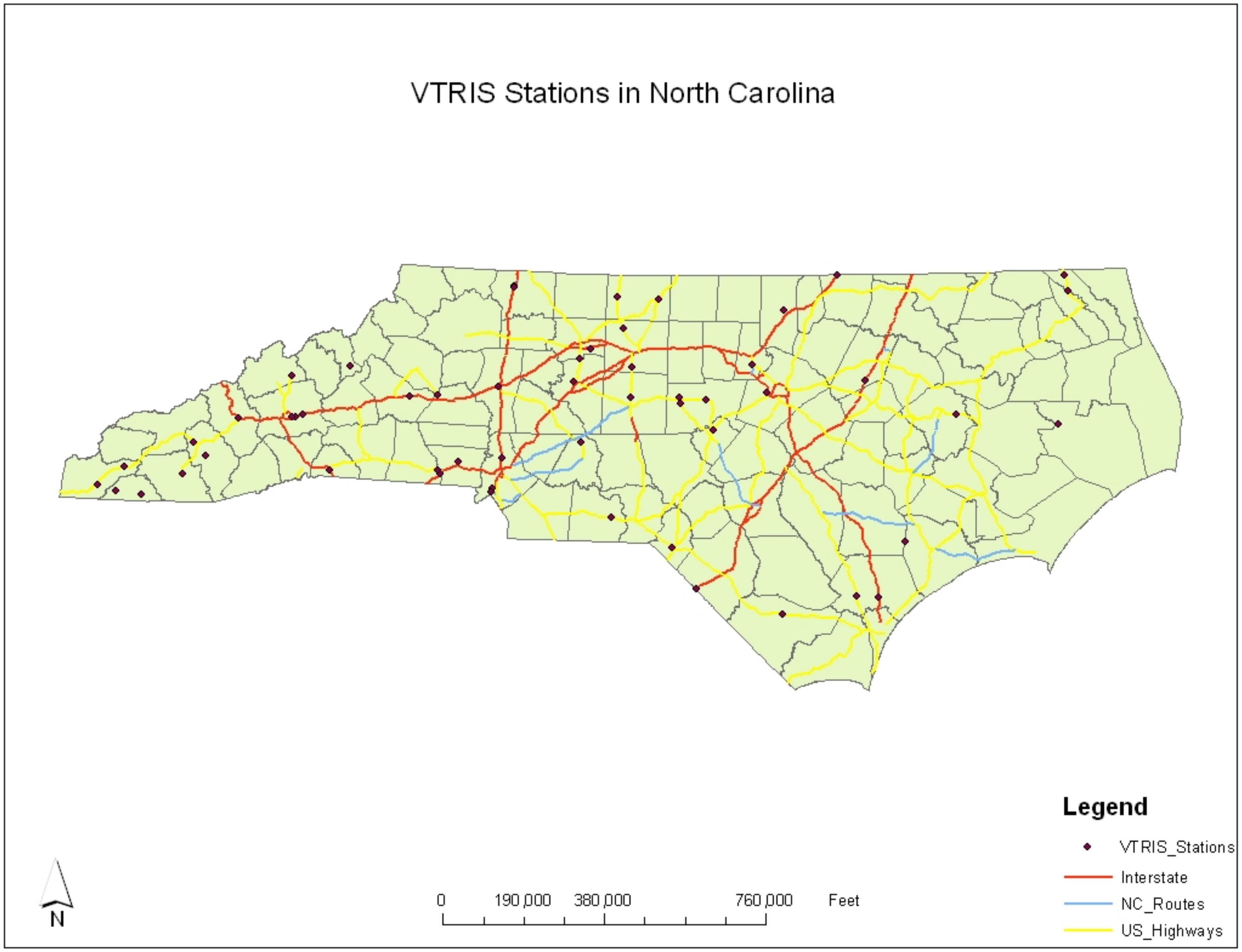
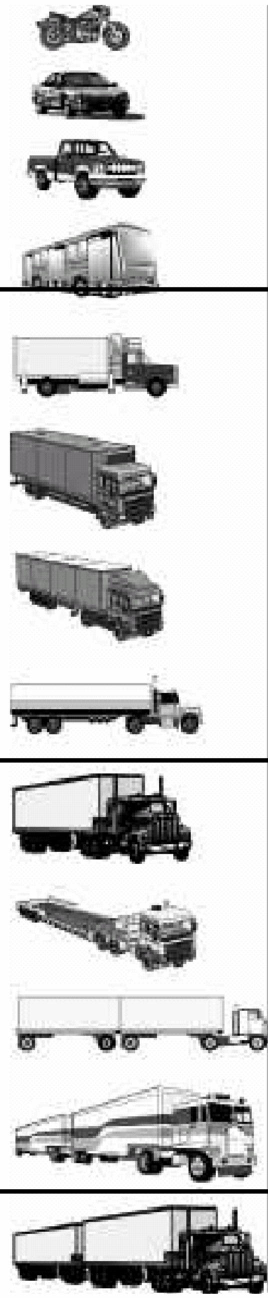


Figure 3-2. FHWA Vehicle Classifications

FHWA VEHICLE CLASSIFICATIONS



1-2 axles	1	Motorcycles
	2	Passenger cars
	3	Two axles and tire single units
	4	Buses
3-5 axles	5	Two axles and tire single units
	6	Three axles single units
	7	Four or more axle singe units
	8	Four or less axle single trailers
6+ axles	9	Five axle single trailers
	10	Six or more axle single trailers
	11	Five or less axle multi-trailers
	12	Six axle multi-trailers
	13	Seven or more axle multi-trailers

Source: Pavement Design Guide 2002; Milestones 2002; TRB, Winter 2001.

Available Tools and Data for Demographics, Economic Development and Traffic

GIS tools such as TransCAD, which NCDOT has adopted as its travel demand modeling software, are used effectively for network-based graphical displays. ArcGIS is another tool that is appropriate for correlating truck data and regional characteristics and performing data correlation, however, it does not have the built-in network functionality that TransCAD has, and it is not as widely used by NCDOT travel demand modelers as TransCAD. (See Appendix A.)

Besides databases for traffic counts and vehicle classifications (see below), there are census demographics, employment, property tax information, and the transportation network. Federal and state databases are available for states, counties, metropolitan areas, census tracts and other categories. The databases are available from local planning agencies, the U.S. Census Bureau, Bureau of Transportation Statistics and other agencies. This information can be merged with GIS data files for highway networks that are available from the same agencies (Appendix A). The data include locations and magnitudes of population and employment by type. Highway networks are modeled by facility type, and they are available as GIS TIGER/line files from several local, state, national and commercial sources.

Traffic Data Sources

The two main data sources for this research include NCDOT vehicle classification counts and the online Vehicle Travel Information Station counts (VTRIS). NCDOT data comes from continuous monitoring stations, short-term count stations, and turning movement count stations. NCDOT data sets include classified traffic counts, station numbers, and detailed descriptions of station locations. In these data sets, traffic volumes are counted on typical days as Average Daily Traffic (ADT) and they are clean, factored, and annualized to Average Annual Daily Traffic (AADT) to be used for trend analysis (Appendix B).

The VTRIS system has valid data, facilitates editing, and summarizes and generates reports on vehicle counts and classifications across the U.S, including North Carolina. There are about 60 VTRIS locations on NC interstates, US routes, and NC routes (Figure 3-1b, Appendix B). VTRIS maintains a permanent database of the station description, vehicle classification counts, and truck weight measurements. VTRIS (WIM) stations usually count traffic 365 days a year. This allows repetitive data averaging and report generation with different options without additional source data processing. Some station annual data must be estimated based on shorter count periods.

VTRIS Tables W-1 and W-2 (http://fhwapap07.fhwa.dot.gov/vtris/) play important roles in this research. The W-1 table displays the characteristics of each weigh-in-motion station (WIM station) based on the information contained in the station description records. The W-2 table displays a summary of the vehicle and the vehicle weight for selected stations by vehicle classification. The vehicle classification data is averaged for each hour and the 24 hourly averages are added for the average daily count. The average daily count is obtained for both typical and atypical days. These data are not factored but they are averaged to generate AADT. Un-factored ADT is acceptable for AADT if the station has a full year of data as VTRIS (WIM) stations do.

The online data set for the Highway Pavement and Monitoring System (HPMS) is a third source considered for this research. However, it does not include classified vehicle data. The most recent online HPMS data archive consists of total AADT data and does not include classified counts or any truck data. Also the online archive has not been updated with latest traffic counts restricting it to a period of 1993 to 2001. According to Traffic survey Unit, NCDOT maintained 60 weigh-in-motion sites in 2004, but the HPMS does not have an updated database. It includes only 15-16 WIM stations on the online map. A compressed file is available for download and the total AADT are identified by link numbers and not by station numbers, which do not match NCDOT station numbers or VTRIS station numbers. A comparative study of these data was impossible as HPMS data were not updated to recent counts and so, not included in the research.

Comparisons of Traffic Data Sources

NCDOT Data

There are hundreds of NC stations on major routes (Interstate routes and US routes) as well as minor some US routes and NC routes (Figure 3-1). ADT observed at each of them is available from NCDOT. The data represent most years from 1992 and provide the basis to calculate ADT growth factors at these stations.

For each ADT year assuming a constant, previously measured truck percentage for each station, the NCDOT data set gives truck volumes by multiplying ADTs by the constant truck percentage. Actual truck counts are not given directly. This procedure for measuring truck percents instead of volumes every third year or so instead of every year implies trucks grow at the same rate as general traffic. Thus, the truck AGF is the same as that for the ADT. Truck growth factors calculated with NCDOT data set are not reliable, even if the data set is factored. The NCDOT data set will not be used in this research.

VTRIS Data

FHWA classifies vehicles as thirteen types (Figure 3-2). NCDOT and VTRIS use different truck classifications (Table 3-1).

In NCDOT projects, trucks include Dual (FHWA classes 4-7) and TTST (FHWA classes 8-13). According to VTRIS, the W-2 table breaks the data down by 13 vehicle types; however, it excludes FHWA class 4 (buses) from truck category. That means VTRIS considers weight information (trucks) for vehicle type 5 through 13 (Table 3-1). In order for this project to be consistent with the NCDOT classifications, VTRIS buses are included with trucks. This means that the calculated VTRIS truck traffic is the sum of displayed truck volumes and buses. Buses, however, are a relatively small count.

The VTRIS database has counts from continuous weigh-in–motion (WIM) and Long Term Pavement Performance (LTPP) sites (Figure 3-1). The VTRIS traffic data measured along a facility include counts and classifications of the number of trucks traveling over the roadway. The WIM VTRIS database contains the distribution of traffic by lane and direction, and it measures the axle loads for each truck class to reliably determine the truck traffic beginning the first year after construction. The counts obtained from these sites are accurate because VTRIS uses the actual axle weights and truck traffic distribution measured on or near the site.

Besides the difference in truck classifications between the NCDOT and VTRIS datasets, the historical data represent different years. Also, NCDOT and VTRIS data collected from continuous count stations such as WIM stations and LTPP stations provide ADT values for total traffic and truck traffic. The approximation of ADT to AADT for total traffic and truck traffic is only valid for the continuous count stations with a complete full year worth of data. Partial data sets are not acceptable for trend analysis and should not be used unless the data set is factored to annualized values (Appendix B). Table 3-2 is a summary of the two data sets considered for the project.

Table 3-1. Comparison of NCDOT and VTRIS Vehicle Classifications

DATA	FHWA Vehicle Classes												
	1 (MC)	2 (Cars)	3 (2A-4T)	4 (Buses)	5 (2A-SU)	6 (3A-SU)	7 (4A-SU)	8 (4A-ST)	9 (5A-ST)	10 (6A-ST)	11 (5A-MT)	12 (6A-MT)	13 (7A-MT)
NCDOT	Passenger Vehicles			Duals				TTSTs					
VTRIS	Passenger Vehicles				Trucks								

Table 3-2. Comparison of NCDOT and VTRIS Data

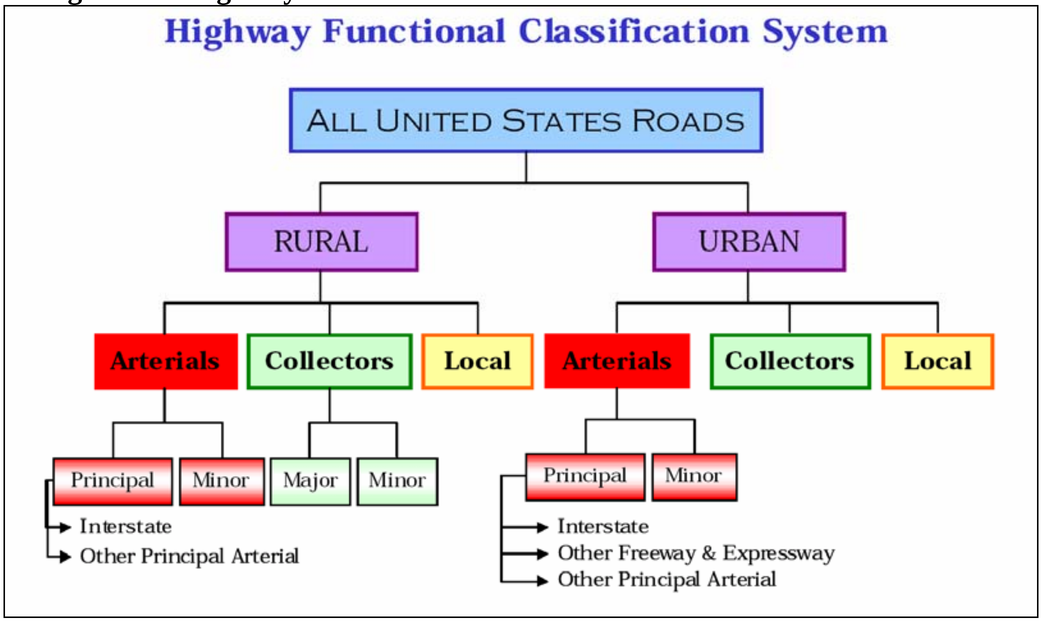
DATA	Identification	Class Counts	Total Traffic	Truck (Duals & TTST)	Location	Route No.	Years of Data
NCDOT	Station Number	Yes	ADT & AADT	ADTT & AADTT	Given	Yes	1992-1996
VTRIS	Station ID	Yes	AADT	ADTT	Given	Yes	1997-2004

Currently, most NCDOT data are partial data sets collected from short-term (48-hour) count stations or turning movement count stations. Most of the counts are not factored or annualized and therefore not included for the development of the model. The ADT from these stations cannot be approximated equal to AADT. Thus, the data must be factored to an annualized value of AADT to convert it to the correct format to be used in trend analysis. These data sets are available from ATR counts and only data from the case study sections on I-95, US64, NC421, and NC279 are annualized (Appendix B). The results of the case studies appear in Chapter 5 and the appendices. All the other ATR data are un-factored, and they are not considered for further analysis.

VTRIS uses functional classes to distinguish different highway classifications (Figure 3-3). The VTRIS database consists of annually classified counts along *rural principal arterials* (interstates) and *rural principal arterial other* (US routes). Separate data reflect urban principal and minor arterials, though they are fewer in number. The types of routes classified by VTRIS are shown in Table 3-3. Arterials provide the highest level of mobility at the highest speed for long uninterrupted travel. The interstate highway system is an arterial network. Arterials generally have higher design standards than other roads and many principal arterials have multiple lanes with some degree of access control. Arterials are broken into principal and minor routes. The rural arterial network provides interstate and inter-county service so that all developed areas are within a reasonable distance of an arterial highway. The urban principal arterial system serves major metropolitan centers, corridors with the highest traffic volume, and those with the longest trip lengths. It carries most trips entering and leaving urban areas, and it provides continuity for all rural arterials that intercept urban boundaries.

Since NCDOT conducts classified counts once in about three years, because some recent years of data are unavailable for the case studies, and because most NCDOT data is unfactored, **the research focus is the VTRIS database**. The VTRIS dataset is the basis of the methodology to forecast truck traffic in North Carolina. The robustness of the VTRIS dataset is exploited in the development of the forecasting methodology. Data at each station for each facility type is manually extracted from VTRIS online database and entered into a spreadsheet for further analysis. (The manual extraction was tedious but seemed to be the most efficient for this research. For larger efforts the “flat ASCII” data files for VTRIS should be obtained and processed.) Since the VTRIS database contains classified counts at each station, vehicles are divided into

Figure 3-3. Highway Functional Classification



Source: A Guide to Highway Functional Classification, Montana DOT

Table 3-3. VTRIS Highway Classification

VTRIS Functional Classes	Highway Classification
Rural Principal Arterial Interstate	Interstate Routes only
Rural Principal Arterial Other	US Routes, some NC Routes and SR Routes

three different categories: Cars (classes 1-3), Duals (classes 4-7), and TTST (classes 8-13). Then the calculated average growth factor and other calculated metrics show the trend of traffic at a particular location. Total traffic growth rates vary from near zero to several percent per year depending on the urban or rural location of the highway. The VTRIS database provides classified counts for the 60 WIM stations currently in North Carolina. (More are planned.) These counts include vehicles of all classes averaged according to weights at the WIM Stations

Highway Pavement Monitoring Systems (HPMS) Data

The HPMS is a USDOT highway information system that includes data on the extent, condition, performance, use, and operating characteristics of the nation's highways. It contains descriptive information and ADTs on many public roads as a mix of universe and sample data for arterial and collector functional systems. Limited information on travel and paved miles is included in summary form for the lowest functional systems.

The HPMS dates from 1978 when it replaced special biennial condition studies that had been conducted by the States since 1965. The HPMS has grown through several modifications since its inception. Changes include coverage and detail to reflect changes in highway systems, legislation, national priorities, new technologies, and reporting.

The major purpose of the HPMS is to support a data driven decision process within FHWA, the DOT, and the Congress. The HPMS provides data in the analysis of highway system condition, performance, and investment needs that make up the biennial Condition and Performance Reports to Congress. These Reports are used by the Congress in establishing both authorization and appropriation legislation, activities that ultimately determine the scope and size of the Federal-aid Highway Program, and determine the level of Federal highway taxation.

The most recent online HPMS data archive consists of total AADT data and does not include classified vehicle counts or any truck data. The online archive has not been updated with latest traffic counts restricting it to a period of 1993 to 2001. According to NCDOT Traffic Survey Unit, NCDOT maintains 60 weigh in motion sites in 2004, but the HPMS does not have an updated database. It includes only 15 or 16 WIM stations on the online map. A compressed file is available for download and the total AADT are identified by link numbers and not by station numbers. The link numbers do not match NCDOT station numbers or VTRIS dataset station numbers. Thus, comparing and complementing NCDOT and VTRIS data with HPMS data is infeasible. Consequently HPMS data were not used in this research.

Growth Factor Estimation

Usually, NCDOT uses linear and exponential models in their traffic forecasts (Traffic Forecasting Utility). General statistical packages can be used also (Appendix C). NCDOT determines the traffic growth factor using the first and last traffic count (AADT) in a sequence. Engineers apply judgment to choose the best growth factor for the project location being studied. On the other hand, **the research methodology uses an Average Growth Factor for the range of the historical data. Instead of engineering judgment the research methodology proposes that the calculated average growth factor be compared to an expected statistical range and be adjusted only if it falls outside that range.** Although the NCDOT method and the research method use two different formulas, the growth factors show similar traffic forecasts for low volume roads, but differences occur for high volume roads.

This research uses the Average Growth Factor (AGF) method because it applies all traffic counts (not just first and last counts), and it is suitable for the VTRIS database. Besides calculating AGF for the cases in this research, the data recorded at WIM stations were tested to determine statistically significant ranges of growth factors by highway type and whether the growth of truck traffic is greater than general traffic (Appendices D and E). The analysis also tested linear regression models to capture causal influences such as NC region, county population and nearby warehouses on truck traffic (Appendix F). While the analysis shows effects, it is difficult to develop a linear regression model of growth factor at the project level for the trucks versus "exogenous" causal data because of the incompatibility of the project location and the data geography. A project location is a specific highway segment, but causal data covers regions.

The VTRIS data given as AADT permits developing alternative traffic growth rates and models. The Annual Growth Factor (GF) is:

$$GF = (T_t - T_{t-1}) / T_{t-1}$$

where: T = AADT (the factored and annualized form of ADT)

In cases where some *years of traffic data are missing or the traffic data varies*, the annual growth rate may be determined by the following equation which is the "first and last year" calculation used by NCDOT. It assumes that each year in the period experiences a constant growth rate.

$$GF = [(T_{fy} - T_{by})/T_{by}] / (fy - by)$$

In order to include the effect of all traffic data within a time period the Average Growth Factor (AGF) may be calculated as shown below. *The AGF is the growth factor proposed by this research.*

$$AGF = \Sigma\ GF / N$$

where:

T = traffic = AADT

GF = annual growth factor

AGF = average annual growth factor

t = year, t-1 = previous year

N = the number of growth factors

fy = future year of a historic or future time period

by = base year of a historic or future time period

If the traffic forecast follows a *linear model* with a "first and last year" GF, as NCDOT often assumes for *Interstate and other major highways*, the future traffic T_{fy} may be determined by:

$$T_{fy} = T_{by} + GF\ (fy - by) = AADT_{fy}$$

This research recommends replacing the GF by the AGF to account for years of variable traffic growth.

$$T_{fy} = T_{by} + AGF\ (fy - by) = AADT_{fy}$$

If the traffic forecast follows an *exponential model*, which NCDOT often assumes for *minor roads that may experience significant traffic growth*, the future traffic T_{fy} may be determined as follows:

$$T_{fy} = T_{by}\ (1 + AGF)^{(fy - by)} = AADT_{fy}$$

Similar forecasting equations represent future values of DUAL and TTST trucks for each VTRIS station or other station for which factored and annualized truck traffic data are available. Thus, for a linear model:

$$DUAL_{fy} = DUAL_{by} + AGF\ (fy - by)$$

$$TTST_{fy} = TTST_{by} + AGF\ (fy - by)$$

and for an exponential model:

$$DUAL_{fy} = DUAL_{by} (1 + AGF)^{(fy - by)}$$

$$TTST_{fy} = TTST_{by} (1 + AGF)^{(fy - by)}$$

The previous truck traffic forecasting equations emphasize that *truck traffic should be forecast separately from AADT before the percentages by truck category are determined.*

$$\%DUAL = (DUAL/AADT) \times 100$$

$$\%TTST = (TTST/AADT) \times 100$$

To support the AGF-based truck and traffic forecasts there are 60 NC VTRIS stations (WIM stations) defined by USDOT and NCDOT. USDOT and NCDOT have scheduled more VTRIS stations for construction. They are located on different VTRIS route types and provide 365-day continuous, classified AADT and truck counts from 1997 to 2004 (the years for this research.) Thus, each VTRIS (WIM) station can provide reliable growth factors for DUAL and TTST trucks and general traffic. For the 60 stations, only 51 have data recorded in the VTRIS online database. These 51 stations consist of 19 stations on Interstates and 32 stations on US and NC arterials. Some of these stations have data only for a single year and therefore it is impossible to develop growth factors from those stations. Such stations are not included in the subsequent analysis and statistical tests. All stations, which have at least two years of data have been included for developing the models. These include 18 stations along Interstates and 27 stations along US and NC arterials.

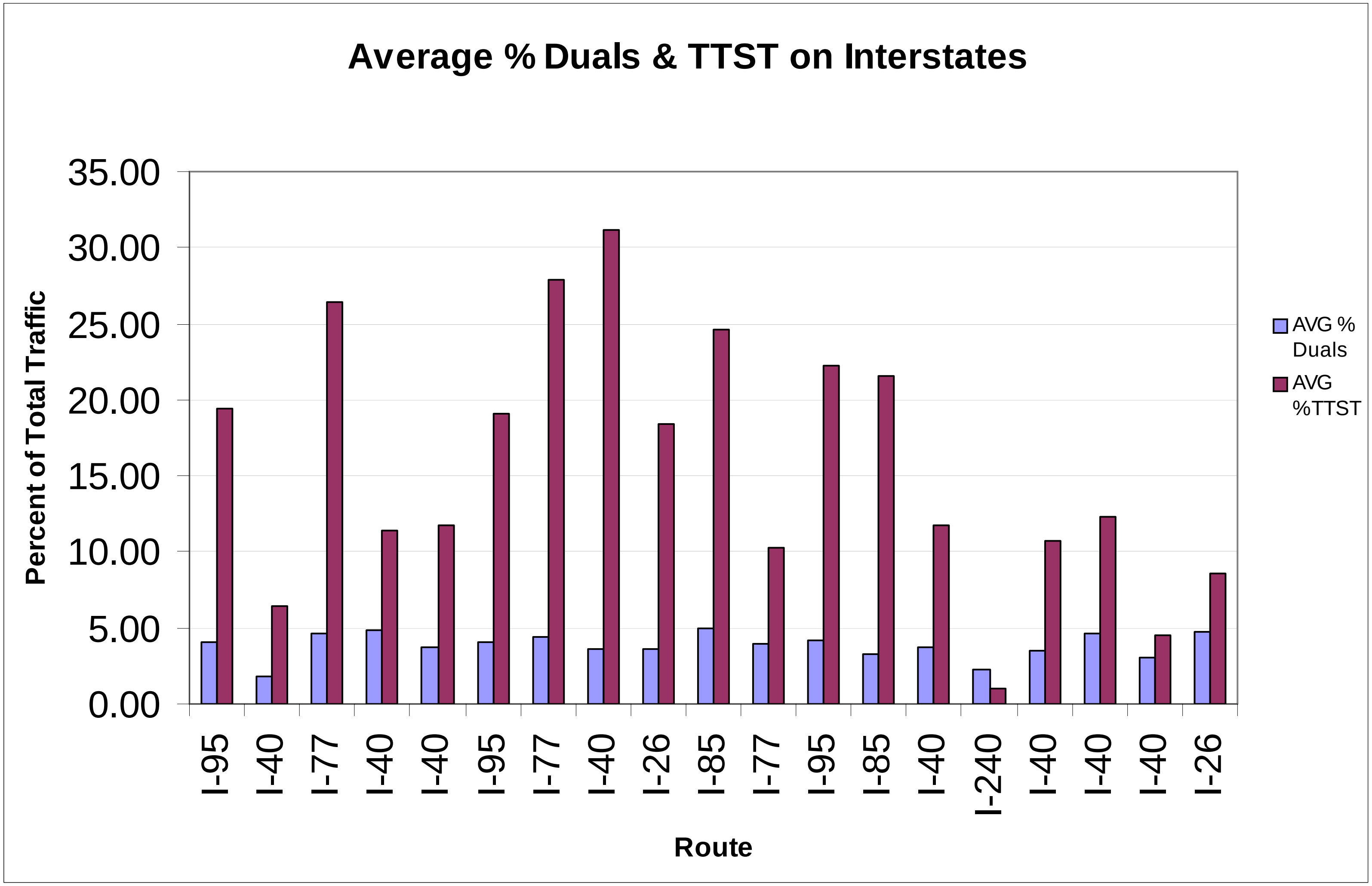
Some stations have missing data between 1997 and 2004. In order to provide uniformity in the growth rate, the research assumes that the growth rate remains constant between the missing years. Average growth factors (AGF) for each VTRIS (WIM) station are calculated for ADT (total traffic), Cars, total trucks, and DUAL and TTST trucks.

Another important product obtained from the dataset is the percentage of Duals and TTSTs in total traffic. The composition of traffic into three categories plays an important role in the development of the model. It leads to developing *default values of percent Duals and percent TTSTs* in cases where a classified count at the project location is unavailable. Table 3-4, Table 3-5 and Figure 3-4 show a summary of results for Interstate routes at WIM stations defined by Strategic Highway Research Program (SHRP) station numbers. Similarly Tables 3-6 and 3-7 and Figure 3-5 show summary results for Arterials Other highways.

Descriptive Statistics of the Data

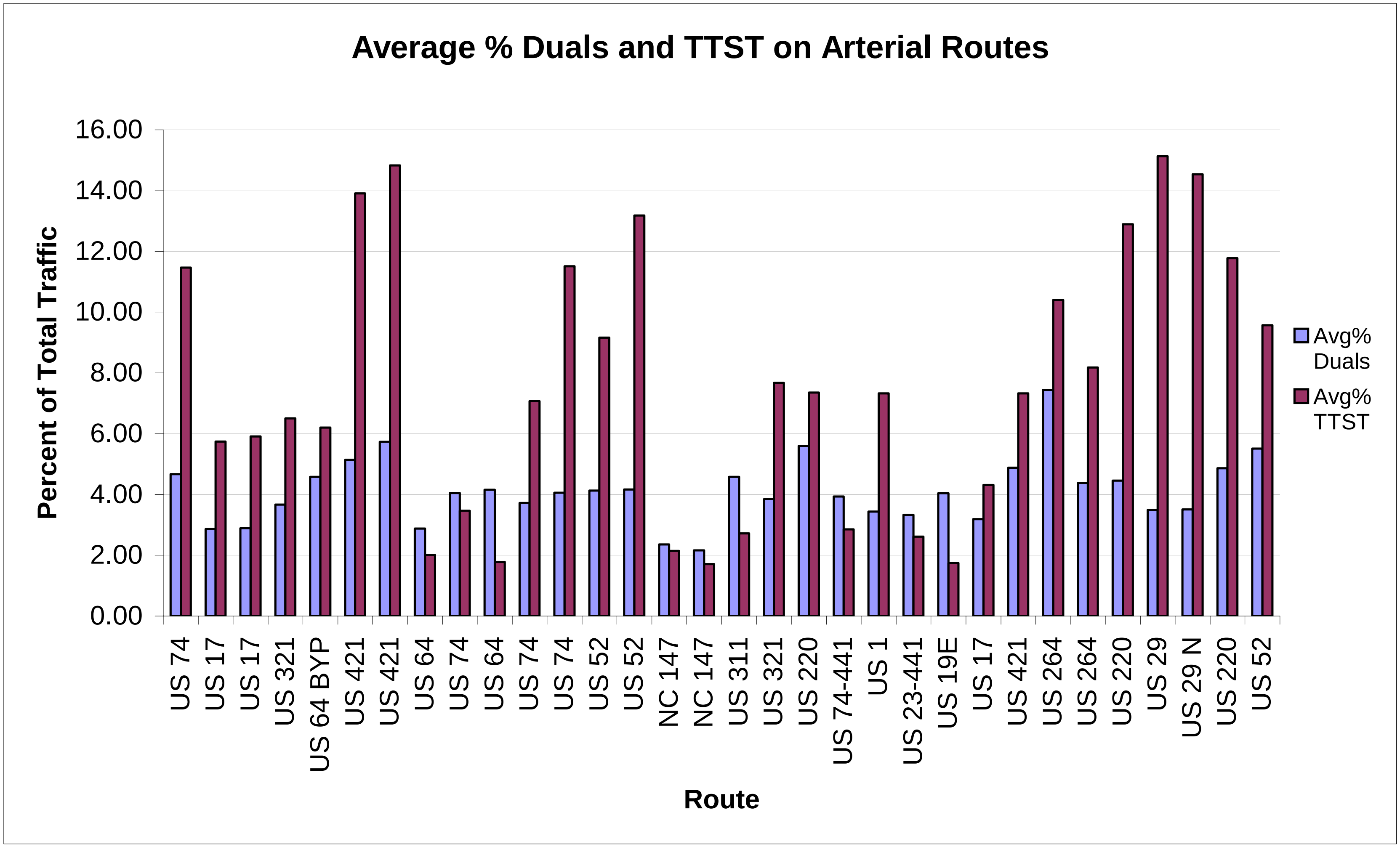
Accurately estimating current and future Dual & TTST volumes is critical because of the effects of trucks on highway congestion and pavement distress. Thus, *the preferred technique for forecasting traffic volumes should include separate forecasts for AADT, Duals, and TTSTs (Appendix C) rather than just forecasting AADT and assuming a percent of Duals and TTSTs applied to the forecasts*. However, the accurate estimation of historic annual percentage of Duals and TTSTs is an important descriptive parameter for highway service. That historic distribution of the percentage of Duals and TTST and resulting volumes and descriptive statistics also

Figure 3-4. Average Percentage Duals and TTSTs at WIM (SHRP) Stations on Interstate Routes, 1997 - 2004



Note: See Table 3-5 for Interstate Station Numbers

Figure 3-5. Average Percentage Duals and TTSTs at WIM (SHRP) Stations on US and NC Arterial Routes, 1997 – 2004



Note: See Tables 3-6 and 3-7 for station numbers.

Table 3-4. Growth Factors for Duals, TTSTs, Trucks, Total Traffic, & Cars at WIM (SHRP) Stations on Interstate Routes, 1997 - 2004

SITE	COUNTY	ROUTE	SHRP#	LOCATION	NEAREST TOWN	#LANES	AGF (Duals)	AGF (TTST)	AGF (Truck)	AGF (ADT)	AGF cars
503	NASH	I-95	373011	.5 MI. SOUTH OF SR 1745	ROCKY MOUNT	2NB	3.53	2.03	1.94	7.86	10.64
506	WAKE	I-40	371006	.8 MI. EAST OF NC 54	RALEIGH	2EB	0.36	-7.22	-5.71	-3.21	-2.98
515	SURRY	I-77	375826	.5 MI. NORTH OF SR 1345	MOUNT AIRY	2NB	5.32	0.18	0.44	-1.77	-2.48
519	BUNCOM	I-40	375037	1.6 MI. WEST OF SR 2838	OTEEN	2WB	0.82	1.03	0.65	1.51	2.09
520	BUNCOM	I-40	371801	1.3 MI. WEST OF SR 2740	SWANNANOA	2WB	-0.50	-0.35	-0.51	-0.08	0.13
527	NASH	I-95	376302*	MP 129 SOUTH BND	ROCKY MOUNT	2SB	7.25	3.67	4.27	2.19	2.13
528	SURRY	I-77	378502*	MP 97.5 SOUTH BND	MOUNT AIRY	2SB	-1.39	-0.48	-0.60	-4.37	-6.13
536	HAYWOO	I-40	374301*	MP 26 WEST BND	CLYDE	2EB, 2WB	3.59	-0.36	0.01	2.71	4.96
537	POLK	I-26	377401*	MP 36.5 WEST BND	COLUMBUS	2EB, 2WB	3.87	3.44	2.75	-4.03	-5.80
538	CLEVELA	I-85	372202*	MP 8.5 NORTH BND	KINGS MOUNTAIN	2NB, 2SB	-1.16	-5.75	-5.03	-0.77	1.06
539	MECKLEN	I-77	375902*	SOUTH OF I-485	CHARLOTTE	3NB, 3SB	0.56	10.07	7.32	-2.91	-4.51
541	ROBESON	I-95	377701*	.4 MI. N. OF EXIT 1B	McDONALD	2NB, 2SB	35.50	13.90	17.06	4.16	-0.11
543	WARREN	I-85	379201*	AT EXIT 233	WISE	2NB, 2SB	7.40	10.36	9.97	2.57	0.24
544	WAKE	I-40	379102*	MP 291 WEST BND	RALEIGH	2WB	-0.50	-0.35	-0.51	-0.08	0.13
556	BUNCOM	I-240	371003*	MP 8.5	ASHEVILLE	2EB, 3WB	-6.54	-2.65	-5.35	-4.95	-4.93
559	BURKE	I-40	371101*	MP 109.5	VALDESE	2EB, 2WB	-6.83	-1.26	-2.65	-7.96	-8.81
557	IREDELL	I-40	374801*	MP 151	STATESVILLE	2EB, 2WB	-6.36	-0.59	-2.19	-5.88	-6.61
542	PENDER	I-40	377001*	.3 MI. WEST OF EXIT 408	ROCKY POINT	2EB, 2WB	17.06	5.36	9.76	8.56	8.47
560	MADISON	I-26	375601*	.1 MI. WEST OF US 19	MARS HILL	2EB, 2WB	-17.05	179.64	74.06	-9.39	-17.76

Source: VTRIS on-line data

Table 3-5. Percentage of Duals, TTST, & Trucks in Total Traffic at WIM (SHRP) Stations on Interstate Routes, 1997 - 2004

SITE	COUNTY	ROUTE	SHRP#	LOCATION	NEAREST TOWN	#LANES	AVG % Duals	AVG %TTST	AVG % Trucks
503	NASH	I-95	373011	.5 MI. SOUTH OF SR 1745	ROCKY MOUNT	2NB	4.10	19.45	23.54
506	WAKE	I-40	371006	.8 MI. EAST OF NC 54	RALEIGH	2EB	1.75	6.49	8.24
515	SURRY	I-77	375826	.5 MI. NORTH OF SR 1345	MOUNT AIRY	2NB	4.68	26.41	31.09
519	BUNCOMBE	I-40	375037	1.6 MI. WEST OF SR 2838	OTEEN	2WB	4.90	11.41	16.31
520	BUNCOMBE	I-40	371801	1.3 MI. WEST OF SR 2740	SWANNANOA	2WB	3.75	11.75	15.50
527	NASH	I-95	376302	MP 129 SOUTH BND	ROCKY MOUNT	2SB	4.02	19.06	23.08
528	SURRY	I-77	378502	MP 97.5 SOUTH BND	MOUNT AIRY	2SB	4.44	27.89	32.33
536	HAYWOOD	I-40	374301	MP 26 WEST BND	CLYDE	2EB, 2WB	3.67	31.21	34.88
537	POLK	I-26	377401	MP 36.5 WEST BND	COLUMBUS	2EB, 2WB	3.59	18.36	21.95
538	CLEVELAND	I-85	372202	MP 8.5 NORTH BND	KINGS MOUNTAIN	2NB, 2SB	4.91	24.64	29.55
539	MECKLENBURG	I-77	375902	SOUTH OF I-485	CHARLOTTE	3NB, 3SB	3.98	10.26	14.25
541	ROBESON	I-95	377701	.4 MI. N. OF EXIT 1B	McDONALD	2NB, 2SB	4.19	22.22	26.41
543	WARREN	I-85	379201	AT EXIT 233	WISE	2NB, 2SB	3.27	21.51	24.77
544	WAKE	I-40	379102	MP 291 WEST BND	RALEIGH	2WB	3.75	11.75	15.50
556	BUNCOMBE	I-240	371003	MP 8.5	ASHEVILLE	2EB, 3WB	2.27	1.03	3.30
559	BURKE	I-40	371101	MP 109.5	VALDESE	2EB, 2WB	3.47	10.75	14.22
557	IREDELL	I-40	374801	MP 151	STATESVILLE	2EB, 2WB	4.57	12.33	16.90
542	PENDER	I-40	377001	.3 MI. WEST OF EXIT 408	ROCKY POINT	2EB, 2WB	3.10	4.48	7.59
560	MADISON	I-26	375601	.1 MI. WEST OF US 19	MARS HILL	2EB, 2WB	4.69	8.63	13.32

Source: VTRIS on-line data

Table 3-6. Growth Factors for Duals, TTST, Trucks, AADT, & Cars at WIM (SHRP) Stations on US & NC Arterial Routes, 1997 - 2004

SITE	COUNTY	ROUTE	SHRP#	LOCATION	NEAREST TOWN	#LANES	AGF(Duals)	AGF(TTST)	AGF (Truck)	AGF(ADT)	AGF(Cars)
501	CAMDEN	US 17	371028	.7 MI. N. OF SR 1231	SOUTH MILLS	2NB	22.12	4.47	10.03	3.69	3.12
540	CAMDEN	US 17	371402	.7 MI. N. OF SR 1231	SOUTH MILLS	2 SB	13.56	7.66	9.56	2.98	2.37
558	CATAWBA	US 321	371701	AT EXIT 44	HICKORY	2NB, 2SB	5.67	5.48	5.55	-1.89	-2.70
508	CHATHAM	US 64 B	371805	.2 MI. EAST OF US 64 BUS	PITTSBORO	2EB, 2WB	11.85	3.71	7.09	-6.34	-7.85
509	CHATHAM	US 421	372824	1.9 MI. SOUTH OF US 64	SILER CITY	2SB	4.99	3.18	3.56	2.00	2.19
525	CHATHAM	US 421	371992	MP 173 SOUTH BND	SILER CITY	2SB	1.07	8.65	5.01	4.31	4.84
535	CHEROKEE	US 74	371902	.3 MI. WEST OF SR 1390	ANDREWS	2EB, 2WB	-8.87	-8.24	-8.97	-1.58	-0.82
533	CLAY	US 64	372101	.5 MI. EAST OF SR 1304	HAYESVILLE	1EB, 1WB	-5.04	-1.36	-4.24	1.88	2.33
517	CLEVELAND	US 74	373008	.7 MI. EAST OF SR 2026	SHELBY	2EB	28.54	11.48	17.08	5.23	3.89
504	COLUMBUS	US 74	371645	1.9 MI. WEST OF SR 1001	WHITEVILLE	2 WB	3.91	-2.31	-0.74	-3.39	-3.74
513	DAVIDSON	US 52	373807	1.6 MI. NORTH OF SR 1508	WELCOME	2NB	-3.18	6.95	1.45	2.32	2.46
531	DAVIDSON	US 52	370200	SOUTH BND MP 89.5	LEXINGTON	2SB	6.98	-0.02	1.52	5.00	5.75
507	DURHAM	NC 147	373816	.4 MI. NORTH OF SR 1940	DURHAM	2NB	9.95	23.15	15.83	7.77	7.43
512	FORSYTH	US 311	371817	.6 MI. EAST OF SR 2698	WINSTON-SALEM	2SB	1.90	6.69	4.73	5.79	5.94
547	GASTON	US 321	373501	.1 MI. SOUTH OF NC 279	DALLAS	3NB, 3SB	-12.54	2.89	-2.55	-3.54	-3.66
511	GUILFORD	US 220	372819	1.6 MI. NORTH OF NC 62	GREENSBORO	2SB	-7.66	2.91	-2.88	2.52	3.54
522	JACKSON	US 74-4	371803	.2 MI. EAST OF SR 1391	WHITTIER	2EB	-7.86	-1.23	-5.55	1.03	1.65
530	LEE	US 1	370900	.3 MI. NORTH OF US 15-501	SANFORD	2NB, 2SB	13.76	2.64	5.94	6.71	6.85
523	MACON	US 23-4	371814	.2 MI. SOUTH OF NC 28	FRANKLIN	2SB	-4.03	-4.95	-4.43	-4.43	-4.40
518	MITCHELL	US 19E	371040	.1 MI. EAST OF SR 1121	SPRUCE PINE	2NB	1.10	4.43	1.52	3.50	3.81
502	PASQUOTANK	US 17	371030	.4 MI. SOUTH OF US 158	ELIZABETH CITY	2SB	19.65	6.02	11.61	4.15	3.57
524	PITT	US 264	377301	MP 59 WEST BND	GREENVILLE	2WB	-2.28	-5.24	-4.07	2.72	4.32
529	PITT	US 264	377302	EAST BND MP 59	GREENVILLE	2EB	1.21	2.96	2.19	4.55	4.99
510	ROCKINGHAM	US 29	375827	1.8 MI. NORTH OF US 158	REIDSVILLE	2SB	3.16	-4.82	-3.36	-1.04	-0.49
526	ROCKINGHAM	US 29 N	377802	1.7 MI. NORTH OF US 158	REIDSVILLE	2NB	5.26	2.15	2.71	1.90	1.75
554	ROCKINGHAM	US 220	377803	.5 MI. SOUTH OF SR 2150	MADISON	2NB, 2SB	-16.30	-1.59	-6.14	-4.32	-3.95
514	STANLY	US 52	371352	.1 MI. NORTH OF NC 8-740	ALBEMARLE	2 SB	-6.98	-7.13	-7.10	-7.48	-7.50

Table 3-7. Percentage Duals, TTSTs, & Trucks in Total Traffic at WIM (SHRP) Stations on US and NC Arterial Routes, 1997 – 2004

SITE	COUNTY	ROUTE	SHRP#	LOCATION	NEAREST TOWN	#LANES	Avg%(Duals)	Avg%(TTST)	Avg%(Trucks)
501	CAMDEN	US 17	371028	.7 MI. N. OF SR 1231	SOUTH MILLS	2NB	4.67	11.46	16.13
540	CAMDEN	US 17	371402	.7 MI. N. OF SR 1231	SOUTH MILLS	2 SB	2.86	5.74	8.60
558	CATAWBA	US 321	371701	AT EXIT 44	HICKORY	2NB, 2SB	2.89	5.91	8.80
508	CHATHAM	US 64 BYP	371805	.2 MI. EAST OF US 64 BUS	PITTSBORO	2EB, 2WB	3.67	6.50	10.17
509	CHATHAM	US 421	372824	1.9 MI. SOUTH OF US 64	SILER CITY	2SB	4.58	6.20	10.78
525	CHATHAM	US 421	371992	MP 173 SOUTH BND	SILER CITY	2SB	5.14	13.91	19.05
535	CHEROKEE	US 74	371902	.3 MI. WEST OF SR 1390	ANDREWS	2EB, 2WB	5.73	14.83	20.57
533	CLAY	US 64	372101	.5 MI. EAST OF SR 1304	HAYESVILLE	1EB, 1WB	2.88	2.01	5.09
517	CLEVELAND	US 74	373008	.7 MI. EAST OF SR 2026	SHELBY	2EB	4.05	3.47	7.51
504	COLUMBUS	US 74	371645	1.9 MI. WEST OF SR 1001	WHITEVILLE	2 WB	4.15	1.78	5.93
513	DAVIDSON	US 52	373807	1.6 MI. NORTH OF SR 1508	WELCOME	2NB	3.72	7.07	10.79
531	DAVIDSON	US 52	370200	SOUTH BND MP 89.5	LEXINGTON	2SB	4.06	11.50	15.56
507	DURHAM	NC 147	373816	.4 MI. NORTH OF SR 1940	DURHAM	2NB	4.12	9.16	13.29
512	FORSYTH	US 311	371817	.6 MI. EAST OF SR 2698	WINSTON-SALEM	2SB	4.17	13.18	17.35
547	GASTON	US 321	373501	.1 MI. SOUTH OF NC 279	DALLAS	3NB, 3SB	2.36	2.15	4.51
511	GUILFORD	US 220	372819	1.6 MI. NORTH OF NC 62	GREENSBORO	2SB	2.16	1.71	3.88
522	JACKSON	US 74-441	371803	.2 MI. EAST OF SR 1391	WHITTIER	2EB	4.58	2.72	7.30
530	LEE	US 1	370900	.3 MI. NORTH OF US 15-501	SANFORD	2NB, 2SB	3.85	7.67	11.52
523	MACON	US 23-441	371814	.2 MI. SOUTH OF NC 28	FRANKLIN	2SB	5.60	7.35	12.95
518	MITCHELL	US 19E	371040	.1 MI. EAST OF SR 1121	SPRUCE PINE	2NB	3.93	2.85	6.79
502	PASQUOTANK	US 17	371030	.4 MI. SOUTH OF US 158	ELIZABETH CITY	2SB	3.44	7.33	10.76
524	PITT	US 264	377301	MP 59 WEST BND	GREENVILLE	2WB	3.33	2.62	5.95
529	PITT	US 264	377302	EAST BND MP 59	GREENVILLE	2EB	4.04	1.74	5.78
510	ROCKINGHAM	US 29	375827	1.8 MI. NORTH OF US 158	REIDSVILLE	2SB	3.19	4.31	7.50
526	ROCKINGHAM	US 29 N	377802	1.7 MI. NORTH OF US 158	REIDSVILLE	2NB	4.88	7.33	12.21
554	ROCKINGHAM	US 220	377803	.5 MI. SOUTH OF SR 2150	MADISON	2NB, 2SB	7.44	10.40	17.84
514	STANLY	US 52	371352	.1 MI. NORTH OF NC 8-740	ALBEMARLE	2 SB	4.38	8.18	12.55

determine the boundaries of the estimates for forecast volumes resulting from the proposed methodology.

Among the descriptive statistics are the mean and the median of a set of data. *The median obtained from a data set, rather than the mean, usually provides the best measure of central tendency if the data has outliers and the sample size is small. More consistent data or data for larger samples use the mean as the better estimate of central tendency, i.e., the average percentage of Duals and TTSTs.* The descriptive statistics provided in Tables 3-8 to 3-11 describe the characteristics and distribution of the WIM data at 19 Interstate stations and 32 stations on NC routes and US routes. Most stations had data from 1997 to 2004. *Small sample sizes of at least 25 are desirable for such analysis, and as more WIM (VTRIS) stations are built the results of this research should be updated. Indeed, as time goes on additional years' data should be added*.

For analysis purposes, sparse datasets with outliers should be avoided to obtain descriptive averages. The analysis results were greatly affected by stations with only a few years of data causing very high or very low growth rates. Therefore, the analysis ignored stations having few years of data and annual growth rates more than 15% for Duals, TTST and Cars.

<u>Growth Rates and Percentages for Trucks on Interstates (VTRIS Data)</u>

After eliminating outliers the Interstate WIM stations numbered 19 and the stations for US and NC highways (Arterials Other) numbered 32. Most stations had data from 1997 to 2004.The sample sizes should be 25 to 30 for small sample size statistics. *The results in Table 3-8 indicate that TTSTs are the largest growth category along interstates. Duals have a smaller positive growth rate than TTSTs, and passenger Cars (classes 1-3) experience a decrease in average growth rate.*

As discussed earlier the traditional forecasting approach at NCDOT is to count, factor and annualize traffic in order to develop a growth rate for AADT from historical trends. *NCDOT often assigns forecast trucks an assumed percentage which is often the base year percentage determined by base year vehicle classification counts. Thus, trucks implicitly have the same growth rate as AADT. In some cases, ad hoc engineering judgment may adjust the growth rates for AADT or percentages for trucks.*

Table 3-8 serves as the foundation for a statistically based rather than ad hoc process to determine growth rates for AADT and trucks (Chapter 4). Table 3-9 provides ranges of expected percents for vehicle classifications that can guide engineering judgment.

The usual NCDOT project-level traffic forecast uses annualized traffic count data from ATR or other long-term count stations. The NCDOT process (Chapter 2) uses the Trend Program (Traffic Forecasting Utility) to develop an annual traffic growth rate and a future estimate of AADT for the project. Percentages of Duals and TTSTs are usually assumed to be base year values or they adjusted using expert judgment and knowledge of special trip generation features of the project or study area.

Table 3-8 serves as a check on the AADT growth rate and it can help rationalize the truck traffic forecasting. Thus, absent long-term traffic counts at or near a project location and special knowledge of future traffic generation at the location, Table 3-8 provides a statistical rationale for estimating growth rates on NC Interstates and setting their limits. Similarly statistics for the 95% the confidence level of Table 3-9 serve as a check on setting truck percentages in the traffic

Table 3-8. Average Growth Factors for Duals, TTSTs, and Cars on NC Rural Interstate Routes, 1997 – 2004

Statistics	*Duals*	*TTST*	*Cars*
Mean	0.59	1.72	-0.69
Standard Error	1.13	1.28	1.23
Median	0.46	-0.09	0.01
Mode	-0.50	-0.35	0.13
Standard Deviation	4.51	5.44	5.22
Sample Variance	20.34	29.56	27.24
Kurtosis	-0.61	0.48	0.05
Skewness	-0.26	0.74	0.59
Range	14.22	21.12	19.45
Minimum	-6.83	-7.22	-8.81
Maximum	7.40	13.90	10.64
Sum	9.40	31.01	-12.51
Count	16.00	18.00	18.00
Confidence Level(95.0%)	2.40	2.70	2.60
Lower Confidence Level	-1.82	-0.98	-3.29
Upper Confidence Level	2.99	4.43	1.90

Sources: VTRIS and Table 3-4

Table 3-9. Percent Duals and Percent TTSTs in Total Traffic on NC Rural Interstates, 1997 – 2004

Statistics	Duals	TTST
Mean	3.85	15.77
Standard Error	0.19	1.94
Median	3.98	12.33
Mode	3.75	11.75
Standard Deviation	0.84	8.44
Sample Variance	0.71	71.29
Kurtosis	1.03	-0.88
Skewness	-1.00	0.16
Range	3.16	30.18
Minimum	1.75	1.03
Maximum	4.91	31.21
Sum	73.11	299.62
Count	19.00	19.00
Confidence Level(95.0%)	0.41	4.07

Sources: VTRIS data and Table 3-5

forecasting process. (See Appendix G for the development growth factor values based on confidence intervals.)

Table 3-9 shows that the mean percent Duals for NC Interstate WIM stations is 3.85 and the median is 3.98. The range of Duals for all stations varies from a minimum of 1.75% to maximum value of 4.91%. The percent Duals on Interstates shows low variability with a variance of 0.71. *This suggests that the contribution of Duals in total traffic is almost constant throughout all the stations and does not form a major fraction of the total trucks along these facility types.* On the other hand, percent TTSTs has more variability ranging from 1.03% to 31.21%. The normality of the Duals data is noted from the mean (3.85) and median (3.98) and lying close to each other. The TTST mean and median are also relatively close. *This suggests that the contribution of TTSTs along Interstates is greater than Duals.* Variability in the data from outliers is avoided by choosing the median as the default value for central tendency. The range acts as a check when forecasting traffic for locations where classified data is unavailable, and the 95% confidence interval serves as a guide for engineering judgment (Appendices G and H).

<u>Growth Rate for US and NC Highways (VTRIS Data for Arterial Others)</u>

Table 3-10 summarizes the results for VTRIS data US and NC routes. The VTRIS WIM stations on these routes number about 30. As for Interstate analysis data outliers are eliminated, which would otherwise affect the mean and confidence intervals. The numbers of samples used for the analysis along arterials are sufficient to develop growth rates. Table 3-10 shows that Duals, TTSTs, and Cars have similar mean growth rates. *Since the data locations are relatively few statistically the best measure of central tendency for default growth rates is the median for each vehicle type.* By choosing the median, the forecaster will reduce the impact of outlying rates that are unusually high or low. The resulting growth rates and confidence intervals can serve as default values for locations where traffic counts are unavailable or as guidelines for checking forecasts at project locations where traffic counts are available.

Table 3-11 summarizes the percentages of Duals and TTSTs on US and NC routes that have VTRIS WIM stations. The mean percent Duals for arterials is 4.12 with a median of 4.05. The range of Duals for all stations varies from 2.16% to 7.44%. *This range acts as a default rate when classified data is unavailable or as a check while forecasting traffic for project locations. For example, NCDOT could use the upper and lower limits of the confidence intervals to guide their selection of truck percentages in project-level traffic forecasting.*

From the analysis for descriptive statistics (Tables 3-10, 3-11), *it can be inferred that the percentages of Duals and TTSTs in total traffic along arterials follow a normal distribution as the mean is near the median. Since some of the stations do not have data in the period of 1997-2004, the median of the dataset would be a better estimate of central tendency. The default values for percentage Duals, TTST and Trucks could be obtained from the median of the dataset.*

Q-Q plots are another approach to determining the mean after adjusting for outliers (Appendices G and H). The plots in Appendix H clearly show outliers from the linear plot which identifies the range of normal data from which the mean may be calculated. The following tables illustrate the results of using the VTRIS data before and after removing the outliers.

Comparing the tables with and without outliers removed (Tables 3-12 to 3-15) indicates that:

- The sample sizes are small and need to be increased to at least 30 or more for more definitive results.
- Interstate results are similar for Duals and TTSTs.

- Principal arterial results differ for Duals and are similar for TTSTs.
- Because the analyses differ somewhat, percentage vehicles are not included in the Q-Q plot analysis, but ADT is.

As NCDOT expands its truck and traffic count program new urban and rural WIM (VTRIS) stations will become operational and the mean and confidence analysis can be updated.

Table 3-10. Average Growth Factors for Duals, TTST, and Cars on US and NC Rural Arterial Highways, 1997 – 2004

Statistics	Duals	TTST	Cars
Mean	1.13	1.75	1.32
Standard Error	1.55	1	0.82
Median	1.21	2.9	2.37
Mode	#N/A	#N/A	#N/A
Standard Deviation	7.42	5.1	4.26
Sample Variance	55.07	26.06	18.11
Kurtosis	-0.80	-0.59	-0.39
Skewness	0.04	-0.29	-0.73
Range	26.29	19.72	15.28
Minimum	-12.54	-8.24	-7.85
Maximum	13.76	11.48	7.43
Sum	25.93	45.39	35.68
Count	23.00	26	27.00
Confidence Level(95.0%)	3.21	2.06	1.68
Lower Confidence Level	-2.08	-0.32	-0.36
Upper Confidence Level	4.34	3.81	3.01

Sources: VTRIS data and Table 3-6

Table 3-11: Percent Duals and Percent TTSTs in Total Traffic on US and NC Rural Arterial Highways, 1997 – 2004

Statistics	Duals	TTST
Mean	4.12	7.59
Standard Error	0.19	0.77
Median	4.05	7.33
Mode	#N/A	#N/A
Standard Deviation	1.07	4.37
Sample Variance	1.15	19.07
Kurtosis	1.80	-1.16
Skewness	0.80	0.22
Range	5.28	13.42
Minimum	2.16	1.71
Maximum	7.44	15.13
Sum	131.72	242.99
Count	32.00	32.00
Confidence Level(95.0%)	0.39	1.57

Sources: VTRIS and Table 3-7

Table 3-12. Rural Interstates – VTRIS Data 1997-2004

	Duals	TTSTs	Cars
Mean AGF	0.59%	1.72%	-0.69%
Lower 95% CL AGF	-1.82%	-0.98%	-3.29%
Upper 95% CL AGF	2.99%	4.43%	1.90%
Mean % Vehicles	3.85%	15.77%	80.38%

Cars represent FHWA vehicle classes 1-3, Duals 4-7 and TTSTs 8-13.

Table 3-13. Rural Principal Arterials – VTRIS Data 1997-2004

	Duals	TTSTs	Cars
Mean AGF	1.13%	1.75%	1.32%
Lower 95% CL AGF	-2.08%	-0.32%	-0.36%
Upper 95% CL AGF	4.34%	3.81%	3.01%
Mean % Vehicles	4.12%	7.59%	88.29%

Table 3-14. Rural Interstates – VTRIS Data 1997-2004 with Outliers Removed

	Duals	TTSTs	Cars	ADT
Mean AGF	0.79%	1.87%	~	-0.40
Lower 95% CL AGF	-1.70%	-0.80%	~	-2.80
Upper 95% CL AGF	3.25%	4.56%	~	2.06
Mean % Vehicles	~	~	~	~
Sample Size	16	18	~	19

Table 3-15. Rural Principal Arterials – VTRIS Data 1997-2004 with Outliers Removed

	Duals	TTSTs	Cars	ADT
Mean AGF	3.34%	1.65%	~	1.41%
Lower 95% CL AGF	-0.80%	-0.30%	~	-0.20%
Upper 95% CL AGF	7.52%	3.66%	~	3.02%
Mean % Vehicles	~	~	~	~
Sample Size	27	26	~	27

Statistical Analysis of Test Results

Is Truck Traffic Growing Faster than Auto Traffic in North Carolina: T-Tests

This discussion describes procedures for testing the anecdotal observation that truck traffic is growing faster than auto traffic in North Carolina. Statistical Analysis Software compares the growth rate of trucks (class 4-13) to general traffic (class 1-3). The test begins by claiming that the mean difference μ in growth rates between the two classes of the vehicle population is equal to some postulated value of μ_0. This statement about the value of the population parameter is called the null hypothesis, or H_0. The test determines if the average growth factor of trucks is greater than average growth factor for cars.

The distinguishing character of the paired sample is that for each observation in the first group at one station (truck growth rate) there is a corresponding observation in the second group (general traffic). Analysts frequently employ pairing in an attempt to control for extraneous sources of variation that might otherwise influence the results of the comparison.

Hypothesis Testing for Interstate Routes

To determine if the growth of trucks is more than the growth rate of general traffic on Interstates, the analyzed data from VTRIS forms a one-sided paired t-test. Using the t-test on the data, the effect of truck growth relative to general traffic can be determined (Appendix D). The test assumes that the populations are normally distributed and that the samples are dependent.

The Null Hypothesis states that there is no difference in the growth factors between trucks and total traffic.

H_0: Null Hypothesis $\mu_1 - \mu_2 = 0$

The Alternate Hypothesis states that the truck growth factor is greater than normal traffic (AADT).

H1: Alternate Hypothesis $\mu_1 - \mu_2 > 0$

where

μ_1 = mean growth factor for truck traffic
μ_2 = mean growth factor for general traffic

SAS performs a one-sided t-test at a 95% confidence level to determine the statistical significance of the test. SAS gives a p-value for a two-sided test, therefore for a one-sided t-test the p-value should be divided by two. From the t-test using the normal approximation, the p-value for the one-sided test is found to be 0.06 which is only slightly greater than 0.05. Therefore, the null hypothesis may not be rejected at the 95% confidence level for the dataset of North Carolina Interstate WIM stations. In other words, the average growth factors for trucks and general traffic at Interstate WIM stations are similar. However, since the p-value of 0.06 obtained from the t-test is close to 0.05, a larger sample size may change the result. *At the 90% level the hypothesis is rejected implying that trucks are growing faster than general traffic.*

Hypothesis Testing for Arterials Routes

To determine if the growth of trucks is more than general traffic on US and NC arterials, the VTRIS dataset is again used to perform a one-sided paired t-test (Appendix E). The test proceeds similarly to that for Interstate routes with the same assumptions, null hypothesis, alternate hypothesis, and normal approximation. The resulting p-value for the one-sided test is 0.2754 which is much greater than 0.05. Therefore, the null hypothesis is not rejected *with the conclusion that trucks growth rates on US and NC arterials are not higher than general traffic growth rates.*

Regression Analysis for Causal Factors Related to Truck Traffic Growth

The research addressed the probable influence on truck traffic of causal factors like population, economic development, geographical location, facility type and others. Regression helps investigate the change in a dependent variable called a response (truck growth rate) to changes in independent variables known as the explanatory variables (causal factors – highway type, population, warehouses, NC region). As a general rule, it is preferred to include in a regression model only those explanatory variables that help predict the observed variability in the response (truck growth rate). Then the coefficients of the causal variables can be estimated by regression methods to indicate the size of their effects on truck traffic.

The model is usually developed based on a combination of statistical and non-statistical considerations. Initially, the analyst must have a knowledge of which variables are important, that is, causal. This effort used variables for facility type (Interstates and Arterials), warehouses, NC geographic region (eastern, central, and western) and population.

The regression results are shown in Appendix F based on traffic data for 51 stations along Interstates and Arterials in NC and based on data for the causal variables. It is seen that there is no significant influence from any of the causal variables selected for analysis. This could be because the data is limited to VTRIS database of 51 stations which are primarily rural. The results suggest that observed growth in truck traffic comes from influences beyond North Carolina such as economic conditions. This also suggests that the growth in truck traffic on the VTRIS rural facilities may be due to through truck traffic.

Chapter Summary

Truck traffic is a primary determinant in the design and maintenance of bridge structures, pavements, and highway geometry. Accurate counts of current truck traffic and forecasts of future truck traffic are, therefore, critically important to NCDOT. However, truck traffic is not sampled or counted annually at each automatic traffic recorder and other critical highway locations. Instead, truck traffic is estimated to be a constant annual percentage of vehicular traffic for up to three years until the next cycle of counts can be made. Such an assumption may tend to under or over-estimate actual truck traffic. In reality anecdotal NC evidence and counts from North Carolina and other states suggest that actual truck traffic is increasing. Possible reasons include “just in time” truck delivery strategies, accelerated development and growth in North Carolina cities, increasing imports, and an overall increase in truck traffic passing through North Carolina.

This chapter examines traffic data sources and applies statistical methods to compare traffic growth for total traffic, cars, and trucks at WIM station locations on Interstate, US and NC routes in North Carolina. Potential causal factors underlying the growth are evaluated. Statistically based guidelines for choosing truck growth rates are proposed as substitutes for the current judgmental approach of assuming a constant truck percentage through the forecast period.

The results of this chapter support the Chapter 4 that proposes a new methodology to forecast total traffic (AADT), Duals and TTSTs. A summary of the results are presented below.

<u>Growth Factor Estimates for Interstate, US and NC Routes</u>

This chapter proposes methods to establish confident growth factors for AADT, Cars, Duals and TTSTs. It also demonstrates how future volumes for trucks can be independently estimated from AADT. Cars, Duals and TTSTs should be forecast individually and the results added for the future total AADT.

Judgmental choices for growth rates in traffic forecasting studies can be supported and strengthened by statistical data. Data supporting the results include approximately 50 WIM station locations that collected annualized and classified traffic data for the years 1997 to 2004. This study develops tables of average growth factors and ranges of growth factors for Interstates, US and NC highways in North Carolina. Statistical analysis of the traffic data establish average growth rates for AADT, Duals, and TTSTs, and the analysis identifies the 95% confidence levels for expected growth rates of cars and trucks by facility type. Rather than using ad hoc engineering judgment, the results propose that estimated growth rates used to forecast future traffic for highway projects should range from the lower rate of the confidence intervals established in this chapter to the upper rate in the confidence interval.

- If the estimated growth factor for the traffic forecast of a proposed highway project is between the lower and upper rates in the confidence interval, the value obtained from the forecast is used.
- If the estimated growth factor is lower than the range of the confidence interval it should be set to the lower value. However, if the lower rate is negative the prudent annual growth rate for the forecast should be set to zero or the usual one or two percent that NCDOT often uses for project locations with little anticipated traffic growth.
- If the estimated growth factor is higher than the range of the confidence interval it should be set to the upper value.
- Appropriate growth rates for segments without annualized traffic counts are the means of the vehicle class by facility type lacking other information. If adequate data exist and a site shows a decrease in growth rate, the weighted mean value of the growth rate for the facility type could be used, or the rate could be set to a minimal 1% or 2% as NCDOT currently does for lower volume roads. Such assumptions will allow for some minimal future traffic growth and appropriate project design even if recent traffic trends are low.

For project locations where the dataset at the site is limited and a traffic or truck forecast is desired, it may be inappropriate to use the growth rates obtained from the counts at this location. In such cases the growth rates may be excessively large or small or negative and may not be characteristic of the site or the facility type. This ambiguity and potential project over design or under design is avoided by choosing the default growth rate values by facility type and vehicle class from the VTRIS analysis in this chapter.

Truck Traffic on North Carolina Interstate Routes

The growth factor analysis conducted on the VTRIS dataset of this Chapter can answer the research questions asked in Chapter 1. The answers to the following questions specifically describe the truck traffic conditions for the years 1997 – 2004 at 19 WIM stations. Conditions at other Interstate locations may vary; however, the answers are a good indication of what is happening generally.

1. Is truck traffic growing faster than general traffic?

The results obtained from the statistical summary in Table 3-8 show that the mean growth rates of Duals and TTSTs are greater than that for cars for the years 1997-2004. It can also been seen that the mean growth rate for Cars (classes 1-3) shows a decline for the same years. Mean or median values do not confirm that trucks are growing faster than cars. In order to substantiate the analysis, a t-test must be conducted to test the hypothesis that trucks are growing faster than cars. The t-test results show that at 95% confidence level, there is not enough evidence to state that average truck growth rates for Duals and TTSTs differ from general traffic growth rates (classes 1-3). Results for the t-test for 90% confidence do indicate an increase for trucks (Appendix D, E).

2. How is truck traffic growth rate affected by facility type (Interstate, US, and NC route), by geographic location (eastern, central, and western North Carolina), urban or rural region, proximity to Interstates truck generators (warehouses), and factors such as regional population and economic development?

Regression analysis with available data considered some of the causal factors on truck traffic growth. Factors not considered were urban or rural classification, proximity of project location to major routes, and economic development. Results show that truck growth rates have no dependence on population, geographic region, warehouses, or facility type. Additional data may be helpful to find such relations.

4. What data sources and analytical procedures are available, and how can they be integrated with expert judgment to produce the best estimates of truck traffic for a project?

The descriptive statistics in this chapter provide estimates of average growth rates and default growth rates. These values are obtained relatively quickly by using available historic data from VTRIS. Otherwise, more local project traffic counts are necessary and they must be factored and annualized.

5. How can simple changes in the current truck traffic forecasting process lead to better traffic forecasts?

The important change recommended by this research is that growth factors for three different classes- Cars (light vehicles), Duals, and TTSTs – be determined rather than a single AADT growth factor and constant percentages for Duals and TTSTs. Also, ad hoc adjustments in growth rate based on experience and judgment can be systematized by guidelines based on statewide means and medians of growth rates and the range of values by facility type expected within a 95% confidence interval. The sum of the forecast vehicle classes should provide the total AADT. Future percent vehicles should be based on the forecast vehicle types (light vehicles, Duals, and TTST) and AADT.

<u>Truck Traffic on North Carolina US and NC Arterials</u>

1. Is truck traffic growing faster than general traffic on North Carolina arterials (US and NC routes)?

Analysis of truck count data at 31 US and NC WIM stations shows that the mean growth rate of TTSTs is greater than the mean growth rates of Duals and Cars (FHWA classes 1-3) and that the mean growth rate of (classes 8-13) is greater than that of Duals (classes 4-7). Statistical tests, however, show that at 95% confidence level, there is not enough evidence to state that truck growth rates are higher than general traffic growth rates on US and NC arterials.

2. How is truck traffic growth rate affected by facility type (Interstate, US, NC, SR) considering geographic location (eastern, central, and western North Carolina), urban or rural region, proximity to Interstates and other truck generators, and factors such as regional population and economic development?

Regression analysis considering causal factors such as geographical regions, population distribution, number of transportation warehouse for each county, and facility type was used to determine the effects on truck traffic growth. The analysis did not show a causal relationship.

3. As projects are identified should new truck counts be accomplished or can default values be used for some minor facilities and bridges with limited truck traffic?

In cases where historic trends are unavailable, the default values obtained from the statistical test results in this research can be applied at the project location and modified with care by the forecaster. See for example Tables 3-8 to 3-11. Additional data and future research for other project locations and facility types will be helpful.

4. What data sources and analytical procedures are available, and how can they be integrated with expert judgment to produce the best estimates of truck traffic for a project?

Descriptive statistics provide estimates of average growth rates for WIM station on North Carolina arterials. The growth factor estimates may transfer to arterial projects when local project traffic counts are not available or are not factored and annualized.

5. How can simple changes in the current truck traffic forecasting process lead to better traffic forecasts?

Growth factors should be determined separately for light vehicles, Dual trucks, and TTST trucks. The sum of the forecast vehicle classes should provide the total AADT. Future percent vehicles should be based on the forecast vehicle types (light vehicles, Duals, and TTST) and AADT. Descriptive statistics and ranges of growth factors within specific confidence intervals should guide the selection of growth factors for arterial highways in North Carolina.

CHAPTER 4: TRUCK TRAFFIC FORECASTING METHODS

Chapter Introduction

This chapter uses the results of the previous chapter and explains four methods that can be used to forecast trucks:

- Trend Program (NCDOT Data)
- Trend Program (VTRIS Data)
- Average Growth Factor (VTRIS Data and Statistical Checks)
- Growth Factor Ratio (VTRIS Data and Statistical Checks)

Defining Model Structure

After analyzing and testing the available datasets discussed in the previous chapter, the next step of this research involves defining the methodology for forecasting truck traffic. A subsequent chapter will test the methodology with available data sources, however, the general procedure will be to locate the study area for the forecast, gather available historic traffic data, and supplement the available data with traffic counts that may need to be annualized.

Depending on the location for the highway project study area, data may be available on GIS shape files that can be queried with GIS techniques. A GIS approach may prove advantageous to provide the organization and efficiency of data retrieval to researchers and engineers. The motivation for the methodology with a GIS interface is to facilitate access to truck and other traffic data such as growth factors and nearby regional data.

Trend Program (NCDOT)

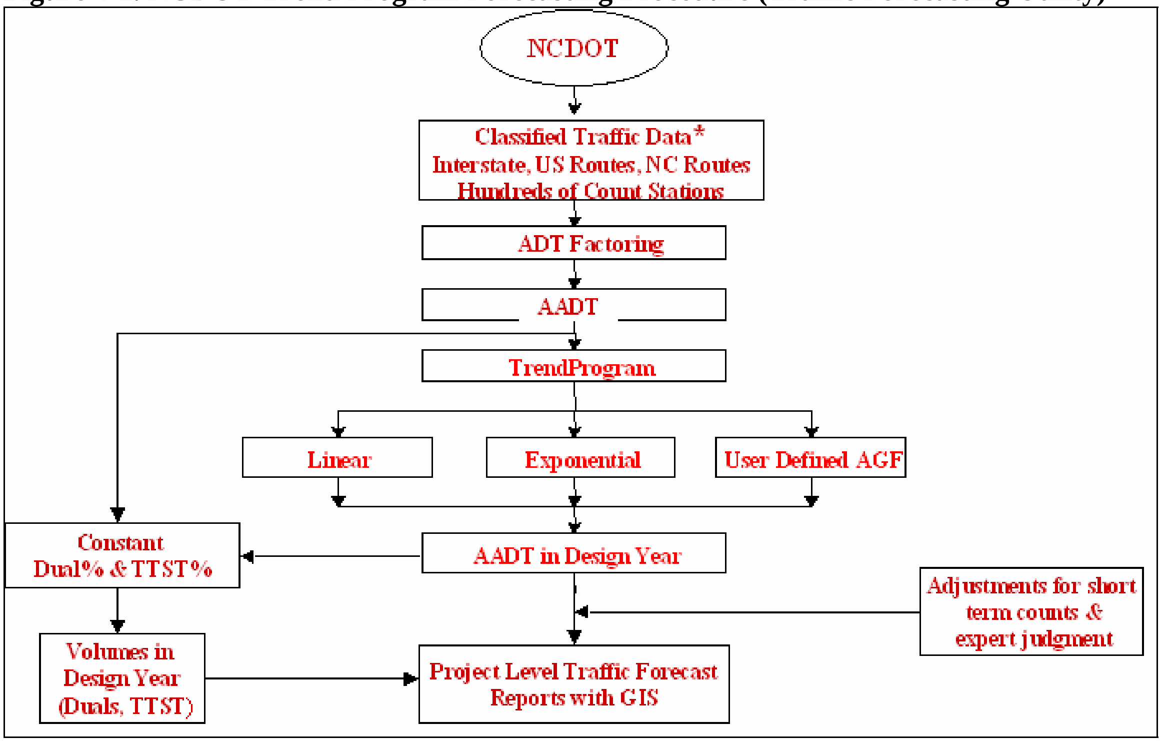
The most common approach for traffic forecasts by NCDOT is performed using the Trend Program spreadsheet as described in Chapter Two of this report. The Trend Program update is called the Traffic Forecasting Utility. This method utilizes available data from ADT datasets provided by the Traffic Survey Unit (TSU). Also, the spreadsheet accepts a user defined growth rate, which is usually based on the engineer's experience and judgment. Figure 4-1 describes the usual process for a traffic forecast conducted at NCDOT using Trend Program.

Percent Duals and percent TTSTs are obtained from classified traffic counts done once every three years or so at selected ATR locations. In most NCDOT traffic forecasts, percent Duals and percent TTSTs are assumed to remain the same from the base year to the future year. In the research methodology, the percentage Duals and TTSTs are not assumed constant. Truck traffic volumes are calculated directly from NCDOT truck counts, VTRIS, and other data. Then truck percentages can be determined based on the usual future year forecast of AADT. A statistical comparison of the forecasted truck values at the project location is also performed after the forecast to determine if they are reasonable.

Trend Program with VTRIS Data

VTRIS data contain consistent annualized truck traffic information for the period 1997-2004. VTRIS data are recorded at Weigh in Motion (WIM) stations and include truck weight information as well as classified vehicle counts. This data can be used directly for traffic forecasts. It is rare to have a project location directly on a VTRIS station. If the project falls on a VTRIS station or in its vicinity, the data can be directly used to forecast traffic using the Trend Program (Figure 4-2). If a VTRIS station does not fall nearby, then forecasting follows either the Average Growth Factor Method (Figure 4-3) or Growth Factor Ratio Method (Figure 4-4).

Figure 4-1. NCDOT Trend Program Forecasting Procedure (Traffic Forecasting Utility)



Average Growth Factor (AGF) Method

There are five steps involved in the Average Growth Factor (AGF) methodology. They follow a structure similar to that used to forecast traffic using the traditional growth factor strategy of using first and last traffic items in an historical sequence of data. The steps include:

- Selection of project location using GIS
- Data collection, analysis, and GIS attributes
- Selection of growth rates and percentage trucks
- Developing future traffic volumes
- Check for Accuracy

Appendices I to K demonstrate this methodology for several case studies along Interstate, NC, and State Routes in North Carolina. Appendix L presents an interesting case that uses Average Growth Factor to forecast trucks on I-95 in order to locate an "electrified truck stop" to reduce idling and emissions. The results of the case studies demonstrate that the average growth factor method can provide good traffic forecasts.

Following the initial location selection and analysis of the average growth factor, the next step involves locating the station on an existing GIS map and database. This process uses ArcMap to locate the WIM station of interest in the GIS model of the road network. From the GIS database developed, attributes such as WIM (VTRIS) station number(s), routes, traffic data, station locations, route types, demographic and economic data, etc. can be referenced to appropriate locations.

Figure 4-2. Traffic Forecasting Procedures

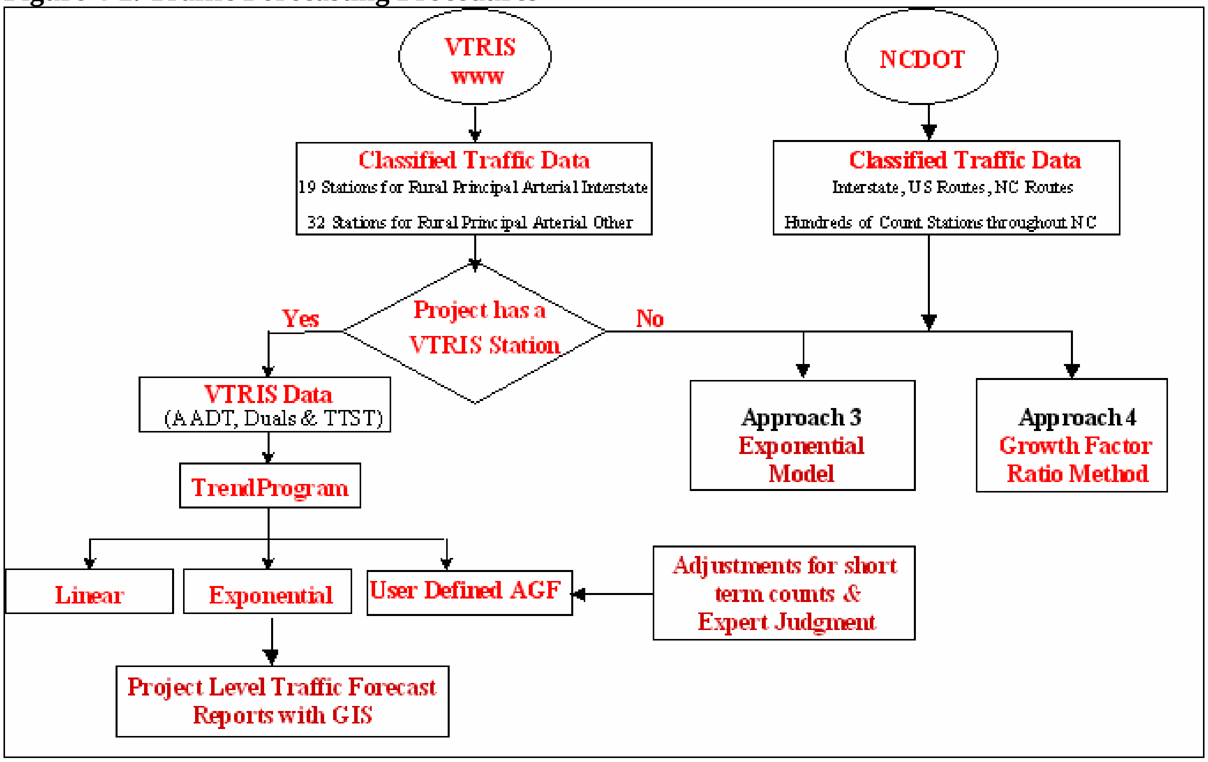


Figure 4-3. AGF Method for Traffic Forecasting

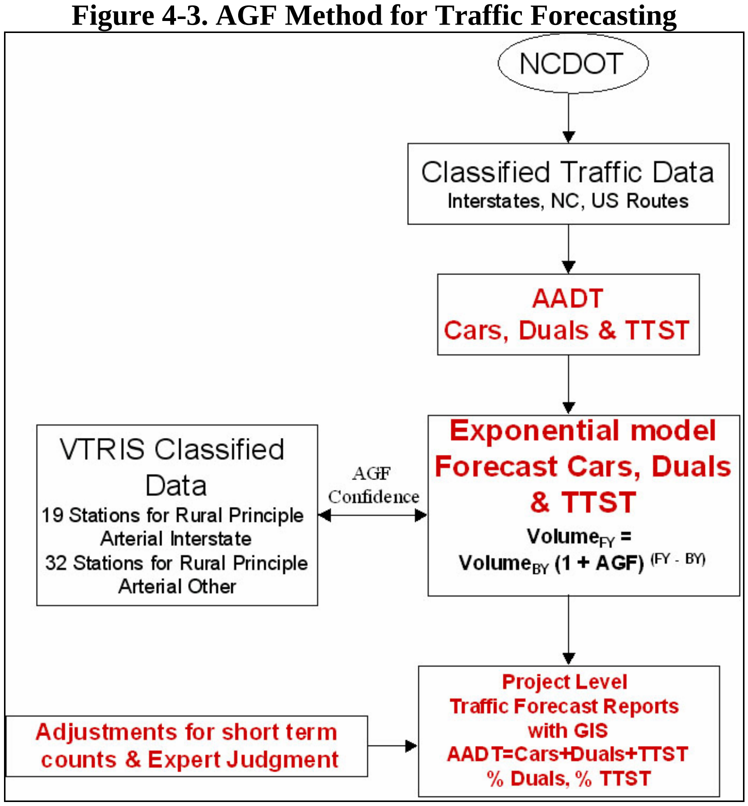
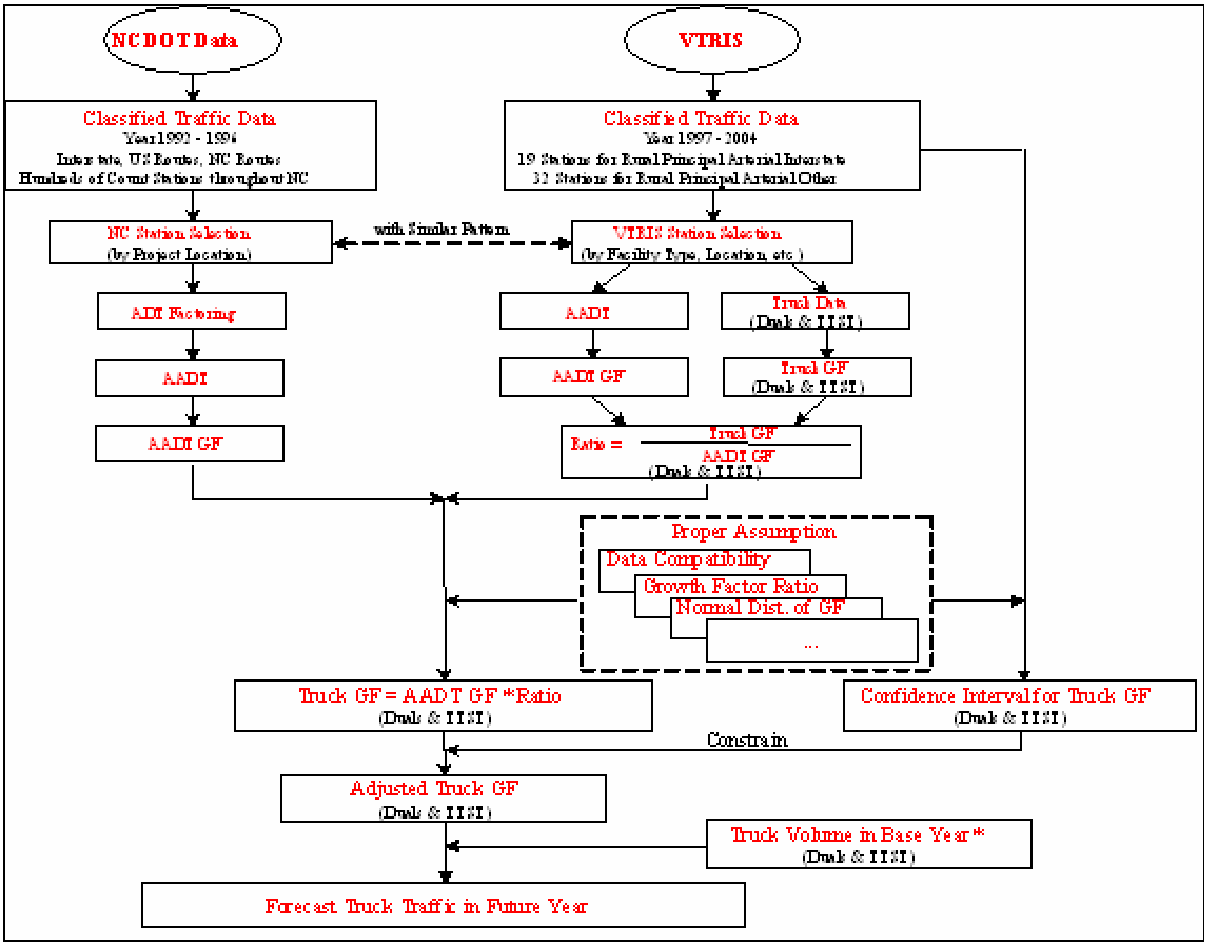


Figure 4-4. Growth Factor Ratio Method of Traffic Forecasting



The steps for applying an existing GIS network model or developing one are described below.

Step 1: Selection of project location using GIS

Project location can be easily identified using the geographical capability of GIS. From the GIS shapefile, identify the site using the county shapefile and DOT roads layer. This can be effectively performed by using the "select by attribute" capabilities' of GIS. Once the project is located, using the VTRIS shapefile, nearby VTRIS/WIM stations can be identified.

For model development the initial step involves collecting appropriate datasets at the project location from NCDOT Traffic Survey Unit. The data available at the project location may or may not consist of historical trends. In cases where historical counts are unavailable, the latest count at the specific location is used and chosen as base year data.

If the counts are divided according to vehicle classifications, then passenger Cars, Duals and TTSTs are separately analyzed. For each category, yearly growth rates and average growth factors at the site are determined.

In cases where vehicle classified counts are unavailable, percent Duals and TTSTs should be assumed to be equal to the mean or median value of the data analysis as described in Chapter 3. Depending on the project location, similar locations along the same facility type may be chosen and appropriate growth factors for the facility type can be applied along the same route.

If there are no VTRIS/WIM stations in the county, a similar county with similar socioeconomic characteristics should be chosen. In order to choose that, the GIS display can help in selecting a similar county based on population, transportation warehouses, and income. From a neighboring county VTRIS station, the pattern of growth of Duals and TTSTs can be determined. For a county which has VTRIS station the station growth factors may apply directly if the facility type, facility location and surrounding areas are similar.

The values corresponding to a similar VTRIS station are checked with the mean and confidence intervals obtained for the facility type as explained in Chapter 3 and Appendix G.

Step 2. Data collection, analysis and GIS attributes

The next step required to determine growth factor and forecast traffic involves collecting data and performing basic growth factor analysis at the project location. Factored and annualized data provided from NCDOT Traffic Survey Unit may be used or VTRIS data may be used if the VTRIS WIM station is the same or is similar to the project location (Figure 4-2).

Annual Growth Factors (GFs) for each vehicle category (Cars, Duals, and TTSTs) are computed separately from the data. If counts for each year are not available at the project location, it is assumed that the growth factor remains constant between the years of missing data and growth rates for the years are calculated using formula 1. Finally the Average Growth Factor (AGF) is calculated using formula 3.

$$GF = \frac{T_t - T_{t-1}}{T_{t-1}} \qquad (1)$$

In cases where intermediate years of data are unavailable and only an initial and final year count are available, the annual growth rate during the time period can be computed from formula 2. This calculation follows an assumption that each year in between the time period experiences a constant growth rate.

$$GF = \frac{\left(\frac{T_{fy} - T_{by}}{T_{by}}\right)}{fy - by} \qquad (2)$$

$$AGF = \frac{\sum GF}{N} \qquad (3)$$

where: T = traffic

GF = annual growth factor

AGF = average annual growth factor

t = year, t-1 = previous year

N = the number of growth factors

fy = future year

by = base year

The percentage Duals and TTSTs at the project location are computed using formulas 4 and 5.

$$\%DUALS = \frac{Duals}{AADT} x100 \qquad (4)$$

$$\%TTST = \frac{TTST}{AADT} x100 \qquad (5)$$

Step 3: Selection of growth rates and percentage trucks at project location

The growth rates obtained from the counts at the project site provide the trend at that location. Insufficient data at the study area often forces the traffic engineer into choosing a growth factor based on the engineer's experience. This may or may not be appropriate for the project location. Another important aspect of keeping a constant percentage of Duals and TTSTs may not prove to be accurate unless the engineer reviews the pattern of truck activity along the facility type.

From the procedures mentioned in Chapter 3 of the report, the engineer can directly choose to select the most confident growth rate from the statistical summaries by facility type and urban/rural location.. The growth of Duals, TTSTs, and Cars is checked with the confidence level developed for the facility type. The forecasted growth rate is limited within this confidence interval. If the project site shows a growth of traffic, the forecasts should be limited by checking the upper confidence level for growth rates for each vehicle category. In the other case if the site shows a decline in growth, the forecasted growth rate is limited by the lower confidence level. The engineer may choose the growth rate at the project location if the historical growth rate falls between the confidence intervals.

Step 4: Developing future traffic volumes.

The final step develops forecasts for future truck traffic in the study area. To perform this step, truck traffic growth factors chosen in Step 3 are used in formulas 2 and 3 to develop the forecast. The percentages of Duals and TTSTs for the design year are computed using formulas 5 and 6.

$$CARS_{fy} = CARS_{by}(1 + AGF)^{(fy-by)} \qquad (1)$$

$$DUALS_{fy} = DUALS_{by}(1 + AGF)^{(fy-by)} \qquad (2)$$

$$TTST_{fy} = TTST_{by}(1 + AGF)^{(fy-by)} \qquad (3)$$

$$AADT = CARS + DUALS + TTST \qquad (4)$$

$$\%DUALS = \frac{Duals}{AADT} x100 \qquad (5)$$

$$\%TTST = \frac{TTST}{AADT} x100 \qquad (6)$$

Step 5: Check for accuracy

The final traffic volumes obtained as a result of the above forecasting methodology are checked for accuracy. The percentages of Duals and TTSTs in total traffic are calculated for the base year of 2003. For the forecasted year of 2020, the percentages of Duals and TTSTs are again calculated and compared with the base year percentages.

Growth Factor Ratio Method

The premise of the Growth Factor Ratio (GFR) method is stated below.

For a pair of NC and VTRIS stations with similar locations (which means they are adjacent to each other, or they are located in areas with the same route type, similar demographic and economic conditions, etc.), the ratios of classified trucks (Duals and TTSTs) growth factor to AADT growth factor will be constant.

This idea can be presented by formulas as below:

$$Ratio_1 = \frac{Duals\_GF_{NC}}{AADT\_GF_{NC}} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \qquad (1)$$

$$Ratio_2 = \frac{TTST\_GF_{NC}}{AADT\_GF_{NC}} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \qquad (2)$$

Thus, growth factors of trucks, Duals and TTSTs, for NC stations could be calculated by the formulas below:

$$Duals\_GF_{NC} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC} = Ratio_1 \times AADT\_GF_{NC} \quad (3)$$

$$TTST\_GF_{NC} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC} = Ratio_2 \times AADT\_GF_{NC} \quad (4)$$

As calculated by formulas 3 and 4, the calculated growth factors of Duals and TTSTs would be used to forecast truck traffic if their values are reasonable. Unfortunately, however, the calculated growth factors may be too large or too small (even negative). In order to bound them, 95% confidence level intervals of the mean AGF for classified traffic discussed above will be applied to test if the calculated growth factors are reasonable. If the calculated growth factor falls in the confidence interval, it can be used with confidence; otherwise, the lower bound and upper bound values will be taken if the calculated growth factors exceed the intervals.

<u>Selecting a VTRIS (WIM) Station to Match a NCDOT Station</u>

In order to employ the growth factor ratio method, a VTRIS (WIM) station should be found matching the project location if possible and route type, urban/rural area, and demographic and economic conditions. Basically, the nearest VTRIS (WIM) station on the same route is the desired one. If no

VTRIS station is on this route, check other VTRIS stations located on similar routes and consider demographic and economic conditions, in urban/rural areas, and then select the most appropriate one.

Determine Growth Factor

Sometimes, the calculated truck growth factors are much larger or smaller (even negative). These growth factors may represent appropriate traffic trends at count stations within a short period of time, but that is not reasonable for long-term traffic forecasting. The confidence intervals listed in Table 3-8 and Table 3-10 provide a good way to capture normal traffic trends, which offset effects of some sudden and significant changes on traffic growth rates and thus can be used for the long-term forecasting.

In the growth factor ratio method, the 95% confidence level interval is used to calibrate the calculated growth factors. Compared with confidence intervals listed in Table 3-8 and Table 3-10, if calculated growth factors of Duals and TTSTs are greater than the upper bound of the 95% confidence interval, the upper value of the confidence interval is used as a reasonable growth rate. The same logic applies for growth factors lower (even negative) than the lower bound, i.e., choose the lower bound as the smallest value.

Forecasting

Forecasting is done using the same formulas described in the AGF method, i.e. apply the formulas.

Limitations of the Methodology

The methodology is most appropriate for NC Arterial Routes and NC Interstates. The methodology, growth factors and statistics should be applied only to projects in North Carolina. The data used for the methodology is composed of classified counts recorded at VTRIS (weigh in motion) locations along rural principal interstates and rural principle arterials. Therefore, the range of statistical results including default growth rates is most efficiently applied to similar routes. The same methodology would prove to be effective in other states, but a different set of data and statistical test results would be required to develop the GFR. With more weigh in motion locations throughout the state, this methodology can be expanded.

This methodology provides a good estimate of truck and other traffic using available data along rural principal interstates and rural principal arterials. Since the data available are limited to 19 stations along NC Interstates and 27 stations along NC Arterials, more WIM stations would help in acting as a strong archive of truck traffic data along these routes. An advantage of the methodology is possible reduction of frequent classified traffic counts at several locations along NC Arterials and NC Interstates. As a recommendation, increase the number of WIM stations along NC and SR routes would also help in developing a separate database for developing default growth rates and percentage of trucks along these routes to obtain near optimum growth trends at project locations.

This methodology utilizes a constant growth rate throughout the design period. Since the default growth rates obtained are a function of, or characteristics of, the functional class, it provides a good estimate of traffic for the future year.

This methodology does not account for socio-economic trends. The forecasting procedure and selection of default values are entirely dependent on limited available data and statistical results obtained from the data. Also, the network structures, economy, and other effects on through traffic along Interstates were not considered in the research.

Chapter Summary

The Trend Program and its upgrade Traffic Forecasting Utility are the current spreadsheet methods used for forecasting project-level traffic at NCDOT. They use the first and last traffic count in an historic series of data to establish a growth factor for AADT. Dual and TTST percentages are usually chosen as constants equal to the base year values. Future year AADT forecasts may be developed from linear, exponential or regression models with adjustments based on engineering experience. The method typically uses NCDOT factored counts, and it can also use VTRIS data. Results can be compared against expected norms for NC facilities.

The Average Growth Factor method uses all the data in a sequence of historic traffic data, not just the first and last data points. Growth factors are determined year by year for Cars, Duals, and TTSTs, as well as AADT. The results are averaged by category to determine AGFs to use in exponential forecast models. Results are checked against expected statistical norms by road facility type to help ensure 95% confidence.

The Growth Factor Ratio method uses VTRIS data to establish Dual and TTST growth rates as well as AADT growth rates. The results are used to forecast truck and total traffic, or truck forecasts from VTRIS data can be combined with AADT forecasts from NCDOT traffic data at the project location. Results may be checked against 95% confidence level forecasted NC traffic by facility type.

Using confidence levels will help the traffic forecaster avoid over estimation or under estimation of growth rates for each vehicle class. Experience and judgment may also suggest adjustments to growth rates.

The Average Growth Factor and Growth Factor Ratio methods are applied to case studies and documented in Chapter 5 and the Appendices. Chapter 6 summarizes the research and describes the findings with recommendations for future research.

CHAPTER 5: CASE STUDIES

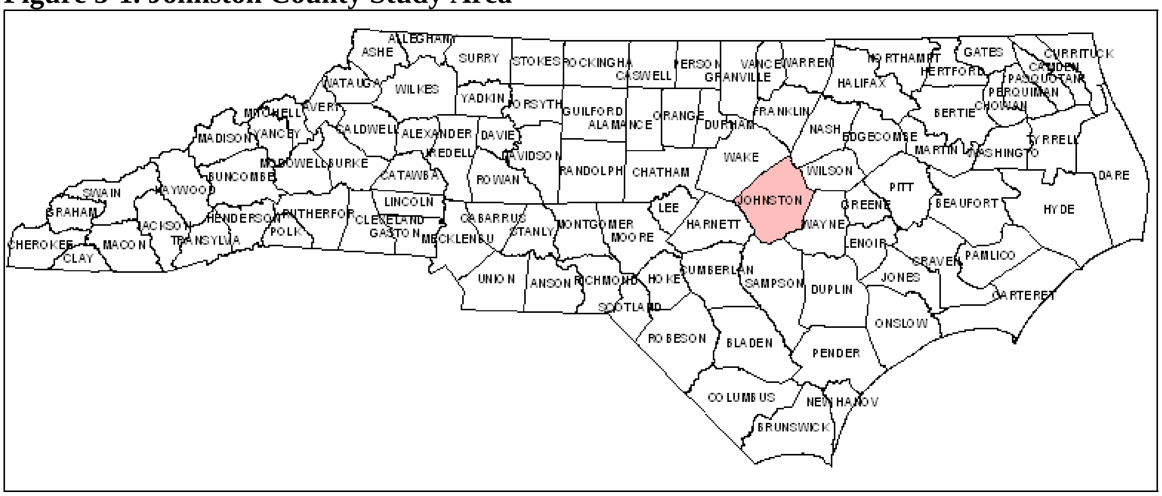
This and following case studies use a format recommended in *Guidelines for Project Level Traffic Forecasting* (NCDOT 2003). Additional case studies appear in the Appendices and follow the same format.

I-95 Traffic Forecasts Using the Average Growth Factor

Project Description

The I-95 case study involves a forecast of total traffic on I-95 in Johnston County near Station 5009. Future year forecast volumes need to be obtained for possible widening and checking for probable pavement overlay for the design year. The base year for the project is 2003 and the future year is 2020. NCDOT has historic data for I-95 at Station 5009, which is located between NC 50 and SR 1178 in Johnston County.

Figure 5-1. Johnston County Study Area



Project Study Area

Johnston County is bordered by Wake County on the west, Harnett County on the southwest, Sampson County on the south, Wayne County on the southeast, Wilson County on the northeast, and Franklin County on the northwest (Figure 5-1). This study includes the section located near Station 5009.

Traffic Data Collection

NCDOT has historic data for Station 5009 which lies between NC 50 and SR 1178 (Keen Road) on I-95 in Johnston County. The NCDOT traffic unit has historical classified counts at Station 5009 for 1991, 1996, 1998 and 2003.

NCDOT factored the data at the project location using continuous vehicle classification data captured at the Weigh-In-Motion (WIM) station W7701, I-95, north of the South Carolina state line, in Robeson County. Data is captured using the FHWA 13 vehicle class scheme in hourly totals by class by lane. The factoring method is demonstrated in Appendix B for US 64.

I-95 data is screened to identify the typical traffic patterns for the station. Atypical days due to holidays, weather, accidents, and other events are excluded. All averages, factors, and seasonal statistics used in the factoring procedures are based on typical days only. This procedure complies with the AASHTO standard. A minimum of 48 hours of data is collected at each station using the FHWA scheme in hourly totals by class by lane. Factoring is applied to the two-way totals at the station (all lanes combined); however, data checks are performed at the individual lane level. Factors are applied by class to generate annual averages (AADT). The classes are then combined to provide the NCDOT vehicle classes typically used for traffic forecasting and design.

Base Year and Future Year

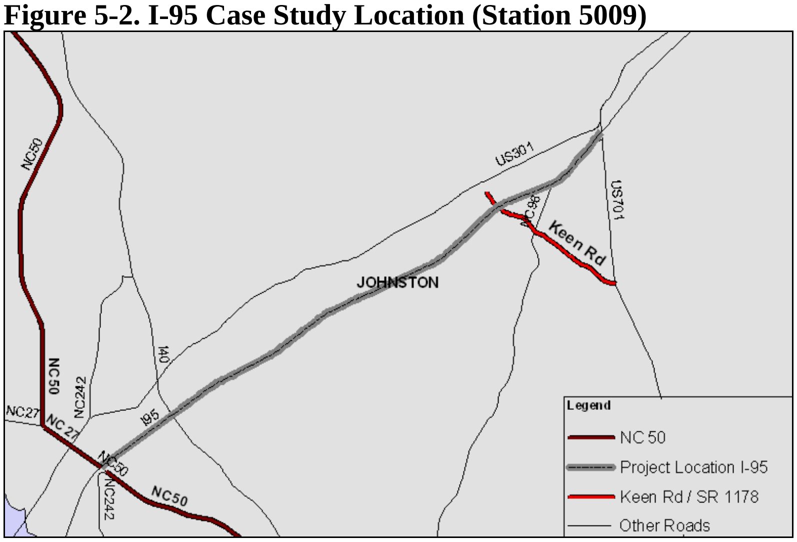
Data for the base year 2003 is used for forecasting traffic volume for the future year 2020.

Average Growth Factor (AGF) methodology

Step 1: Selection of project location using GIS

Project location can be easily identified and located using the geographical capability of GIS. The project location is identified using the NC counties shapefile and DOT roads layer. The selection of project location is effectively performed using the "select by attribute" capabilities in ArcMap from the respective shapefiles.

Figure 5-2. I-95 Case Study Location (Station 5009)



Step 2. Data collection and analysis

The next step required for growth factor selection and forecast development involves collecting appropriate datasets and performing basic growth factor analysis at the project location. Factored and annualized data provided by the NCDOT traffic survey unit is shown in Table 5-1.

Table 5-1. I-95, Station 5009

Year	AADT	CARS	DUALS	TTST
1991	34972	30932	883	3158
1996	41505	35890	948	4667
1998	44141	35627	1649	6865
2003	56974	46959	1968	8046

Annual Growth Factors (GFs) for each vehicle category (Cars, Duals, and TTSTs) are computed separately from the above data. Continuous counts for each year are not available at the project location, otherwise, formula 1 could be used. Therefore, to calculate annual growth factors, it is assumed that growth remains constant between the years of missing data and growth rates for the years are calculated using formula 2. The Average Growth Factor (AGF) results from formula 3.

$$GF = \frac{T_t - T_{t-1}}{T_{t-1}} \qquad (1)$$

In cases where sequential years of data are unavailable, the annual growth rate during the time period can be computed from formula 2 and letting "fy" and "by" be the last and first year of available data, respectively. Assuming that each year in the time period experiences a constant growth rate which is equivalent to the usual NCDOT approach.

$$GF = \frac{\left(\frac{T_{fy} - T_{by}}{T_{by}}\right)}{fy - by} \qquad (2)$$

$$AGF = \frac{\sum GF}{N} \qquad (3)$$

where:

T = traffic

GF = Annual Growth Factor

AGF = Average Annual Growth Factor

t = year, t-1 = previous year

N = the number of growth factors

fy = future year

by = base year

The percentages of Duals and TTSTs at the project location are computed from Table 5.1 using formulas 4 and 5.

$$\%DUALS = \frac{Duals}{AADT} x100 \qquad (4)$$

$$\%TTST = \frac{TTST}{AADT} x100 \qquad (5)$$

Table 5.2 shows the summary of the analysis conducted at the project location (Station 5009). The results obtained from the analysis are used in step 3 to select growth rates for developing forecasts at the study area.

Table 5-2. Average Growth factors and Percentage Duals and TTSTs

Analysis Result Summary for base year traffic (2003)				
AGF Cars	AGF Duals	AGF TTST	% Duals	% TTST
3.07%	14.11%	12.19%	3.46%	14.12%

Step 3: Selection of growth rates and percentage trucks at project location

Results obtained from historic counts at the project location show that there is an increase of Cars, Duals and TTSTs. The growth rates obtained are the results from the limited historic counts (Table 5.1) available at the project location.

Based on the results obtained from statistical analysis on VTRIS data for Interstates, the engineer can now select an appropriate growth rate based on the traffic trends at the project location. Since Station 5009 shows a growth of traffic, the growth rate is checked by the upper confidence level for growth rates for each vehicle category. The AGF values of Table 5.2 are compared with the confidence levels of the Interstate summary statistics results shown in Table 5.3. AGF for each vehicle class is above the upper confidence level for NC Interstates; therefore, the upper confidence level of AGF is used for developing forecasts for the future year. Table 5.4 shows the resulting AGF chosen for the forecast.

Table 5-3. Statistical Results for Interstate Routes - AGF

Statistical Results for Interstate Routes			
Statistics	**AGF (Cars)**	**AGF (Duals)**	**AGF (TTST)**
Mean	**-0.69**	**0.59**	**1.72**
Median	0.01	0.46	-0.09
Mode	0.13	-0.50	-0.35
Standard Deviation	5.22	4.51	5.44
Sample Variance	27.24	20.34	29.56
Minimum	-8.81	-6.83	-7.22
Maximum	10.64	7.40	13.90
Confidence Level(95.0%)	2.60	2.40	2.70
Lower Confidence Level	**-3.29**	**-1.82**	**-0.98**
Upper Confidence Level	**1.90**	**2.99**	**4.43**

Source: VTRIS 1997-2004

Table 5-4. Chosen Average Growth Factors

Growth factor chosen for developing forecasts for 2020			
Method	Cars	Duals	TTST
AGF from Historical Trend	3.07%	14.11%	12.19%
AGF from VTRIS Confidence Intervals	1.90%	3.00%	4.43%

Step 4: Developing future traffic volumes.

This step develops forecasts for future truck traffic in the study area. To perform this step, truck traffic average growth factors computed in Step 3 are used in the following formulas to develop the results. The percentages of Duals and TTSTs for the design year are also computed using formulas 5 and 6.

$$CARS_{fy} = CARS_{by}(1+AGF)^{(fy-by)} \quad (1)$$

$$DUALS_{fy} = DUALS_{by}(1+AGF)^{(fy-by)} \quad (2)$$

$$TTST_{fy} = TTST_{by}(1+AGF)^{(fy-by)} \quad (3)$$

$$AADT = CARS + DUALS + TTST \quad (4)$$

$$\%DUALS = \frac{Duals}{AADT} x100 \quad (5)$$

$$\%TTST = \frac{TTST}{AADT} x100 \quad (6)$$

Table 5.5 shows the results of forecasted traffic and truck class percentages for year 2020.

Table 5-5. Exponential Model Results – AGFs adjusted by confidence intervals

Forecasted Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
Average GF method	64666	3254	16813	84733	3.84%	19.84%

Step 5: Check for accuracy

The final traffic volumes obtained as a result of the Average Growth Factor method are checked for accuracy. The percentages of Duals and TTSTs in total traffic are calculated for the base year of 2003. For the forecasted year of 2020, the percentages of Duals and TTSTs are again calculated and compared with the base year percentages. This check is important and valid since the percentages of Duals and TTSTs follows a normal distribution (Table 5.6).

Table 5-6. Percentage of Duals and TTSTs of Total Traffic

Percentage Duals and TTST of Total Traffic		
Results	% Duals	% TTST
Average GF method 2020	3.84%	19.84%
Base Year 2003	3.46%	14.12%

Comparison and Discussion of Results

The AGF method with and without confidence interval adjustment is compared with growth factors obtained from historical trends developed by linear regression. A summary of the forecast volumes using the methods is shown in Table 5.7.

Table 5-7. Comparison of Traffic Volumes, % Duals and % TTSTs in 2020

Method	Cars	Duals	TTST	AADT	%Cars	%Duals	%TTST
AGF Exp Model (AGF not adjusted)	78477	18551	56821	153848	51.01	12.06	36.93
AGF Exp. Model (AGFs adjusted by CIs)	64666	3254	16813	84733	76.32	3.84	19.84
Linear Model	78606	3470	13580	95656	82.18	3.63	14.20

I-95 Traffic Forecasts Using the NCDOT Trend Program (Traffic Forecasting Utility)

The case study description for the Trend Program analysis of the I-95 section in Johnston County (Station 5009) begins the same as the previous the Average Growth Factor analysis. The results which follow for the Trend Program approach can be used for comparing the approaches.

NCDOT Trend Program

NCDOT generally uses the Trend Program spreadsheet (Traffic Forecasting Utility) to develop forecasts at project locations. Five different models develop forecasts and the engineer chooses the most appropriate forecast based on experience and engineering judgment. The five models are:

1. Average Annual Increment (AAI)
   Based on first and last available data (usually AADT).
   Linear model.
2. Average Annual Rate (AAR)
   Based on first and most recent data (usually AADT).
   Regression between the two points, exponential model.
3. Regression of Increment (RI)
   All available data.
   Linear regression, linear model.
4. Regression Rate (RR)
   All available data.
   Exponential model.
5. User Defined Growth Rate (UR)
   Based on experience. Exponential model.

Linear Equation

$$AADT_{\text{Future Year}} = AADT_{\text{Base Yr}} + \text{AADT Yearly Increment} \times (\text{Future Yr} - \text{Base Yr})$$

Exponential Equation

$$AADT_{\text{Future Year}} = AADT_{\text{Base Yr}} (1 + R)^{(\text{Future Yr} - \text{Base Yr})}$$

For high volume roads like Interstates, NCDOT usually chooses a linear model for forecasts. NCDOT usually uses the exponential model for low volume roads. A user defined growth rate based on engineering judgment can vary depending on the engineer's forecasting experience. The Trend Program is usually applied to total traffic. The percentages of Duals and TTSTs in the base year are usually assumed to be the same in future year forecasts. Rarely will NCDOT forecast trucks separately as percentages or volumes as does the AGF method.

Comparison of trends and forecasted volumes using the Average Growth Factor method from historical trends does not include ad hoc adjustments to the average growth factor. While NCDOT engineers apply user defined growth rates and adjust forecasts using ad hoc methods to obtain reasonable forecasts, the Average Growth Factor method systematically adjusts rates based on statistical upper and lower bounds of growth factors by facility type. Furthermore, the AGF method statistically identifies growth factors for Cars, Duals and TTSTs by facility type that can be used with confidence. **Thus, future NCDOT forecasts with the Trend Program (user defined growth rate) should address different vehicle classes by using the AGF chosen from statistical results and confidence intervals by for facility type.** Tables 5-8 to 5-10 show the results of applying the Trend Program to the I-95 case for each class. Table 5-11 shows the total traffic projections by adding individual class forecasts.

Table 5-8. I-95 Trend Program Results - Cars

HISTORIC DATA:		STATISTICAL RESULTS:					
Year	AADT	AAI - AVG ANN INCREMENT:				1336	
1991	30932	AAR - AVG ANN RATE:				3.5%	
1996	35890	RI - REGRESSION OF INC:				1296	
1998	35627	RR - REGRESSION RATE:				3.4%	
2003	46959	UR - USER-DEFINED RATE:				1.9%	
				Y		LN(Y)	
		SLOPE		1295.932		0.034	
		Y-INTERCEPT		-2550625.1		-56.9	
		CORRELATION		0.9468		0.9612	
		R-SQUARED		0.8965		0.9239	
		DEG. FREEDOM		2		2	
		FUTURE PROJECTIONS:					
		Year	AAI	AAR	RI	RR	UR
		2003	46959	46959	45128	45203	46959
		2005	49630	50343	47719	48359	48760
		2010	56308	59908	54199	57249	53572
		2015	62986	71290	60679	67773	58858
		2020	69664	84835	67158	80232	64667
		2025	76342	100954	73638	94981	71048
		2030	83020	120135	80118	112441	78059

Table 5-9. I-95 Trend Program Results - Duals

HISTORIC DATA:		STATISTICAL RESULTS:					
Year	AADT	AAI - AVG ANN INCREMENT:				90	
1991	883	AAR - AVG ANN RATE:				6.9%	
1996	948	RI - REGRESSION OF INC:				97	
1998	1649	RR - REGRESSION RATE:				7.5%	
2003	1968	UR - USER-DEFINED RATE:				3.0%	
				Y		LN(Y)	
		SLOPE		97.446		0.072	
		Y-INTERCEPT		-193237.6		-137.6	
		CORRELATION		0.9090		0.9024	
		R-SQUARED		0.8263		0.8143	
		DEG. FREEDOM		2		2	
		FUTURE PROJECTIONS:					
		Year	AAI	AAR	RI	RR	UR
		2003	1968	1968	1947	1983	1968
		2005	2149	2249	2142	2292	2088
		2010	2601	3141	2629	3293	2420
		2015	3053	4386	3116	4731	2806

				2020	3505	6125	3603	6797	3253	
				2025	3957	8553	4090	9765	3771	
				2030	4409	11945	4578	14029	4371	

Table 5-10. I-95 Trend Program Results - TTSTs

	HISTORIC DATA:			STATISTICAL RESULTS:						
	Year	AADT		AAI - AVG ANN INCREMENT:				407		
	1991	3158		AAR - AVG ANN RATE:				8.1%		
	1996	4667		RI - REGRESSION OF INC:				426		
	1998	6865		RR - REGRESSION RATE:				8.4%		
	2003	8046		UR - USER-DEFINED RATE:				4.4%		
						Y		LN(Y)		
				SLOPE		426.027		0.081		
				Y-INTERCEPT		-845092.0		-153.3		
				CORRELATION		0.9661		0.9620		
				R-SQUARED		0.9334		0.9254		
				DEG. FREEDOM		2		2		
				FUTURE PROJECTIONS:						
				Year	AAI	AAR	RI	RR	UR	
				2003	8046	8046	8240	8687	8046	
				2005	8861	9403	9092	10215	8770	
				2010	10897	13884	11222	15319	10876	
				2015	12934	20500	13352	22973	13489	
				2020	14971	30268	15483	34452	16730	
				2025	17007	44691	17613	51665	20749	
				2030	19044	65987	19743	77479	25733	

Table 5-11. I-95 Trend Program Total Traffic Forecast

Year	AAI	AAR	RI	RR	UR
2020	88140	121228	86244	121481	84650

Note:

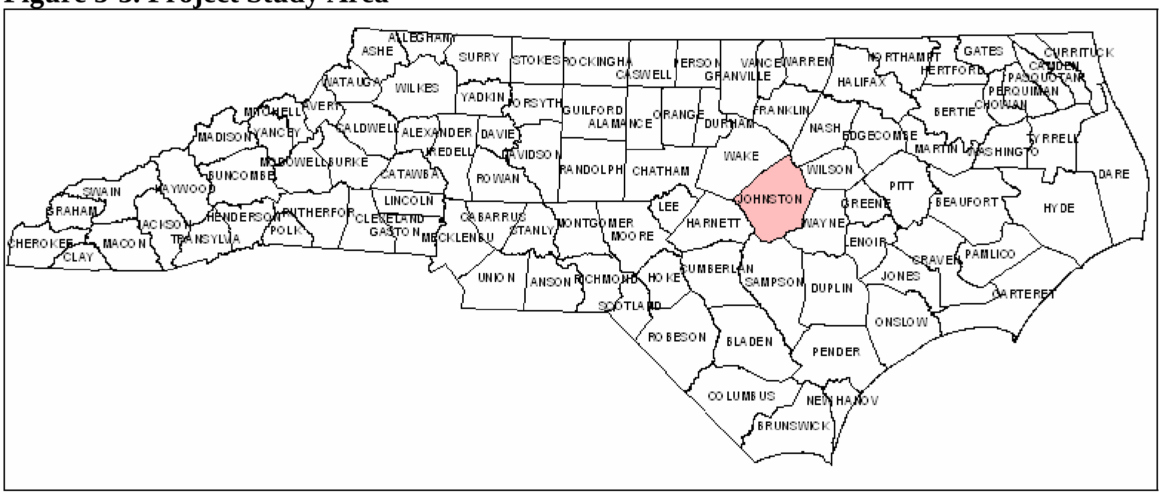
AAI average annual increment with two available counts, linear model forecast.
AAR average annual growth rate with two available counts, exponential model forecast.
RI regression increment with multiple counts, linear model regression forecast.
RR regression rate with multiple data, exponential model regression.
UR user defined growth rate, linear or exponential model depending on facility type.

I-95 Case Study Using the Growth Factor Ratio Method

This case study repeats the previous total traffic forecast on I-95 in Johnston County near Station 5009. This forecast, however, uses the Growth Factor Ratio Method instead of the Average Growth Factor Method. Again, assume that future year forecast volumes are needed for possible widening and checking for probable pavement overlay for the design year. The base year for the project is 2003 and the future year is 2020. NCDOT has historic data for I-95 at Station 5009, which is located between NC 50 and SR 1178 in Johnston County.

The Project Description, Study Area and Traffic Data Collection are nearly the same except for the "matching station" to develop the Growth Factor Ration. The major difference is the forecasting approach using the Growth Factor Ratio.

Figure 5-3. Project Study Area



Analysis of Growth Factor

The Growth Factor method is one of the most common methods used for traffic forecasting. Annual Growth Factor (GF) follows formula 1.

$$GF = \frac{T_t - T_{t-1}}{T_{t-1}} \qquad (1)$$

In cases where sequential years of data are unavailable, a constant growth factor is assumed to be held during the time period. Following this assumption, the desired growth rate can be calculated by formula 2.

$$GF = \sqrt[(fy-by)]{T_{fy} / T_{by}} - 1 \qquad (2)$$

The Average Annual Growth Factor (AGF) is calculated by formula 3.

$$AGF = \frac{\sum GF}{N} \qquad (3)$$

Thus, the traffic volume in the future year can be calculated from formula 4.

$$T_{fy} = T_{by}(1 + AGF)^{(fy-by)} \quad (4)$$

where:

T = traffic

fy = future year, by = base year

GF = Annual Growth Factor

AGF = Average Annual Growth Factor

t = year, t-1 = previous year

N = the number of annual growth factors

Analysis of NC Station Data

NCDOT has historic data for Station 5009 which lies between NC 50 and SR 1178 on I-95 in Johnston County. The NCDOT traffic unit provided historical classified counts at Station 5009, for 1991, 1996, 1998 and 2003.

The ADT from the count station can not be approximated equal to AADT. Thus, the data must be factored to an annualized value of AADT to obtain the correct format to be used in trend analysis. Factoring of the data at the project location is developed from continuous vehicle classification data captured at the Weigh-In-Motion (WIM) station W7701, I-95, north of the South Carolina state line, in Robeson County. Atypical days due to holidays, weather, accidents, and other events are excluded. All averages, factors, and seasonal statistics used in the factoring procedures are based on typical days only. Factors are applied to generate annual averages (AADT), as shown in Table 5-12.

Table 5-12. Historic AADT for Station 5009

Station	Route	County	Year	AADT
5009	I-95	Johnston	1991	34972
5009	I-95	Johnston	1996	41505
5009	I-95	Johnston	1998	44141
5009	I-95	Johnston	2003	56974

Table 5-13 shows the summary of the Average Growth Factor analysis conducted at the project location (Station 5009) using the formulas mentioned above.

Table 5-13. Average Growth Factor for Station 5009

Station	Route	County	AADT AGF
5009	I-95	Johnston	4.16%

Analysis of Confidence Intervals for the Average Growth Factor

With the new VTRIS data, there are 19 stations for facility type Arterial Interstate and 27 stations for Arterial Other. The data span is from 1997 to 2004.

Assuming that the growth factors of Duals and TTSTs follow a normal distribution for the different route types (Arterial Interstate and Arterial Other), the analysis of growth factors at the VTRIS (WIM) stations (Chapter 3 and Appendix G) provides the results in Table 5-14. Depending on the calculated value of the AGF the confidence intervals provide guidance for selecting reasonable values of AGF as discussed below.

- If the estimated AGF for the traffic forecast of a proposed highway project is between the lower and upper rates in the confidence interval, the value obtained from the forecast is used.

- If the AGF is lower than the range of the confidence interval it should be set to the lower value, and if it is higher than the range of the confidence interval it should be set to the upper value.

- Appropriate growth rates for segments without annualized traffic counts are the means of the vehicle class by facility type lacking other information.

- If adequate data exist and a site shows a decrease in growth rate, the weighted mean value of the growth rate for the facility type could be used, or the rate could be set to a minimal 1% or 2% as NCDOT currently does for lower volume roads. Such assumptions will allow for some minimal future traffic growth and appropriate project design even if recent traffic trends are low.

- For project locations where the dataset at the site is limited and a traffic or truck forecast is desired, it may be inappropriate to use the growth rates obtained from the counts at this location. In such cases the growth rates may be excessively large or small or negative and may not be characteristic of the site or the facility type. This ambiguity and potential project over-design or under-design is avoided by choosing the default growth rate values from the VTRIS analysis.

- Predicting forecasts for Cars, Duals and TTSTs separately is important. Then add the results for total traffic.

Table 5-14. Confidence Intervals for Average Growth Factor (Appendix G)

Route Type	Classified Traffic	Sample Size	Lower 95% CL Mean of AGF	Mean of AGF	Upper 95% CL Mean of AGF
Rural Principal Arterial Interstate	Duals	16	-1.70%	0.79%	3.25%
	TTST	18	-0.80%	1.87%	4.56%
	ADT	19	-2.80%	-0.40%	2.06%
Rural Principal Arterial Other	Duals	27	-0.80%	3.34%	7.52%
	TTST	26	-0.30%	1.65%	3.66%
	ADT	27	-0.20%	1.41%	3.02%

Traffic Forecasting Using the Growth Factor Ratio

The Growth Factor Ratio (GFR) provides an alternative approach to the Average Growth Factor (AGF). It attempts to transfer the growth factor analysis from one project location with adequate traffic data to a similar location with little data.

If a pair of North Carolina traffic count stations is at similar locations with the same (or similar) characteristics for route, urban/rural area, internal and through truck traffic, and demographic and economic conditions, the classified traffic (Duals, TTSTs, and ADT) should grow with similar rates. Thus, the ratio of classified truck (Duals and TTSTs) growth factor to AADT growth factor should be constant.

Therefore, the premise of the Growth Factor Ratio method is stated below:

For a pair of NC count stations with similar locations (which means they are adjacent to each other, or they are located in areas with the same or similar route type, traffic characteristics, demographic and economic conditions, etc.), the ratios of classified trucks (Duals and TTSTs) growth factor to AADT growth factor will be constant.

This idea is illustrated by formulas 5 and 6:

$$Ratio_1 = \frac{Duals\_GF_{NC}}{AADT\_GF_{NC}} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \tag{5}$$

$$Ratio_2 = \frac{TTST\_GF_{NC}}{AADT\_GF_{NC}} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \tag{6}$$

Thus, growth factors of trucks (Duals and TTSTs) for NC stations can be calculated by the formulas 7 and 8.

$$Duals\_GF_{NC} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC} = Ratio_1 \times AADT\_GF_{NC} \tag{7}$$

$$TTST\_GF_{NC} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC} = Ratio_2 \times AADT\_GF_{NC} \tag{8}$$

As calculated by formulas 7 and 8, the calculated growth factors of Duals and TTSTs can be used to forecast truck traffic if their values are reasonable. Unfortunately, however, the calculated growth factors may be too large or too small (even negative). In order to constrain them, 95% confidence level intervals of the mean AGF for classified traffic discussed above will be applied to test if the calculated growth factors are reasonable. If the calculated growth factor falls in the confidence interval, it can be used with confidence; otherwise, the lower bound or upper bound values will be taken if the calculated growth factors exceed the intervals.

Selecting a VTRIS (WIM) Station to Match a NC Station

In order to employ the growth factor ratio method, a VTRIS (WIM) station should be found matching Station 5009 if possible and route type, urban/rural area, demographic and economic conditions. Basically, the nearest VTRIS (WIM) station on the same route is the desired one. If no VTRIS station is on the route, consider demographic and economic conditions, check other VTRIS stations located on similar routes in urban/rural areas, and then select the most appropriate one.

After checking the original available VTRIS (WIM) stations, there are three VTRIS (WIM) stations on I-95. Table 5-15 shows the details.

Table 5-15. VRTIS Stations under Consideration for Growth Factor Ratio

Station	COUNTY	ROUTE	LOCATION	NEAREST TOWN	AGF (Duals)	AGF (TTST)	AGF (AADT)
373011	NASH	I-95	.5 MI. SOUTH OF SR 1745	ROCKY MOUNT	3.53%	2.03%	7.86%
377701	ROBESON	I-95	.4 MI. N. OF EXIT 1B	McDONALD	35.50%	13.90%	4.16%
376302	NASH	I-95	MP 129 SOUTH BND	ROCKY MOUNT	7.25%	3.67%	2.19%

Both VTRIS stations 373011 and 376302 are in Nash County, adjacent to Rocky Mount, with US64 passing by. VTRIS station 377701 is in Robeson County, adjacent to McDonald, with US74 passing by. Comparing demographic data and Auto and Truck registration of Nash and Robeson Counties with Johnston County, we find Robeson County matches Johnston County better than Nash County does in these aspects of generating truck growth. Also, the AADT growth rate for station 377701 is 4.16%, which happens to be same as Station 5009's (see Table 5-15), which implies that station 377701 has a more similar traffic growth pattern to Station 5009 than the other two VTRIS stations. Therefore, VTRIS station 377701 in Robeson County is the appropriate one for use. (This is just an example, which only aims at clarification. Other factors should be taken into account to select the appropriate VTRIS station.)

Also, please notice here that the selected VTRIS station (#377701) happens to be an outlier while the confidence interval of the truck growth factor is developed. However, the station selection procedure will not be impacted by the outlier. Appendix H discusses this point in detail.

Determining Growth Factor

As discussed above, VTRIS station 377701 is the most appropriate station similar to NC Station 5009. Therefore, the Growth Factors of Duals and TTSTs of NC Station 5009 can be calculated following formulas 7 and 8.

$$Duals\_GF_{NC5009} = \frac{Duals\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC5009} = \frac{0.3550}{0.0416} \times 0.0416 = 35.50\%$$

$$TTST\_GF_{NC5009} = \frac{TTST\_GF_{VTRIS}}{AADT\_GF_{VTRIS}} \times AADT\_GF_{NC5009} = \frac{0.1390}{0.0416} \times 0.0416 = 13.90\%$$

Sometimes, the calculated truck growth factors are too large or too small (even negative). These growth factors probably represent appropriate traffic trends at count stations within a short period of time, but are not reasonable for long-term traffic forecasting. The confidence intervals listed in Table 5-14 provide a good way to capture normal traffic trends, which offset effects of some sudden and significant changes on traffic growth rates and thus can be used for the long-term forecasting.

In the Growth Factor Ratio method, the 95% confidence level interval is used to calibrate the calculated growth factors. Compared with confidence intervals listed in Table 5-14, calculated growth factors of Duals and TTSTs are both greater than the upper bound of the 95% confidence interval; therefore, the upper value of the confidence interval is used as the reasonable growth rate. Finally, the calibrated growth factors for usage in forecasting are shown in Table 5-16.

Table 5-16. Growth Factor Calibration

	Duals AGF	TTST AGF	AADT AGF
Before Calibration	35.50%	13.90%	4.16%
Lower 95% CL	-1.70%	-0.80%	-2.80%
Upper 95% CL	3.25%	4.56%	2.06%
After Calibration	3.25%	4.56%	2.06%

Forecasting

For project A, the base year is 2003, and truck traffic needs to be forecasted in the design year 2020. Usually, the truck volume in the base year should be determined by survey data or default truck percentage. In this case study, Station 5009 has truck data (Duals and TTSTs) in the base year 2003, as Table 5-17 shows. Following formula 4, the volumes of Duals and TTSTs in 2020 are forecasted. Table 5-18 and Figure 5-4 show the forecasted values.

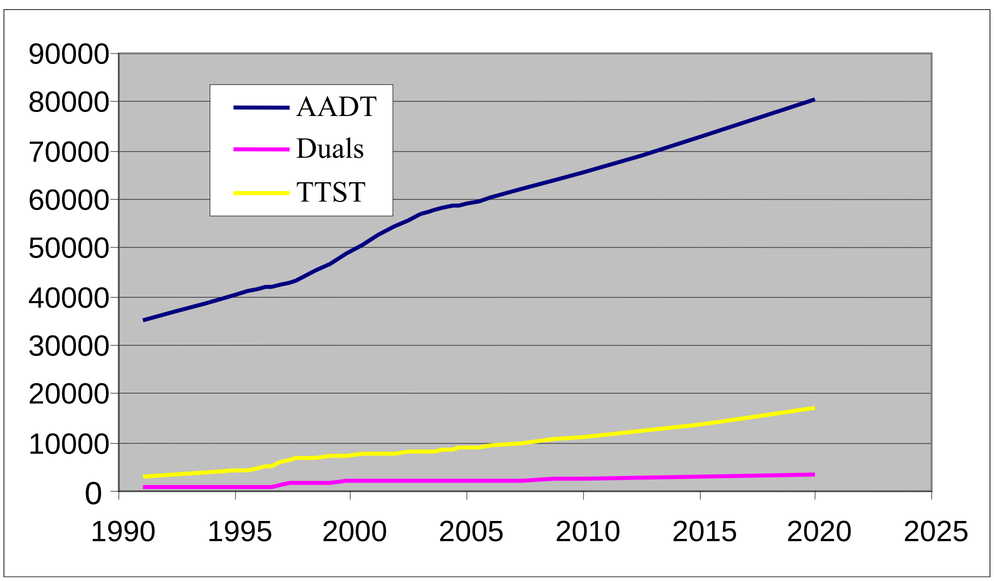
Table 5-17. Classified Data in Base Year 2003 – I-95 Station 5009

Station	Year	Duals	TTST	AADT
5009	2003	1968	8046	56974

Table 5-18. Growth Factor Ratio Truck Forecasting – I-95 Station 5009

Year	Duals	TTST	AADT	Duals%	TTST%
1991	883	3158	34972	2.52%	9.03%
1996	948	4667	41505	2.28%	11.24%
1998	1649	6865	44141	3.74%	15.55%
2003	1968	8046	56974	3.45%	14.12%
2005	2098	8797	59346	3.54%	14.82%
2010	2462	10994	65715	3.75%	16.73%
2015	2889	13739	72769	3.97%	18.88%
2020	3390	17171	80579	4.21%	21.31%

Figure 5-4. GFR Truck Forecasting Trends – I-95 Station 5009



Comparison of the Growth Factor Ratio with Other Methods

It is clear that the average growth factors are different between the historic GF method (without GF calibration) and GFR method (with GF calibration). By these two different methods, Duals and TTSTs are forecasted. Table 5-19, Figure 5-5 and Figure 5-6 show the comparisons of forecasting results obtained from the two methods, where the historic GF method is taken as the Traffic Forecasting Utility method using exponential extrapolation and first and last available data. In fairness, however, it is unlikely that NCDOT would use exponential extrapolation and large growth factors. The comparisons illustrate how the GFR method with confidence interval adjustments produces reasonable forecasts.

Table 5-19. Comparison of the GFR Method and Historic GF Method (TFU)

Year	Duals		TTST	
	Historic GF Method	GFR Method	Historic GF Method	GFR Method
1991	883	883	3158	3158
1996	948	948	4667	4667
1998	1649	1649	6865	6865
2003	1968	1968	8046	8046
2005	3613	2098	10438	8797
2010	16504	2462	20010	10994
2015	75387	2889	38359	13739
2020	344344	3390	73533	17171

Figure 5-5. Duals Forecasting Comparison

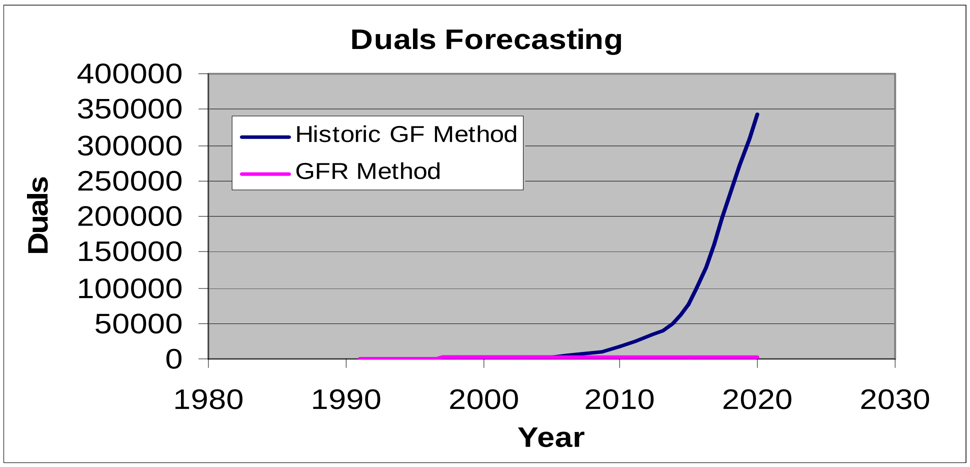
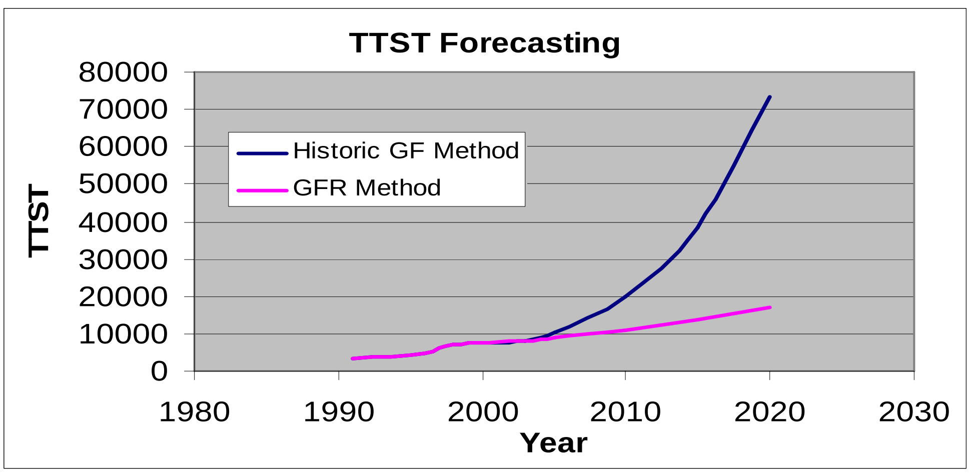


Figure 5-6. TTST Forecasting Comparison

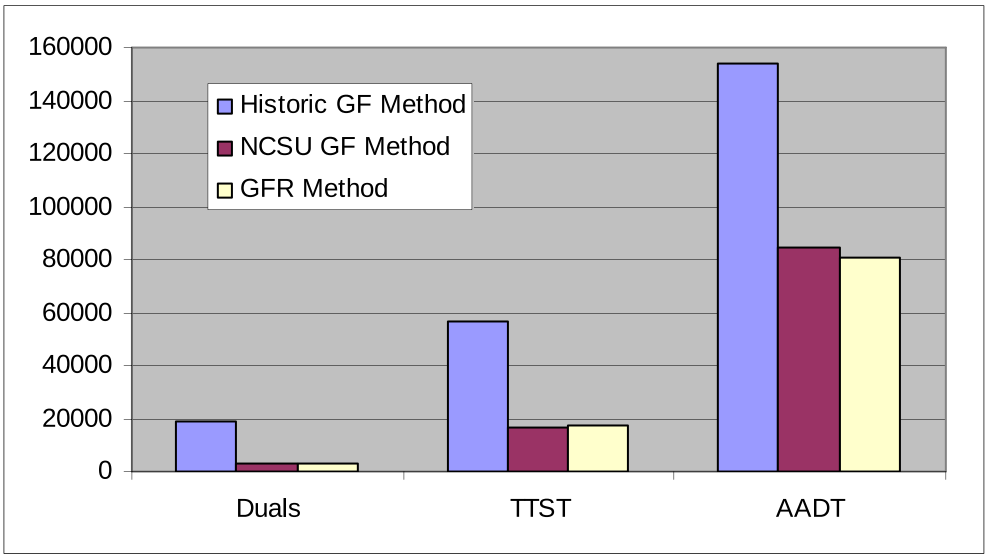


The historic GF method forecasts the truck volumes by using the average growth factor directly obtained from the historic data and without calibration against confidence intervals. Therefore, the historic growth factors are larger (35.50% for Duals and 13.9% for TTSTs) than for the GFR factors. The corresponding forecasts of truck volumes are also extremely large in 2020 and are not reasonable. Besides the historic NCDOT GF exponential method that is based on the first and last traffic data in the historic record, the traffic forecaster can use the exponential AGF method that averages annual historic traffic growth factors, or the linear GFR method that extrapolates traffic. A summary of the forecasting results in 2020 by the three methods are shown in Table 5-20 and Figure 5-7.

Table 5-20. Comparison of Three Methods for 2020 I-95 Traffic

Method	Duals	TTST	AADT	Duals%	TTST%
Historic GF Method	18551	56821	153848	12.06%	36.93%
AGF Method	3254	16813	84733	3.84%	19.84%
GFR Method	3390	17171	80579	4.21%	21.31%

Figure 5-7. Comparisons of Three Methods



It is clear that the forecasting results by GFR method and AGF method are similar with each other. However, forecasting results by the historic GF method show a significant difference.

Growth Factor Ratio Findings

- Combining statistical analysis and data variation displays (e.g. Q-Q plot analysis) is helpful to eliminate outliers.
-
- Some new VTRIS stations have abnormal growth factors, e.g. station 377701 in Robeson County. These outliers are primarily caused by the short-term survey period of a year. New construction and short-term socioeconomic changes also partly contribute to the abnormal growth factors.

- Ignoring the effect of the few outlier stations, we can find that growth factors of classified traffic (Duals, TTSTs and ADT) almost follow a normal distribution (Appendix H).

- Growth factors derived from VTRIS data follow NCDOT expectations. ADT keeps a fairly low growth rate, around 1% or 2%, regardless of route types. Truck growth factors are clearly greater than ADT, and the mean truck growth factors range from 1% to 4%. The upper bounds of the confidence interval for truck growth factors range from 2% to 7.5%, according to different route types and vehicle classes.

- The Growth Factor Ratio method has similar forecasting results as the Average Growth Factor method. Without confidence interval adjustment or subjective growth factor adjustments, the historic growth factor method used by the Traffic Forecasting Utility (Trend Program) produces unreasonable results.

<u>Suggestions for Future Application of Growth Factor Ratio Method</u>

- More truck data (VTRIS stations) is needed. Data collection is a fundamental issue for traffic forecasts. Sufficient data sources can lead to a satisfactory forecasting quality. Better datasets should include more VTRIS stations which have classified traffic counts and longer survey periods.

- Avoid using single and new count stations whose short-term traffic counts may cause abnormal growth factors.

- The developed confidence intervals for growth factors are recommended to be used for long-term traffic forecasts. The confidence interval provides the range of traffic growth rate under normal conditions, thus can filter abnormal traffic growth rates caused by data deficiencies or sudden socioeconomic changes.

- According to the station selection procedure in the Growth Factor Ratio method, the basic principal is to select the most similar VTRIS station which matches the NC count station. Here, all related factors such as socioeconomic patterns, geographic attributes and constructions should be taken into account.

- The Growth Factor Ratio method responds to some forecasting concerns of NCDOT: low ADT growth rate and fairly high truck growth rate.

- Growth factor confidence intervals can help NCDOT engineers choose appropriate growth rates.

- While sample sizes for VTRIS stations are sufficient for this exploratory research, more data and count locations would be beneficial. As time goes on, the results should be updated.

The results of a truck forecasts like those presented previously for I-95 in Johnston County are the basis of highway planning and design. The following summary cases illustrate how truck traffic forecasts affect an important environmental initiative to reduce diesel truck idling and how the impacts truck traffic forecasts affect on highway capacity design and pavement design. Appendices L, M and N provide detailed discussions.

Comparing Forecasting Methods: Trend Program, Average Growth Factor, and Growth Factor Ratio

The forecasting results of all the methods used in this study may be summarized and compared as shown in Table 5-21. For the AGF models and the GFR model the individual vehicle classes were separately forecasted and the results added to determine AADT. Then percent Duals and TTST were determined. For the Trend Program models individual forecasts were made for the vehicle classes and AADT.

The "**bold**" results are most similar and seem reasonable in terms of vehicle class forecasts and percentages and AADT forecasts. The reasonable AGF and GFR forecasts consider all the available data and they are based on the 95% confidence level guidelines developed in this research. **The results also indicate that the Trend Program and its User Defined Growth Factor (UR) produce comparable results when all the available data are used and the growth factors by vehicle class are selected based on Confidence Interval guidelines.**

Table 5-21. Comparison of Forecasting Methods for 2020 I-95 Traffic

Method	Cars	Duals	TTST	AADT	Duals%	TTST%
AGF Exp Model (Historic GF) (AGF not adjusted)	78447	18551	56821	153848	12.06%	36.93%
AGF Exp. Model (NCSU) (AGFs adjusted by CIs)	**64666**	**3254**	**16813**	**84733**	**3.84%**	**19.84%**
GFR Method, no outliers (AGFs adjusted by CIs)	~	**3390**	**17171**	**80579**	**4.21%**	**21.31%**
Linear Model	78606	3470	13580	95656	3.63%	14.20%
Trend Program: AAI	69664	3505	14971	88144	3.98%	16.98%
Trend Program: AAR	84835	6125	30268	113749	5.38%	26.61%
Trend Program: RI	67158	3603	15483	86248	4.18%	17.95%
Trend Program: RR	80232	6797	34452	110705	6.14%	31.12%
Trend Program: UR	**64667**	**3253**	**16730**	**86693**	**3.75%**	**19.30%**

Using GIS and Average Growth Factor Truck Forecasts to Locate Truck Stop Electrification Sites on I-95

Truck Stop Electrification allows truckers to purchase electrical services to run on-board cooling, heating, communication and other systems instead of idling truck engines during mandatory rest stops. As a result, fuel is saved and truck emissions are reduced.

Converting existing truck stop locations into Truck Stop Electrification (TSE) locations is becoming more common because of the increase in long-haul trucking, new regulations on maximum daily driver hours, the high cost of truck idling, and the pollutants released by idling trucks. Currently, there are no TSE locations south of Pennsylvania on Interstate 95 (I-95). Appendix L identifies commercial truck stops located along the I-95 corridor in North Carolina that would be candidates for a truck stop electrification installation by the year 2010. These candidate locations are identified through the use of ranking criteria and a combination of GIS and spreadsheet analysis. Ranking criteria for the truck stops included projected truck traffic based on the Average Growth Factor method, local land use, population density, local diesel emissions, parking capacity, and proximity to I-95. Weighting each truck stop versus the criteria, the Sadler Truck Plaza in Dunn, NC, at Exit 75 on I-95 ranks as the most desirable TSE location along the I-95 corridor in NC based on the evaluation criteria. Nine other truck stop locations were also acceptable candidates. Additional data collection of truck stop attributes such as truck traffic, truck stop utilization and air quality data can improve the selection model.

Truck Traffic Impacts on I-95 Highway Design

The volume of vehicles on some North Carolina highways continues to rise each year. Furthermore, truck volumes on several of these highways are growing faster than that of passenger vehicles and some experts believe that trucks will almost double in the next ten years. Trucks typically travel at a slower speed than passenger vehicles and occupy more space on the highway. Thus, trucks have a greater influence on the number of lanes than passenger vehicles. Additionally, the number of lanes and the average daily traffic influence free flow speed and level of service on highway segments. As the number of lanes increase, so does the ease at which vehicles can avoid slower traffic. On the other hand, as the AADT increases, vehicle maneuverability decreases. More significantly, increasing truck volumes further enhance congestion and delay if additional lanes are not available for other vehicles.

Appendix M analyzes the sensitivity of the number of lanes on I-95 to average annual daily traffic (AADT) and to varying percent trucks of total AADT. Also, the study examines the level of service of a roadway with changing AADT and percent trucks. The Highway Capacity Manual (HCM 2000) and Highway Capacity Software (HCS 2000) are used to perform the sensitivity analysis.

Results of the analysis in Appendix M indicate that as percent trucks increase, the maximum AADT must decrease to maintain a required level of service. At LOS B as truck percentages increase from 2% to 25% the capacity of traffic on a facility drops around ten percent. For example, if a highway facility of four lanes has two percent trucks, it will carry about 45,000 ADT at LOS B. If trucks increase to 25% then AADT must drop around ten percent to about 40,700 to maintain LOS B. Also, as percent trucks increase, the maximum AADT must decrease more for an eight lane facility compared to a four lane facility to maintain the initial LOS. For example, as the percent trucks increase from 2% to 25%, AADT must decrease by 10.2% or 9,200 vehicles per day for an eight lane highway to maintain the original LOS B. AADT decreases by only 9.5% or 4,600 vehicles per day for a four lane highway. Yet, decreasing AADT (which implies decreasing automobile traffic) is not likely to occur when truck percentages increase. Thus, increases in truck traffic percentages will cause highway LOS to get worse.

Appendix M shows additional results and implications for highway construction as future truck traffic increases.

Truck Traffic Impacts on I-95 Pavement Design and Cost

Trucks cause significant damage to pavement structures. Depending on the highway, traffic increases annually as much as several percent per year. In some locations, truck account for up to 30% of the total traffic. Truck traffic is often assumed to grow the same as the general traffic, but national and regional data suggest that the truck volumes increase at a higher rate than total traffic. Hence, it is imperative to know the effect of the variation of truck traffic percentages on pavement design and construction cost. To study this effect, Appendix N describes a sensitivity analysis of I-95 pavement design to the variation of truck traffic volumes in terms of cost/linear foot.

The analysis included three types of flexible pavement with soil stabilization: full depth asphalt pavement, flexible pavement with Aggregate Base Course (ABC) and flexible pavement with Cement Treated Aggregate Base Course (CTABC). The approach for the sensitivity analysis used the NCDOT pavement design spreadsheet procedure and tested sample designs to get the thickness and cost/LF for different percentages of Duals and TTST. The sensitivity study estimated the overall thickness of pavement and cost/LF for variations of truck traffic percentages. The results provide a level of accuracy required in truck traffic forecasts.

The sensitivity study identifies three distinct ranges of truck volumes in terms of ESALs that affect pavement design. Interestingly, the mid range of truck forecasts shows the greatest sensitivity of pavement design in terms of cost/LF. Such mid range forecasts are consistent with US routes such as US 64. Thus, accurate truck traffic forecasting is especially critical for routes carrying mid-range truck volumes such as US routes.

Chapter Summary

The I-95 case study for Johnston County provides a demonstration of the Average Growth Factor method and the Growth Factor Ratio method. Factored I-95 traffic data and class counts from NCDOT provide the historical basis for the trend line forecast with a linear model. The calculated growth factors by vehicle class are greater than the typical values for NC Interstates so they are set to the upper limit of the confidence interval unless there is other information to confirm the higher values of growth factors. The AGF and GFR forecasts are compared to each other and to results using the several options in the Trend Program (Traffic Forecasting Utility). While the AGF and GFR forecasts for AADT, Duals and TTSTs were approximately the same and reasonable, the Trend Program forecasts seemed high and unreasonable.

These demonstrations illustrate how AGF and GFR forecasts can be validated by the expected values of growth rate based on statistical confidence intervals.

Besides the I-95 case study for comparing the AGF, GFR and Trend Program forecasting methods, this chapter summarized the results of appendix case studies illustrating for I-95 the use of truck traffic forecasting for locating an electrified truck stop, for selecting the number of lanes in highway design, and designing pavement thickness.

CHAPTER 6: FINDINGS AND RECOMMENDATIONS

Summary

Truck traffic forecasting is critical for highway and pavement design, but insufficient historical classified truck data makes truck traffic forecasting difficult for highway improvement projects. The traditional method of assuming a constant percentage of truck in base year traffic and future year traffic for Duals and TTST causes concern for design engineers because the constant truck percentage assumption does not reflect the reality of increasing truck volumes. To help rectify this problem this project develops project-level truck forecasting methods that use historical data and replace subjective estimates of truck growth rates with statistically based ranges of expected truck growth rates depending on facility type. The method uses available data from VTRIS and a general GIS shapefile for easy retrieval of data and locations of viable data recording stations.

The growth of Dual and TTST truck traffic on Interstates has been tested using t-tests and proven to be statistically significant at the 90% confidence interval and larger than the growth of light vehicles (Cars). While the findings are based on limited data, they suggest that future traffic forecasts should include and separately forecast Duals and TTSTs.

Findings

Methodology

The methodology developed in this project provides a selection of truck forecasting tools and a range of growth factor values that an engineer can use with confidence. It illustrates the importance of choosing a verified growth factor rather than a value solely based on prior experience. Another advantage of the statistical analysis lies in the opportunity to check proposed growth factors.

The proposed methodology for developing truck traffic growth factors and forecasts provides consistent, reproducible, defensible results. The analytical methods incorporate a set of commonly used data sources and techniques to forecast AADT and vehicle traffic by class and facility type. Statistically based growth factors guide the selection of reliable growth factors and percentages of Duals and TTSTs depending on highway type.

The results are based on limited available data. They should be updated as more WIM stations are built throughout the state and more on-line VTRIS data becomes available. The current results reflect 1997-2004 VTRIS data for only 19 rural stations along NC Interstates and 32 rural stations along NC Arterials (other) – US, NC and some SR routes. Also, the VTRIS stations are only located in rural areas. Urban or suburban locations are desirable to expand the applicability of the proposed confidence intervals on expected truck growth rates by facility type.

North Carolina Traffic Trends Based on 1997-2004 VTRIS Data

- Mean AGF TTST is greater than the mean AGF Duals on NC Interstates.
- Mean AGF TTST is about the same as the mean AGF Duals on NC Arterials.
- The mean AGF for light vehicles (Cars) on Interstates shows a decline.
- At 95% confidence level, there is no significant difference between Dual and TTST truck growth factors and light vehicle growth factors for NC Arterials and NC Interstates.
- At 90% confidence level, there is significant difference in Dual and TTST truck and light vehicle growth factors on NC Interstates.

- According to regression analysis truck growth factors in North Carolina are not a statistically significant function of geographic location, facility type, population distribution and proximity to warehouses.

Products

As a result of the methodology and data used for the project, the following products are available for use at NCDOT.

- Two new traffic forecasting methods (AGF and GFR).
- Statistical tests to check growth factors for traffic by class on rural Interstates, US and NC routes in North Carolina.
- Default growth factors to use where data is sparse.
- A GIS shapefile for Statewide VTRIS (Weigh in Motion) stations (51 WIM and LTPP stations).
- A statewide 1997-2004 spreadsheet and database for the VTRIS archive including classified counts for Cars, Duals and TTSTs. A methodology for integrating tools and data for traffic forecasts.
- A GIS methodology for integrating growth factor methods and data from VTRIS, land use files, the Census and other sources that describe economic trends for traffic forecasts.
- Four case study demonstrations of the growth factor methods.
- A sensitivity study of highway design for lanes and level of service versus truck volumes.
- A pavement design sensitivity study of cost per linear foot versus truck volumes.
- An application of GIS and average growth factor methods to locate an electrified truck stop an Interstate.

Conclusions

There are four major conclusions from this research:

- There is statistical evidence that trucks are a significant percentage of vehicles on North Carolina highways, and growth rates for heavy trucks exceed those for light vehicles, especially on Interstates.
- Traffic forecasts should not be based on trends that consider only the first and last years in a sequence of historical traffic data. Rather, each year's historical traffic data should be included in the calculation of the growth factor.
- Dual and TTST truck volumes should be forecast independently of lighter vehicles for highway projects. Truck percentages should not be assumed equal at the base and future years for the forecast, rather vehicle volumes by class should be calculated or estimated using available data and valid statistical guidelines. Truck percentages should be determined after the total AADT is found by adding the individual vehicle volume forecasts.
- Statistically based guidelines (confidence interval tables) should guide the calculation and selection of growth factors.

Recommendations

- The NCDOT Trend Program (Traffic Forecasting Utility) should be revised to include the Average Growth Factor method, Growth Factor Ratio method, and Confidence Interval guidelines developed from this research.
- When using the Trend Program (TFU) apply the following recommendations:

- Traffic forecasts for total traffic or any vehicle class should not be based on trends that consider only the first and last years in a sequence of historical traffic data. Rather, each year's historical traffic data should be included in the calculation of the growth factor.
- Dual and TTST truck volumes should be forecast independently of lighter vehicles for highway projects. Truck percentages should not be assumed equal at the base and future years for the forecast, rather vehicle volumes by class should be calculated or estimated using available data and valid statistical guidelines. Truck percentages should be determined after the total AADT is found by adding the individual vehicle volume forecasts.
- Statistically based guidelines (confidence interval tables) should guide the calculation and selection of growth factors.

- The results of this study, in particular the historical vehicle class data and confidence interval tables, should be updated as more WIM stations are installed throughout North Carolina and as more VTRIS data become available.
- As more traffic data collection resources become available at NCDOT, special attention should be given to secondary highways (NC and SR routes) that are not currently included in the VTRIS database used in this study and that are particularly attractive to permitted and non-permitted over-weight trucks.
- The prototype GIS methodology for processing VTRIS vehicle class data, calculating vehicle class growth rates, and displaying the results with land use and other map images should be more fully developed and demonstrated operationally.

Future Research

This research project has demonstrated the importance of including trucks in traffic forecasts. However, the results, though state of the practice, are limited to traffic forecasts on "isolated" highway links. Highway network effects are not addressed; hence, policy level questions regarding alternative highway improvements and traffic divergence to alternate routes cannot be tested. Also, the methods are simple trend forecasts of past history. There is no accounting for causal factors such as economic, land use, technology or political forces. Furthermore, all forecasts are uncertain, an element ignored in this effort. All these issues are fruitful areas for future research.

Specific future research topics are:

- Develop a program to use annual traffic counts from VTRIS stations to update the confidence intervals and related growth factors for traffic.
- Extend the statistical analysis developed in this study from rural VTRIS stations to urban VTRIS stations and non-VTRIS NCDOT automatic traffic recorder (ATR) stations throughout the state.
- Rewrite the NCDOT Trend Program (Traffic Forecasting Utility) to include the Average Growth Factor and Growth Factor Ratio methods developed in this study. Most importantly include the Confidence Interval guidelines for selecting and checking growth factors.
- Use the recently developed NCDOT Redbook Wizard to integrate traffic forecasts (based on growth factor guidelines developed in this research) and benefit-cost estimates in the feasibility evaluation of highway projects.
- Develop a prototype truck network model for North Carolina. This model would be similar in function to regional or city travel demand models. It could forecast deficiencies in the state truck network at truck and general traffic volumes increase, and it could test alternative improvements.
- Integrate truck traffic databases (class counts by highway type and location) and network-based truck traffic forecasts to develop truck traffic "profiles". The profiles could describe the truck traffic between NC origins and destinations by truck type, frequency and other factors

such as overweight and oversize. Relate the profiles to pavement maintenance, structure design, and funding issues.

CHAPTER 7: IMPLEMENTATION AND TECHNOLOGY TRANSFER PLAN

Truck traffic is significantly growing year by year because of the dynamics of the U.S. economy. Increased truck traffic, however, increases traffic congestion and impacts on pavement and bridge structures. Good forecasts of truck traffic are critical to the design procedures of NCDOT. Thus, the results of this research must be transferred to appropriate NCDOT users.

The research products can be used by the Transportation Planning Branch to forecast truck volumes to support a variety of transportation improvements including highway widening, pavement and bridge design, and identification of future network deficiencies. The research products include new traffic forecasting applications of standard statistical methods that are adaptable to the current NCDOT Traffic Forecasting Utility (Trend Program) and GIS implementations. Thus, NCDOT staff should be able to apply the research products directly with little or no training. The extensive documentation, spreadsheets and data related to this technical report will facilitate the transfer the technology to the users. However, in-house or external training are options.

Transportation Planning Branch staff are preparing *Best Practice Guidelines for Traffic Forecasting*. The *Guidelines* will be based on NCDOT practice, peer DOT practice, and a research project report *Guidelines for NCDOT Project-Level Traffic Forecasting* (Stone 2002). The results of this important truck traffic research, *North Carolina Forecasts for Truck Traffic*, should also be included in the TPB *Guidelines* effort. Thus, TPB should coordinate its efforts with the traffic forecasting needs of other NCDOT units including Traffic Surveys, Pavement Management, and Bridge Maintenance.

Specific implementation tasks include:

- Modify the existing NCDOT Traffic Forecasting Utility (Trend Program) to incorporate the confidence intervals to help users select reasonable traffic and truck growth factors.
- Modify the Traffic Forecasting Utility to include the Average Growth Factor and Growth Factor Ratio methods developed in this research.
- Modify the Traffic Forecasting Utility with Q-Q plots or similar statistical methods to test for normal distributions and outliers of traffic data that should be removed before a forecast is prepared.
- Modify the Traffic Forecasting Utility to:
  - Individually forecast Passenger Vehicles, Duals and TTSTs.
  - Sum the results for AADT from forecast passenger vehicles, Duals and TTSTs.
  - Separately calculate future values of percent Passenger Vehicles, Duals, and TTSTs based on individual forecasts for Passenger Vehicles, Duals, TTSTs, and calculated AADT.
- Update the current VTRIS database for to include traffic data beyond 2004 and recalculate confidence intervals.
- Provide the products of this research to the Traffic Surveys Unit and discuss data upgrade opportunities based on new traffic count programs.
- Provide the results of this research to the Traffic Forecasting Unit.
- Discuss NCDOT training requirements with the authors and ITRE.

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APPENDIX A: GIS METHODS AND WIM STATIONS

This appendix summarizes the procedure of generating the WIM station shapefile for the state of North Carolina. The weigh-in-motion (WIM) systems provide massive amounts of valuable data related to trucks and general traffic. There are about 60 WIM stations located along Interstates, US, State, and NC routes.

Quality Assurance (QA) procedures are conducted regularly to point out problems at the WIM site and help maintain the system throughout the site design life. The need for quality assurance prompted the development of software programs that are used to validate data and point to problems occurring at the WIM site. These programs include the Long Term Pavement Performance (LTPP) QA software, the Vehicle Travel Information System (VTRIS) and individual state software.

The data used for this project uses VTRIS database for all WIM locations throughout North Carolina. The VTRIS software replaces the Truck Weight Software and uses the standards, formats, and methods specified by the Traffic Monitoring Guide (TMG). VTRIS is a recommended, but not required, method to submit data to the Federal Highway Administration (FHWA) in a uniform format. The software validates, summarizes, and generates reports on vehicle travel characteristics by lane and by direction in the TMG format.

The VTRIS software develops and maintains a permanent database of the WIM data. Traffic data is available from 1997-2002 for the state of North Carolina. It can be viewed using the W-2 table from http://apps.fhwa.dot.gov/vtris/vtris.aspx. The data are validated by VTRIS before inclusion into the VTRIS maintained database. The validation process can be adjusted for each station's site characteristics and user defined parameters for axle spacing and axle weights. Errors detected by the software can be viewed to determine the type of error and whether or not to include the record in the database. The software also converts the WIM data to metric units, thus complying with the FHWA Metric Conversion Plan.

The data obtained from 1997-2002 in W-2 table is grouped by station number (i.e. SHRP#) and converted to excel format for analysis. Growth factor for each station for total traffic, duals, TTST, and total trucks are calculated. This table is used to join with the new WIM shapefile.

Data

Shapefiles used for the editing

- DOT roads layer dotroads.shp
- National Highway system layer nhs98all.shp
- WIM stations layer wim37.shp
- Counties layer all_counties.shp

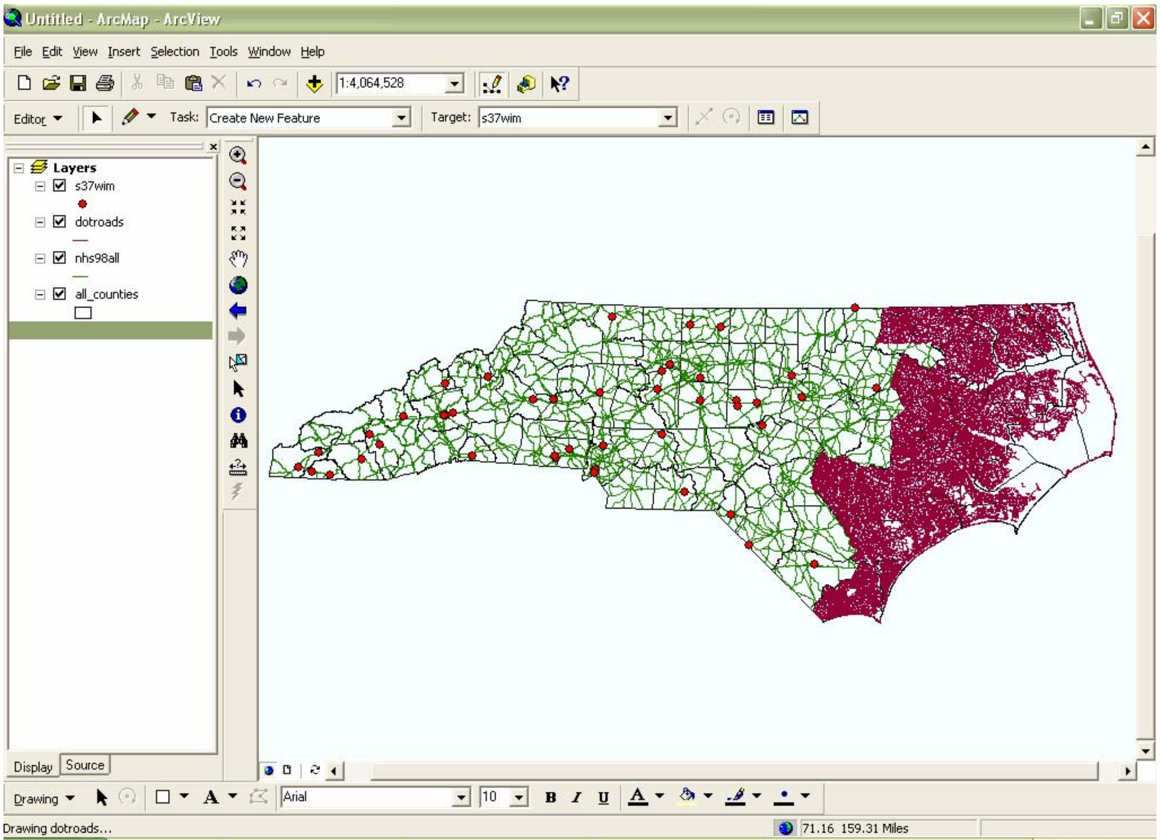
MS Excel file

- VTRIS stations.xls

Creating the Shapefile and Editing

Open ArcMap

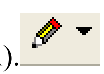
- Add the shapefiles to the Data View.
- Set the display units in miles.



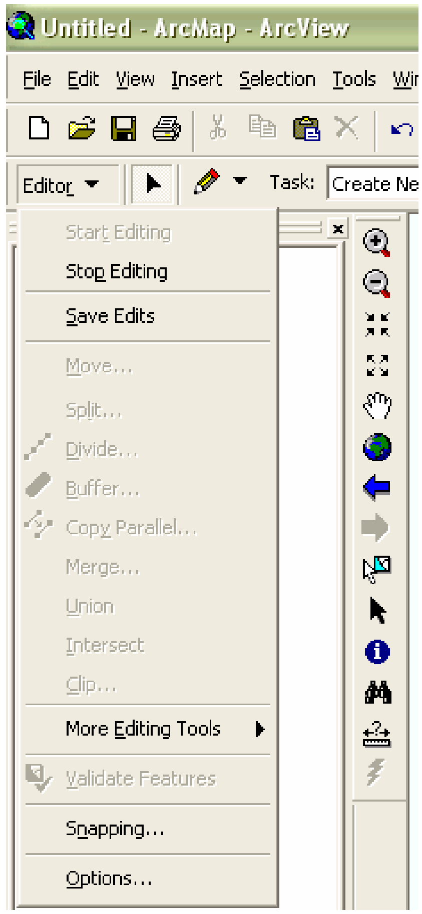
- Open the Editor toolbar (View/Toolbars/Editor)

- In the Editor toolbar click Editor/Start Editing. You may be given an option of a folder or database from which you want to edit data. Choose the folder where s37wim.shp lies and click OK.

- In the Editor toolbar click Create New Feature in the Task window then scroll to and select the shapefile to edit within the Target window.

- In the Editor toolbar click the Create New Feature icon (it looks like a short pencil). 

- Before adding a new feature snapping is switched on. The vertex of the s37wim is to be snapped with the edge of the dotroads layer. A snapping tolerance of 20 is given for maximum accuracy. The checkbox for showing snapping tips is also checked.



- The location description of WIM stations is used to create a new feature on the s37wim layer. Stations are located on the road network and are referenced to specific distance from major roads, mileposts, exits, or major towns.

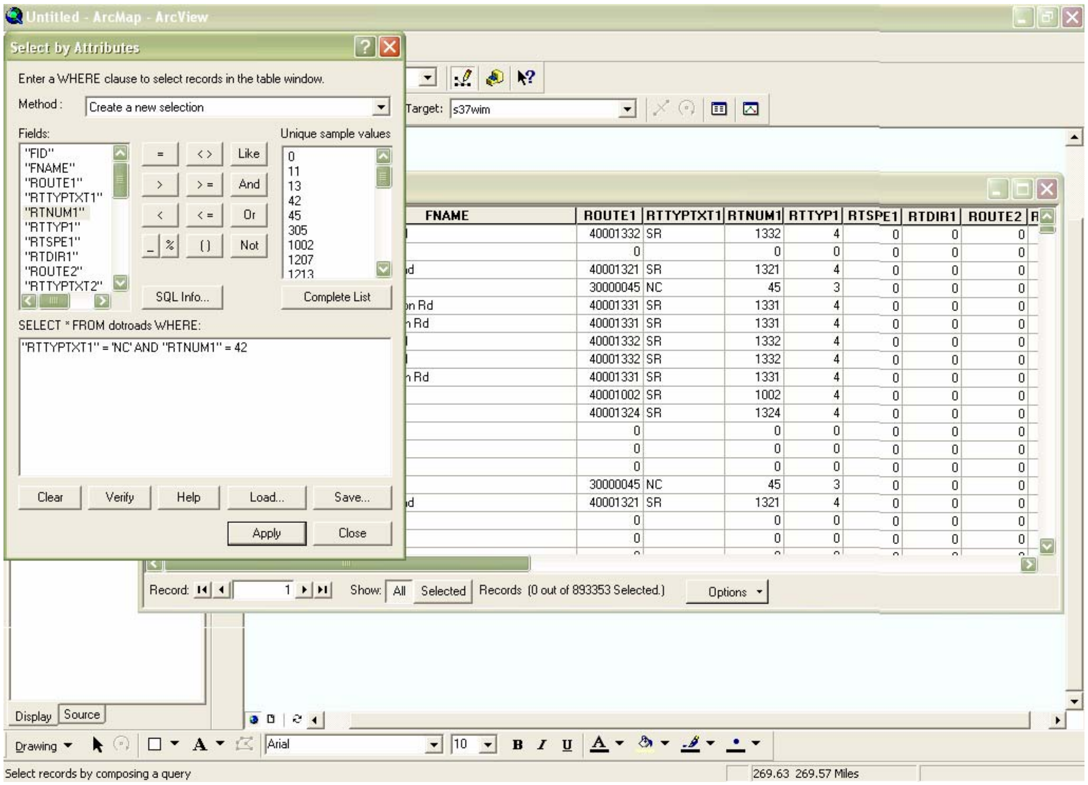
- First the route on which the stations are located is selected from the dotroads layer using selection by attributes.

- The reference for the WIM station is used to determine the exact location of the station. In cases where distance from an intersection route is given, the measuring tool is used to locate the new station. 

- A new station is added on using add new feature tool.

- Since the wim37.shp is a point layer, new point features are created and a row for the new feature is added in the attribute table.

- After the new feature is added to the s37wim shapefile, click on the attribute table  on the editor toolbar and add the station ID number to the new feature.



- When finished editing, click Editor/Stop Editing and click Yes in the Save window.

Joining Two Tables

The WIM data collected from VTRIS website is analyzed and saved as a excel file named VTRIS stations.xls. The file is saved to a dbaseIV format in order to be read into ArcMap. In order to perform a table join, both tables should have one column similar. The attribute table for s37wim.shp contains a column for station ID named STTNID and the VTRIS station.dbf has SHRP# column that matches the STTNID column.

- In ArcMap Add Data and select the file (you won't see it on ArcMap unless you select the Source tab in the Table of Contents window)

- Right click s37wim layer and select 'Join' to join the dbase table.

- The join is based on the field STTNID in the wim layer and SHRP# field in the dbase table.

- The two tables are joined together and the attribute table in the wim layer displays the joined output.

- In order to associate the join into the shapefile, the wim layer is exported and saved as a new shapefile.

- Right click on wim layer click data→ Export, select use the same coordinate system as the data frame and save the output shapefile as VTRIS_stations.shp.

- A new shapefile with the joined attribute table is obtained.

This shapefile can be used to locate statewide weigh-in-motion stations. Once the station number is identified, the data corresponding to that particular station can be obtained from the on-line VTRIS spreadsheet. The data include the VTRIS data:

- station characteristics;
- station location;
- annual traffic classification counts by lane and direction;
- axle spacings;
- vehicle weights, etc.;

and additional analysis is associated with the spreadsheet:

- average growth factor for the range of the traffic data including AADT and composite vehicle classes corresponding to the NCDOT truck classifications Dual and TTST;
- growth factor ratios;
- growth factors commonly used with the NCDOT Traffic Forecasting Utility (Trend Program);
- statistical checks and guidelines based on QQ plots and confidence intervals to help the analysis validate and choose appropriate growth factors.

The analyst can incorporate the resulting VTRIS shapefile and database with local, regional, statewide and national databases for NCDOT project locations, economic trends, land use, building permits, traffic generators, planned industrial sites, and the like to provide additional insight to the traffic trends, growth factors and traffic forecasts being developed.

APPENDIX B: TRAFFIC FACTORING AND ANNUALIZING FOR US 64

As a senior at NC State University, Elizabeth Runey developed this appendix as a special short term research project. She worked with the engineers at the NCDOT Traffic Surveys Unit and learned to clean, factor and annualize raw traffic counts. This appendix documents those procedures. Her effort was funded by the Southeastern Transportation Center.

The Truck Traffic Forecasting Problem

Because highway and pavement design depend on accurate truck traffic forecasts, special efforts must be taken to count, classify, factor and annualize truck traffic counts. If reliable historical truck counts are available, better forecasts of future truck traffic may be made for highway improvements. However, the process for developing good historical truck counts is complex and the usual forecasting assumption is to assume that the future year truck traffic is the same percentage of total traffic (AADT) as the base year traffic. Then forecasts are made for AADT and the assumed constant truck percentages are applied to the future year. The difficulty with this assumption is that truck traffic may increase faster than general traffic. Such truck traffic increases have, indeed, occurred on Interstate and other truck routes.

For these reasons this paper demonstrates the process to develop reliable historical truck traffic.

Traffic Data and Counters

Daily vehicle traffic and truck traffic are recorded by hundreds of count stations throughout the state each year. These stations include continuous monitoring count stations such as Weigh-in-Motion (WIM) stations, Automatic Traffic Recording (ATRs) stations, and Long-Term Pavement Performance (LTPP) stations, as well as, short-term count stations (electronic counts) and turning movement count stations (manual counts). All of the stations collect total ADT, but only some of the stations count vehicles using thethe FHWA classification scheme (Classes 1-13) or the NCDOT classification scheme (Passenger Vehicles, Dual Axle Trucks - Duals, and Truck Tractor Single Trailers -TTSTs)

The continuous monitoring stations collect typical "everyday" traffic data and atypical daily traffic data which might reflect construction delays, weather conditions, and special event traffic. Continuous count stations collect a full year's worth of data and the averaged ADT is approximately equal to the annualized Average Annual Daily Traffic (AADT) for that data set. Data from continuous count stations with partial data sets, short-term count stations, and turning movement count stations must be factored to an annualized value to get AADT. Factoring accounts for traffic on atypical days when seasonal effects, construction, weather or other events interfere with typical traffic patterns. It is important to factor and annualize short term and turning movement data sets as well as partial annual data sets to develop consistent AADT estimates for trend analysis and forecasting.

VTRIS stations, including some WIM and LTPP stations, collect continuous ADT data. These stations are consistent with other ATR stations. The average ADT at VTRIS stations is approximately equal to the factored AADT for these stations as long as the station collects a full year's worth of data. All VTRIS stations must be checked for complete data sets before being used in a forecast. VTRIS data is available at apps.fhwa.dot.gov/vtris/ and the VTRIS tables are defined in the Heavy Vehicle Travel Information System Field Manual located at www.fhwa.dot.gov/ohim/tvtw/hvtis.htm .

Annualized data eliminate the effects of seasonal and other variability in vehicle traffic and thus can be used to estimate historic growth patterns. To annualize counts, historic ADT data from a continuous count station is examined and screened to identify typical days. Annualized data represent typical days of the year being considered. The typical days determine which days of count data to average and create factors for each month and day of the week to use to adjust the atypical traffic data. From the factors, seasonality ratios are developed and graphed to check for outlying data. The resulting factors from the continuous traffic counters are then used to adjust traffic counts from other stations that count traffic for periods shorter than a year.

The continuous count stations provide a baseline for adjusting traffic data from non-continuous count stations. There are fewer continuous count stations than other stations which may be closer to highway projects that need traffic forecasts. Thus, the continuous count stations provide the factors to adjust the local, non-continuous counts in order to develop good traffic forecasts for the project. The critical assumption, however, the two stations experience similar traffic. Usually this occurs if the two stations are relatively close to each other, are on the same highway or similar highways and have similar urban or rural land use development in the area.

Assuming the continuous count station reflects traffic variations that are appropriate for the project of interest are similar, its factors are applied to available data sets for the project under consideration. These data sets include continuous count stations, short-term count stations, turning movement stations, and special project counts, all of which have to be factored and annualized. Also, the available data sets may be from the corridor of interest or from a nearby similar corridor. Factoring the local count data using the baseline factors from the continuous count stations provides Average Annual Daily Traffic (AADT), which is the correct format for forecasting traffic demand for the local project of interest. A case study of US 64 is provided as an example of the annualizing procedure.

US 64 Example

A case study of the US 64 corridor west of Raleigh illustrates the concepts of traffic data factoring and annualizing. The analysis develops consistent estimates of current year total traffic and truck traffic. These current year estimates are necessary to forecast future total traffic and truck traffic demand for traffic improvement projects.

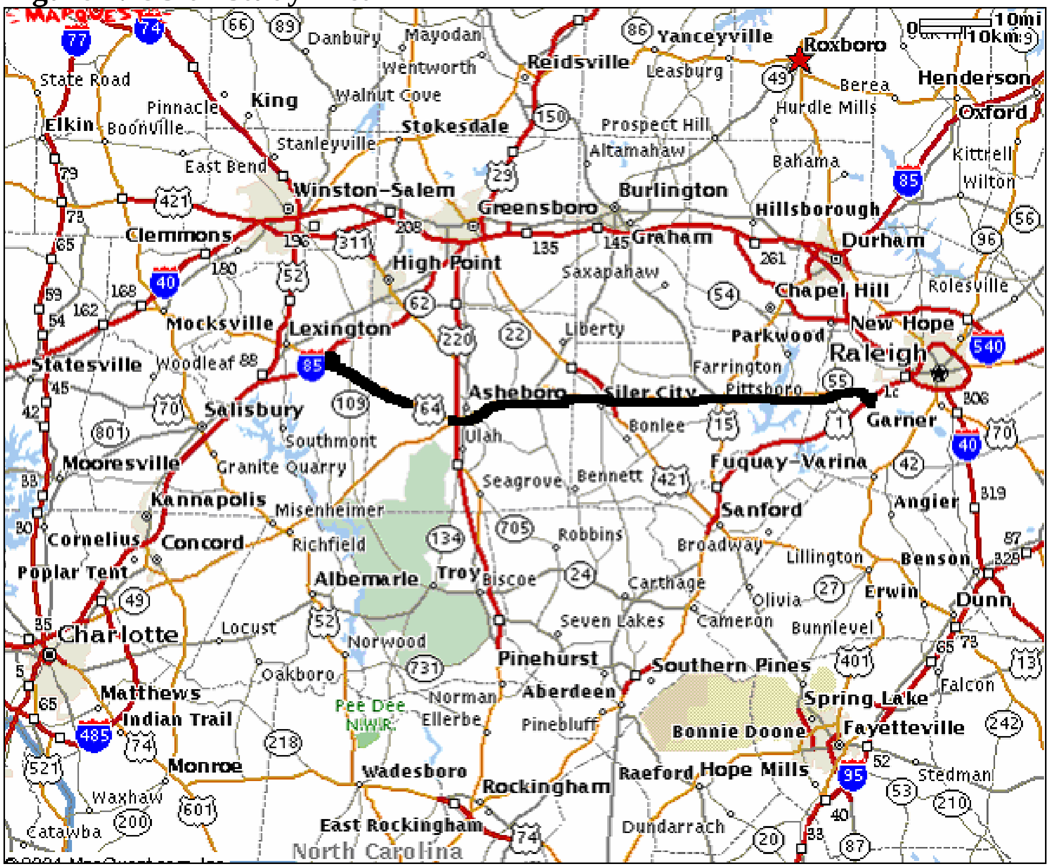
The study area for the case study is along US 64 from I-85 in Davidson County to US 1 in Wake County (Figure 1). The corridor passes through rural areas in the counties of Davidson, Randolph, Chatham, and Wake. US 64 is an east/west route and serves as a major truck route for North Carolina. Areas of potential growth along US 64 include Asheboro, Siler City, and Pittsboro.

Continuous monitoring stations provide raw vehicle classification data for the thirteen vehicle classes specified by FHWA. Additionally, continuous monitoring stations provide detailed information about the character of travel as it varies on different days of the week and different months of the year. The US 64 vehicle classification data come from continuous monitoring Station 371805. This is a WIM Station (W1805) on the US 64 Bypass, 0.2 miles east (west??) of US 64 Business near Pittsboro (Figure 2).Please locate on map. The Bypass carries a major portion of the truck traffic to alleviate through traffic on US 64 Business through Pittsboro. The vehicle classification data include hourly counts for both directions and for each lane of the four-lane facility from March 1, 2003 to February 29, 2004. W1805 classifies traffic??. Statistics generated from this data are used to factor short-term vehicle class counts and turning movement counts at Stations 1801 and 1805 (??) (Figure 2) to calculate AADT and forecast traffic on US 64. Station 1801, which is ATR Station 25 is used as a reference for typical days of the year from 3/1/2003 to 2/29/2004. This station is located along US 64 two miles west of SR 1008 in Chatham County, NC (Figure 2). This Station provides good count data in both directions and does/does classify vehicles??. The typical days are flagged and used to screen the W1805 data for typical days using NCDOT Microsoft Access tools. A demonstration of the MS

Access tool can be seen in "GIS application for the Seasonal Analysis of Traffic Data, Development of Seasonal Factors and Seasonal Adjustment of Roadways" provided by the NCDOT Traffic Survey Unit. The link to this report is

http://www.ncdot.org/planning/statewide/traffic_survey/research/seasonal/ .

Figure 1: US 64 Study Area



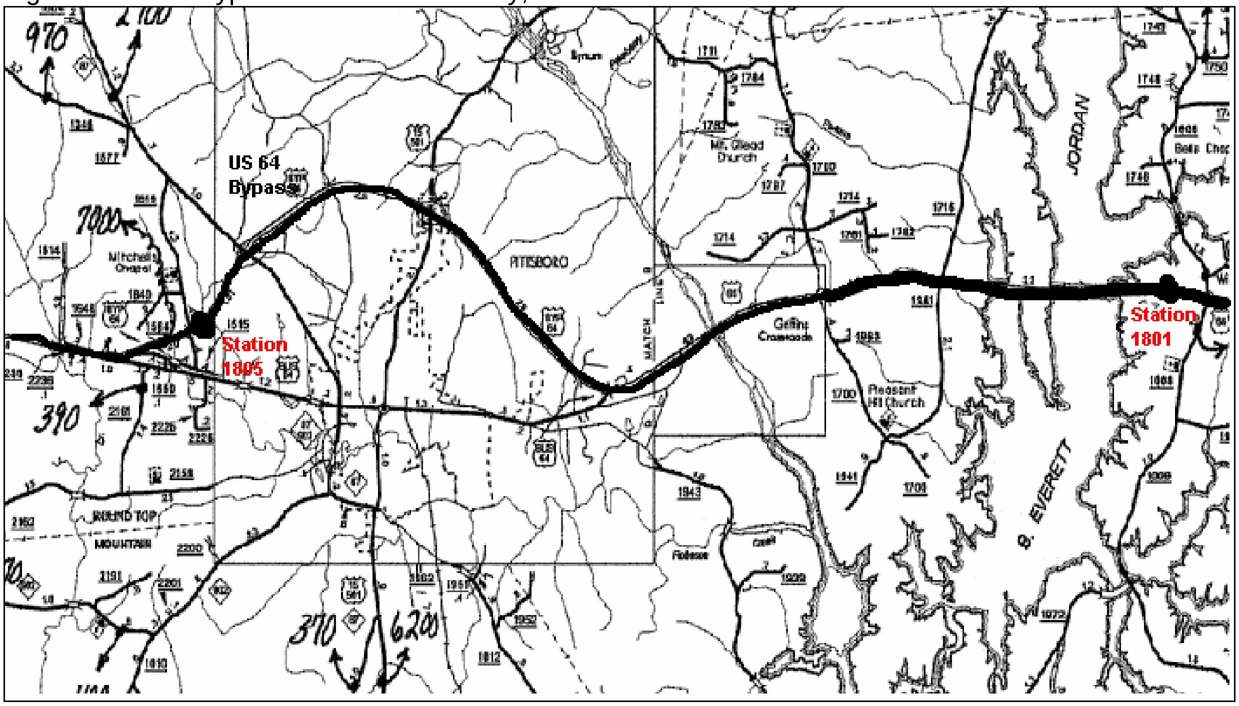
Source: www.mapquest.com

Visual scans edit Stations 1801 and 1805 and eliminate atypical days due to known holidays, weather, accidents, and other events. All averages, factors, and seasonal statistics calculated in the annualization of Station W1805, which does not have continuous traffic data, are based on typical days identified at Station 1801, which does have continuous data. These results from the MS Access queries are transferred to MS Excel to be applied to raw Station W1805 ADT data to get a factored and annualized estimate for AADT for the year of interest.

Creating Average Annual Daily Vehicle Traffic (AADVT) Factors and Seasonality Ratios

1. The MS Access tool uses the typical days identified from Station W1801 to compare and screen the 365 days of raw classification data of Station W1805 for the same time period. The results give good data days or typical days for Station W1805.

Figure 2: US 64 Bypass in Chatham County, NC



Source: http://www.ncdot.org/planning/statewide/gis/DataDist/GISTrafSurvMaps.html

2. The typical days of Station W1805 are averaged and summed with queries created in MS Access by Kent Taylor (NCDOT Traffic Surveys Unit). A sample of the formulas used in the MS Access queries can be seen in Attachment A. Results from the program include:
   - Average Day of Week Vehicle Traffic by Month (ADWVT): For the FHWA 13 vehicle classifications, the average volume is calculated for each day of the week (Sunday – Saturday; 1-7) and for each of the twelve months. Also, the 13 FHWA classes are summed into passenger vehicles, Duals, and TTSTs to represent the NCDOT classification scheme that is typically used for traffic forecasting and design at NCDOT. This results in 84 values for the year (seven daily factors for each of the 12 months)(Attachment B, Table 1). The results show Average Day of the Week Vehicle Traffic by Month (ADWVT). Months 1 and 2 for are shown below.
   - Average Annual Day of Week Vehicle Traffic (AADWVT): The FHWA and NCDOT vehicle class volumes for each day of the week for the entire year are calculated. This results in seven values. Also, the percent of passenger vehicles, Duals, and TTSTs are calculated for the total AADWVT.(Tables 2 and 3).
   - Average Annual Daily Vehicle Traffic (AADVT): AADVT are the average FHWA and NC DOT vehicle class volumes representing a typical day in that year. This results in a single value. Also, the percent of passenger vehicles, Duals, and TTSTs are calculated for the total AADVT. (Tables 4 and 5).

3. From these tables and further execution of another MS Access query, class factors are developed. The factors are calculated for both the FHWA 13-vehicle classification scheme and for the NC DOT vehicle classification scheme (passenger vehicles, Duals, and TTSTs).
   - Factors for each day of the week and for each month are created. The factors are the ratio of AADVT to ADWVT. See Attachment C, Table 1: Factors. See the following table, Table 4: Factors for Months 1 and 2 for a sample of the Factors table in Appendix C. A large factor represents a low volume of traffic for that day of week for that month.

4. The ADWVT, AADWVT, AADVT, and factor tables created in MS Access are transferred to MS Excel for further analysis. The analysis includes:
   - A graph of the Average Day of Week Vehicle Traffic (ADWVT) for each month-day of week. (Attachment D, Figure 1) for W1805 on US 64 Bypass East of US64 Business.
   - A table of the seasonal variability of vehicle traffic on US 64 at Station W 1805 for both the FHWA 13-vehicle classification scheme and for the NCDOT vehicle classification scheme (passenger vehicles, Duals, and TTSTs). (Attachment E, Table 1) Note that the: Seasonal Ratios are based on seasonality which is defined as the ratio of ADWVT to AADVT. These ratios are the inverse of the factors calculated for Station W1805. A large ratio represents a high volume of traffic for that day of week during that month.
   - A graph of the seasonality ratios for the 13 FHWA vehicle classes and for the NC DOT classes(Attachment E, Figure 1 and 2) for W1805, US 64 Bypass East of US 64 Business
   - Iterative checks of the ADWVT and seasonality graphs to look for outlying data.

Table 1: Average Day of Week Vehicle Traffic by Month (ADWVT) for Months 1 and 2

Station	Month	DOW	MD	FHWA Class ADWVT													NCDOT Class ADWVT			Total
				C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	Pass Veh	Duals	TTST	
371805	1	1	11	6	4867	760	8	84	8	0	3	116	0	2	4	0	5633	100	125	5858
371805	1	2	12	22	5002	1146	38	325	74	2	46	592	4	6	7	6	6170	439	661	7270
371805	1	3	13	20	5078	1187	61	309	74	2	52	586	13	4	9	3	6285	446	667	7398
371805	1	4	14	18	5089	1183	57	311	85	1	64	614	10	6	6	3	6290	454	703	7447
371805	1	5	15	18	5172	1220	60	296	68	1	62	621	11	4	8	2	6410	425	708	7543
371805	1	6	16	20	6757	1445	56	306	68	2	53	549	8	6	4	4	8222	432	624	9278
371805	1	7	17	4	4414	822	12	105	17	1	6	145	4	1	2	0	5240	135	158	5533
371805	2	1	21	28	5453	842	12	104	8	0	6	102	0	1	4	0	6323	124	113	6560
371805	2	2	22	17	4989	1172	60	285	66	0	52	529	6	4	6	3	6178	411	600	7189
371805	2	3	23	14	4669	1087	60	296	58	1	46	569	12	6	9	4	5770	415	646	6831
371805	2	4	24	16	5146	1246	64	321	67	1	56	588	10	4	8	5	6408	453	671	7532
371805	2	5	25	21	5085	1211	72	310	53	3	62	563	10	7	7	2	6317	438	651	7406
371805	2	6	26	33	7261	1544	68	339	67	3	52	530	9	5	6	3	8838	477	605	9920
371805	2	7	27	15	5614	982	25	141	15	0	8	136	3	1	1	0	6611	181	149	6941

Table 2: Average Annual Day of Week Vehicle Traffic (AADWVT)

Station	DOW	MD	FHWA Class ADWVT													NCDOT Class ADWVT			Total
			C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	Pass Veh	Duals	TTST	
371805	1	131	56	6653	1047	13	114	8	0	15	95	1	1	3	0	7756	135	115	8006
371805	2	132	25	5335	1251	56	293	68	2	56	585	10	5	7	3	6611	419	666	7696
371805	3	133	27	5414	1256	65	314	69	3	60	602	12	5	7	3	6697	451	689	7837
371805	4	134	27	5485	1270	74	311	73	2	63	614	11	4	7	3	6782	460	702	7944
371805	5	135	29	5763	1334	72	321	70	3	67	610	12	5	6	3	7126	466	703	8295
371805	6	136	40	7632	1593	67	320	65	2	61	557	11	5	4	2	9265	454	640	10359
371805	7	137	33	6600	1200	21	156	18	1	17	136	3	1	2	1	7833	196	160	8189

Table 3: NCDOT Class % Average Annual Day of Week Vehicle Traffic (AADWVT)

NCDOT Class %AADWVT		
Pass Veh	Duals	TTST
96.9%	1.7%	1.4%
85.9%	5.4%	8.7%
85.5%	5.8%	8.8%
85.4%	5.8%	8.8%
85.9%	5.6%	8.5%
89.4%	4.4%	6.2%
95.7%	2.4%	2.0%

Table 4: Annual Average Daily Vehicle Traffic (AADVT)

Station	DOW	MD	FHWA Class ADWVT													NCDOT Class ADWVT			Total
			C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	Pass Veh	Duals	TTST	
371805	NA	NA	34	6126	1279	53	261	53	2	48	457	8	4	5	2	7439	369	524	8332

Table 5: NCDOT Class % Average Annual Daily Vehicle Traffic (AADVT)

NCDOT Class %AAWVT		
Pass Veh	Duals	TTST
89.3%	4.4%	6.3%

Table 6: Factors for Months 1 and 2

Station	Month	DOW	FHWA Class Factors													NCDOT Class Factors			Total
			C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	Pass Veh	Duals	TTST	
371805	1	1	5.67	1.26	1.68	6.62	3.11	6.62	1	16	3.94	1	2	1.25	1	1.32	3.69	4.19	1.42
371805	1	2	1.55	1.22	1.12	1.39	0.80	0.72	1	1.04	0.77	2	0.67	0.71	0.33	1.21	0.84	0.79	1.15
371805	1	3	1.70	1.21	1.08	0.87	0.84	0.72	1	0.92	0.78	0.62	1.00	0.56	0.67	1.18	0.83	0.79	1.13
371805	1	4	1.89	1.20	1.08	0.93	0.84	0.62	2	0.75	0.74	0.80	0.67	0.83	0.67	1.18	0.81	0.75	1.12
371805	1	5	1.89	1.18	1.05	0.88	0.88	0.78	2	0.77	0.74	0.73	1	0.62	1	1.16	0.87	0.74	1.10
371805	1	6	1.70	0.91	0.89	0.95	0.85	0.78	1	0.91	0.83	1	0.67	1.25	0.50	0.90	0.85	0.84	0.90
371805	1	7	8.50	1.39	1.56	4.42	2.49	3.12	2	8.00	3.15	2	4	2.50	1	1.42	2.73	3.32	1.51
371805	2	1	1.21	1.12	1.52	4.42	2.51	6.62	1	8.00	4.48	1	4	1.25	1	1.18	2.98	4.64	1.27
371805	2	2	2.00	1.23	1.09	0.88	0.92	0.80	1	0.92	0.86	1.33	1	0.83	0.67	1.20	0.90	0.87	1.16
371805	2	3	2.43	1.31	1.18	0.88	0.88	0.91	2	1.04	0.80	0.67	0.67	0.56	0.50	1.29	0.89	0.81	1.22
371805	2	4	2.12	1.19	1.03	0.83	0.81	0.79	2	0.86	0.78	0.80	1	0.62	0.40	1.16	0.81	0.78	1.11
371805	2	5	1.62	1.20	1.06	0.74	0.84	1.00	0.67	0.77	0.81	0.80	0.57	0.71	1	1.18	0.84	0.80	1.13
371805	2	6	1.03	0.84	0.83	0.78	0.77	0.79	0.67	0.92	0.86	0.89	0.80	0.83	0.67	0.84	0.77	0.87	0.84
371805	2	7	2.27	1.09	1.30	2.12	1.85	3.53	1	6.00	3.36	2.67	4	5.00	1	1.13	2.04	3.52	1.20

Creating Average Annual Daily Vehicle Traffic (AADVT)

Once the factors and seasonality ratios are checked and confirmed, the factors are applied to all available vehicle class data sets.

The data sets include partial data sets from continuous counts, short-term counts, and turning movement counts. To obtain the data sets, it is first necessary to identify all the station locations and ID numbers as well as special projects completed in the study area. All continuous count and short-term count station identifications and special project identifications are located on databases in the NCDOT Traffic Survey Unit network. Turning movement identifications from year 2000 and previous years are located on a NCDOT Traffic Survey Unit database, but the turning movement identifications after year 2000 must be looked-up from a hard copy binder located in the NCDOT Traffic Survey Unit office.

Once the data sets are identified, then the data sets must be retrieved. The turning movement count data sets are available in electronic format but continuous count data, short-term count data, and special project data are only available in paper copy. Thus, using the station ID numbers and the special project ID numbers, one must search through files located at the NCDOT archive room and at the NCDOT Traffic Survey Unit office.

Using Continuous Count Partial Data Sets

Continuous count stations include Weigh-in-Motion (WIM) stations, Long-Term Pavement Performance (LTPP) stations, and Automatic Traffic Recording (ATR) stations. All the stations collect total ADT for each year, but for this study only the stations which collect ADT for each of the thirteen vehicle classes each year are used and factored. A complete year of ADT data can be averaged directly without editing out atypical days and factoring???? to determine AADT. If the station fails to collect a complete year of data, then the data is a partial data set and must be edited and factored to before calculating an annualized value of AADT for that year.

Not all continuous count stations have complete data sets for each year. Sometimes continuous count stations are temporarily out of service due to equipment failure, repairs, and/or calibration. In the case of partial data sets, the factors are applied to data on two typical days out of the set. The vehicle class two-way volume totals (all lanes and both directions combined) for each typical day are multiplied by the corresponding factors for that month and day of week. This results in two AADT volumes. Next, the AADT volumes are averaged to get the AADT for that year. See Table 5(7?): Conversion of ADT to AADVT for the data set of Station 1803 in year 2001.

Using Short-Term Vehicle Classification Data

Short-term vehicle classification count data are collected on typical days only, usually for special projects. If an atypical traffic pattern occurs during the count, the station is recounted. A minimum of 48 hours of data is collected at each station. The FHWA classification scheme is used to count hourly traffic totals for all 13 vehicle classes by direction and by lane.

Short-term vehicle classification counts from year 1987 to 2004are available for several locations on the US 64 corridor. . The data are not in electronic format, and the paper copies are not stored in the same location. All legacy station data and data up to year 1999 are stored at the NCDOT archive room. Data from the year 2000 to 2004 are stored at the NCDOT Traffic Survey Unit office in various locations.

Short-term count data are treated like continuous count data to obtain AADT. The vehicle two-way totals (all lanes and both directions combined) for each 24-hour count are multiplied by the corresponding factors for that specific month and day of week. If only 24 hours of data exist for that year at that station, then the total vehicle classification volumes are directly multiplied by the corresponding factors. This results in the Average Annual Daily Vehicle Traffic (AADVT) for the station for that year. Where there are 48 hours of vehicle classification data, each daily vehicle total is multiplied by its corresponding factors. Then, the AADVTs for both days are averaged to get the AADVT for that year at that station. An example of this procedure can be seen in Table 5.

Table 7: Conversion of ADT to AADVT for the Dataset of Station 1803 in year 2001

Sta.	Date	Dr	Ln	Month	DOW	MC	Cars	2A-4T	Bus	2A-SU	3A-SU	4A-SU	4A-ST	5A-ST	6A-ST	5A-MT	6A-MT	7A-MT	Total
1803	8/6/01	7	1	8	2	59	2464	591	25	157	90	1	72	270	1	3	1	0	3734
1803	8/6/01	7	2	8	2	7	687	146	7	26	6	0	12	21	0	0	0	0	912
1803	8/6/01	3	1	8	2	30	2562	594	32	142	64	0	104	225	4	2	2	1	3762
1803	8/6/01	3	2	8	2	5	680	134	3	27	5	1	16	16	0	1	1	0	889
1803	8/6/01	Total		8	2	101	6393	1465	67	352	165	2	204	532	5	6	4	1	9297
		Factors		8	2	1.26	1.1	1.02	1	0.9	0.95	1	0.87	0.77	1.6	0.67	0.83	1	1.05
1803	Day 1	AADVT				127	7032	1494	67	317	157	2	177	410	8	4	3	1	9800
1803	8/7/01	7	1	8	3	44	2676	613	25	172	74	2	68	256	6	8	5	0	3949
1803	8/7/01	7	2	8	3	6	638	145	7	31	7	0	13	33	0	0	0	0	880
1803	8/7/01	3	1	8	3	45	2627	583	24	171	67	0	94	225	4	2	1	0	3843
1803	8/7/01	3	2	8	3	3	632	147	6	38	8	0	19	24	1	0	0	0	878
1803	8/7/01	Total		8	3	98	6573	1488	62	412	156	2	194	538	11	10	6	0	9550
		Factors		8	3	1.31	1.09	1.02	0.87	0.85	0.91	0.4	0.77	0.78	1.6	0.8	1	0.5	1.04
1803	Day 2	AADVT				128	7165	1518	54	350	142	1	149	420	18	8	6	0	9958
1803	Avg	2001 AADVT				128	7098	1506	60	334	149	1	163	415	13	6	5	1	9879

Using Turning Movement Counts

Turning movement data are used to supplement the continuous count data and short-term count data. Because some sections of US 64 have less than two years of vehicle count data, turning movement counts from various special projects are used to obtain enough data for trend analysis. Turning movement count data are collected at intersections on typical days only. If an incomplete count is taken, the intersection is recounted. The counts are collected in 15-minute time intervals for two eight-hour shifts. The two eight-hour counts are usually taken on different days of the week and at different times of the day. The two eight-hour counts are then projected to a 24-hour count to give ADT. One leg of the intersection includes a special NCDOT classification count along US 64 to exhibit influences natural to the intersection. The classification counts designate Duals, TTSTs, Twins and total trucks from total traffic. For this project, TTSTs and Twins are combined under the TTST classification. The eight-hour shift truck counts are projected to ADT as well.

Turning movements for the year 2000 and previous years are found from the Turning Movement Database located on the NCDOT Traffic Survey Unit network. Turning movements from year 2001 to the 2004 are not available in the Database and must be accessed from a separate location only available in hard copy format. For each turning movement count, the factors corresponding to the month and day of week with which each eight-hour count was taken are averaged. The average of the two factor sets is multiplied by the projected 24-hour total vehicle classification counts. The product is the average annual daily vehicle traffic (AADVT) for that station at that year (Table 8):

Table 8: AADT for Turning Movement Station 142 in year 1996 in Chatham County

Day	Date	Month	DOW	Pass. Veh.	Duals	TTST	
Day 1 Factors	4/23/1996	4	3	1.1	0.82	0.77	
Day 2 Factors	4/24/1996	4	4	0.99	0.77	0.79	
Average Factors				1.045	0.795	0.78	Total
Average Daily vehicle Traffic				6534	359	740	7633
1996 AADVT				6828	285	577	7691

Using Special Project Data Sets

Special projects or case studies involving the US 64 corridor are evaluated as well. The special projects provide additional vehicle classification counts at different locations on different years. Special project data includes additional short-term counts and turning movement counts. The projects must be identified on the NCDOT Traffic Survey Unit network or on the hard copy binder listing and then pulled from files in the NCDOT achieve room. The short-term counts and turning movement counts from special projects are treated like the other counts. The factors are applied to the ADT data to obtain AADT. Unfortunately, no NCDOT projects undertaken by the Traffic Survey Unit are applicable to the US 64 study.

Results

Grouping Stations / Sectioning the US 64 Corridor

The continuous count stations, short-term count stations, and the turning movement stations are combined and grouped into segments along the US64 corridor between I-85 in Davidson County and US 1 in Wake County. The segments are based on traffic volumes and traffic characteristics specific to that area. Also, land use, population, and other routes/bypasses are considered in the development of the segments along US 64. Nine segments along the US 64 corridor are developed for this project and each segment has a range of annualized AADT values suitable for forecasting.

Turning Movement Request for Data

Each station grouping or segment of the US 64 corridor is evaluated to determine if sufficient data are available for forecasting. If a segment lacks a sufficient range of data years for trend analysis, then requests for turning movement data are made. Nine requests for data were made for the US 64 case study to obtain 2004 classification turning movement counts. Each request included a sketch of the intersection, the approach for which the truck count is to be taken, an intersection description, and a map of the area. A sample of the US 64 request for data in Randolph County can be seen in Attachment F. After four to six weeks the turning movement count data was available to factor and add to the MS Excel spreadsheet to use for forecasting.

Forecasting

For each of the nine segments along US 64, there is a suitable range of AADT vehicle class data. This data is in proper format to use in various forecasting techniques such as trend analysis, regression analysis, or growth factor method. Along with the AADT data used in forecasting, the forecaster can determine the "development capacity" or economic opportunity for the city, county or region that the highway serves and if there is significant long term traffic growth potential or other capacity constraints like narrow bridges, no bypass, etc.

Conclusions and Recommendations

Annualizing vehicle classification data is an iterative process. It requires a continuous check of the MS Access queries as well as the factors, graphs, and ratios in MS Excel. The US 64 corridor required three main data sources: continuous monitoring counts, short-term counts, and turning movement counts. Not every corridor will have all three data resources available and some corridors may have other data resources useful such as special projects.

Several recommendations to consider with the annualization process include:

- Put all traffic data in electronic format. An on-line GIS file with station identifications, count data, and previous forecasts would facilitate the data gathering process.
- Develop a "toolbox" of data references where data resources and methodology can be selected for each project and different type of corridor.
- Consider developing a range of AADT values depending on the sensitivity analysis of the factors. The potential variation of AADT values for a given year may need to be considered and may need to include a standard deviation or a maximum/minimum AADT value for that year at that station.

- Calculate average monthly daily vehicle traffic (AMDVT) along with AADT to view the highest expected traffic during the year instead of the average traffic during the year. Then, the variation of AMDVT can be viewed month to month as well as in the seasonality ratios and graphs.
- Compare population and economic growth to general traffic growth determined from the annualized AADVT values to verify forecasts.

APPENDIX C: LINEAR REGRESSION MODELS

Using the VTRIS database, a linear regression model is created for each facility type. NCDOT usually applies linear model for forecasts on high volume roads like Interstates and an exponential model for low volume roads.

Linear Equation

$\text{Cars}_{\text{Future Year}} = \text{Cars}_{\text{Base Yr}} + \text{Parameter estimate for Cars x (YYYY)}$

$\text{Duals}_{\text{Future Year}} = \text{Duals}_{\text{Base Yr}} + \text{Parameter estimate for Duals x (YYYY)}$

$\text{TTST}_{\text{Future Year}} = \text{TTST}_{\text{Base Yr}} + \text{Parameter estimate for TTST x (YYYY)}$

$\text{AADT}_{\text{Future Year}} = \text{Cars}_{\text{Base Yr}} + \text{Duals}_{\text{Base Yr}} + \text{TTST}_{\text{Base Yr}}$

Comparision of Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
Historic Growth Rate	78477	18551	56821	153848	16.07%	49.22%
AGF Method	64666	3254	16813	84733	3.84%	19.84%
Linear Regression Method	78606	3470	13580	95656	3.63%	14.20%

Parameter Estimate for Linear Model			
	Cars	Duals	TTST
Linear Regression	0.74	2.74	15.67

Simple Linear Regression for Duals on Interstate Facilities

```
The SAS System 00:50 Tuesday, April 5, 2005   1

                                  Obs      t     count

                                    1    1998     1010
                                    2    1999      996
                                    3    1998     1948
                                    4    1999     1782
                                    5    2000     1938
                                    6    2001     1766
                                    7    2003     2436
                                    8    2004     2284
                                    9    1998     1084
                                   10    1999      896
                                   11    2000     1504
                                   12    2001      978
                                   13    2003     1141
                                   14    2004     1172
                                   15    1997     1152
                                   16    1998     1582
                                   17    1999     1112
                                   18    2000     1344
                                   19    2001     1160
                                   20    2002     1232
                                   21    2003     1234
                                   22    1998     1548
                                   23    1999     1380
                                   24    2000     1402
                                   25    2001     1388
                                   26    2003     1627
                                   27    2004     1613
                                   28    2001     2750
                                   29    2002     2958
```

30	2003	2912
31	2000	717
32	2001	698
33	2002	815
34	2003	825
35	2004	826
36	1998	992
37	1999	1186
38	2000	1190
39	2001	1144
40	2002	1390
41	2003	1372
42	2001	1352
43	2002	1466
44	2003	1353
45	2003	1192
46	2004	1114
47	2003	2577
48	2004	2413
49	2003	1611
50	2004	1501
51	2000	865
52	2001	829
53	2002	923
54	2000	2069
55	2001	1947
56	2002	2265
57	2003	1950
58	2001	676
59	2002	726
60	2001	2696
61	2002	2711

The SAS System 00:50 Tuesday, April 5, 2005 3

The REG Procedure
Model: MODEL1
Dependent Variable: count

NOTE: No intercept in model. R-Square is redefined.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	134942201	134942201	366.97	<.0001
Error	60	22063405	367723		
Uncorrected Total	61	157005606			

Root MSE	606.40203	R-Square	0.8595
Dependent Mean	1487.21311	Adj R-Sq	0.8571
Coeff Var	40.77439		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
t	1	0.74322	0.03880	19.16	<.0001

Volume of Duals in year ‘t’ = Volume of Duals in Base year + Parameter Estimate x ‘t’

Simple Linear Regression for TTSTs on Interstate Facilities

```
The SAS System         01:21 Tuesday, April 5, 2005   1
```

Obs	t	count
1	1998	6312
2	1999	6282
3	1998	4394
4	1999	5304
5	2000	5322
6	2001	3646
7	2003	4666
8	2004	4740
9	1998	5928
10	1999	6692
11	2000	7126
12	2001	5936
13	2003	6284
14	2004	5988
15	1997	5268
16	1998	5476
17	1999	6150
18	2000	7164
19	2001	5812
20	2002	5988
21	2003	5706
22	1998	4628
23	1999	4998
24	2000	5006
25	2001	4348
26	2003	4367
27	2004	4498
28	2001	3840
29	2002	4350
30	2003	3782
31	2000	3779
32	2001	3478
33	2002	4258
34	2003	4088
35	2004	4222
36	1998	4802
37	1999	5668
38	2000	6202
39	2001	5822
40	2002	6126
41	2003	5624
42	2001	5294
43	2002	5872
44	2003	4383
45	2001	915
46	2004	1062
47	2003	528
48	2004	514
49	2003	6738
50	2004	6698
51	2003	4850
52	2004	4789
53	2000	7880
54	2001	6726
55	2002	7662
56	2000	11300
57	2001	10071
58	2002	10498
59	2003	9384
60	2001	6533
61	2002	7441
62	2001	4390
63	2002	4845
64	2001	6625
65	2002	7292

```
The SAS System         01:21 Tuesday, April 5, 2005   3

                       The REG Procedure
                         Model: MODEL1
                   Dependent Variable: count
```

NOTE: No intercept in model. R-Square is redefined.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	1953483303	1953483303	490.11	<.0001
Error	64	255093075	3985829		
Uncorrected Total	65	2208576378			

Root MSE	1996.45418	R-Square	0.8845
Dependent Mean	5482.46154	Adj R-Sq	0.8827
Coeff Var	36.41529		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
t	1	2.73935	0.12374	22.14	<.0001

Volume of TTST in year 't' = Volume of TTST in Base year + Parameter Estimate x 't'

Simple Linear Regression for Cars on Interstate Facilities

The SAS System 01:21 Tuesday, April 5, 2005 4

Obs	t	count
1	1998	15770
2	1999	14804
3	1998	33882
4	1999	37170
5	2000	27438
6	2001	24288
7	2003	48108
8	2004	42990
9	1998	17664
10	1999	15030
11	2000	18946
12	2001	15074
13	2003	17207
14	2004	15454
15	1997	16984
16	1998	30296
17	1999	22134
18	2000	24182
19	2001	21876
20	2002	26670
21	2003	24216
22	1998	32742
23	1999	29308
24	2000	32608
25	2001	32624
26	2003	39610
27	2004	35293
28	2001	68912
29	2002	75684
30	2003	70638
31	2000	17897
32	2001	18499
33	2002	17113
34	2003	18129
35	2004	13597
36	1998	24768
37	1999	23628
38	2000	19244
39	2001	21634
40	2002	23738
41	2003	26502
42	2001	72892
43	2002	78352

44	2003	67818
45	2001	18156
46	2004	22768
47	2003	50326
48	2004	47843
49	2003	46886
50	2004	43788
51	2003	40299
52	2004	36750
53	2000	14517
54	2001	16017
55	2002	15952
56	2000	29761
57	2001	27002
58	2002	30984
59	2003	30275
60	2001	23124
61	2002	23098
62	2001	16120
63	2002	16159
64	2001	59551
65	2002	56864

The SAS System 01:21 Tuesday, April 5, 2005 6

The REG Procedure
Model: MODEL1
Dependent Variable: count

NOTE: No intercept in model. R-Square is redefined.

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	63896012994	63896012994	217.50	<.0001
Error	64	18801328837	293770763		
Uncorrected Total	65	82697341831			

Root MSE	17140	R-Square	0.7726
Dependent Mean	31349	Adj R-Sq	0.7691
Coeff Var	54.67483		

Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
t	1	15.66677	1.06230	14.75	<.0001

Volume of Cars in year ‘t’ = Volume of Car in Base year + Parameter Estimate x ‘t’

APPENDIX D: T-TEST FOR NC INTERSTATES

Hypothesis Testing for Interstate Routes

To determine if the growth of trucks is more than general traffic, the analyzed data from VTRIS is used to perform a one sided paired t-test is performed. Using the t-test on the data, the effect of truck growth relative to general traffic can be determined.

Assumptions:

We assume the populations are normally distributed.
Samples are dependent

Null Hypothesis - Null Hypothesis states that there is no difference in the growth factors between trucks and total traffic.
H_0: Null Hypothesis $\mu_1 - \mu_2 = 0$

Alternate Hypothesis -Alternate Hypothesis states that the truck growth factor is greater than normal traffic.
H1: Alternate Hypothesis $\mu_1 - \mu_2 > 0$
where
μ_1 Mean growth factor for truck traffic
μ_2 Mean growth factor for general traffic

A one-sided t-test is conducted using SAS program at 95 % confidence level to determine the statistical significance of the test. SAS gives p-value for two-sided test, therefore for one-sided t-test; p-value should be divided by two.

SAS program for paired T-Test to compare the mean growth rates of trucks and cars for NC Interstates

```
data Class;
input TruckGF CarGF;
Diff=TruckGF-CarGF;
Datalines;
1.94  10.64
-5.71 -2.98
0.44  -2.48
0.65  2.09
-0.51 0.13
4.27  2.13
-0.60 -6.13
0.01  4.96
2.75  -5.80
-5.03 1.06
7.32  -4.51
17.06 -0.11
9.76  8.47
9.97  0.24
-0.51 0.13
-5.35 -4.93
-2.19 -6.61
-2.65 -8.81
```

```
;
run;
proc print data=Class;
run;
proc means data=Class mean std t prt;
var Diff;
proc ttest data=Class;
paired TruckGF*CarGF;
run;
```

Output

```
          The SAS System        17:23 Monday, December 13, 2004  22
```

Obs	Truck GF	CarGF	Diff
1	1.94	10.64	-8.70
2	-5.71	-2.98	-2.73
3	0.44	-2.48	2.92
4	0.65	2.09	-1.44
5	-0.51	0.13	-0.64
6	4.27	2.13	2.14
7	-0.60	-6.13	5.53
8	0.01	4.96	-4.95
9	2.75	-5.80	8.55
10	-5.03	1.06	-6.09
11	7.32	-4.51	11.83
12	17.06	-0.11	17.17
13	9.76	8.47	1.29
14	9.97	0.24	9.73
15	-0.51	0.13	-0.64
16	-5.35	-4.93	-0.42
17	-2.19	-6.61	4.42
18	-2.65	-8.81	6.16

The TTEST Procedure

Statistics

Difference	N	Lower CL Mean	Mean	Upper CL Mean	Lower CL Std Dev	Std Dev	Upper CL Std Dev	Std Err
TruckGF - CarGF	18	-0.84	2.4517	5.7436	4.9674	6.6198	9.9241	1.5603

T-Tests

Difference	DF	t Value	Pr > |t|
TruckGF - CarGF	17	1.57	0.1345

Results

From the t-test using normal approximation, the p- value for the one sided test is found to be 0.06 which is greater than 0.05, therefore we do not reject the null hypothesis and conclude that we do not have enough evidence to conclude that trucks growth rates are higher than general traffic growth rates. Since the p-value obtained from the t-test is very close to 0.05, a bigger sample size could prove better to confirm the test results.

APPENDIX E: T-TEST FOR NC ARTERIALS

Hypothesis Testing for Arterials Routes

To determine if the growth of trucks is more than general traffic, the analyzed data from VTRIS is used to perform a one sided paired t-test is performed. Using the t-test on the data, the effect of truck growth relative to general traffic can be determined.

Assumptions:

We assume the populations are normally distributed.
Samples are dependent

Null Hypothesis - Null Hypothesis states that there is no difference in the growth factors between trucks and total traffic.
H_0: Null Hypothesis $\mu_1 - \mu_2 = 0$

Alternate Hypothesis -Alternate Hypothesis states that the truck growth factor is greater than normal traffic.
H1: Alternate Hypothesis $\mu_1 - \mu_2 > 0$
Where
μ_1 Mean growth factor for truck traffic
μ_2 Mean growth factor for general traffic

A one-sided t-test is conducted using SAS program at 95 % confidence level to determine the statistical significance of the test.

SAS gives p-value for two-sided test, therefore for one-sided t-test, p-value should be divided by two.

SAS program for paired T-Test to compare the mean growth rates of trucks and cars for Arterials

```
data Class;
input TruckGF CarGF;
Diff=TruckGF-CarGF;
Datalines;
15.83 7.43
10.03 3.12
11.61 3.57
-0.74 -3.74
7.09  -7.85
3.56  2.19
-3.36 -0.49
-2.88 3.54
4.73  5.94
1.45  2.46
-7.10 -7.50
17.08 3.89
1.52  3.81
-5.55 1.65
-4.43 -4.40
-4.07 4.32
5.01  4.84
```

```
2.71  1.75
2.19  4.99
5.94  6.85
1.52  5.75
-4.24 2.33
-8.97 -0.82
9.56  2.37
-2.55 -3.66
-6.14 -3.95
5.55  -2.70
;
run;
proc print data=Class;
run;
proc means data=Class mean std t prt;
var Diff;
proc ttest data=Class;
paired TruckGF*CarGF;
run;
```

Output

```
      The SAS System        17:23 Monday, December 13, 2004  13

                                   Truck
                          Obs         GF     CarGF       Diff

                            1      15.83      7.43       8.40
                            2      10.03      3.12       6.91
                            3      11.61      3.57       8.04
                            4      -0.74     -3.74       3.00
                            5       7.09     -7.85      14.94
                            6       3.56      2.19       1.37
                            7      -3.36     -0.49      -2.87
                            8      -2.88      3.54      -6.42
                            9       4.73      5.94      -1.21
                           10       1.45      2.46      -1.01
                           11      -7.10     -7.50       0.40
                           12      17.08      3.89      13.19
                           13       1.52      3.81      -2.29
                           14      -5.55      1.65      -7.20
                           15      -4.43     -4.40      -0.03
                           16      -4.07      4.32      -8.39
                           17       5.01      4.84       0.17
                           18       2.71      1.75       0.96
                           19       2.19      4.99      -2.80
                           20       5.94      6.85      -0.91
                           21       1.52      5.75      -4.23
                           22      -4.24      2.33      -6.57
                           23      -8.97     -0.82      -8.15
                           24       9.56      2.37       7.19
                           25      -2.55     -3.66       1.11
                           26      -6.14     -3.95      -2.19
                           27       5.55     -2.70       8.25

                             The TTEST Procedure

                                  Statistics

                           Lower CL     Upper CL  Lower CL          Upper CL
Difference          N       Mean    Mean      Mean   Std Dev  Std Dev   Std Dev  Std Err

TruckGF - CarGF     27     -1.749  0.7281    3.2049    4.9305   6.2608    8.5801   1.2049

                                   T-Tests

                          Difference              DF     t Value     Pr > |t|

                          TruckGF - CarGF         26        0.60       0.5509
```

Results

From the above output, SAS gives the p-value for two sided test, therefore half of the p-value is used for a one sided test. Using t-test assuming normal approximation, the p- value for the one sided test is found to be 0.2754 which is greater than 0.05, therefore we do not reject the null hypothesis and conclude that trucks growth rates are not higher than general traffic growth rates.

APPENDIX F: MULTIVARIABLE REGRESSION ANALYSIS

This analysis evaluates the effects of population, number of warehouses, and geographic region on interstate and arterial traffic.

The SAS System 00:12 Thursday, December 16, 2004 49

Obs	TYPE	% DUALS	Population	Warehouse	Region
1	Arterial	4.67	LOW	26	2
2	Interstate	4.90	LOW	131	3
3	Interstate	3.75	LOW	131	3
4	Interstate	2.27	LOW	131	3
5	Interstate	3.47	LOW	35	3
6	Arterial	2.86	LOW	4	1
7	Arterial	2.89	LOW	4	1
8	Arterial	3.67	MODERATE	125	2
9	Arterial	4.58	LOW	23	2
10	Arterial	5.14	LOW	23	2
11	Arterial	5.73	LOW	23	2
12	Arterial	2.88	LOW	7	3
13	Arterial	4.05	LOW	7	3
14	Arterial	4.15	LOW	3	3
15	Interstate	4.91	LOW	46	3
16	Arterial	3.72	LOW	46	3
17	Arterial	4.06	LOW	50	1
18	Arterial	4.12	MODERATE	72	2
19	Arterial	4.17	MODERATE	72	2
20	Arterial	2.36	MODERATE	109	2
21	Arterial	2.16	MODERATE	109	2
22	Arterial	4.58	HIGH	174	2
23	Arterial	3.85	MODERATE	76	2
24	Arterial	5.60	HIGH	313	2
25	Interstate	3.67	LOW	32	3
26	Interstate	4.57	MODERATE	111	2
27	Arterial	3.93	LOW	13	3
28	Arterial	3.44	LOW	28	2
29	Arterial	3.33	LOW	18	3
30	Interstate	4.69	LOW	13	3
31	Interstate	3.98	HIGH	656	2
32	Arterial	4.04	LOW	11	3
33	Interstate	4.10	LOW	56	2
34	Interstate	4.02	LOW	56	2
35	Arterial	3.19	LOW	24	1
36	Interstate	3.10	LOW	22	1
37	Arterial	4.88	LOW	22	1
38	Arterial	7.44	MODERATE	70	1
39	Arterial	4.38	MODERATE	70	1
40	Interstate	3.59	LOW	5	3
41	Arterial	4.46	MODERATE	117	2
42	Interstate	4.19	MODERATE	71	2
43	Arterial	3.49	LOW	46	2
44	Arterial	3.51	LOW	46	2
45	Arterial	4.87	LOW	46	2
46	Arterial	5.51	LOW	26	2
47	Interstate	4.68	LOW	82	3
48	Interstate	4.44	LOW	82	3
49	Interstate	1.75	HIGH	399	2
50	Interstate	3.75	HIGH	399	2
51	Interstate	3.27	LOW	15	2

The SAS System 00:12 Thursday, December 16, 2004 50

The GLM Procedure

Class Level Information

Class	Levels	Values
TYPE	2	Arterial Interstate
Population	3	HIGH LOW MODERATE
Region	3	1 2 3

Number of observations 51

The GLM Procedure

Dependent Variable: GF

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1.35824110	0.22637352	0.21	0.9725
Error	44	47.89559419	1.08853623		
Corrected Total	50	49.25383529			

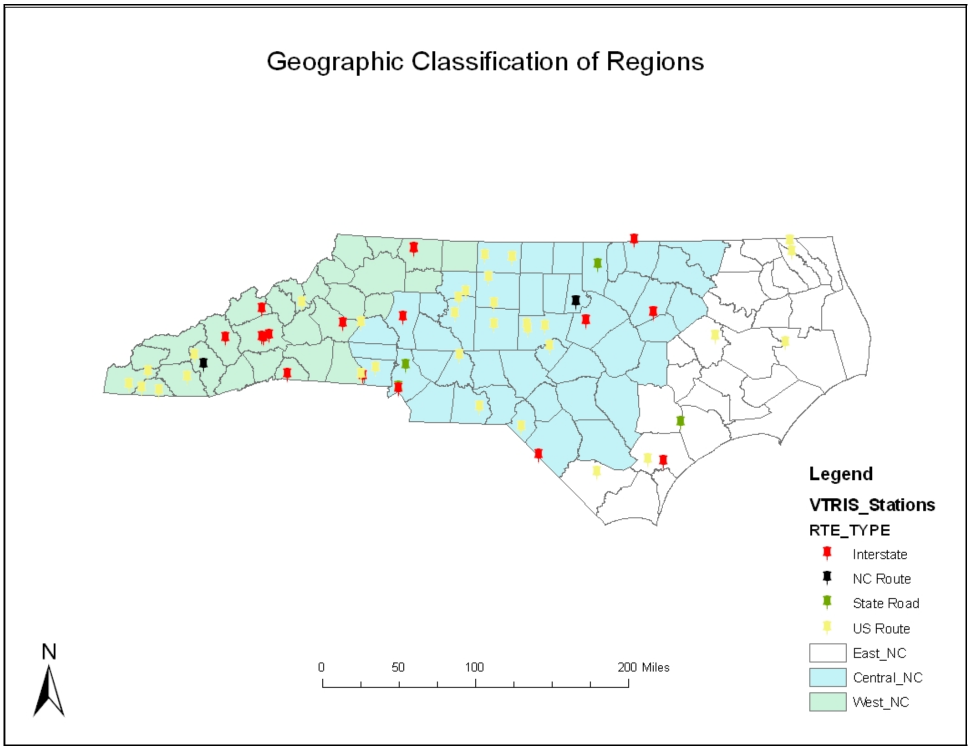
R-Square	Coeff Var	Root MSE	GF Mean
0.027576	25.98008	1.043329	4.015882

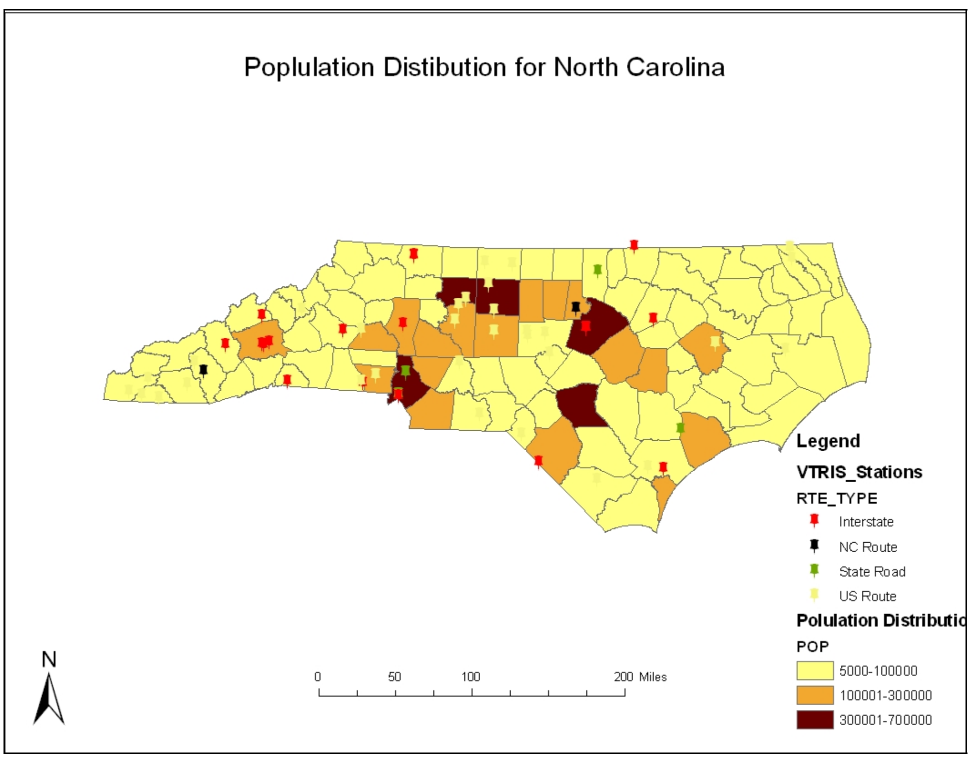
Source	DF	Type I SS	Mean Square	F Value	Pr > F
TYPE	1	0.85989500	0.85989500	0.79	0.3789
Population	2	0.04884820	0.02442410	0.02	0.9778
Warehouse	1	0.39187595	0.39187595	0.36	0.5516
Region	2	0.05762196	0.02881098	0.03	0.9739

Source	DF	Type III SS	Mean Square	F Value	Pr > F
TYPE	1	0.16921666	0.16921666	0.16	0.6953
Population	2	0.25713950	0.12856975	0.12	0.8889
Warehouse	1	0.40166263	0.40166263	0.37	0.5467
Region	2	0.05762196	0.02881098	0.03	0.9739

Parameter		Estimate		Standard Error	t Value	Pr > |t|
Intercept		4.076501628	B	0.62027298	6.57	<.0001
TYPE	Arterial	0.142717629	B	0.36197410	0.39	0.6953
TYPE	Interstate	0.000000000	B	.	.	.
Population	HIGH	0.367731947	B	0.96171268	0.38	0.7040
Population	LOW	-0.145918846	B	0.44049498	-0.33	0.7420
Population	MODERATE	0.000000000	B	.	.	.
Warehouse		-0.001701048		0.00280032	-0.61	0.5467
Region	1	0.064619412	B	0.48210248	0.13	0.8940
Region	2	0.091026027	B	0.39720938	0.23	0.8198
Region	3	0.000000000	B	.	.	.

NOTE: The X'X matrix has been found to be singular, and a generalized inverse was used to solve the normal equations. Terms whose estimates are followed by the letter 'B' are not uniquely estimable.


Geographic Classification of Regions
Legend
VTRIS_Stations
RTE_TYPE
Interstate
NC Route
State Road
US Route
East_NC
Central_NC
West_NC
N
0
50
100
200 Miles


Poplulation Distibution for North Carolina
Legend
VTRIS_Stations
RTE_TYPE
Interstate
NC Route
State Road
US Route
Polulation Distributio
POP
5000-100000
100001-300000
300001-700000
N
0
50
100
200 Miles

APPENDIX G: AVERAGE GROWTH FACTORS AND CONFIDENCE INTERVALS

Early Average Growth Factors and Confidence Intervals

With old VTRIS data (37 stations, 1997-2002), the confidence intervals for growth factors of Duals, TTST and ADT for each functional category are shown as below.

Route Type	Classified Traffic	Sample Size	Lower 95% CL Mean of AGF	Mean of AGF	Upper 95% CL Mean of AGF
Rural Principal Arterial Interstate	Duals	14	0.82%	6.27%	11.72%
	TTST	14	1.02%	4.65%	8.27%
	ADT	14	-1.70%	1.56%	4.79%
Rural Principal Arterial Other	Duals	23	-0.30%	4.82%	9.91%
	TTST	23	-0.70%	3.83%	8.38%
	ADT	23	1.97%	3.34%	4.72%

Updated Average Growth Factors and Confidence Intervals

<u>Introduction of the Dataset</u>

Old analysis of truck growth is based on old VTRIS data. Now, new VTRIS data is available, and the differences between the new data and old one include:

- New VTRIS Stations
  According to old VTRIS data, there are totally 14 stations for arterial interstate category, and 22 ones for arterial other category. The new data includes 19 stations for arterial interstate, and 27 ones for arterial other. Obviously, the sample size increases.

- Wider Time Span of Data
  Old VTRIS data is from 1997 to 2002, while new dataset range from 1997 to 2004.

Growth Factor Analysis

Based on the new VTRIS data, average growth factors are updated for each station. In order to calibrate the assumption that, for different route types, the average growth factors of classified traffic (Duals, TTST and ADT) follow normal distribution, a set of Q-Q plot analysis is conducted. Appendix B provides sets of tables and figures which summarize Q-Q plot analysis. In these figures, one plotted point represents the average growth factor for one VTRIS station.

The Q-Q plots show that the slopes are nearly linear except few abnormal observations, which indicate the assumption of the normal distribution is correct.

From the Q-Q plot, we can see there are four outliers for arterial interstate category, and one outlier for arterial other category. After removing these outliers, updated confidence intervals are developed as the Table 1 shows below.

Table 1. Confidence Intervals for Classified Traffic Growth Factor

Route Type	Classified Traffic	Sample Size	Lower 95% CL Mean of AGF	Mean of AGF	Upper 95% CL Mean of AGF
Rural Principal Arterial Interstate	Duals	16	-1.70%	0.79%	3.25%
	TTST	18	-0.80%	1.87%	4.56%
	ADT	19	-2.80%	-0.40%	2.06%
Rural Principal Arterial Other	Duals	27	-0.80%	3.34%	7.52%
	TTST	26	-0.30%	1.65%	3.66%
	ADT	27	-0.20%	1.41%	3.02%

Analysis of Outliers

From the Q-Q plots (Appendix H) it is clearly seen that truck (Duals & TTST) average growth factors follow the normal distribution pretty well on the arterial interstate and arterial other after accounting for a few outliers. Table 2 gives a summary of all growth factor outliers (highlighted cells). There are three outliers for Duals and one for TTST in the arterial interstate category; while only one outlier exists for TTST in the arterial other category.

Table 2. Summary of Outliers

Func. Class	SHRP#	ROUTE	COUNTY	LOCATION	NEAREST TOWN	#LANES	AGF Duals	AGF TTST	Years of Data
Arterial Interstate	377701	I-95	ROBESON	.4 MI. N. OF EXIT 1B	McDONAL D	2NB, 2SB	35.50%	13.90%	2001-2002
	377001	I-40	PENDER	.3 MI. WEST OF EXIT 408	ROCKY POINT	2EB, 2WB	14.77%	5.09%	2001, 2004
	375601	I-26	MADISON	.1 MI. WEST OF US 19	MARS HILL	2EB, 2WB	-17.05%	179.64%	2003-2004
Arterial Other	373816	NC147	DURHAM	.4 MI. NORTH OF SR 1940	DURHAM	2NB	9.95%	23.15%	2001-2004

All of these abnormal truck growth factors can be accounted for by data deficiency, socioeconomic contexts or physical characteristics of transportation facilities. In the past years, cases such as population, change of numbers of lanes, transportation construction, etc, may result in enormously varied truck growth at different locations.

For example, VTRIS station #377701, on I-95 in Robeson county, has average growth factors 35.50% and 13.90 for Duals and TTST, respectively. Both of them are fairly large, and the average growth factor of Duals is even an outlier in terms of the Q-Q plot.

After checking VTRIS dataset, we find that only two years' counts (2001 and 2002) are available for station #377701. The period of two years is obviously a fairly short term. Sudden significant changes of traffic volume, especially trucks, may occur during the course of so short time period, which, therefore, is not able to reflect a long-term traffic trend. The data deficiency can partly account for outliers.

We can also check the socioeconomic context of Robeson county at first. Table 3 provides the growth rate of population, vehicle registration and industry establishment for eight counties along I-95 in the past fifteen years. It indicates that Robeson county ranks comparatively high among the eight counties in terms of socioeconomic context.

Table 3. Socioeconomic Context Comparison of Counties

County along I-95	Growth Rate		
	Population	Auto & Truck Registration	Establishment of Industries
Cumberland	12%	21%	10%
Halifax	3%	9%	-5%
Harnet	46%	42%	15%
Johnston	68%	53%	31%
Nash	18%	18%	1%
Northampton	7%	10%	0%
Robeson	22%	18%	5%
Wilson	15%	13%	6%

In the sample of VTRIS stations we use for analysis, there are other two stations, #373011 and #376302, on I-95 besides the station #377701 mentioned above, and both of them are in Nash county. Table 4 compares the socioeconomic patterns and truck growth factors of these three VTRIS stations.

Table 4. Comparison of Three VTRIS Stations on I-95

Station	County	Growth Rate			AGF	
		Population	Vehicle Registration	Establishment of Industries	Duals	TTST
373011	Nash	18%	18%	1%	3.53%	2.03%
376302	Nash	18%	18%	1%	7.25%	3.67%
377701	Robeson	22%	18%	5%	35.50%	13.90%

Compared to Nash county, Robeson county has higher growth rates of population and new industries, which is able to partly explain the larger growth factors of Duals and TTST (especially Duals) on station #377701.

From the geographic point of view, we can find that I-95 serves as the only interstate gateway to South Carolina in the east-south area of NC. Most of the goods transported between east-northern states or eastern ports in North Carolina and South Carolina will focus on following I-95 through station #377701. Therefore, a large number of trucks and a pretty high truck growth rate will be expected at station #377701.

Taking into account new constructions, so many proposed or under-construction links such as I-74 and US-1 are forcing the segment of I-95 nearby station #377701 to be a more and more important shortcut. Although outliers are removed for developing the appropriate confidence interval of the truck growth factor, they will still stay in the VTRIS station set by which the station selection procedure is conducted. Filtering outlier aims to obtain a reasonable truck growth factor for a long-term forecasting, which doesn't conflict with matching two different locations by similar contexts in the growth factor ratio method. If a proposed project is located at somewhere with contexts similar to some outlier, its calculated growth factor will also be abnormal and can not be used directly for a long-term truck forecasting. The developed confidence interval will calibrate the raw truck growth factor for the long-term forecasting.

Appendix H: Q-Q Plots for Duals, TTSTs, and Cars

Table H-1. Q-Q Plot Analysis for Duals AGF on Rural Principal Arterial Interstate

Station (SHRP#)	AGF (Duals)	Order j	Probability Levels (j-0.5)/n	Strandard Normal Quantiles q(j)
375601	-17.05%	1	0.026	-1.938
371101	-6.83%	2	0.079	-1.412
371003	-6.54%	3	0.132	-1.119
374801	-6.36%	4	0.184	-0.899
379102	-1.56%	5	0.237	-0.716
378502	-1.39%	6	0.289	-0.555
372202	-1.16%	7	0.342	-0.407
371006	0.36%	8	0.395	-0.267
375902	0.56%	9	0.447	-0.132
371801	0.90%	10	0.500	0.000
375037	3.34%	11	0.553	0.132
373011	3.53%	12	0.605	0.267
374301	3.59%	13	0.658	0.407
377401	3.87%	14	0.711	0.555
375826	5.71%	15	0.763	0.716
376302	7.25%	16	0.816	0.899
379201	7.40%	17	0.868	1.119
377001	14.77%	18	0.921	1.412
377701	35.50%	19	0.974	1.938

Figure H-1. Q-Q Plot for Duals AGF on Rural Principal Arterial Interstate

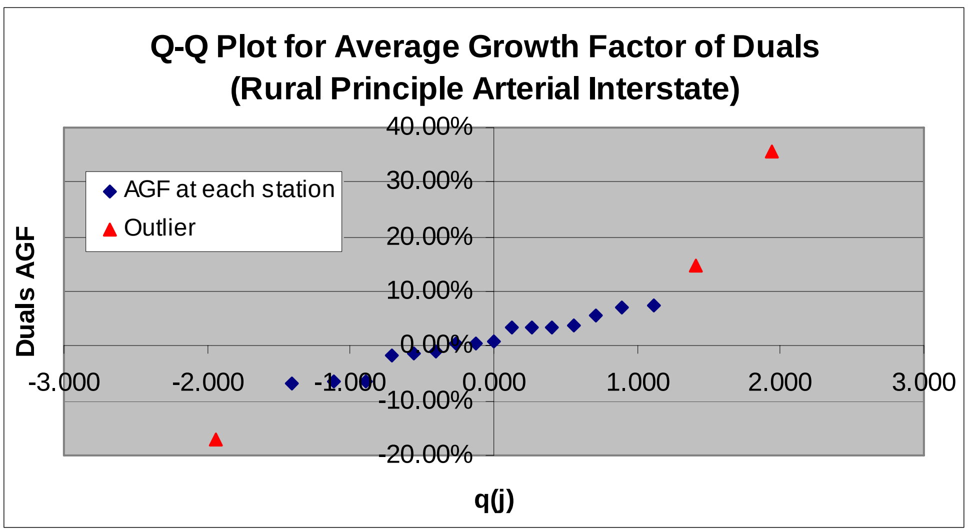


Table H-2. Q-Q Plot Analysis for TTST AGF on Rural Principal Arterial Interstate

Station (SHRP#)	AGF (TTST)	Order j	Probability Levels (j-0.5)/n	Strandard Normal Quantiles q(j)
371006	-7.22%	1	0.026	-1.938
372202	-5.75%	2	0.079	-1.412
371003	-2.65%	3	0.132	-1.119
371101	-1.26%	4	0.184	-0.899
374801	-0.59%	5	0.237	-0.716
378502	-0.48%	6	0.289	-0.555
374301	-0.36%	7	0.342	-0.407
371801	-0.26%	8	0.395	-0.267
379102	0.11%	9	0.447	-0.132
375826	0.62%	10	0.500	0.000
373011	2.03%	11	0.553	0.132
375037	2.90%	12	0.605	0.267
377401	3.44%	13	0.658	0.407
376302	3.67%	14	0.711	0.555
377001	5.09%	15	0.763	0.716
375902	10.07%	16	0.816	0.899
379201	10.36%	17	0.868	1.119
377701	13.90%	18	0.921	1.412
375601	179.64%	19	0.974	1.938

Figure H-2. Q-Q Plot for TTST AGF on Rural Principal Arterial Interstate

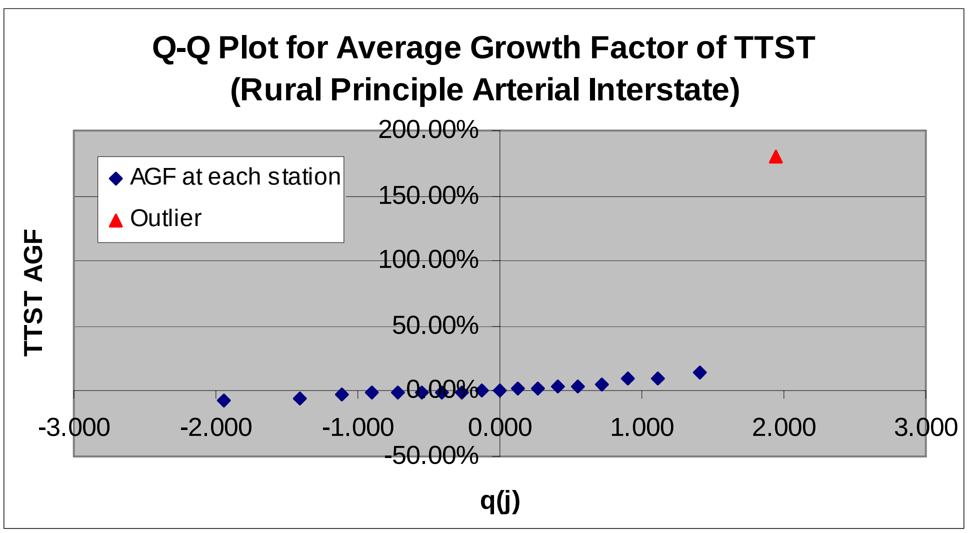


Table H-3. Q-Q Plot Analysis for ADT AGF on Rural Principal Arterial Interstate

Station (SHRP#)	AGF (ADT)	Order j	Probability Levels (j-0.5)/n	Strandard Normal Quantiles q(j)
375601	-9.39%	1	0.026	-1.938
371101	-7.96%	2	0.079	-1.412
374801	-5.88%	3	0.132	-1.119
371003	-4.95%	4	0.184	-0.899
378502	-4.37%	5	0.237	-0.716
377401	-4.03%	6	0.289	-0.555
371006	-3.21%	7	0.342	-0.407
375902	-2.91%	8	0.395	-0.267
372202	-0.77%	9	0.447	-0.132
375826	-0.53%	10	0.500	0.000
371801	1.37%	11	0.553	0.132
379102	1.55%	12	0.605	0.267
376302	2.19%	13	0.658	0.407
379201	2.57%	14	0.711	0.555
374301	2.71%	15	0.763	0.716
377701	4.16%	16	0.816	0.899
375037	6.22%	17	0.868	1.119
373011	7.86%	18	0.921	1.412
377001	7.92%	19	0.974	1.938

Figure H-3. Q-Q Plot for ADT AGF on Rural Principal Arterial Interstate

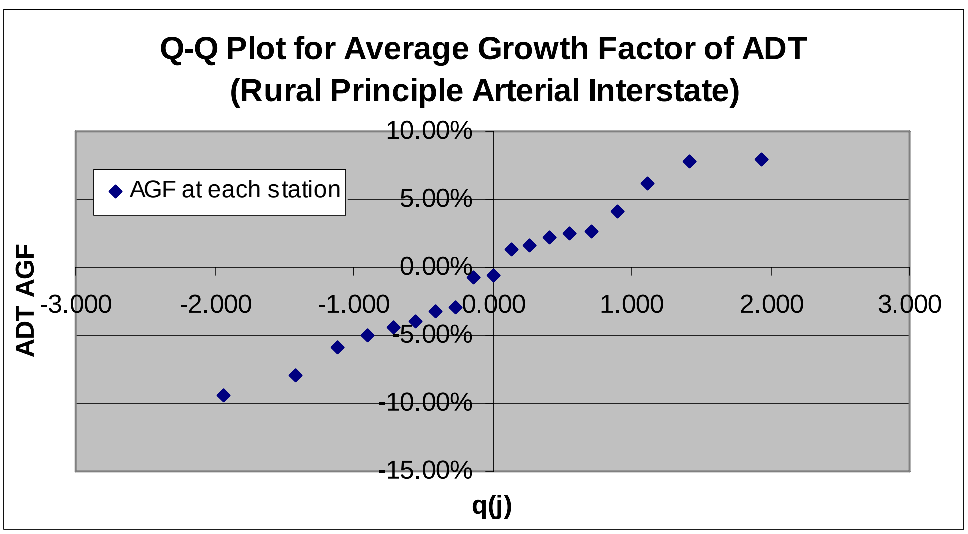


Table H-4. Q-Q Plot Analysis for Duals AGF on Rural Principal Arterial Other

Station (SHRP#)	AGF (Duals)	Order j	Probability Levels (j-0.5)/n	Strandard Normal Quantiles q(j)
377803	-16.30%	1	0.019	-2.085
373501	-12.54%	2	0.056	-1.593
371902	-8.87%	3	0.093	-1.325
371352	-6.98%	4	0.130	-1.128
371803	-6.81%	5	0.167	-0.967
372819	-6.32%	6	0.204	-0.828
372101	-5.04%	7	0.241	-0.704
373807	-3.18%	8	0.278	-0.589
377301	-2.28%	9	0.315	-0.482
371814	-2.05%	10	0.352	-0.380
371040	1.10%	11	0.389	-0.282
377302	1.21%	12	0.426	-0.187
371992	1.44%	13	0.463	-0.093
375827	3.16%	14	0.500	0.000
371645	3.91%	15	0.537	0.093
372824	4.99%	16	0.574	0.187
377802	5.26%	17	0.611	0.282
371701	5.67%	18	0.648	0.380
370200	6.98%	19	0.685	0.482
371817	7.34%	20	0.722	0.589
373816	9.95%	21	0.759	0.704
371805	11.85%	22	0.796	0.828
371402	13.56%	23	0.833	0.967
370900	13.76%	24	0.870	1.128
371030	19.65%	25	0.907	1.325
371028	22.12%	26	0.944	1.593
373008	28.54%	27	0.981	2.085

Figure H-4. Q-Q Plot for Duals AGF on Rural Principal Arterial Other

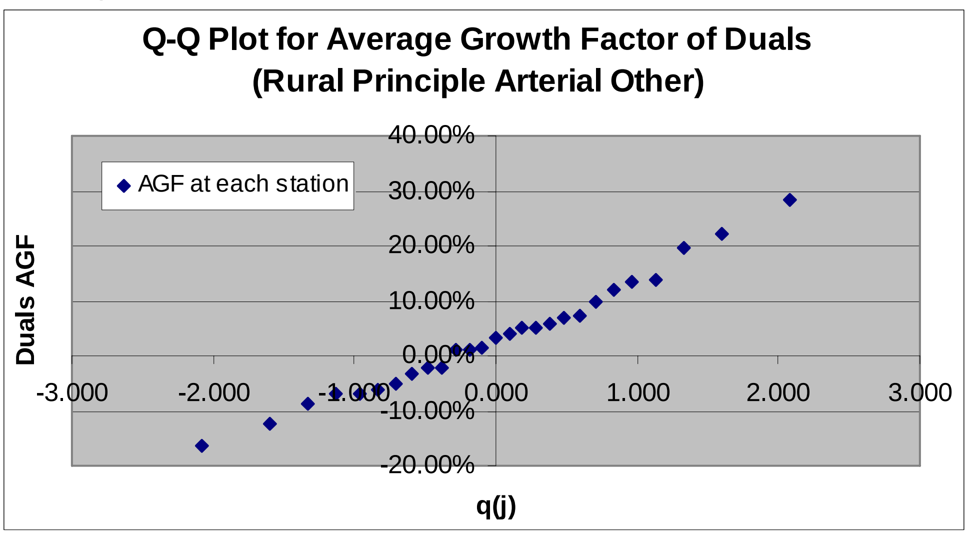


Table H-5. Q-Q Plot Analysis for TTST AGF on Rural Principal Arterial Other

Station (SHRP#)	AGF (ADT)	Order j	Probability Levels (j-0.5)/n	Strandard Normal Quantiles q(j)
371902	-8.24%	1	0.019	-2.085
371352	-7.13%	2	0.056	-1.593
377301	-5.24%	3	0.093	-1.325
375827	-4.82%	4	0.130	-1.128
371814	-3.14%	5	0.167	-0.967
371803	-2.82%	6	0.204	-0.828
371645	-2.31%	7	0.241	-0.704
377803	-1.59%	8	0.278	-0.589
372101	-1.36%	9	0.315	-0.482
370200	-0.02%	10	0.352	-0.380
377802	2.15%	11	0.389	-0.282
370900	2.64%	12	0.426	-0.187
373501	2.89%	13	0.463	-0.093
372819	2.91%	14	0.500	0.000
377302	2.96%	15	0.537	0.093
372824	3.18%	16	0.574	0.187
371805	3.71%	17	0.611	0.282
371040	4.43%	18	0.648	0.380
371028	4.47%	19	0.685	0.482
371701	5.48%	20	0.722	0.589
371817	5.93%	21	0.759	0.704
371030	6.02%	22	0.796	0.828
371992	6.84%	23	0.833	0.967
373807	6.95%	24	0.870	1.128
371402	7.66%	25	0.907	1.325
373008	11.48%	26	0.944	1.593
373816	23.15%	27	0.981	2.085

Figure H-5. Q-Q Plot for TTST AGF on Rural Principal Arterial Other

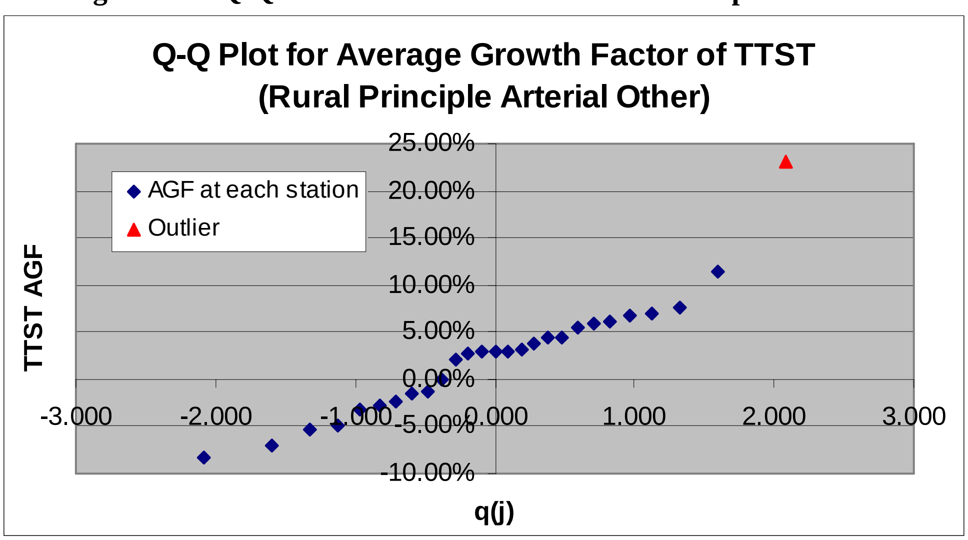
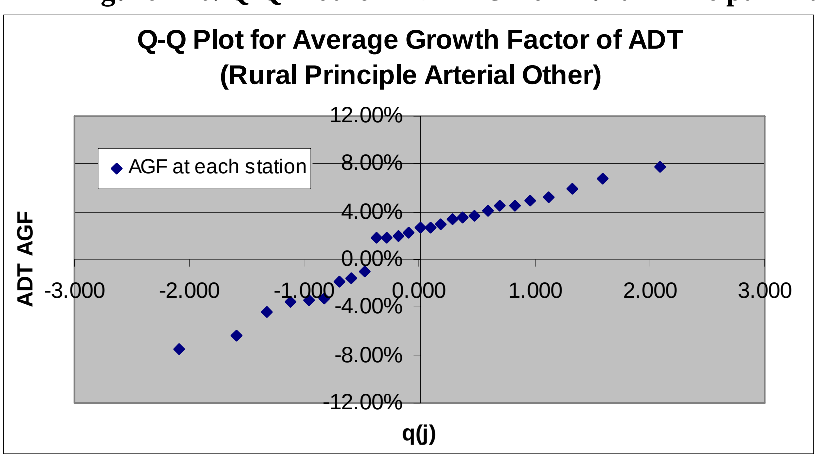


Table H-6. Q-Q Plot Analysis for ADT AGF on Rural Principal Arterial Other

Station (SHRP#)	AGF (ADT)	Order j	Probability Levels (j-0.5)/n	Strandard Normal Quantiles q(j)
371352	-7.48%	1	0.019	-2.085
371805	-6.34%	2	0.056	-1.593
377803	-4.32%	3	0.093	-1.325
373501	-3.54%	4	0.130	-1.128
371645	-3.39%	5	0.167	-0.967
371814	-3.23%	6	0.204	-0.828
371701	-1.89%	7	0.241	-0.704
371902	-1.58%	8	0.278	-0.589
375827	-1.04%	9	0.315	-0.482
372101	1.88%	10	0.352	-0.380
377802	1.90%	11	0.389	-0.282
372824	2.00%	12	0.426	-0.187
373807	2.32%	13	0.463	-0.093
377301	2.72%	14	0.500	0.000
371803	2.73%	15	0.537	0.093
371402	2.98%	16	0.574	0.187
372819	3.40%	17	0.611	0.282
371040	3.50%	18	0.648	0.380
371028	3.69%	19	0.685	0.482
371030	4.15%	20	0.722	0.589
371992	4.49%	21	0.759	0.704
377302	4.55%	22	0.796	0.828
370200	5.00%	23	0.833	0.967
373008	5.23%	24	0.870	1.128
371817	5.87%	25	0.907	1.325
370900	6.71%	26	0.944	1.593
373816	7.77%	27	0.981	2.085

Figure H-6. Q-Q Plot for ADT AGF on Rural Principal Arterial Other

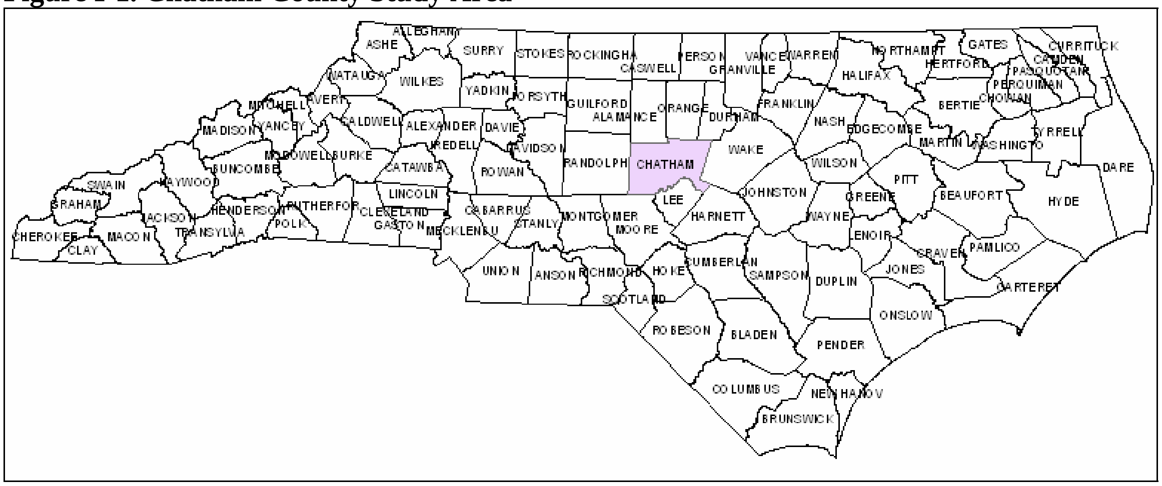


APPENDIX I: US-64 CASE STUDY

Case Study

The US-64 case requires a total traffic forecast on US-64 in Chatham County near Station 1803. Future year forecast volumes need to be obtained for possible widening and checking for probable pavement overlay for the design year. The base year for the project is 2004 and the future year is 2020. NCDOT has historic data for US-64, Station 1803, from US 421 to US 64 Bypass, in Chatham County. Figure I-1 shows the location of Chatham County.

Figure I-1. Chatham County Study Area



Traffic Data Collection

NCDOT has historic data for Station 1803 from US 421 to US 64 Bypass, in Chatham County. The NCDOT traffic unit provided historical classified counts at Station 1803 for 1998, 2001 and 2004.

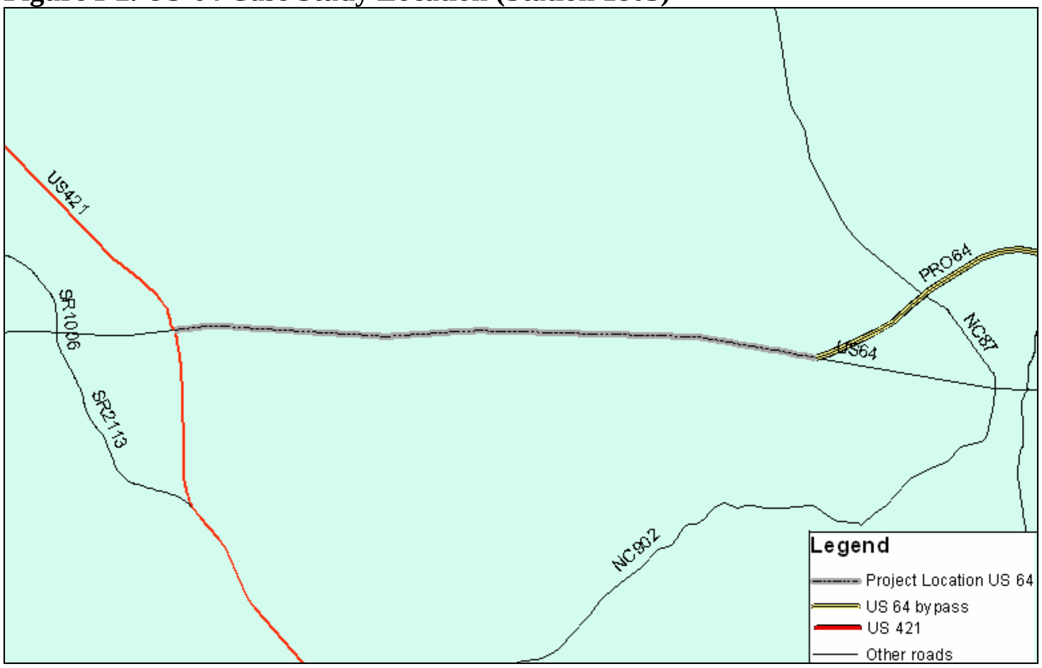
Continuous vehicle classification data is captured at the Weigh-In-Motion (WIM) Station W1805 located on US-64 Bypass, west of US-64 Business, in Chatham County. Data is captured using the FHWA 13 vehicle class scheme in hourly totals by class by lane. Data is screened to identify the typical traffic patterns for the station. Atypical days due to holidays, weather, accidents, and other events are excluded. All averages, factors, and seasonal statistics used in the factoring procedures are based on typical days only. This complies with the AASHTO standard for this type of data. A minimum of 48 hours of data is collected at each station using the FHWA scheme in hourly totals by class by lane. Factoring is applied to the two-way totals at the station (all lanes combined); however, data checks are performed at the individual lane level. Factors are applied by class to generate annual averages (AADVT). The classes are combined to provide the NCDOT vehicle classes typically used for traffic forecasting and design. A detailed procedure for factoring is mentioned in Appendix C. 2004 base year data is used for forecasting traffic volume for the future year 2020.

Forecasting Procedure

Step 1: Selection of project location using GIS

Project location can be easily identified and located using the geographical capability of GIS. The project location is identified using the NC counties shapefile and DOT roads layer. The selection of project location is effectively performed using the "select by attribute" capabilities in ArcMap from the respective shapefiles.

Figure I-2. US-64 Case Study Location (Station 1803)



Step 2. Data collection and analysis

The next step required for growth factor selection and forecast development involves collecting appropriate datasets and performing basic growth factor analysis at the project location. Factored and annualized data provided from NCDOT traffic survey unit is shown in Table I-1.

Table I-1. US-64, Station 1803

Station	Year	AADVT	CARS	DUALS	TTST
1803	1998	6777	5858	366	553
1803	2001	9879	8732	545	602
1803	2004	11671	10312	486	873

Annual Growth Factor (GF) for each vehicle category (Cars, Duals, and TTSTs) are computed separately from the above data. Continuous counts for each year are not available at the project location. Therefore, to calculate annual growth factors, it is assumed that growth factor remains constant between the years of missing data and growth rates for the years are calculated using formula 2. The average growth factor (AGF) is calculated using formula 3.

$$GF = \frac{T_t - T_{t-1}}{T_{t-1}} \qquad (1)$$

$$GF = \frac{\left(\dfrac{T_{fy} - T_{by}}{T_{by}}\right)}{fy - by} \qquad (2)$$

$$AGF = \frac{\sum GF}{N} \qquad (3)$$

where:

T = traffic

GF = Annual Growth Factor

AGF = Average Annual Growth Factor

t = year, t-1 = previous year

N = the number of growth factors

fy = future year

by = base year

The percentage of Duals and TTSTs at the project location are computed using formulas 4 and 5.

$$\%DUALS = \frac{Duals}{AADT} x100 \qquad (4)$$

$$\%TTST = \frac{TTST}{AADT} x100 \qquad (5)$$

Table I-2 shows the summary of the analysis conducted at the project location (Station 1803). The results obtained from the analysis are used in step 3 to select growth rates for developing forecasts at the study area.

Table I-2. Average Growth factors and Percentage Duals and TTSTs

Analysis Result Summary for base year traffic (2004)				
AGF Cars	AGF Duals	AGF TTST	% Duals	% TTST
11.19%	6.36%	8.98%	4.16%	7.48%

Step 3: Selection of growth rates and percentage trucks at project location

Results obtained from historic counts at the project location show that there is an increase of Cars, Duals and TTSTs. The growth rates obtained are the results from the limited historic counts (Table I-1) available at the project location.

Based on the results obtained from statistical analysis on the dataset in Chapter 3, the engineer can now directly select the most confident growth rate based on the traffic trends at the project location. Since the project site shows a growth of traffic, the growth rate is checked by the upper confidence level for growth rates for each vehicle category. The AGF values of Table I-2 are compared with the confidence levels of the NC Arterials summary statistics results shown in Table 3-10. AGF for each vehicle class is above the upper confidence level for NC Arterials; therefore, the upper confidence interval of AGF is used for developing forecasts for future year. Table I-3 shows the analysis results and chosen growth rates for developing forecasts.

Table I-3. Growth factor options for developing forecasts

Growth factor chosen for developing forecasts for 2020			
Result	Cars	Duals	TTST
Analysis Results	11.19%	6.36%	8.98%
Chosen Growth Rate	3.01%	4.34%	3.81%

Step 4: Developing future traffic volumes.

This step develops forecasts for future truck traffic in the study area. To perform this step, truck traffic average growth factors chosen in Step 3 are used in the following formulas to develop the result. The percentages of Duals and TTSTs for the design year are also computed using formulas 5 and 6.

$$CARS_{fy} = CARS_{by}(1 + AGF)^{(fy-by)} \quad (1)$$

$$DUALS_{fy} = DUALS_{by}(1 + AGF)^{(fy-by)} \quad (2)$$

$$TTST_{fy} = TTST_{by}(1 + AGF)^{(fy-by)} \quad (3)$$

$$AADT = CARS + DUALS + TTST \quad (4)$$

$$\%DUALS = \frac{Duals}{AADT} x100 \quad (5)$$

$$\%TTST = \frac{TTST}{AADT} x100 \quad (6)$$

Table I-4 shows the results of forecasted traffic and truck class percentages for year 2020.

Table I-4. Exponential Model Results

Forecasted Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
Average GF method	16573	959	1588	19120	5.02%	8.31%

Step 5: Check for accuracy

The final traffic volumes obtained as a result of the Average Growth Factor methodology are checked for accuracy. The percentages of Duals and TTSTs in total traffic are calculated for the base year of 2004. For the forecasted year of 2020, the percentages of Duals and TTSTs are again calculated (Table I-5) and compared with the base year percentages. This check is important and valid since the percentages of Duals and TTSTs follow a normal distribution as mentioned in the descriptive statistics of Chapter 3.

Table I-5. Percentages of Duals and TTSTs of Total Traffic

Percentage Duals and TTST of Total Traffic		
Results	% Duals	% TTST
Average GF method 2020	5.02%	8.31%
Base Year 2004	4.16%	7.48%

NCDOT forecasting procedure

The average growth factor method used by NCDOT is used to forecast future traffic for 2020. The growth rates obtained from the historical data are used without considering other influences and no further adjustments are made to growth rates obtained from given data. Since the data available at the project location is limited to only three years, the other NCDOT forecasting methods mentioned in Chapter 2 are not used for comparison of results at the project location. The general NCDOT average growth factor method is used to compare the results of the NCSU methodology developed above. The average growth rate obtained in step 2 of the above methodology is directly used for developing forecast for each vehicle category using the formulas 1-6 described in step 4.

Figure I-3. Comparison of Volume Trends (Vehicle Classes 1-13)

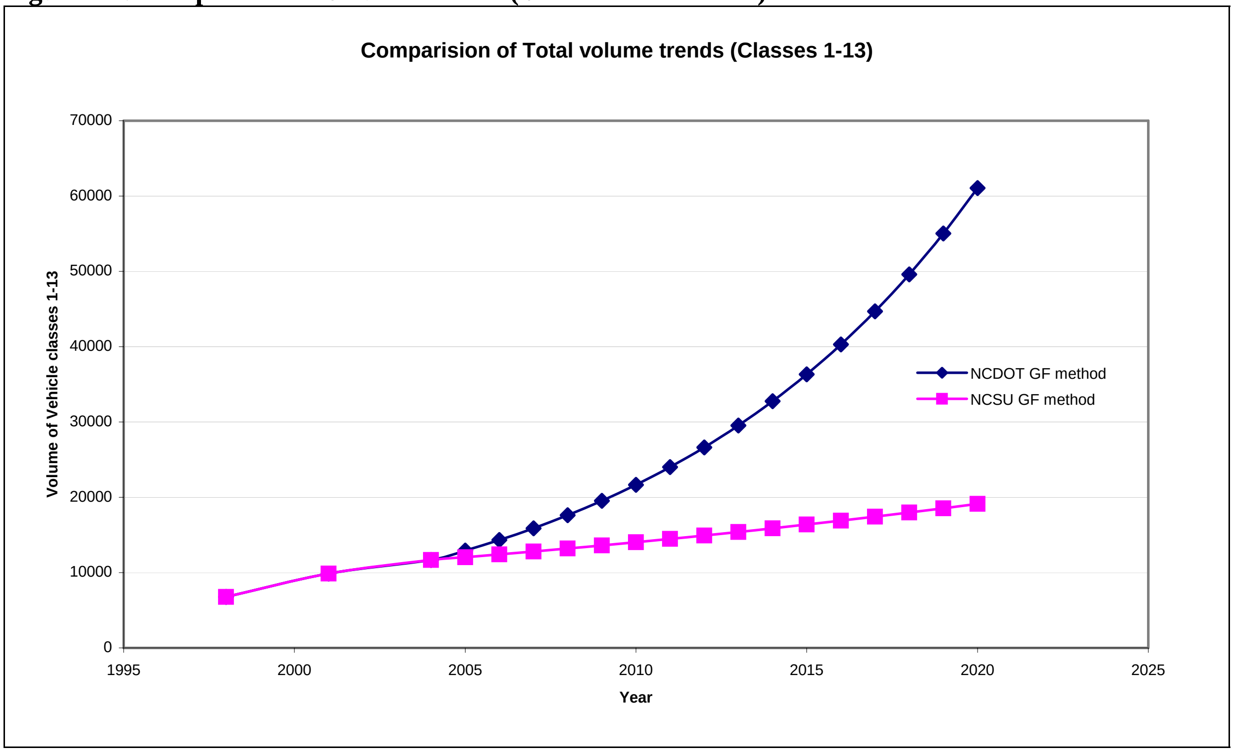


Figure I-4. Comparison of Volume Trends for Cars (Vehicle Classes 1-3)

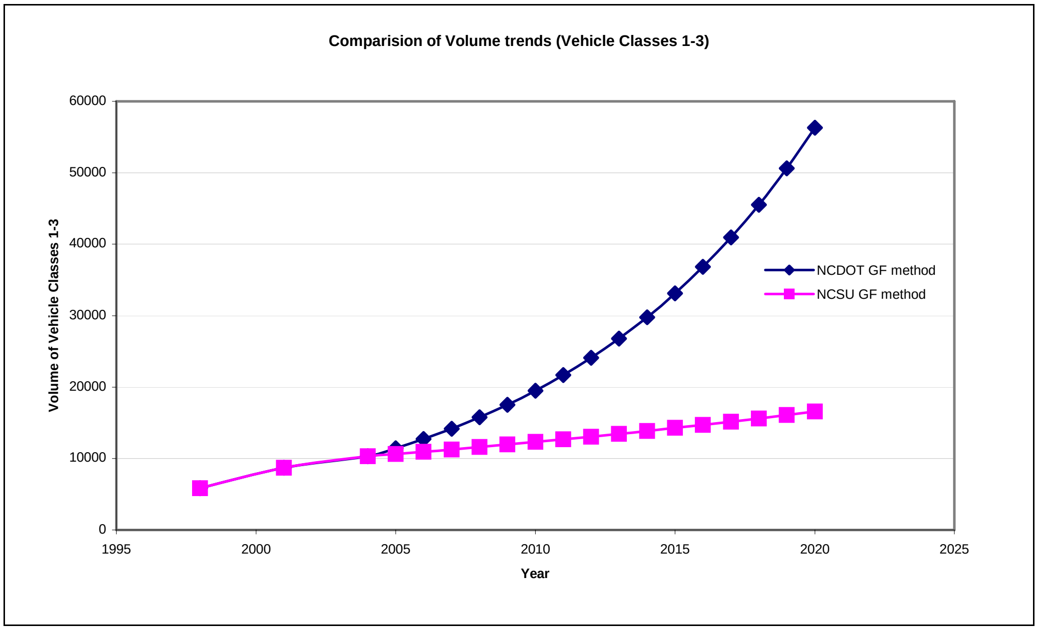


Figure I-5. Comparison of Volumes Trends for Duals (Vehicle Classes 4-7)

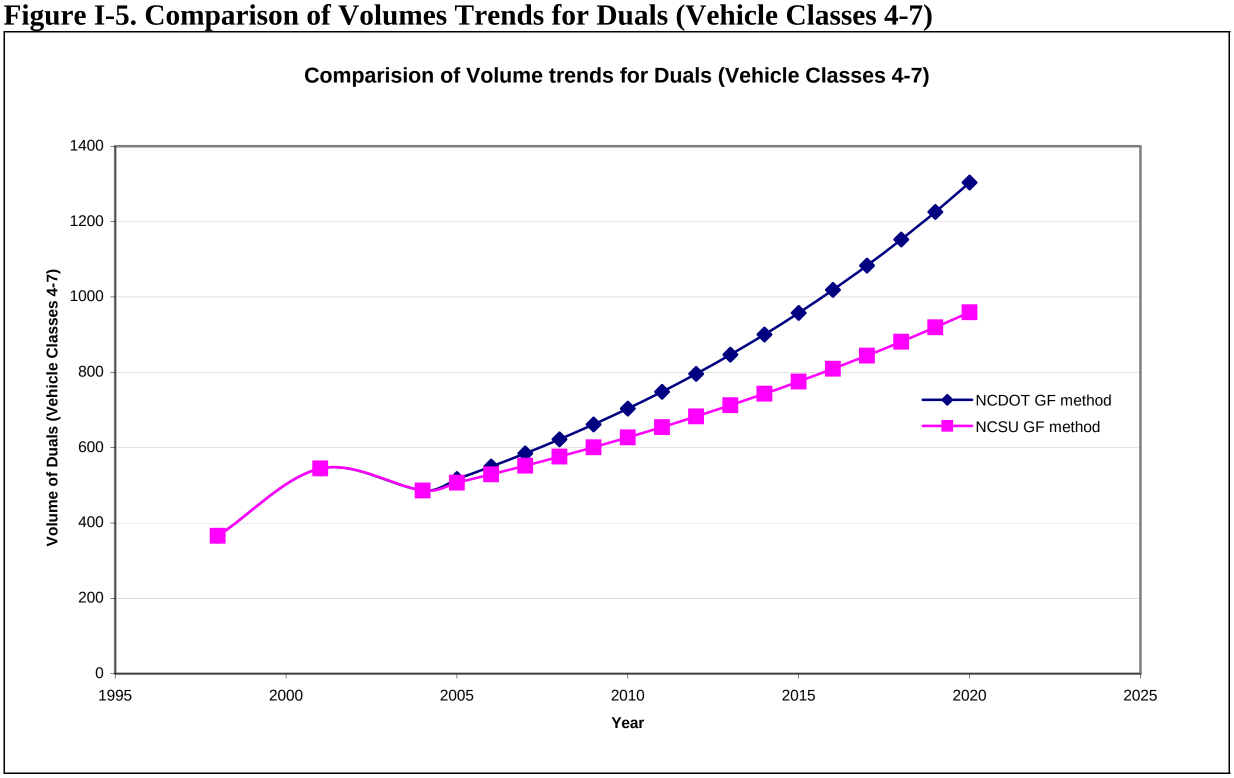
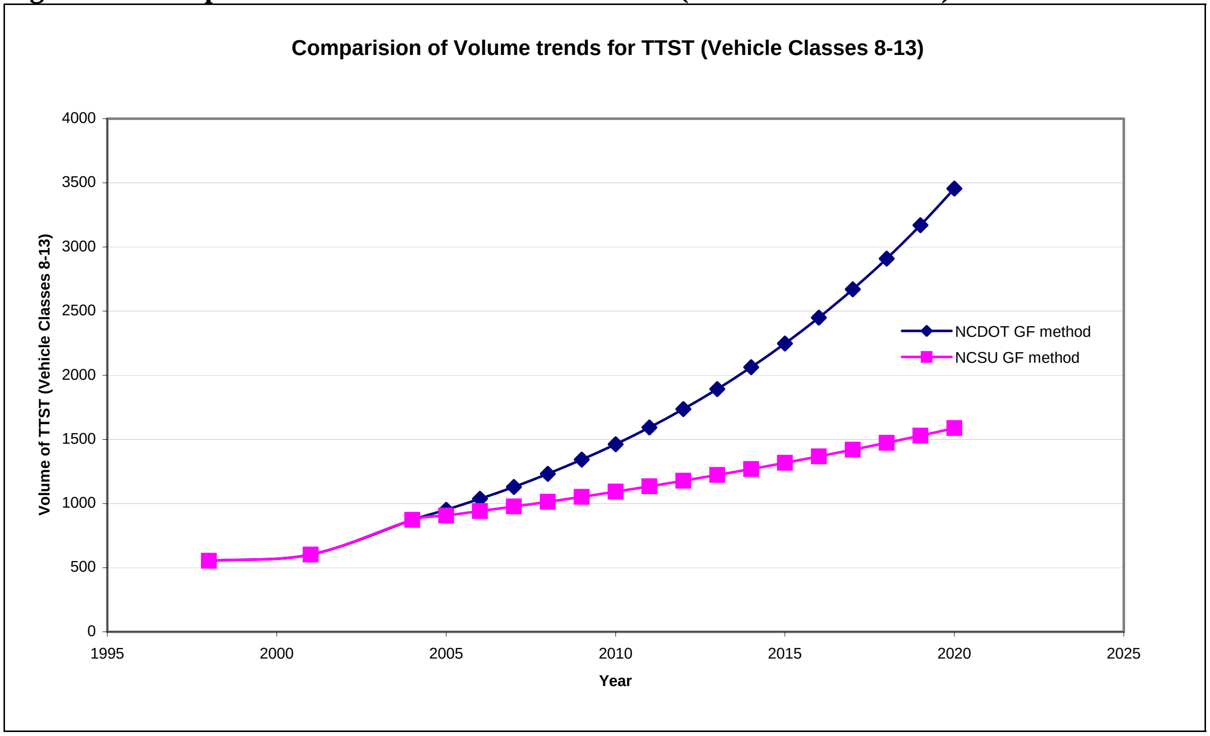


Figure I-6. Comparison of Volume Trends for TTSTs (Vehicle Classes 8-13)



Comparison and discussion of results

In order to test the usability of the newly developed NCSU method, traffic volume trends obtained from each method are plotted for each vehicle category (Cars, Duals and TTSTs) and are shown in Figure I-3 to I-6. A summary of the forecast volumes using both methods is also shown in Table I-6.

Table I-6. Comparison of Traffic Volumes, % Duals and % TTSTs in 2020

Comparision of Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
Historic GF method	56293	1304	3455	61052	2.14%	5.66%
Average GF method	16573	959	1588	19120	5.02%	8.31%

From Figure I-3 to I-6 and Table I-6, it is seen that using the historic growth factor at the project location would overestimate the traffic volume at the project location. Since each vehicle category is forecasted separately, the total AADT is largely affected by higher growth rate of Duals and TTSTs.

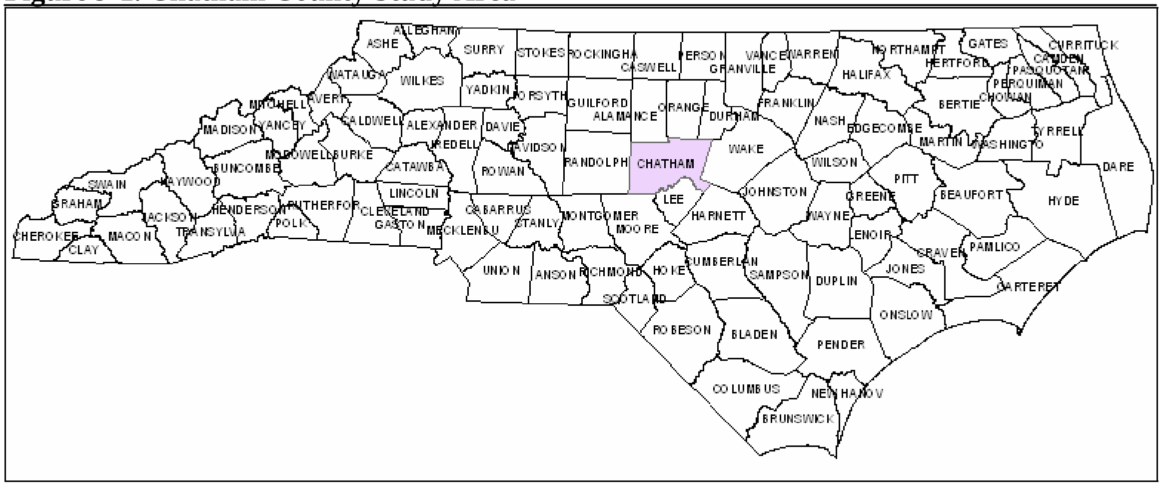
The AGF method of forecasts has results with lower chances of overestimation at the project location. Also as a check, the percentages of Duals and TTSTs in 2020 are very reasonable compared to the base year percentages (Table I-5).

APPENDIX J: US 421 CASE STUDY

Case Study

This case requires a total traffic forecast on US-421 in Chatham County near Station 0004. Future year forecast volumes need to be obtained for a possible widening and checking for probable pavement overlay for the design year. The base year for the project is 2003 and the future year is 2020. NCDOT has historic data for US-421, Station 0004, between US 421 and NC 902 in Chatham County.

Figure J-1. Chatham County Study Area



Project Study Area

Chatham County is bordered by Wake County on the east, Randolph County on the west, Alamance, Durham and Orange counties on the north, and Lee and Moore counties on the south (Figure J-1). This study includes only the section located near Station 0004.

Traffic Data Collection

NCDOT has historic data for Station 0004 on US 421 between SR 2113 and NC 902 in Chatham County. The NCDOT traffic unit provided historical classified counts at Station 0004 for 2003 only.

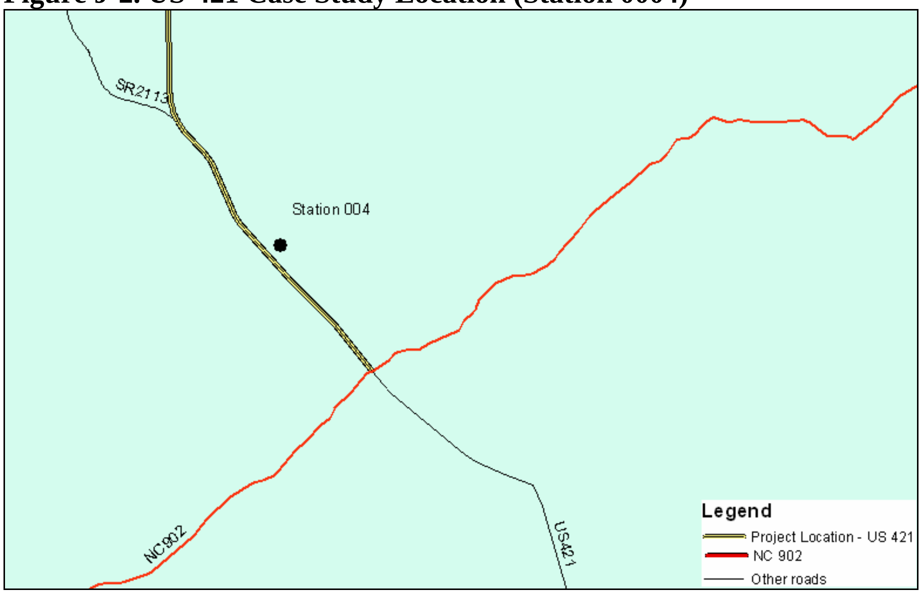
The factoring procedure for the data at the project location is developed from continuous vehicle classification data captured at Weigh-In-Motion (WIM) Station 1805 on the US 64 bypass in Chatham County. Class data includes the FHWA 13 vehicle classes in hourly totals by class by lane. Data is screened to identify the typical traffic patterns for the station. Atypical days due to holidays, weather, accidents, and other events are excluded. All averages, factors, and seasonal statistics used in the factoring procedures are based on typical days only. This complies with the AASHTO standard for this type of data. A minimum of 48 hours of data are collected at each station using the FHWA scheme in hourly totals by class by lane. Factoring is applied to the two-way totals at the station (all lanes combined); however, data checks are performed at the individual lane level. Factors are applied by class to generate annual averages (AADVT). The classes are combined to provide the NCDOT vehicle classes typically used for traffic forecasting and design. A detailed procedure for factoring is described in Appendix B. 2003 base year data is used for forecasting traffic volume for the future year 2020.

Forecasting Procedure

Step 1: Selection of project location using GIS

GIS easily identifies and locates the project location by using the NC counties shapefile and DOT roads layer. The selection of project location is effectively performed using the "select by attribute" capabilities in ArcMap from the respective shape files.

Figure J-2. US-421 Case Study Location (Station 0004)



Step 2. Data collection and analysis

The next step required for growth factor selection and forecast development involves collecting appropriate datasets and performing basic growth factor analysis at the project location. Factored and annualized data provided from NCDOT traffic survey unit is shown in Table J-1.

Table J-1. US-421, Station 0004

Station	Year	AADVT	CARS	DUALS	TTST
4	2003	38060	35898	1478	684

Step 3: Selection of growth rates and percentage trucks at project location

Based on the results obtained from statistical analysis on the dataset in Chapter 3, the engineer can now directly select the most confident growth rate based on the traffic trends at the project location. Since there was only data available for one year at the project location, the growth rate for each vehicle class can be taken as the median value from the NC Arterials data in Chapter 3. Table J-2 shows the analysis results and chosen growth rates for developing forecasts.

Table J-2. Growth factor options for developing forecasts

Growth factor chosen for developing forecasts for 2020			
Method	Cars	Duals	TTST
NCSU GF method	2.37%	1.21%	2.90%

Step 4: Developing future traffic volumes.

This step develops forecasts for future truck traffic in the study area. To perform this step, truck traffic average growth factors chosen in Step 3 are used in the following formulas to develop the result. The percentages of Duals and TTSTs for the design year are also computed using formulas 5 and 6.

$$CARS_{fy} = CARS_{by}(1+AGF)^{(fy-by)} \qquad (1)$$

$$DUALS_{fy} = DUALS_{by}(1+AGF)^{(fy-by)} \qquad (2)$$

$$TTST_{fy} = TTST_{by}(1+AGF)^{(fy-by)} \qquad (3)$$

$$AADT = CARS + DUALS + TTST \qquad (4)$$

$$\%DUALS = \frac{Duals}{AADT} x100 \qquad (5)$$

$$\%TTST = \frac{TTST}{AADT} x100 \qquad (6)$$

Table J-4 shows the results of forecasted traffic and truck class percentages for year 2020.

Table J-4. Exponential Model Results

Forecasted Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
NCSU GF method	53457	1813	1113	56383	3.23%	2.08%

Step 5: Check for accuracy

The final traffic volumes obtained as a result of the Average Growth Factor methodology are checked for accuracy. The percentages of Duals and TTSTs in total traffic are calculated for the base year of 2003. For the forecasted year of 2020, the percentages of Duals and TTSTs are again calculated (Table J-5) and compared with the base year percentages. This check is important and valid since the percentages of Duals and TTSTs follow a normal distribution as mentioned in the descriptive statistics of Chapter 3.

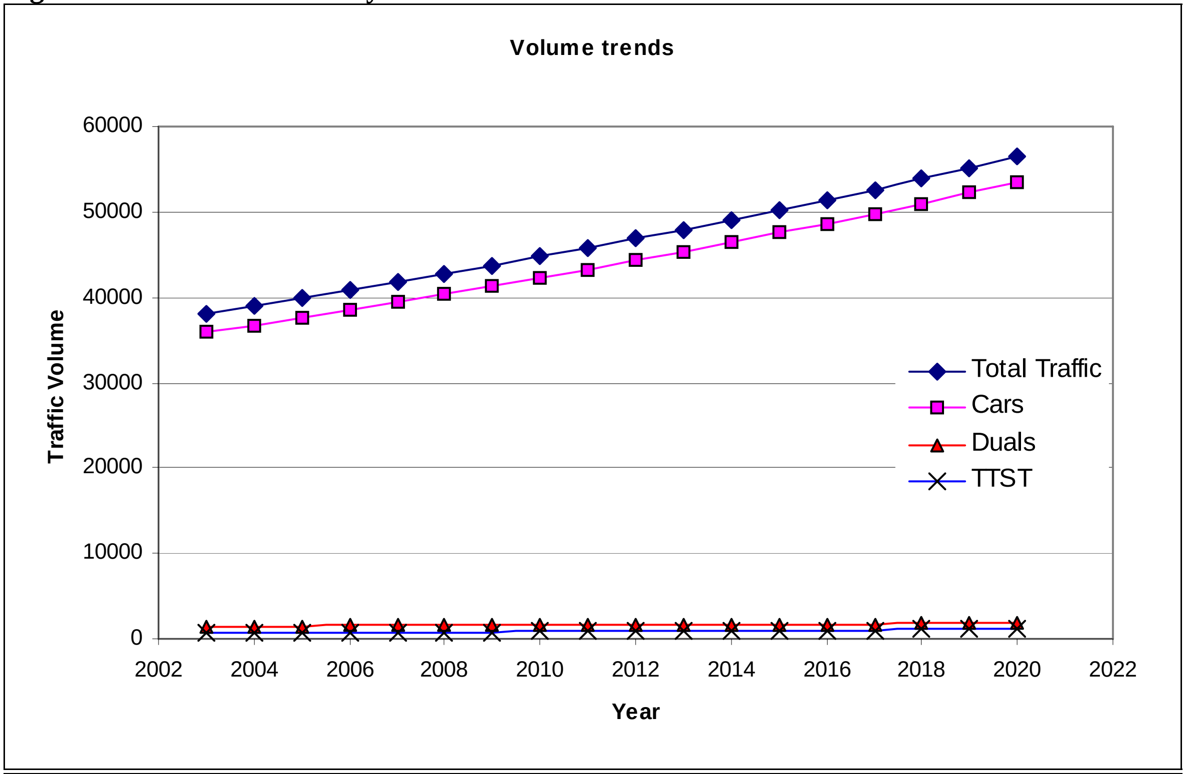
Table J-5. Percentages of Duals and TTSTs of Total Traffic

Percentage Duals and TTST of Total Traffic		
Results	% Duals	% TTST
NCSU GF method 2020	3.23%	2.08%
Base Year 2003	3.88%	1.91%

<u>NCDOT Forecasting Procedure</u>

Since there is only one year of data available at the location NCDOT practice for this NC route would be to assume a reasonable annual percent growth like 1% to 3% for ADT. Future year truck percents would likely be assumed the same as those for the base year.

Figure J-3. Volume Trends by Class



<u>Comparison and Discussion of Results</u>

In order to test the usability of the newly developed NCSU method, traffic volume trends are plotted in Figure J-3. A summary of the forecast volumes using the NCSU method is also shown in Table J-6.

Table J-6. Comparison of Traffic Volumes, % Duals and % TTSTs in 2020

Comparision of Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
NCSU GF method	53457	1813	1113	56383	3.23%	2.08%

From charts J-5 to J-8 and Table J-12, it is seen that using an average growth factor at the project location would overestimate the traffic volume at the project location. Since each vehicle category is forecasted separately, the total AADT is largely affected by higher growth rate of duals and TTST. Another important finding is the high percentage of duals and TTST in total traffic. This percentage is compared to the percentage duals and TTST of base year in Table J-4.

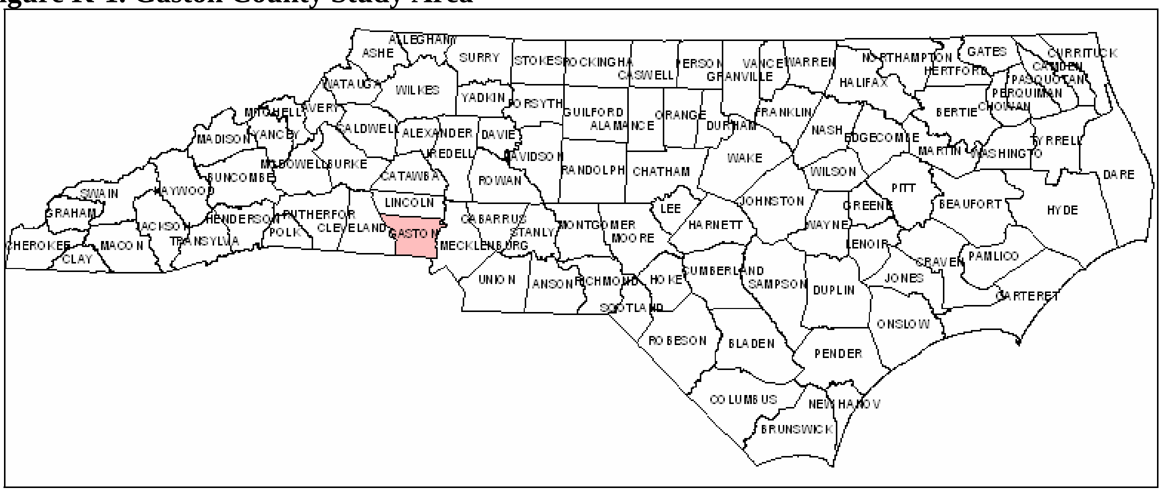
The NCSU forecast has results with lower chances of overestimation at the project location. Also as a check, the percentages of Duals and TTSTs in 2020 are very reasonable compared to the base year percentages (Table J-5).

APPENDIX K: NC 279 CASE STUDY

Case Study

The NC 279 case requires a total traffic forecast on NC 279 in Gaston County near Station 3502. Future year forecast volumes need to be obtained for possible widening and checking for probable pavement overlay for the design year. The base year for the project is 2004 and the future year is 2020. NCDOT has historic data for NC 279 at Station 3502 which is located south of Baltic Street in Gaston County.

Figure K-1. Gaston County Study Area



Project Study Area

Gaston County is bordered by Cleveland County on the west, Lincoln County on the north, Mecklenburg County on the east, and South Carolina on the south (Figure K-1). This study includes only the section located near Station 3502.

Traffic Data Collection

NCDOT has historic data for Station 3502 which is located south of Baltic Street on NC 279, in Gaston County. The NCDOT traffic unit provided historical classified counts at Station 3502 for 1999 and 2000, and 2004 VTRIS data.

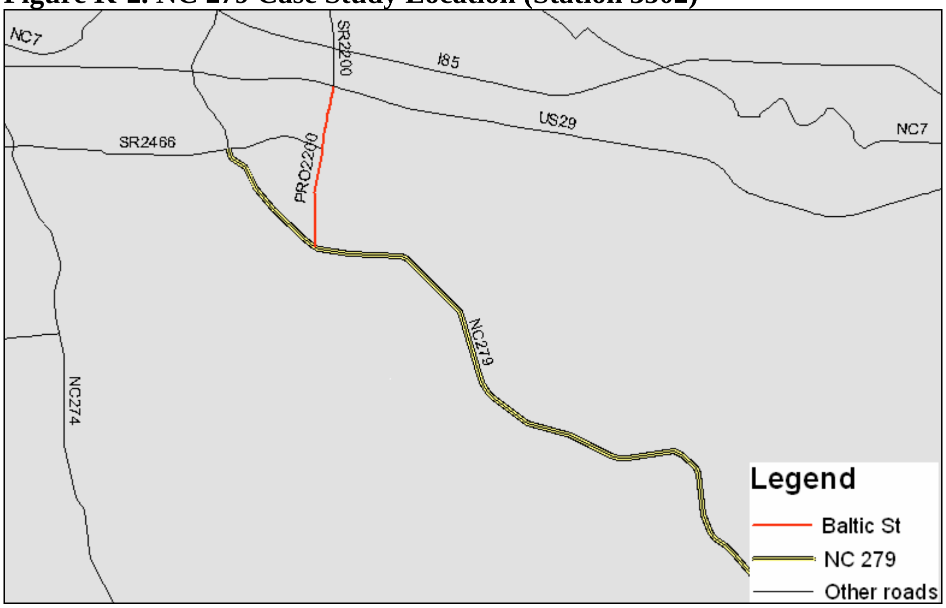
Continuous vehicle classification data is captured at the Weigh-In-Motion (WIM) Stations W5903 located on Harris Boulevard in Mecklenburg County and W5901 located on Arrowood Road in Mecklenburg County. Data is captured using the FHWA 13 vehicle class scheme in hourly totals by class by lane. Data is screened to identify the typical traffic patterns for the station. Atypical days due to holidays, weather, accidents, and other events are excluded. All averages, factors, and seasonal statistics used in the factoring procedures are based on typical days only. This complies with the AASHTO standard for this type of data. A minimum of 48 hours of data is collected at each station using the FHWA scheme in hourly totals by class by lane. Factoring is applied to the two-way totals at the station (all lanes combined); however, data checks are performed at the individual lane level. Factors are applied by class to generate annual averages (AADVT). The classes are combined to provide the NCDOT vehicle classes typically used for traffic forecasting and design. A detailed procedure for factoring is mentioned in Appendix B. 2004 base year data is used for forecasting traffic volume for the future year 2020.

Forecasting Procedure

Step 1: Selection of project location using GIS

Project location can be easily identified and located using the geographical capability of GIS. The project location is identified using the NC counties shapefile and the DOT roads layer. The selection of project location is effectively performed using the "select by attribute" capabilities in ArcMap from the respective shapefiles.

Figure K-2. NC 279 Case Study Location (Station 3502)



Step 2. Data collection and analysis

The next step required for growth factor selection and forecast development involves collecting appropriate datasets and performing basic growth factor analysis at the project location. Factored and annualized data provided from NCDOT traffic survey unit is shown in Table K-1.

Table K-1. NC 279, Station 3502

Station	Year	AADVT	CARS	DUALS	TTST
3502	1999	16746	16081	385	280
3502	2000	16904	16144	490	271
3502	2004	16819	15976	702	142

Annual Growth Factors (GFs) for each vehicle category (Cars, Duals, and TTSTs) are computed separately from the above data. Continuous counts for each year are not available at the project location. Therefore, to calculate annual growth factors, it is assumed that growth remains constant between the years of missing data and growth rates for the years are calculated using formula 2. The Average Growth Factor (AGF) is calculated using formula 3.

$$GF = \frac{T_t - T_{t-1}}{T_{t-1}} \qquad (1)$$

$$GF = \frac{\left(\frac{T_{fy} - T_{by}}{T_{by}} \right)}{fy - by} \qquad (2)$$

$$AGF = \frac{\sum GF}{N} \qquad (3)$$

where:

T = traffic

GF = Annual Growth Factor

AGF = Average Annual Growth Factor

t = year, t-1 = previous year

N = the number of growth factors

fy = future year

by = base year

The percentage of Duals and TTSTs at the project location are computed from Table K-1 using formulas 4 and 5.

$$\%DUALS = \frac{Duals}{AADT} x100 \qquad (4)$$

$$\%TTST = \frac{TTST}{AADT} x100 \qquad (5)$$

Table K-2 shows the summary of the analysis conducted at the project location (Station 3502). The results obtained from the analysis are used in step 3 to select growth rates for developing forecasts at the study area.

Table K-2. Average Growth factors and Percentage Duals and TTSTs

Analysis Result Summary for base year traffic (2003)				
AGF Cars	AGF Duals	AGF TTST	% Duals	% TTST
0.07%	19.00%	-7.57%	4.17%	0.84%

Step 3: Selection of growth rates and percentage trucks at project location

Results obtained from historic counts at the project location show that there is an increase of Cars and Duals but a decrease of TTSTs. The growth rates obtained rely on the limited historic counts (Table K-1) available at the project location.

Based on the results obtained from statistical analysis on the dataset in Chapter 3, the engineer can now select an appropriate growth rate based on the traffic trends at the project location. Since the project location shows a growth of Cars and Duals, the growth rate is checked by the upper confidence level for growth rates for each vehicle category. The AGF values of Table K-2 are compared with the confidence levels of the NC Arterials summary statistics results shown in Table 3-10. AGF Duals is above the upper confidence level for NC Arterials; therefore, the upper confidence level of AGF is used for developing forecasts for the future year. Table K-3 shows the resulting AGFs chosen for the forecast. Growth factors Cars and TTSTs are median values and for Duals upper confidence level value.

Table K-3. Growth factor options for developing forecasts

Growth factor chosen for developing forecasts for 2020			
Method	Cars	Duals	TTST
NCDOT GF method	0.07%	19.00%	-7.57%
NCSU GF method	2.37%	4.34%	2.90%

Step 4: Developing future traffic volumes.

This step develops forecasts for future truck traffic in the study area. To perform this step, truck traffic average growth factors chosen in Step 3 are used in the following formulas to develop the result. The percentages of Duals and TTSTs for the design year are also computed using formulas 5 and 6.

$$CARS_{fy} = CARS_{by}(1 + AGF)^{(fy-by)} \quad (1)$$

$$DUALS_{fy} = DUALS_{by}(1 + AGF)^{(fy-by)} \quad (2)$$

$$TTST_{fy} = TTST_{by}(1 + AGF)^{(fy-by)} \quad (3)$$

$$AADT = CARS + DUALS + TTST \quad (4)$$

$$\%DUALS = \frac{Duals}{AADT} x100 \quad (5)$$

$$\%TTST = \frac{TTST}{AADT} x100 \quad (6)$$

Table K-4 shows the results of forecasted traffic and truck class percentages for year 2020.

Table K-4. Exponential AGF Model Results

Forecasted Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
Average GF method	23239	1385	224	24848	5.58%	0.90%

Step 5: Check for accuracy

The final traffic volumes obtained as a result of the Average Growth Factor methodology are checked for accuracy. The percentages of Duals and TTSTs in total traffic are calculated for the base year of 2004. For the forecasted year of 2020, the percentages of Duals and TTSTs are again calculated (Table K-5) and compared with the base year percentages. This check is important and valid since the percentages of Duals and TTSTs follow a normal distribution as mentioned in the descriptive statistics of Chapter 3.

Table K-5. Percentages of Duals and TTSTs of Total Traffic

Percentage Duals and TTST of Total Traffic		
Results	% Duals	% TTST
Average GF method 2020	5.58%	0.90%
Base Year 2004	4.17%	0.84%

NCDOT Forecasting Procedure

The average growth factor method used by NCDOT is used to forecast future traffic for 2020. The growth rates obtained from the historical data are used without considering other influences and no further adjustments are made to growth rates obtained from given data. Since the data available at the project location is limited to only three years, the other NCDOT forecasting methods mentioned in Chapter 2 are not used for comparison of results at the project location. The general NCDOT average growth factor method is used to compare the results of the NCSU methodology developed above. The average growth rate obtained in step 2 of the above methodology is directly used for developing forecast for each vehicle category using formulas 1-6 described in step 4.

Figure K-3. Comparison of Volume Trends (Vehicle Classes 1-13)

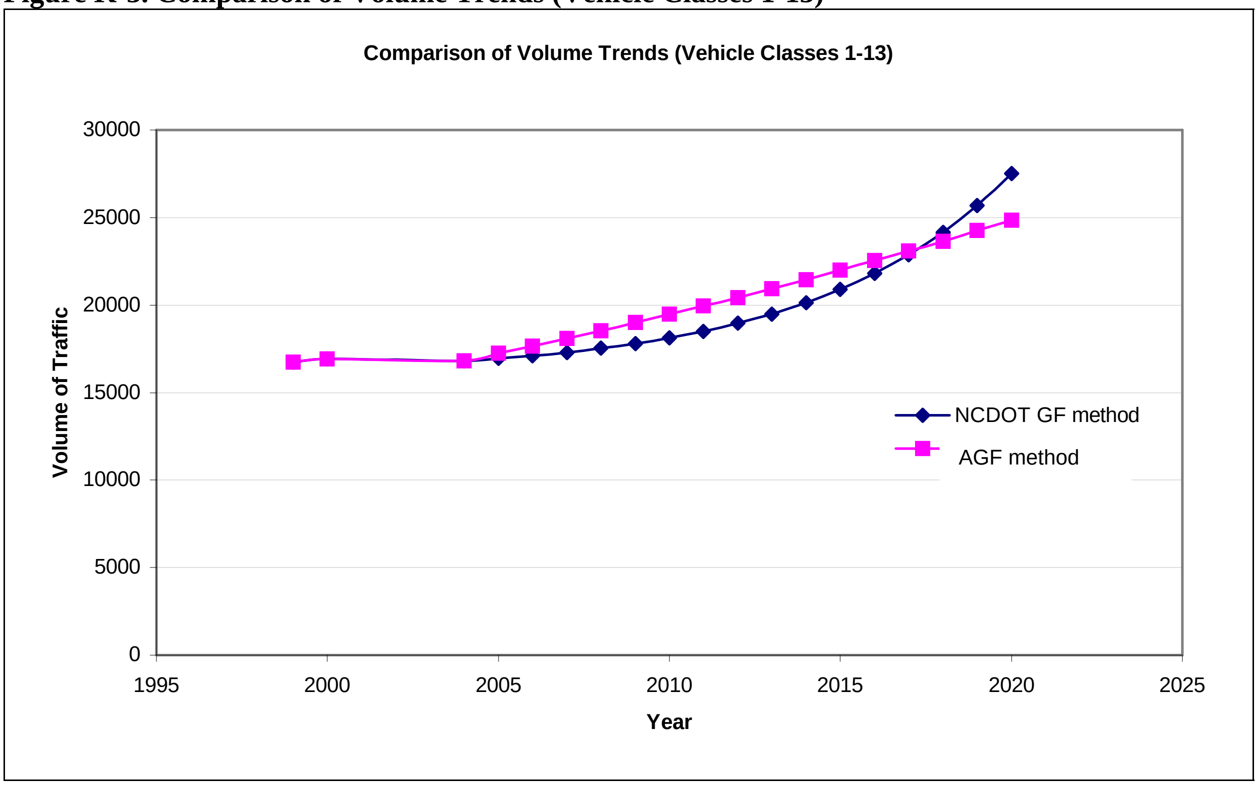


Figure K-4. Comparison of Volume Trends for Cars (Vehicle Classes 1-3)

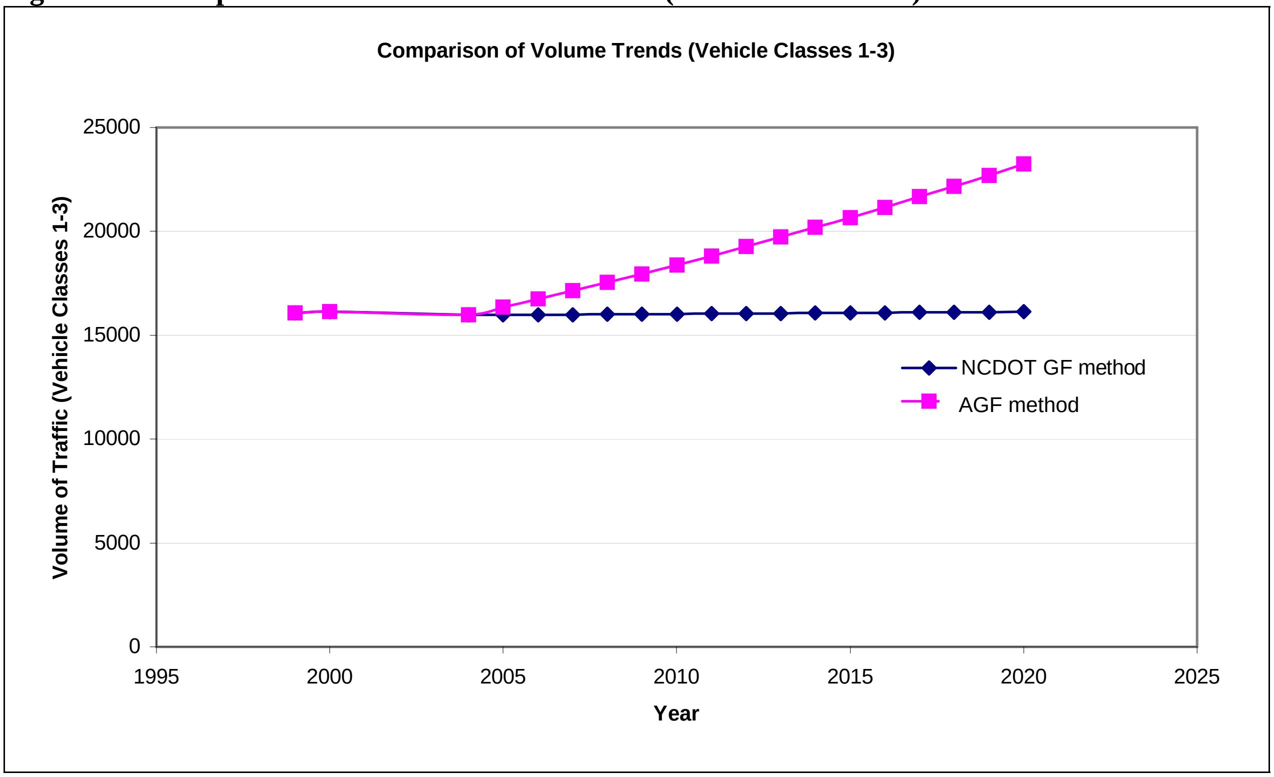


Figure K-5. Comparison of Volumes Trends for Duals (Vehicle Classes 4-7)

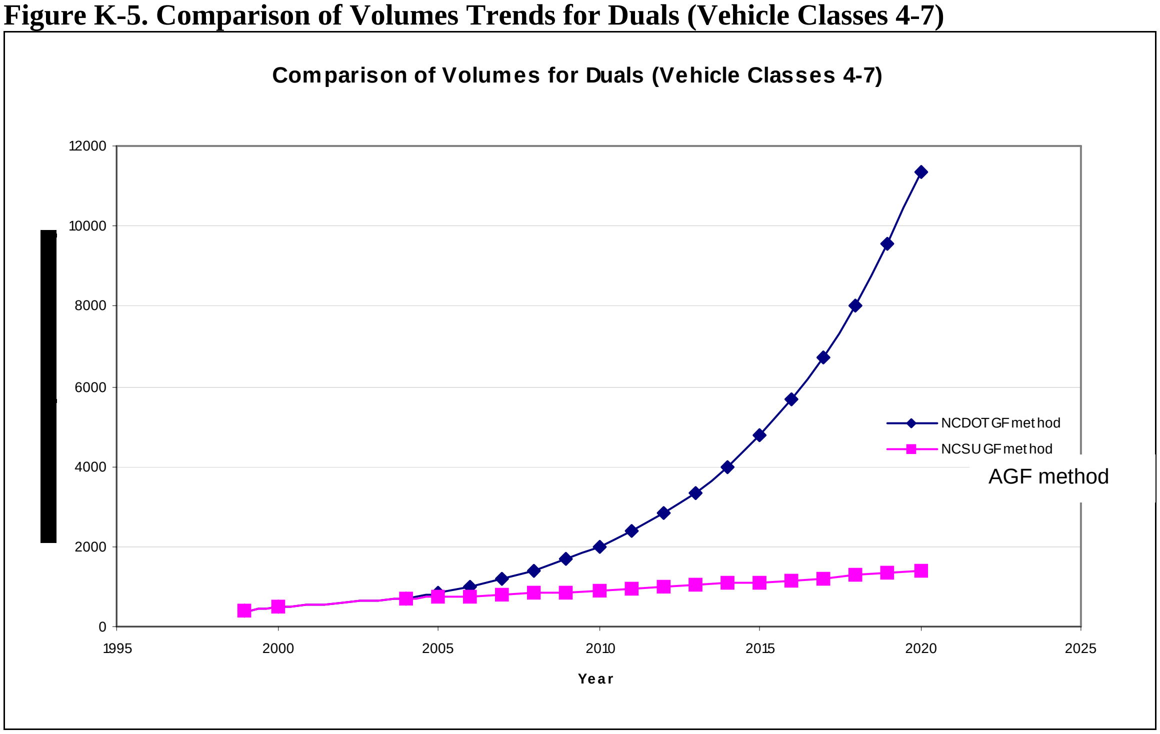
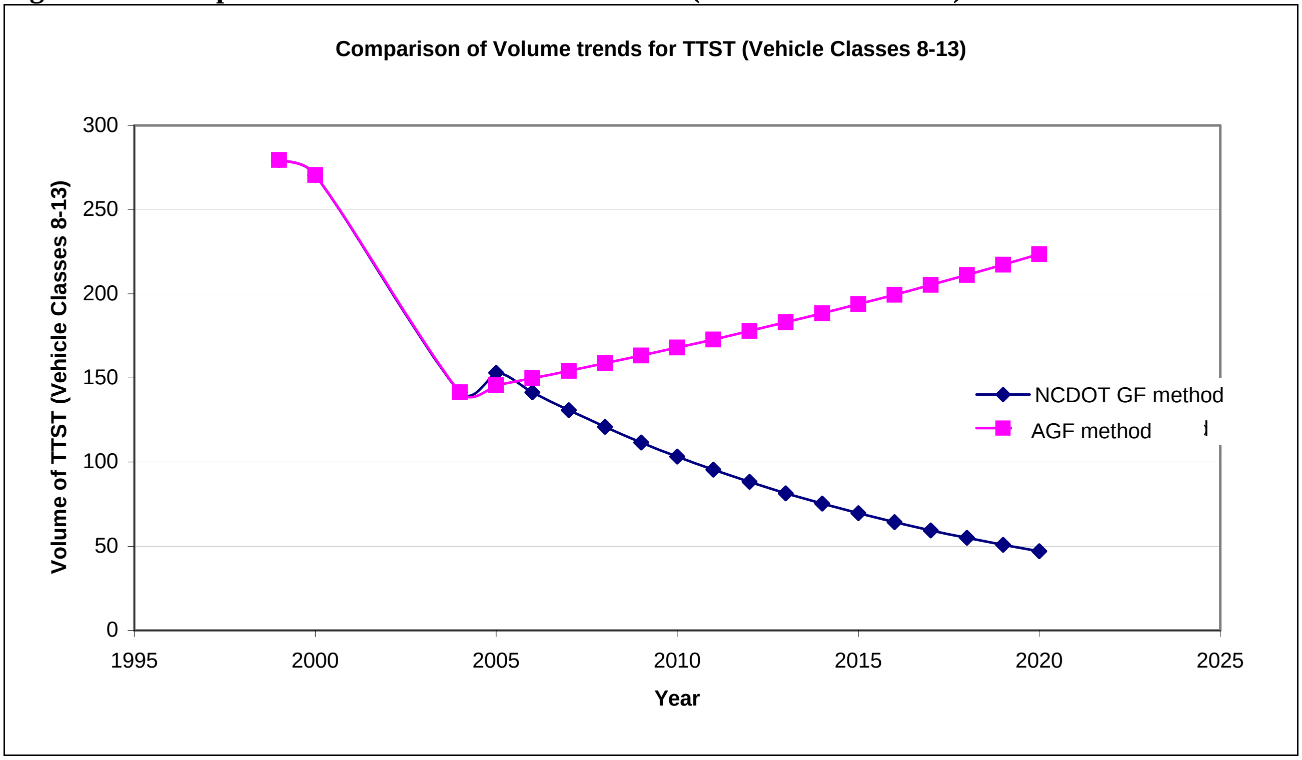


Figure K-6. Comparison of Volume Trends for TTSTs (Vehicle Classes 8-13)



Comparison and Discussion of Results

In order to test the reasonableness of the AGF method, traffic volume trends are plotted for each vehicle category (Cars, Duals and TTSTs) and are shown in Figures J-3 to J-6. A summary of the forecast volumes using both methods is also shown in Table K-6.

Table K-6. Comparison of Traffic Volumes, % Duals and % TTSTs in 2020

Comparison of Traffic Volumes, % Duals and % TTST in 2020						
Method	Cars	Duals	TTST	Total AADT	% Duals	% TTST
Historic GF method	16122	11349	47	27519	41.24%	0.17%
Average GF method	23239	1385	224	24848	5.58%	0.90%

For total traffic in 2020 the NCDOT and AGF methods produce similar results (Figure K-3). The two methods produce quite different results when individual vehicle classes are forecast. The NCDOT method seems to under estimate Cars and TTSTs and over estimate Duals compared to the AGF method. The problem of sparse data (Table K-1) contributes to the conflicting results. Additional study is warranted. However, the AGF method of forecasts has results with lower chances of over or under estimation of vehicle classes because of the confidence interval checks. at the project location. Also as a check, the percentages of Duals and TTSTs in 2020 (Table K-5) are reasonable compared to the base year percentages.

APPENDIX L: USING AVERAGE GROWTH FACTOR AND GIS METHODS TO LOCATE TRUCK STOP ELECTRIFICATION SITES ON I-95

This case study developed from a graduate student project by Elizabeth Harris in CE 501at NC State University. Using truck traffic forecasts with the Average Growth Factor method developed in this research was an important step in the analysis. The analysis was subsequently presented at TRB in 2006. The material is used with the permission of the author.

Introduction

Truck Stop Electrification (TSE) installations along interstate highways in the United States are increasing because TSE addresses numerous problems caused by extended truck idling during mandated truck driver rest periods. Because of the popularity of the "just in time" delivery strategy, every year more trucks travel the interstate highway system. The United States Department of Transportation (USDOT) mandates that every long-haul trucker rest for ten hours following driving for an eleven-hour period. During this rest period, truckers typically go to a public or privately managed rest area and idle their engines in order to keep their fuel warm and/or for climate control and amenities in their cabin while they rest. This idling is noisy, consumes truck fuel, and releases carbon dioxide (CO_2), nitrogen oxides (NOx), carbon monoxide (CO), sulfur dioxide (SO_2), and other pollutants into the local air, affecting the air quality of nearby communities. These impacts have caused several communities and states across the United States to limit truck idling in their jurisdictions.

By electrifying truck stops, truckers can obtain the energy they need to climate control their cabins and run personal appliances while reducing the amount of truck fuel wasted, noise emitted, and pollutants released. Reducing the waste of truck fuel also cuts costs for trucking companies and the businesses that hire them to transport freight. One commonly used TSE installation, the Advanced Travel Center Electrification system provided by IdleAire Technologies Corporation (IdleAire), charges $1.40 an hour for a hookup to electricity and ventilation services. A single trucker's savings from using TSE could be up to $3,000 a year in fuel and other costs *(1)*.

In North Carolina, there is currently only one TSE site, located off Interstate 85/40 at Exit 157 near Mebane, operated by IdleAire. This site opened in October 2004 with approximately 50 TSE bays. The Mebane TSE installation was part of a three-site, 159-bay TSE installation along I-85 in Georgia, South Carolina, and North Carolina *(1)*. There are plans to install another 50-bay TSE site in NC along Interstate 85 (I-85) at Exit 71 in Salisbury, NC for a cost of $900,000 *(2)*. Both the United States Environmental Protection Agency (EPA) and the Northeast States for Coordinated Air Use Management (NESCAUM) are considering additional TSE sites along Interstate 95 (I-95) in NC. Currently, the I-95 corridor is served only by TSE sites in New York and Pennsylvania *(3,4)*.

Scope and Objectives

This study identifies ideal TSE sites along I-95 in North Carolina, with a design year of 2010 for the TSE sites. The geographical scope of this study is limited to the I-95 corridor in NC because the other major interstate corridor, I-85/40, is already served by one TSE site and there is one TSE site planned for 200?. Furthermore, I-95 is a major US north/south route and carries heavy national, long haul truck traffic.

Candidate TSE sites are restricted to privately-owned commercial truck stops because TSE installations have typically been constructed at existing truck stop sites due to the lower installation cost of using existing parking spaces and the available amenities at commercial truck stops. The surplus of private truck stop parking spaces in North Carolina (approximately two private parking spaces for each truck) also encourages considering only existing commercial truck stops, instead of building new truck stops, for TSE *(5)*. There are no local or state anti-idling regulations in NC, and this study assumes IdleAire would administer the TSE site(s) I suggest not over promoting IdleAire *(6)*. IdleAire's TSE sites are well distributed across the United States, their TSE solution requires no costly truck equipment or retrofits, and they already operate a TSE location in NC (Mebane).

The objectives of this TSE site selection study are three-fold. The first objective is to forecast truck traffic at each exit along I-95 in North Carolina to the year 2010. Developing criteria to rank the potential TSE sites along I-95 is the second objective, and the final objective is to use the ranking criteria to identify and rank the TSE sites using Geographic Information Systems (GIS) and spreadsheet analysis.

Analytical Approach

Previous I-95 TSE Site Identification Efforts

NESCAUM and the EPA have previously identified ideal TSE sites along I-95 in North Carolina. NESCAUM ranked TSE sites along I-95 based on the factors listed below *(4)*.

Site Density	Truck stop spaces available within a ten-mile (16.1 km) radius
Usage	Demand/Supply ratio for parking spaces, by state *(5)*
Growth	Percent increase in truck stop parking spaces, by state *(5)*
Critical Mass	Factor includes parking, air quality, usage, and public health risk
Capacity	Parking capacity of the truck stop (approximated from a range)
Ozone	One hour and eight hour ozone attainment in airshed
Census	Population per square mile (2.6 km^2), determined by county
Risk	Public health cancer risk
Regulatory Impetus	Existence of local/state anti-idling regulations

The top ten TSE sites that NESCAUM identified along I-95 in NC are shown in Table L-1. The top ranked TSE site in NC was the Lakewood Travel Center at Exit 168. The NESCAUM ranking factors *usage*, *growth*, and *critical mass* are not applicable to this study because they were developed from statewide data, which would not assist in ranking NC-only truck stops. Also, in this study the population density was obtained at the census block level, not at a county level, since many of the truck stops are in the same county. Regulatory impetus is not relevant to NC because there are no anti-idling regulations at this time in NC. The NESCAUM analysis only used spreadsheets, did not focus on transportation engineering factors such as traffic, and did not utilize GIS analysis. Only the results of the spreadsheet analysis were mapped using GIS and distributed on the web (*4).*

The EPA also produced a list, but no ranking, of potential TSE locations along I-95 in NC *(3)*. No criteria were given for the EPA list. Each truck stop on the EPA list was also included in the NESCAUM analysis. The truck stops identified by the EPA as possible sites for TSE are indicated in bold in Table L-1.

Table L-L-1. NESCAUM Final Ranking of Ideal TSE Locations Along I-95 in NC

State Rank	Truck Stop Name	City	State	Exit #	Parking Capacity
1	**LAKEWOOD TRAVEL CENTER**	Halifax	NC	168	175
2	**TRAVELCENTERS OF AMERICA**	Kenly	NC	106	275
3	**Robin Hood BP Travel Plaza**	Dunn	NC	77	150
4	301 Truck Stop	Fayetteville	NC	52	15
4	**SADLER TRAVEL PLAZA**	Dunn	NC	75	90
4	**M & N TRUCK STOP**	Selma	NC	97	80
4	Speedway 8560 Pilot 58	Pleasant Hill	NC	180	35
5	Minute Man Food Mart #24	Lumberton	NC	22	100
5	**WILCO TRAVEL PLAZA 218**	Kenly	NC	106	150
6	L & L Truck Stop	Selma	NC	101	50

Forecasting Truck Traffic

One factor the NESCAUM rankings did not include was truck traffic past the truck stop location. As truck traffic increases near a truck stop, there is a greater demand for truck parking there, more potential adverse idling impacts, and greater need for TSE. To determine the truck traffic along I-95, the Federal Highway Administration (FHWA) Vehicle Travel Information System (VTRIS) database of truck traffic data was queried to obtain the average annual daily truck traffic and the percent of total annual average daily traffic (AADT) that is trucks (percent trucks) along the I-95 corridor in NC *(7)*.

Along this corridor, there are VTRIS stations with data near Exit 1 at the North Carolina / South Carolina state line and Exit 127 about two-thirds the distance from South Carolina to Virginia . The dataset at Exit 1 was used to represent the percent of trucks from Exits 1-61 and the dataset at Exit 127 was used for Exits 65-181. The percent trucks for Exit 1 in 2004 was 17.2% with an average growth factor of 1.8%, and the percent trucks for Exit 127 in 2003 was 17.3% with an average growth factor of 1.8%. The percent trucks in the base year was then projected using a growth factor model to the year 2010, to give 19.6% percent trucks in 2010 at Exit 1 and 21.7% at Exit 127. It should be noted that the growth factor for Exit 1 was based on only two years of data. Make more data a recommendation for future study.

The average annual daily traffic (AADT) at each exit along I-95 in NC was determined using traffic survey county maps developed by the North Carolina DOT (NCDOT) *(8)*. Maps are available for the years 1999-2003 and display the AADT for both directions on each segment between two exits of I-95. The AADT for each exit was taken to be the average of the segment directly north and directly south of the exit. The 2003 AADT of the intersecting roads at each exit was also recorded for the intersecting road segments east and west of I-95 and averaged to get the intersecting AADT value for each exit.

A growth factor model was used to project the AADT values to the year 2010. An average annual growth factor model was chosen because it did not require intense individual regression analyses of the approximately 60 exits and because a growth factor model is reasonable to predict six to seven years in advance. The AADT values for 1999 were excluded from the average annual growth factor calculations because they were unusually high. (Boom economy in 1999.)The AADT values for 2010 were then multiplied by the percent trucks found from the VTRIS data to get average annual daily truck traffic for 2010 for each exit.

GIS and Spreadsheet Analysis

The next step in the TSE location analysis obtained GIS data layers for census, state and county boundaries, roads and land use. This step also compiled diesel NOx and CO emissions data by county *(9)* and truck stop data from NESCAUM *(4)*. Figure L-1 illustrates a GIS data layer showing the I-95 corridor counties with their respective NOx emissions data.

> The 2010 projected traffic data for each exit, compiled in a spreadsheet, was joined using the GIS application with a GIS data layer of I-95 exits. This step displayed the average annual daily truck traffic forecasted for 2010 at each exit (Figure L-2a). The same procedure was followed with the 2003 intersecting AADT data to map the amount of intersecting traffic at each exit (Figure L-2b). Figure L-2 shows how much truck traffic is expected by 2010 on I-95 and how much intersecting total traffic there is at each exit, which is an additional source of truck traffic at that I-95 exit.

A spreadsheet Table L-of the truck stops and their addresses was geocoded to create a GIS data layer with a point for each truck stop. This truck stop layer also had the attributes of the spreadsheet Table L-including exit number, county, and parking capacity. The traffic, land use type, emissions values, and population density of the local area or exit where each truck stop is located were joined to each truck stop in the attribute Table L-of the truck stops data layer. This resulted in an attribute Table L-with the land use, population density, emissions, 2010 truck traffic, 2003 intersecting traffic, and number of spaces. Next, a one mile (1.6 km) buffer was created along I-95, and those truck stops outside of the buffer were then excluded from the truck stops layer because they would be too far from the interstate to easily attract trucks, leaving only those truck stops within one mile (1.6 km) of I-95. The elimination of truck stops further than one mile (1.6 km) from I-95 and with less than 50 spaces reduced the TSE site candidates to ten truck stops. Greater detail about the analyses used can be obtained from the author.

Ranking TSE Sites

The attribute Table L-of the truck stops GIS data layer was imported into a spreadsheet program in order to rank the ten truck stops based on the following criteria:

- Projected Truck traffic at that location in 2010
- Intersecting 2003 traffic volumes
- Local land use
- Population density by census block in population/mile^2
- County emissions, by county, tons/year NOx released by diesel trucks
- Parking capacity by truck stop, with truck stops with less than 50 spaces eliminated

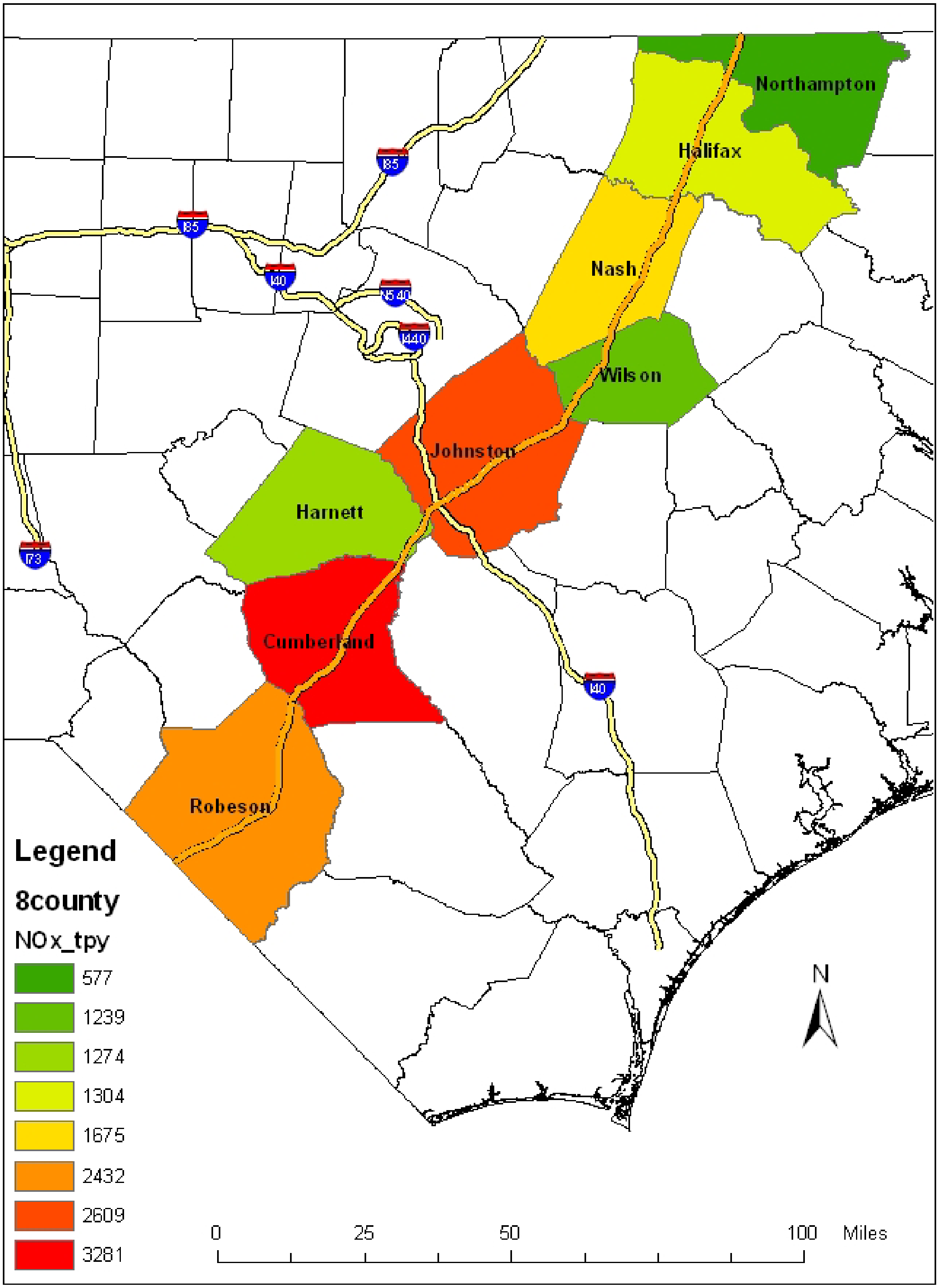
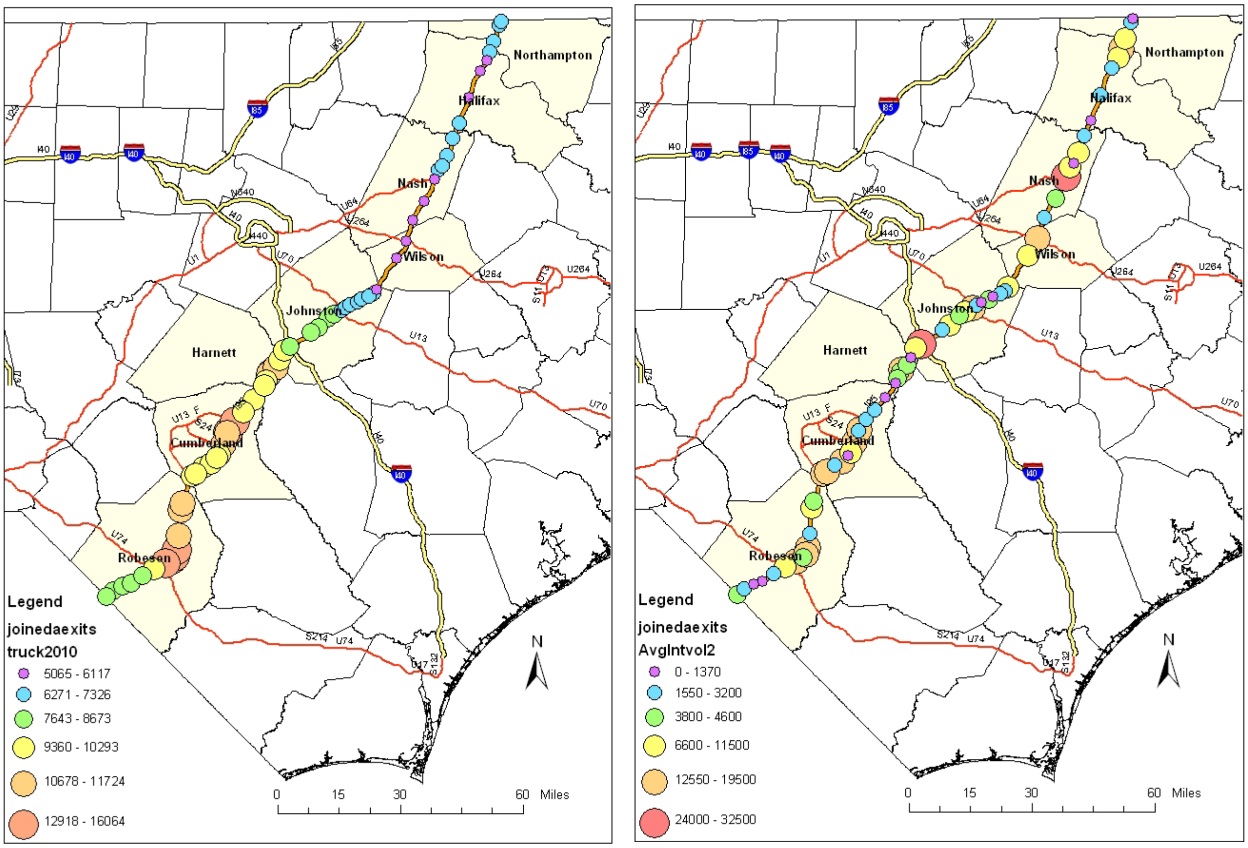


Figure L-L-1. NOx Emissions by County in Tons per Year.



(a) (b)

Figure L-L-2 (a) 2010 forecasted annual average daily truck traffic volumes (both directions) by I-95 exit. (b) 2003 average annual daily traffic intersecting an I-95 exit (both directions).

The requirement that an ideal TSE site would have at least 50 spaces results from IdleAire's minimum requirement of 50 spaces *(10)*, and from the objective of minimizing costs by not building additional truck parking spaces. The NESCAUM criteria and the availability of available data influenced the contents of the ranking criteria. For example, ozone air quality is not monitored in every county in NC, so the ozone values would not be useful in ranking, however, there are detailed emissions data available for each county by type of emission source, such as diesel trucks. In this case, using diesel truck emissions data is more relevant to identifying potential TSE sites than ozone attainment.

After determining the ranking criteria, the criteria were weighted based on the author's opinion of how much each criterion influences a truck stop site being an ideal location for TSE. The ranking Table L-with the weights for the criteria is shown in Table L-2 and the maximum score a truck stop can achieve is 100. (Weights are critical factors that need justification/explanation, citation of previous weight, or a sensitivity study.)

To calculate the final ranking, each truck stop was first ranked within each of the six ranking criteria in Table L-2. For example, the truck stops were ranked by parking capacity by dividing each truck stop parking capacity by the maximum truck stop parking capacity of the ten truck stop sample and then multiplying by 100. These individual criteria rankings were then multiplied by the criteria's weight and summed to obtain the final score. This method was chosen in hopes of keeping the proportional relationships of the truck stops to each other intact. The final rankings of each truck stop are shown in Table L-3.

TABLE L-L-2. RANKING CRITERIA AND WEIGHTS FOR IDEAL TSE LOCATION MODEL

Ranking Criteria	% Weight
2010 forecasted truck traffic	30
Land use	25
Population Density	20
Diesel emissions (Nox)	10
Intersecting traffic volume	10
Parking Capacity	5
TOTAL	100

TABLE L-Table L-L-3. Final Rankings of the Ten Candidate TSE Sites Along I-95 in North Carolina

Rank	Score	Truck Stop Name	City	Exit	Capacity	2010 Truck Traffic
1	70	**Sadler Travel Plaza**	Dunn	75	90	10678
2	68	**Minute Man Food Mart #24**	Lumberton	22	100	13160
3	62	**M & N Truck Stop**	Selma	97	80	7060
4	50	**Robin Hood BP Travel Plaza**	Dunn	77	150	10149
5	49	**L & L Truck Stop**	Selma	101	50	7060
5	49	Speedway/Pilot #55	Dunn	77	75	10149
7	44	**TravelCenters of America**	Kenly	106	275	6432
8	42	**Wilco Travel Plaza 218**	Kenly	106	150	6432
9	39	Big Boy's Truck Stop - Citgo	Kenly	105	100	6429
9	39	**Lakewood Travel Center**	Halifax	168	175	5888

Looking at the NESCAUM rankings, the top-ranked Lakewood truck stop ranked last in this study because traffic data was included. Since Lakewood had low traffic volumes compared to the other truck stops, its score was reduced. The eight truck stops that also were ranked in the top ten of NESCAUM's rankings are indicated in bold type in Table L-3. These eight include all six EPA ideal TSE sites. L & L Truck Stop and Minute Man Food Mart were not EPA candidate TSE sites, but ranked highly in this study, primarily due to nearby high traffic volumes.

Findings, Conclusions and Recommendations

Based on the rankings in Table L-3, the best TSE location along the I-95 corridor in NC is Sadler Travel Plaza (Dunn, NC) at Exit 75 with a score of 70. The Minute Man Food Mart in Lumberton, NC at Exit 22 was the second most ideal TSE location, with a score of 68. (The factor weights would likely change these results, hence, a sensitivity study should at least be called for in the recommendations for future study.) These two locations ranked highly because they have the two largest forecast truck traffic volumes, which had the greatest weight in the rankings. Sadler Travel Plaza is the only truck stop of the ten that is within a residential/urban land use location, and, hence, locating a TSE there will provide the greatest improvement in air quality to nearby people. Also, it is within six miles of the I-40/I-95 interchange and will likely benefit the most truckers. These three factors helped to give it the top ranking. Supporting the results of this study is the consensus between the EPA list, NESCAUM rankings and this study's rankings on six of the sites being "ideal" despite different rankings, criteria, and weights.

The analytical approach of this paper is limited by the quality of the GIS and tabular data used and by the author's choice of ranking criteria and weights (good point). A more intensive investigation into ideal TSE sites would yield more data items to evaluate. And a sensitivity (ok!) study could determine the elasticity of the rankings to the chosen weights. Future refinements to this preliminary study should include additional data on the truck stops including amenities, utilization, and willingness of truck stop operators to have TSE installed. Data collection can also be improved for truck traffic and air quality measures.

Acknowledgements

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APPENDIX M: TRUCK TRAFFIC IMPACTS ON HIGHWAY DESIGN

As a senior at NC State University, Elizabeth Runey developed this appendix as a special short term research project. She worked with the research team and applied highway design and capacity methods to develop a sensitivity analysis of the effects of trucks on highway level of service (LOS). This appendix documents her work, which was funded by the Southeastern Transportation Center.

Introduction

The volume of vehicles on some North Carolina highways continues to rise each year. Furthermore, truck volumes on several of these highways are growing faster than that of passenger vehicles and some experts believe that trucks will almost double in the next ten years. Trucks typically travel at a slower speed than passenger vehicles and occupy more space on the highway. Thus, trucks have a greater influence on the number of lanes than passenger vehicles. Additionally, the number of lanes and the average daily traffic influence free flow speed and level of service on highway segments. As the number of lanes increase, so does the ease at which vehicles can avoid slower traffic. On the other hand, as the AADT increases, vehicle maneuverability decreases. More significantly, increasing truck volumes further enhance congestion and delay if additional lanes are not available for other vehicles.

Scope

This study analyzes the sensitivity of number of lanes to average annual daily traffic (AADT) and to varying percent trucks of total AADT. Also, the study examines the level of service of a roadway with changing AADT and percent trucks. The Highway Capacity Manual (HCM 2000) and Highway Capacity Software (HCS 2000) are used to perform the sensitivity analysis.

The analysis includes:

1. Maximum AADT values for a given number of lanes, percent trucks, and level of service B.
2. Number of lanes for level of service B and varying AADT values and percent trucks.
3. Level of service for a given number of lanes and varying AADT and percent trucks.
4. A case study of I-95 in Johnston County evaluating the number of highway lanes for a given AADT at 2 and 25 percent trucks of total AADT for a level of service A and B.

The number of lanes and the AADT represent the entire freeway segment (both directions of the highway). The numbers of lanes analyzed are 4, 6, and 8 and the percent trucks ranges from 2 to 25 percent. A case study of Interstate 95 is used as part of the analysis. Data for the case study comes from station 215 located just north of Smithfield in Johnston County, NC. In the absence of local data, HCM 2000 standards are used to complete each analysis. Several assumptions are made.

- The desired level of service (LOS) is B
- The peak hour factor (PHF) is 0.9. The HCM 2000 uses a peak hour factor of 0.92 for urban areas and 0.88 for rural areas. Station 215 is located in a suburban area; thus, a peak hour factor of 0.90 is used in the case study.
- The terrain is level
- There are no recreational vehicles
- The driver population factor (fp) is 1
- The peak hour portion of AADT (K) is 0.9
- The peak hour direction proportion (D) is 0.55
- The base free flow speed (BFFS) is 70mph

Analysis

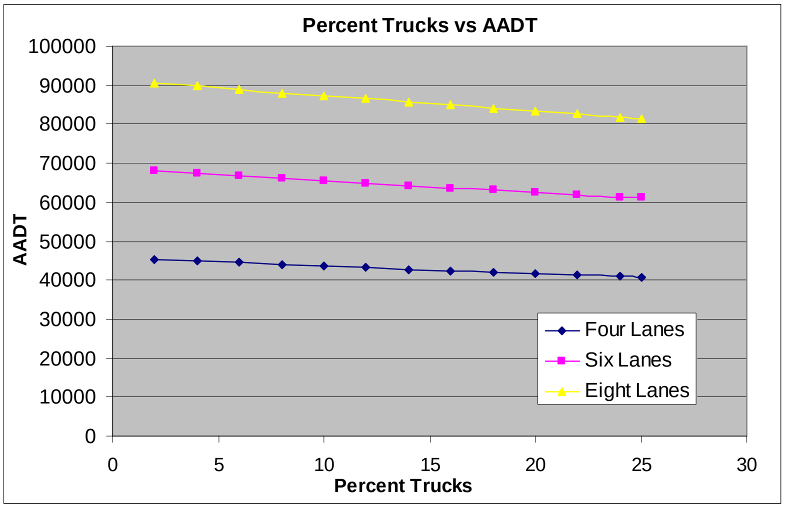
The Highway Capacity Software 2000 program is used to perform basic freeway design analysis. First, the maximum AADT value is found for level of service B and a given number of lanes and percent trucks (Table M-1, Figure M- 1). Second, the required number of lanes is found for a given ADT and percent trucks on a corridor of level of service B (Table M-2, Figure M- 2). Third, the level of service for a corridor is found given a set number of lanes and varying AADT values and percent trucks (Appendix A, Table M-3). Fourth, a case study of I-95 in Johnston County evaluates the number of highway lanes for a given ADT at 5 and 25 percent trucks of total ADT (Table M-4).

In the first step of the analysis, the volume of traffic acceptable for a desired LOS B is found for highways of 4, 6, and 8 lanes with percent trucks ranging from 2 to 25%. The threshold AADT value for a given number of lanes is determined by specifying the percent trucks then entering in AADT values until the number of lanes change. This maximum AADT is rounded to three significant digits and the process is repeated for each percent trucks and then for each number of lanes (Table M-1 and Figure M- 1).

Table M-1: Maximum Average Annual Daily Traffic for LOS B and Percent Trucks

% Trucks	4 lanes	6 lanes	8 lanes
2	45300	68100	90700
4	44900	67400	89800
6	44500	66700	89000
8	44100	66100	88100
10	43600	65500	87300
12	43200	64800	86500
14	42800	64200	85600
16	42400	63600	84900
18	42100	63100	84100
20	41700	62500	83300
22	41300	61900	82600
24	40900	61400	81800
25	40700	61100	81500

Figure M- 1: Maximum AADT for LOS B and Percent Trucks

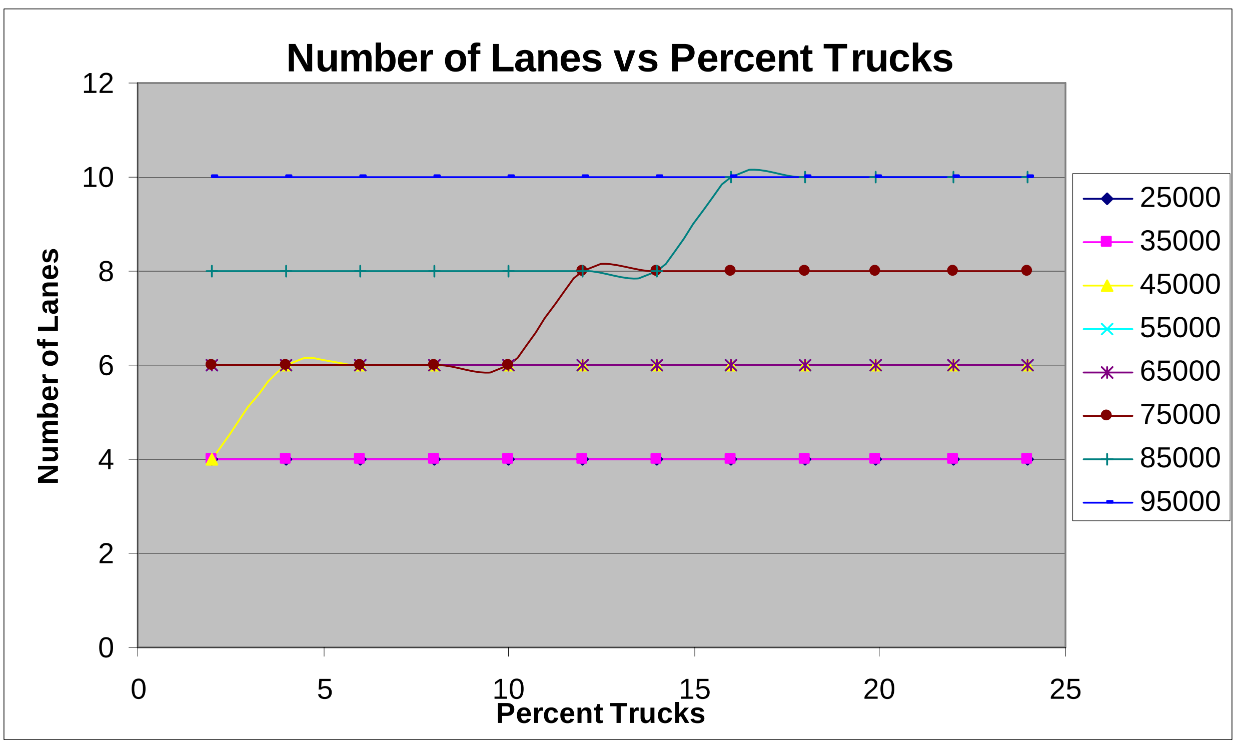


In the second step of the analysis, the number of lanes required for a highway operating at level of service B is found using HCS 2000. Inputting AADT and percent trucks along with the assumed flow rate data and planning data into HCS 2000, the number of lanes is determined. The traffic volumes range from 25,000 to 95,000 vehicles per day and the percent trucks ranges from 2 to 25 percent (Table M-2, Figure M- 2).

Table M-2: Required Number of Lanes for LOS B given AADT and Percent Trucks

% T	25000	35000	45000	55000	65000	75000	85000	95000
2	4	4	4	6	6	6	8	10
4	4	4	6	6	6	6	8	10
6	4	4	6	6	6	6	8	10
8	4	4	6	6	6	6	8	10
10	4	4	6	6	6	6	8	10
12	4	4	6	6	6	8	8	10
14	4	4	6	6	6	8	8	10
16	4	4	6	6	6	8	10	10
18	4	4	6	6	6	8	10	10
20	4	4	6	6	6	8	10	10
22	4	4	6	6	6	8	10	10
24	4	4	6	6	6	8	10	10

Figure M- 2: Number of Lanes given ADT and % Trucks



In the third step of the analysis, the level of service is found for a corridor with a given number of lanes and varying AADT values and percent trucks. For a 4, 6, 8, and 10 lane facility the LOS is determined for AADT values ranging from 25,000 to 95,000 vehicles per day with varying percent trucks from two to twenty five percent. (Appendix A). Table M-3 shows the LOS for each highway facility with an AADT of 55,000 and varying percent trucks.

Table M-3: Level of Service for AADT of 55,000 and Varying Percent Trucks

% T	4	6	8	10
2	C	B	A	A
4	C	B	A	A
6	C	B	B	A
8	C	B	B	A
10	C	B	B	A
12	C	B	B	A
14	C	B	B	A
16	C	B	B	A
18	C	B	B	A
20	C	B	B	A
22	C	B	B	A
24	C	B	B	A
25	C	B	B	A

The fourth step of the analysis shows AADT as a function of number of lanes using a case study of I-95. Average annual daily traffic data from station 215 is used as input for the HCS 2000 planning data. The data ranges from 24,000 to 40,800 and from year 1990 to 2001. Using the assumptions stated above with the AADT data from station 215, the number of lanes is found for the I-95 segment. Furthermore, the numbers of lanes for the case study are evaluated for an AADT of 2 and 25 percent trucks and level of service A and level of service B (Table M-4).

Table M-4: Number of Lanes for I-95 Case Study

YEAR	ADT	LOS A: 2% Trucks	LOS A: 25% Trucks	LOS B: 2% Trucks	LOS B: 25% Trucks
1993	24000	4	4	4	4
1990	26800	4	6	4	4
1991	27400	6	6	4	4
1994	29500	6	6	4	4
1992	30700	6	6	4	4
1996	33800	6	6	4	4
2000	36000	6	6	4	4
2001	36000	6	6	4	4
1995	36100	6	6	4	4
1999	38000	6	8	4	4
1998	40000	8	8	4	4
1997	40800	8	8	4	6

Results

As percent trucks increase, the maximum AADT must decrease to maintain a required level of service. Table M-1 and Figure M- 1 show that as truck percentages increase from 2% to 25% the capacity of traffic on a facility drops around ten percent for a LOS B. For example, if a highway facility of four lanes has two percent trucks, it will carry about 45,000 ADT at LOS B. If trucks grow to twenty five percent then AADT must drop around ten percent to about 40,700 to maintain LOS B. Also, as percent trucks increase, the maximum AADT must decrease more for an eight lane facility rather than a four lane facility to maintain the required LOS. In other words, as the number of lanes increase, there is a larger drop in AADT as trucks grow from two to twenty five percent. For example, as the percent trucks increase from 2 percent to 25 percent, AADT decreases by 10.2% or 9,200 vehicles per day for an eight lane highway and AADT decreases by only 9.5 % or 4,600 vehicles per day for a four lane highway. Decreasing AADT is not likely to occur when truck percentages increase, thus, increases in truck percentages will cause the LOS to get worse.

Table M-2 and Figure M- 2 show that for a constant AADT, additional lanes may be required to maintain a required LOS as the truck percentage increase from two to twenty five percent. More specifically, this data shows that a four lane highway is adequate for ADT of 25,000 and 35,000 for any percent trucks and a six lane highway is adequate for ADT ranging from 45,000 to 65,000 for any percent trucks. When ADT is 75,000 vehicles per day, six lanes are sufficient for percent trucks ranging from 2 to 10 percent but eight lanes are required when the percent trucks are greater than 10 percent. For 85,000 vehicles per day, an eight lane highway is need when percent trucks range from 2 to 14 percent but a ten lane highway is necessary when the percent trucks exceed 14 percent of the total ADT. When the ADT reaches 95,000, a ten lane highway is required for any percent trucks of total ADT. (Table M-5)

Table M-5: Number of Lanes Required for a Specific AADT and Percent Trucks

AADT	LOS B
25000	Four lanes are adequate for LOS B
35000	Four lanes are adequate for LOS B
45000	At % Trucks > 2% six lanes are needed
55000	Six lanes are adequate for LOS B
65000	Six lanes are adequate for LOS B
75000	At % Trucks > 12% eight lanes are needed
85000	At % Trucks > 16% ten lanes are needed
95000	Ten lanes are adequate for LOS B

The analysis of LOS as a function of number of lanes, AADT, and percent trucks showed that increasing the AADT and percent trucks worsens the LOS but as the number of lanes increase the level of service improves. Also, it is more critical for a facility of four lanes to have lower truck percentages than a facility of eight lanes when a certain LOS is to be maintained.

The case study of I-95 in Smithfield, NC shows that a four lane highway is adequate. Six lanes are required when the ADT exceeds 40,800 vehicles per day and has a truck percent of 25. This can be verified by the analysis performed in Table M-1: Maximum Average Daily Traffic for Level of Service B and Varying Percent Trucks

Conclusions

Overall, the number of lanes required for highway design is dependent upon the desired level of service and the volume of trucks on the roadway as a percentage of the average annual daily traffic. As percent trucks of total AADT increase on a highway facility, the number of lanes must increase to provide vehicle maneuverability and flow. This is especially critical for highway facilities with lower number of lanes.

Several other issues can be considered in the sensitivity analysis of number of lanes as a function of average annual daily traffic. The recommendations include:

- Analysis of all desired levels of service
- Case study analysis on a forecast project
- Evaluation for percent trucks of total ADT greater than 25 percent
- Evaluation of capacity constraints on traffic growth

APPENDIX N: TRUCK TRAFFIC IMPACTS ON PAVEMENT DESIGN & COST

Aniruddha Shidhore, candidate for the degree Master of Science of Civil Engineering, prepared this appendix as a student research project. He conducted his work in collaboration with the truck traffic research team. His effort was funded by the Southeastern Transportation Center

Introduction

Trucks cause significant damage to the pavement structures. Depending on the location of the highway, the total amount of traffic increases annually from almost zero to several percent per year. And the truck traffic is often assumed to grow hand in hand with the general traffic, but the national and regional data give us an indication that the truck volumes are increasing at a much higher rate than the total amount of traffic. Hence, it is imperative to know the effect of the variation of truck traffic percentages on pavement design and construction cost. In order to study this effect, a sensitivity analysis of I-95 pavement design to the variation of truck traffic volumes on in terms of cost/linear foot is described in this appendix.

Problem Statement

At present NCDOT conducts forecasts for total traffic and assumes base year and future year truck volume percentages are the same. Yet, truck traffic volume is the major criterion for the design of pavements and bridges and their subsequent maintenance. The designed pavements and bridges must be strong enough and be able to withstand the expected amount of truck traffic. But in recent years it has been observed that the axle weights and the percentage of trucks in the total traffic have increased disproportionately to lighter weight automobiles. Thus, if we assume truck volumes as some percentage of total traffic, there is a greater probability that we would be under-designing the pavements and bridges. This would affect future rehabilitation and maintenance schedules. On the other hand, there have been some reports that pavement designers take into account a factor of safety to compensate for any under-estimates of predicted traffic volumes. Thus, the resulting design could lead to unnecessary waste of money and effort.

Truck traffic volumes in the state of North Carolina have risen by 28 % for the period of 1987-1992. Table N-1 shows increases for 1992-2000. Some professionals in the field of transportation say that truck traffic is going to double for the period of 2000-2010. These factors make the inclusion of truck traffic volumes in the forecast even more critical. Pavement designers are also concerned by the fact that truck percentage in the total traffic have almost doubled in the last decade. Primary routes carrying 8% TTST are now carrying 15% TTST, and Duals percentage has risen from 5% to 8% of the total traffic.

Scope and Objectives

The proposed research project will focus on the effect of consideration of truck traffic volumes in pavement design for I-95 and US-64 routes located in Nash County only. The total traffic volumes and truck percentages used in this analysis are in reference to Legacy stn. # 44 (for I-95) and Legacy stn. # 316 (for US-64). These stations represent highway segments from 1.5 miles south of NC 44 and from NC 58 to SR 1003 for I-95 and US-64 respectively. Trucks in this paper include Duals (FHWA class 4-7) and TTST (FHWA class 7-13).

The analysis is carried out for only three types of flexible pavement constructions (all with soil stabilization):

1. Full depth asphalt pavement,
2. Flexible pavement with Aggregate Base Course (ABC) and
3. Flexible pavement with Cement Treated Aggregate Base Course (CTABC).

The objectives of this study include the following –

- To study the present design procedure of NCDOT from the available pavement design spreadsheet.
- To make sample designs to get the thickness and cost/LF for different percentages of Duals and TTST.
- To develop a sensitivity study of pavement design to the overall thickness of pavement and cost/LF.
- To study the effect of variation of truck traffic percentages to the design thickness and cost/LF.
- To recommend a level of accuracy required in the truck traffic forecast.

Data Sources and Approach

Pavement design is done using the NCDOT design spreadsheet. The NCDOT design spreadsheet is based on AASHTO pavement design methodology. NCDOT Interim Pavement Design Procedure guide is also used for the purpose of design (refer to appendix). The required unit costs for calculating the Cost/LF is obtained from NCDOT (refer appendix Table N- 2).

- Growth factor used for I-95 and US 64 were 5.62 % and 3.92 % respectively.
- The Duals and TTST percent used for analysis are as shown in Table N- 3 (I-95) and Table N- 4 (US 64).
- A planning horizon of 20 years was assumed for both the cases with construction year of 2004 and future year of 2024.
- Number of lanes considered for I-95 and US 64 were 3 and 2 respectively.

The unit costs used in this analysis are from a project whose design length was 10 miles. Hence a design length of 10 miles has been considered in this analysis. This is due to the fact that the unit cost not only depends on type of material but also the quantity of material (larger the quantity lesser the unit cost of that material).

The following design inputs were used:

- Initial year ADT = 56,838 and Projected year ADT = 169,653 (For I-95)
- Initial year ADT = 24,347 and Projected year ADT = 52,532 (For US-64)
- Design life = 20 years
- Directional percentage = 60% in Rural area
- Left side of road – Shoulder, Right side of road – Shoulder

The analysis can be summarized in following steps:

- Present total traffic volumes are found and truck traffic percentages are calculated from the available data.
- Base year and design period for analysis are decided and accordingly future traffic volumes are calculated.

- The selected percentages of Duals and TTST are used as variables in the design analysis keeping the total traffic and the growth rate constant.
- Design is obtained using the NCDOT pavement design spreadsheet for each variation of %Duals-%TTST.
- Care has to be taken that the required Structural Number (SN) does not exceed the Structural Number provided by the design. An increment of 0.25" is used to get the most optimum and economical design.
- Available unit costs are used for the calculation of Cost/LF in the pavement design spreadsheet.
- After conducting repetitive analysis for different percentages of Duals and TTST's, we get Cost/LF which is required for sensitivity analysis. Corresponding ESAL's (Equivalent Single Axle Load) for each variation are also recorded for further analysis. ESAL's are also considered because they are directly related to percentage of truck traffic (More the percentage of trucks, more are the no. of ESAL's).
- Further, the obtained values of ESAL's and Cost/LF for both I-95 and US-64 are merged together and sorted out in ascending order for ease of analysis (refer appendix Table N- 5).
- After obtaining the Cost/LF for each variation, plot of Cost/LF vs. ESAL's is done.
- After conducting the analysis, the results obtained for both the cases were merged to get a composite Chart (Chart N-1) giving us the sensitivity of cost of construction in $/LF with respect to ESAL's over a wide range.

The primary aim of this study was to conduct an analysis of sensitivity of pavement construction cost with respect to "Truck volumes". We are not able to establish this relation directly because of the fact that the NCDOT pavement design spreadsheet had input values of both Duals and TTST's. Hence it is very difficult to convert both these percentages into a segregated truck volume because a different combination of these percentages gives us different values of ESAL's and finally a different design and cost.

To satisfy this deficiency we have to establish a relationship between ESAL's and truck volumes calculated by using certain percentage of Duals or TTST's and keeping a certain constant value of total ADT. The following procedure was adopted:

- A constant ADT value of 10,000 was used.
- One of the two variables (Duals/TTST's) was kept as 0% and the other variable was varied to get the desired truck volume in terms of Duals or TTST.
- ESAL's thus obtained were recorded.

The ESAL's thus obtained were tabulated (Table N- 6 and Table N- 7) and Charts N-3 and Chart N- 4 were plotted with respect to ESAL's versus Duals and TTSTs.

The results found in this analysis can be used by the following steps:

1. Take the input parameters of ADT, Duals % and TTST % from traffic forecasting unit and find out actual volumes of Duals and TTST's.
2. Using these volumes of Duals and TTST's and Chart N-3 or 4 (depending on volume), find out number of ESAL's.
3. Take this ESAL value and apply to Chart N-1. This will give us the cost of construction in $/Linear ft.

Findings

We get three distinct zones (A, B, C) (Chart N-2) which have the following characteristics.

Zone A range – Less than 28.5 million ESAL's
Zone B range – Between 28.5 – 31.5 million ESAL's)
Zone C range – More than 31.5 million ESAL's

In order to get a rough idea of the pavement design for all the three types, three representative designs have been chosen to depict each zone. These depictions can be seen in Chart N- 5 (for Zone A), Chart N- 6 (for Zone B) and Chart N- 7 (for Zone C).

Recommendations

Looking at Chart N- 2 we can infer that sensitivity of cost/LF is the highest in Zone B followed by Zone A and lastly Zone C (thus $B_{sen} > A_{sen} > C_{sen}$). Thus ESAL's $_{(B)}$ are more critical to estimate accurately.

The Chart also denotes the range of ESAL's on the routes which are under consideration. We can see that both Zones A and B fall under the range of US 64. Thus we can conclude that routes carrying mid-range volumes such as US routes are more critical for accurate forecasting than Interstate routes at least for pavement design. This conclusion becomes even more critical as there are many more miles of US-routes than Interstate routes.

Furthermore, Chart N- 2 suggests that if the forecasted traffic in terms of ESAL's falls in the range of Zone B, then engineers should do the traffic forecasting and analysis with greatest accuracy and care. This is due to the fact that even a slight change of traffic would result in significant change in the cost/LF of pavement. More number of traffic counts for each year is also recommended. Secondly, for the forecasted traffic falling in the range of Zones A and C engineers could be more lenient because cost/LF in these zones does not change abruptly with respect to traffic but follows a smooth linear variation.

Future Work

Even though every effort has been made to cover this topic of study to the fullest, there is some scope for future work. This can be listed as follows:

1. This analysis is limited only to a sections of I-95 and US-64 routes in Nash County, which can be extended and a comprehensive study of all the major routes can be done.
2. This analysis is limited to only flexible pavement construction. An analysis which studies sensitivity of rigid pavement design can also be done.
3. NCDOT design spreadsheet uses AASHTO pavement design methodology and has some outdated factors used in it (for example: Soil Support Value (SSV) obtained from CBR value). Instead of using these outdated factors new factors such as Resilient Modulus (MR) can be used. *Furthermore, there is news that AASHTO is coming up with a NEW highway pavement design methodology in the year 2004 and this design could be implemented in the exiting spreadsheet. This implementation could give us a more optimum design. Thus the same study can be done using the NEW AASHTO design methodology.*
4. A study using Mechanistic method of design (Asphalt Institute Method) can also be done.
5. Unit costs of some materials were taken from an adjacent division bid records or from the state average bid records. This may have lead to a more generalized analysis and gave less

reliable results. Similar analysis using accurate unit costs will lead to a more reliable and correct results.

6. This analysis takes into account only the initial construction cost of the pavement and no consideration has been given to the life cycle cost of the pavement. An extensive life cycle cost analysis would lead to a precise and critical result.

Table N- 1

Year	Passenger Vehicles	Duals	TTST	Total	% Passenger Vehicles	% Duals	% TTST	Total truck %
1992	18904	671	3521	23096	81.85	2.90	15.25	18.15
1996	24124	1120	3771	29014	83.14	3.86	13.00	16.86
1998	20768	898	4911	26577	78.14	3.38	18.48	21.86
2000	22805	1361	6136	30303	75.26	4.49	20.25	24.74

Source: WIM data from NCDOT

Table N-2

UNIT, ITEM DESCRIPTION	UNIT COST
SY, LIME TREATED SOIL (SLURRY)	$ 1.50
TON, LIME FOR LIME TREAT SOIL	$ 145.00
TON, STABILIZER AGGREGATE	$ 15.00
TON, AGGREGATE BASE COURSE	$ 12.55
TON, PLT MIX CEM TR BASE COURSE	$ 16.00
TON, PORT CEM FOR PLT MIX CTB	$ 85.00
SY, 7" SOIL CEMENT BASE	$ 1.50
TON, PORT CEM FOR SOIL CEM BASE	$ 85.00
GAL, ASPHALT CURING SEAL	$ 1.30
CY, SHOULDER BORROW	$ 10.33
GAL, PRIME COAT (ON ABC)	$ 1.45
TON, ASPH CEM FOR PLANT MIX PG64-22	$ 170.00
TON, ASPH CEM FOR PLANT MIX PG70-22	$ 203.25
TON, ASPH CEM FOR PLANT MIX PG76-22	$ 346.63
TON, ASPH CONC BASE COUR TYPE B25.0B	$ 40.00
TON, ASPH CONC BASE COUR TYPE B25.0C	$ 30.00
TON, ASPH CONC INTERM COUR TYPE I19.0B	$ 41.00
TON, ASP CONC INTR CRS I19.0C	$ 28.40
TON, ASPH CONC INTERM COUR TYPE I19.0D	$ 31.60
TON, ASP CONC SURF CRS S9.5A	$ 70.00
TON, ASPH CONC SURF COUR TYPE S9.5B	$ 37.00
TON, ASP CONC SURF CRS S12.5C	$ 28.60
TON, ASP CONC SURF CRS S12.5D	$ 34.00
SY, ASPH SURF TR, MT COAT #5 STN	$ 5.00
LF, SHOULDER DRAIN	$ 9.00
LF, 4" SHOULDER DRAIN PIPE	$ 1.30

Source: www.doh.dot.state.nc.us/preconstruct/highway/dsn_srvc/contracts/, "Bid Averages and Pay Item List", 2003 - 6 month Bid Averages

Table N- 3

Distribution of Duals and TTST for I-95

	TTST(% AADT)			Total Truck %		
Ratio (Duals:TTST)	1.0:3.5	1.0:4.0	1.0:4.5	1.0:3.5	1.0:4.0	1.0:4.5
Duals(% AADT)						
3.0	10.50	12.00	13.50	13.50	15.00	16.50
3.5	12.25	14.00	15.75	15.75	17.50	19.25
4.0	14.00	16.00	18.00	18.00	20.00	22.00
4.5	15.75	18.00	20.25	20.25	22.50	24.75
5.0	17.50	20.00	22.50	22.50	25.00	27.50

Table N- 4

Distribution of Duals and TTST for US 64

	TTST(% AADT)			Total Truck %		
Ratio (Duals:TTST)	1.0:3.0	1.0:3.5	1.0:4.0	1.0:3.0	1.0:3.5	1.0:4.0
Duals(% AADT)						
3.0	9.00	10.50	12.00	12.00	13.50	15.00
3.5	10.50	12.25	14.00	14.00	15.75	17.50
4.0	12.00	14.00	16.00	16.00	18.00	20.00
4.5	13.50	15.75	18.00	18.00	20.25	22.50
5.0	15.00	17.50	20.00	20.00	22.50	25.00

Table N- 5

18 kip ESAL's	Full Depth Asphalt	Aggregate base course	Cement soil stabilization
	Cost/LF	Cost/LF	Cost/LF
18,758,807	286.60	264.07	295.26
18,975,672	286.60	264.07	295.27
21,252,752	291.32	269.83	297.83
21,686,482	296.04	269.83	300.42
21,885,275	296.04	269.83	300.42
24,397,292	300.78	275.64	303.01
24,794,878	300.78	275.64	303.01
25,011,743	300.78	275.64	303.01
27,108,102	305.52	279.54	305.60
28,138,210	305.52	281.50	308.21
28,337,003	305.52	281.50	308.21
31,264,678	319.54	294.71	320.09
31,879,129	319.54	294.71	322.71
35,421,254	324.31	300.66	325.33
46,935,020	337.75	318.74	348.87
53,174,936	347.32	324.62	354.12
54,757,523	347.32	324.62	354.12
59,414,851	352.12	328.57	356.76
62,037,425	352.12	330.56	359.41
62,580,026	352.12	330.56	359.41
69,317,327	361.74	336.54	362.06
70,402,529	361.74	336.54	362.06
70,899,914	361.74	336.54	362.06
78,225,033	366.57	340.57	367.38
79,219,802	366.57	340.57	367.38
79,762,403	366.57	342.59	367.38
88,624,893	371.41	346.65	372.73
89,122,277	371.41	346.65	372.73
99,024,752	376.25	352.78	375.42

Table N- 6

For I-95

(Note: Values in cells represent ESAL's)

		DUALS										
	Volume	**2000**	**2100**	**2200**	**2300**	**2400**	**2500**	**2600**	**2700**	**2800**	**2900**	**3000**
	5000	22,266,753	22,371,951	22,477,148	22,582,345	22,687,542	22,792,740	22,897,937	23,003,134	23,108,331	23,213,529	23,318,726
	5250	23,274,894	23,380,091	23,485,288	23,590,485	23,695,683	23,800,880	23,906,077	24,011,274	24,116,472	24,221,669	24,326,866
	5500	24,283,034	24,388,231	24,493,429	24,598,626	24,703,823	24,809,020	24,914,218	25,019,415	25,124,612	25,229,809	25,335,007
	5750	25,291,174	25,396,372	25,501,569	25,606,766	25,711,964	25,817,161	25,922,358	26,027,555	26,132,753	26,237,950	26,343,147
	6000	26,299,315	26,404,512	26,509,709	26,614,907	26,720,104	26,825,301	26,930,498	27,035,696	27,140,893	27,246,090	27,351,287
	6250	27,307,455	27,412,653	27,517,850	27,623,047	27,728,244	27,833,442	27,938,639	28,043,836	28,149,033	28,254,231	28,359,428
	6500	28,315,596	28,420,793	28,525,990	28,631,187	28,736,385	28,841,582	28,946,779	29,051,977	29,157,174	29,262,371	29,367,568
	6750	29,323,736	29,428,933	29,534,131	29,639,328	29,744,525	29,849,722	29,954,920	30,060,117	30,165,314	30,270,511	30,375,709
	7000	30,331,877	30,437,074	30,542,271	30,647,468	30,752,666	30,857,863	30,963,060	31,068,257	31,173,455	31,278,652	31,383,849
	7250	31,340,017	31,445,214	31,550,411	31,655,609	31,760,806	31,866,003	31,971,200	32,076,398	32,181,595	32,286,792	32,391,990
TTST	**7500**	32,348,157	32,453,355	32,558,552	32,663,749	32,768,946	32,874,144	32,979,341	33,084,538	33,189,735	33,294,933	33,400,130
	7750	33,356,298	33,461,495	33,566,692	33,671,890	33,777,087	33,882,284	33,987,481	34,092,679	34,197,876	34,303,073	34,408,270
	8000	34,364,438	34,469,635	34,574,833	34,680,030	34,785,227	34,890,424	34,995,622	35,100,819	35,206,016	35,311,213	35,416,411
	8250	35,372,579	35,477,776	35,582,973	35,688,170	35,793,368	35,898,565	36,003,762	36,108,959	36,214,157	36,319,354	36,424,551
	8500	36,380,719	36,485,916	36,591,113	36,696,311	36,801,508	36,906,705	37,011,902	37,117,100	37,222,297	37,327,494	37,432,692
	8750	37,388,859	37,494,057	37,599,254	37,704,451	37,809,648	37,914,846	38,020,043	38,125,240	38,230,437	38,335,635	38,440,832
	9000	38,397,000	38,502,197	38,607,394	38,712,592	38,817,789	38,922,986	39,028,183	39,133,381	39,238,578	39,343,775	39,448,972
	9250	39,405,140	39,510,337	39,615,535	39,720,732	39,825,929	39,931,126	40,036,324	40,141,521	40,246,718	40,351,915	40,457,113
	9500	40,413,281	40,518,478	40,623,675	40,728,872	40,834,070	40,939,267	41,044,464	41,149,661	41,254,859	41,360,056	41,465,253
	9750	41,421,421	41,526,618	41,631,815	41,737,013	41,842,210	41,947,407	42,052,605	42,157,802	42,262,999	42,368,196	42,473,394
	10000	42,429,561	42,534,759	42,639,956	42,745,153	42,850,350	42,955,548	43,060,745	43,165,942	43,271,139	43,376,337	43,481,534

Table N- 7

For US-64

(Note: Values in cells represent ESAL's)

		DUALS										
	Volume	**1000**	**1100**	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**
	2500	12,525,049	12,643,396	12,761,743	12,880,089	12,998,436	13,116,783	13,235,130	13,353,477	13,471,824	13,590,171	13,708,518
	2750	13,659,207	13,777,554	13,895,901	14,014,247	14,132,594	14,250,941	14,369,288	14,487,635	14,605,982	14,724,329	14,842,676
	3000	14,793,365	14,911,712	15,030,058	15,148,405	15,266,752	15,385,099	15,503,446	15,621,793	15,740,140	15,858,487	15,976,834
	3250	15,927,523	16,045,870	16,164,216	16,282,563	16,400,910	16,519,257	16,637,604	16,755,951	16,874,298	16,992,645	17,110,992
	3500	17,061,681	17,180,027	17,298,374	17,416,721	17,535,068	17,653,415	17,771,762	17,890,109	18,008,456	18,126,803	18,245,150
	3750	18,195,838	18,314,185	18,432,532	18,550,879	18,669,226	18,787,573	18,905,920	19,024,267	19,142,614	19,260,961	19,379,308
	4000	19,329,996	19,448,343	19,566,690	19,685,037	19,803,384	19,921,731	20,040,078	20,158,425	20,276,772	20,395,119	20,513,466
	4250	20,464,154	20,582,501	20,700,848	20,819,195	20,937,542	21,055,889	21,174,236	21,292,583	21,410,930	21,529,277	21,647,624
	4500	21,598,312	21,716,659	21,835,006	21,953,353	22,071,700	22,190,047	22,308,394	22,426,741	22,545,088	22,663,435	22,781,782
	4750	22,732,470	22,850,817	22,969,164	23,087,511	23,205,858	23,324,205	23,442,552	23,560,899	23,679,246	23,797,593	23,915,939
TTST	**5000**	23,866,628	23,984,975	24,103,322	24,221,669	24,340,016	24,458,363	24,576,710	24,695,057	24,813,404	24,931,751	25,050,097
	5250	25,000,786	25,119,133	25,237,480	25,355,827	25,474,174	25,592,521	25,710,868	25,829,215	25,947,562	26,065,908	26,184,255
	5500	26,134,944	26,253,291	26,371,638	26,489,985	26,608,332	26,726,679	26,845,026	26,963,373	27,081,720	27,200,066	27,318,413
	5750	27,269,102	27,387,449	27,505,796	27,624,143	27,742,490	27,860,837	27,979,184	28,097,531	28,215,877	28,334,224	28,452,571
	6000	28,403,260	28,521,607	28,639,954	28,758,301	28,876,648	28,994,995	29,113,342	29,231,689	29,350,035	29,468,382	29,586,729
	6250	29,537,418	29,655,765	29,774,112	29,892,459	30,010,806	30,129,153	30,247,500	30,365,846	30,484,193	30,602,540	30,720,887
	6500	30,671,576	30,789,923	30,908,270	31,026,617	31,144,964	31,263,311	31,381,657	31,500,004	31,618,351	31,736,698	31,855,045
	6750	31,805,734	31,924,081	32,042,428	32,160,775	32,279,122	32,397,469	32,515,815	32,634,162	32,752,509	32,870,856	32,989,203
	7000	32,939,892	33,058,239	33,176,586	33,294,933	33,413,280	33,531,626	33,649,973	33,768,320	33,886,667	34,005,014	34,123,361
	7250	34,074,050	34,192,397	34,310,744	34,429,091	34,547,438	34,665,784	34,784,131	34,902,478	35,020,825	35,139,172	35,257,519
	7500	35,208,208	35,326,555	35,444,902	35,563,249	35,681,595	35,799,942	35,918,289	36,036,636	36,154,983	36,273,330	36,391,677

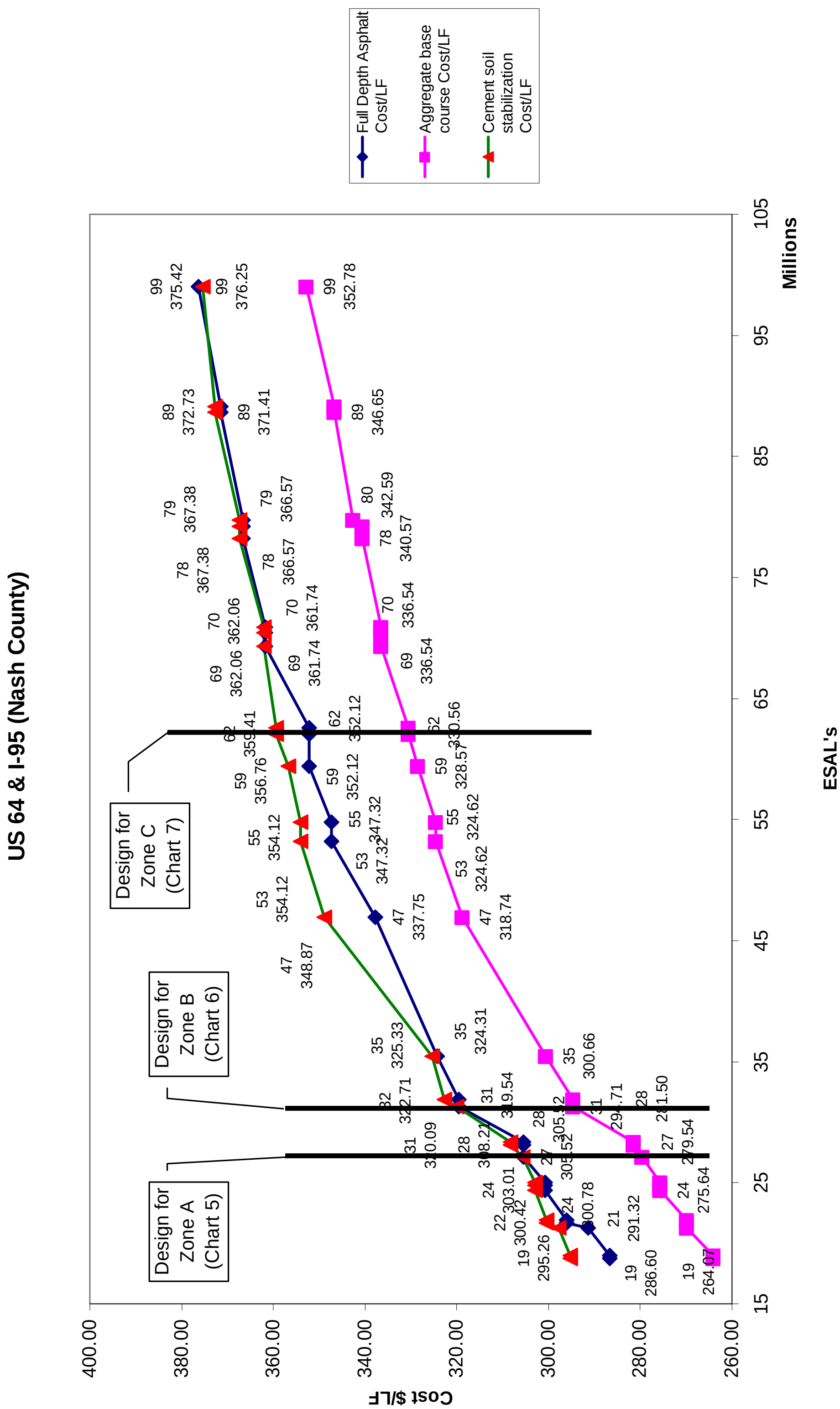

US 64 & I-95 (Nash County)
Cost $/LF
ESAL's
Millions
Full Depth Asphalt Cost/LF
Aggregate base course Cost/LF
Cement soil stabilization Cost/LF
Design for Zone A (Chart 5)
Design for Zone B (Chart 6)
Design for Zone C (Chart 7)

Chart N- 1

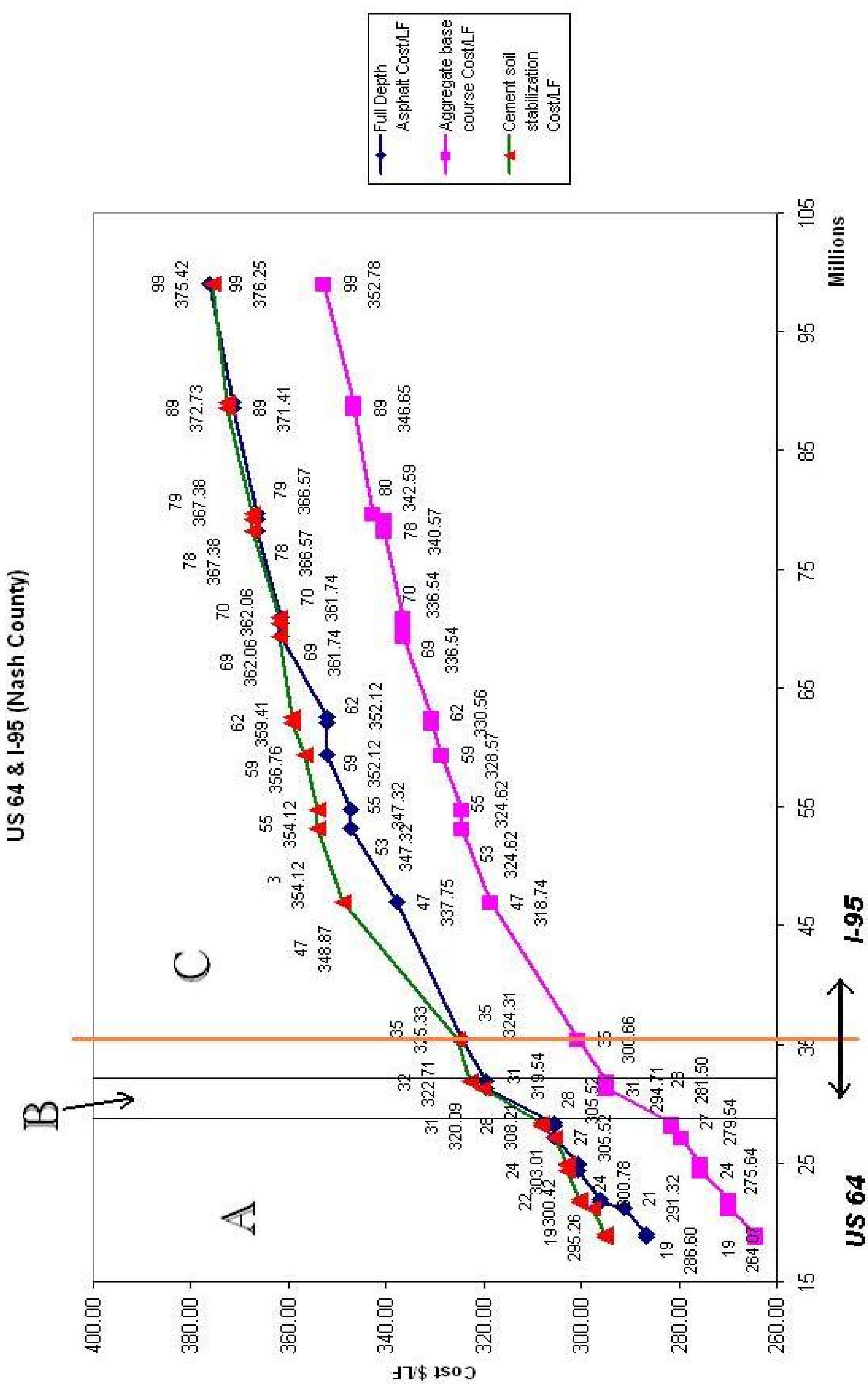

US 64 & I-95 (Nash County)
Full Depth Asphalt Cost/LF
Aggregate base course Cost/LF
Cement soil stabilization Cost/LF
Cost $/LF
ESAL's
Millions
A
B
C
US 64
I-95

Chart N- 2

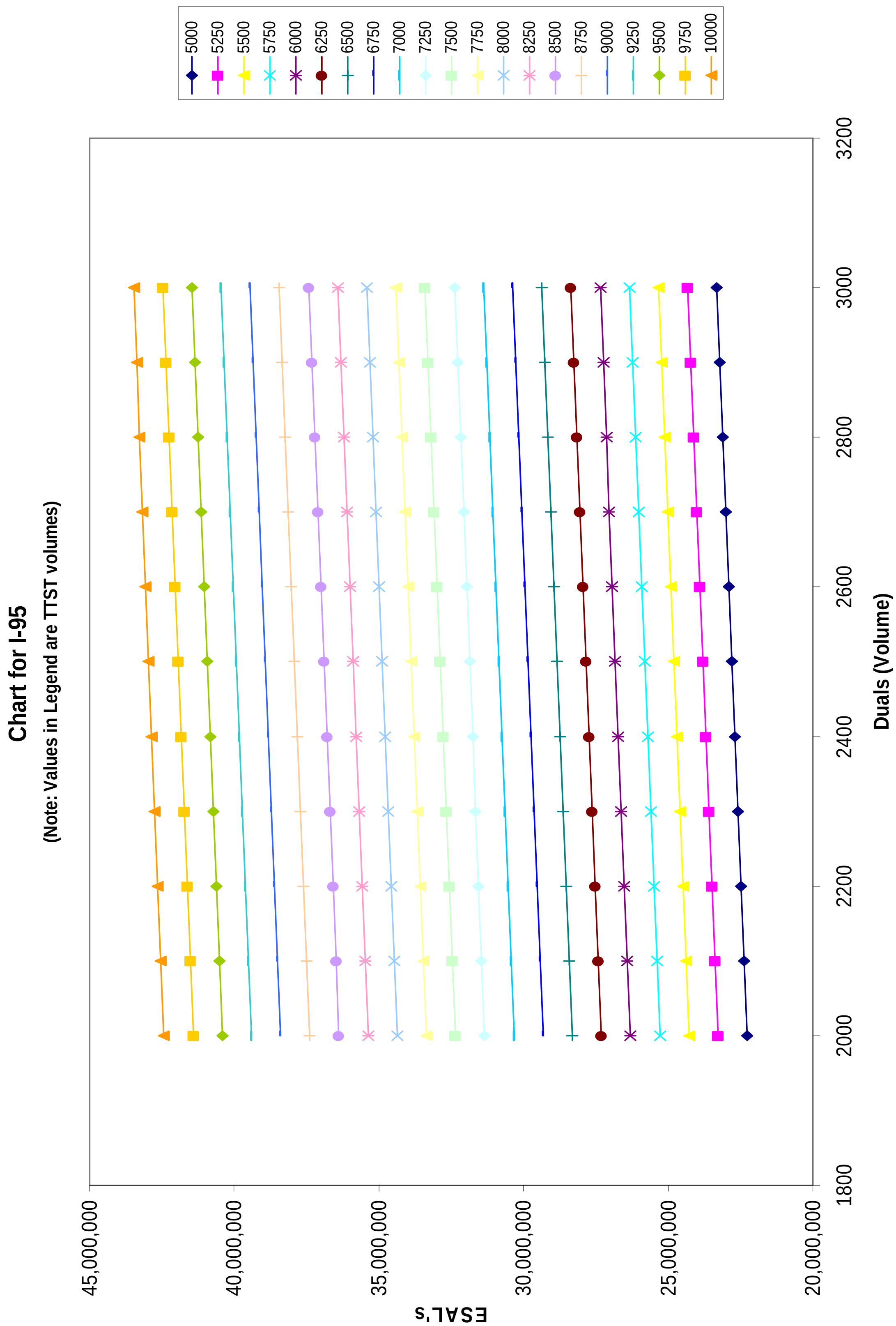


Chart for I-95
(Note: Values in Legend are TTST volumes)
ESAL's
45,000,000
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
Duals (Volume)
1800
2000
2200
2400
2600
2800
3000
3200
5000
5250
5500
5750
6000
6250
6500
6750
7000
7250
7500
7750
8000
8250
8500
8750
9000
9250
9500
9750
10000

Chart N- 3

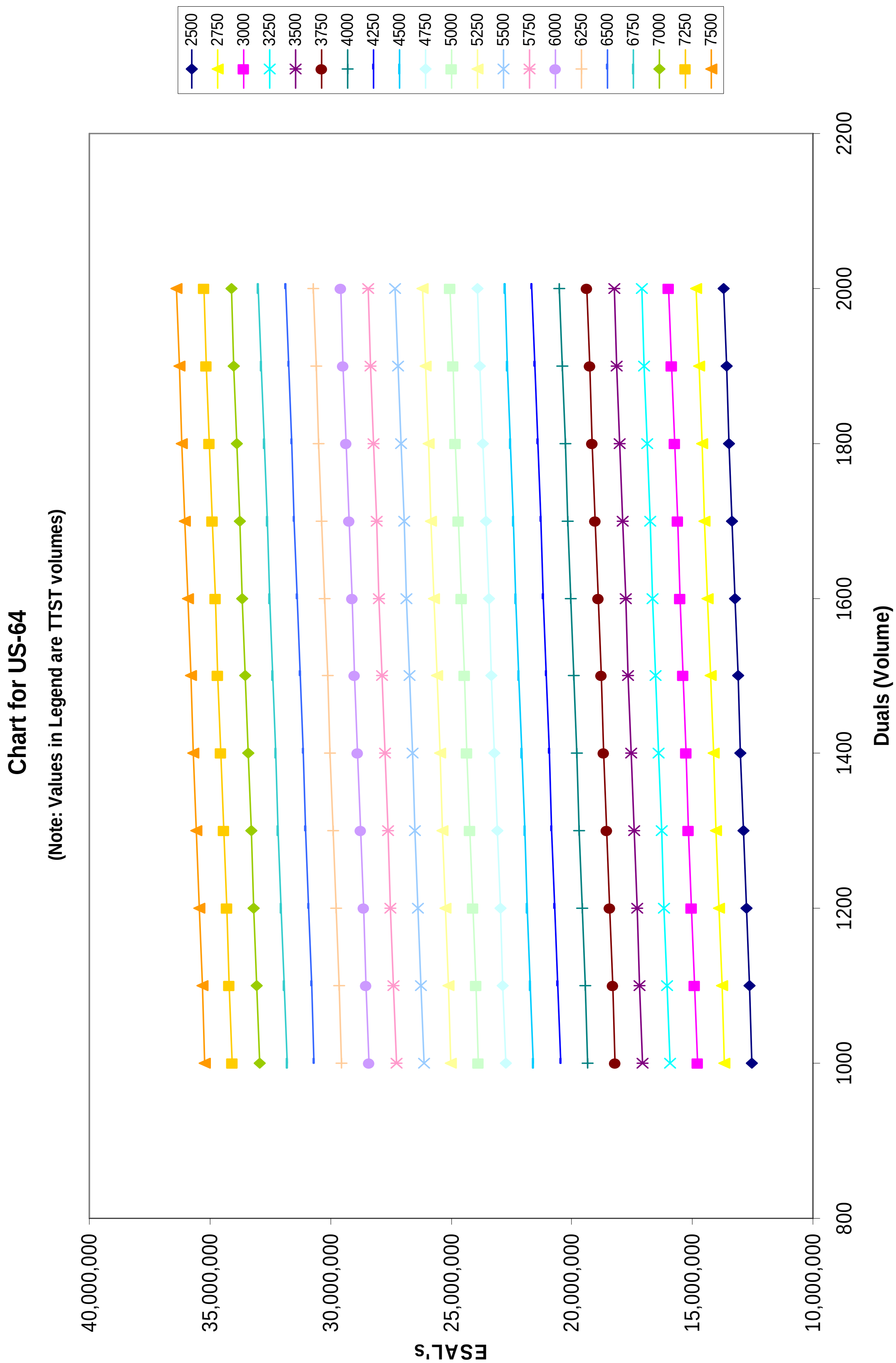


Chart for US-64
(Note: Values in Legend are TTST volumes)
ESAL's
40,000,000
35,000,000
30,000,000
25,000,000
20,000,000
15,000,000
10,000,000
Duals (Volume)
800
1000
1200
1400
1600
1800
2000
2200
2500
2750
3000
3250
3500
3750
4000
4250
4500
4750
5000
5250
5500
5750
6000
6250
6500
6750
7000
7250
7500

Chart N- 4

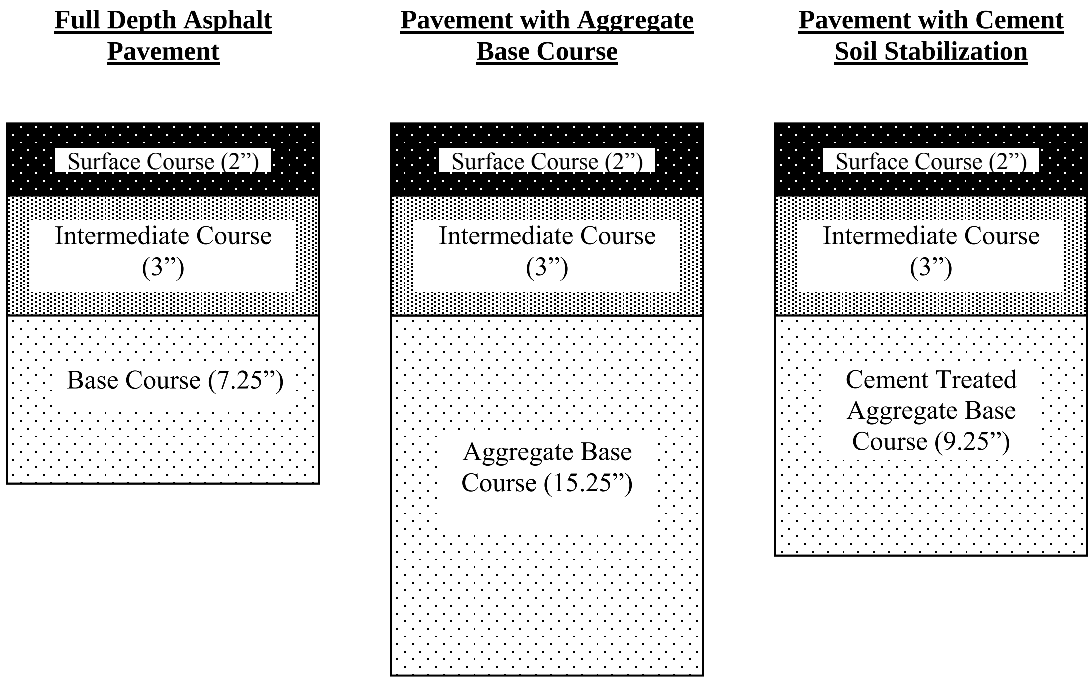


Chart N- 5

Pavement Design for Zone A

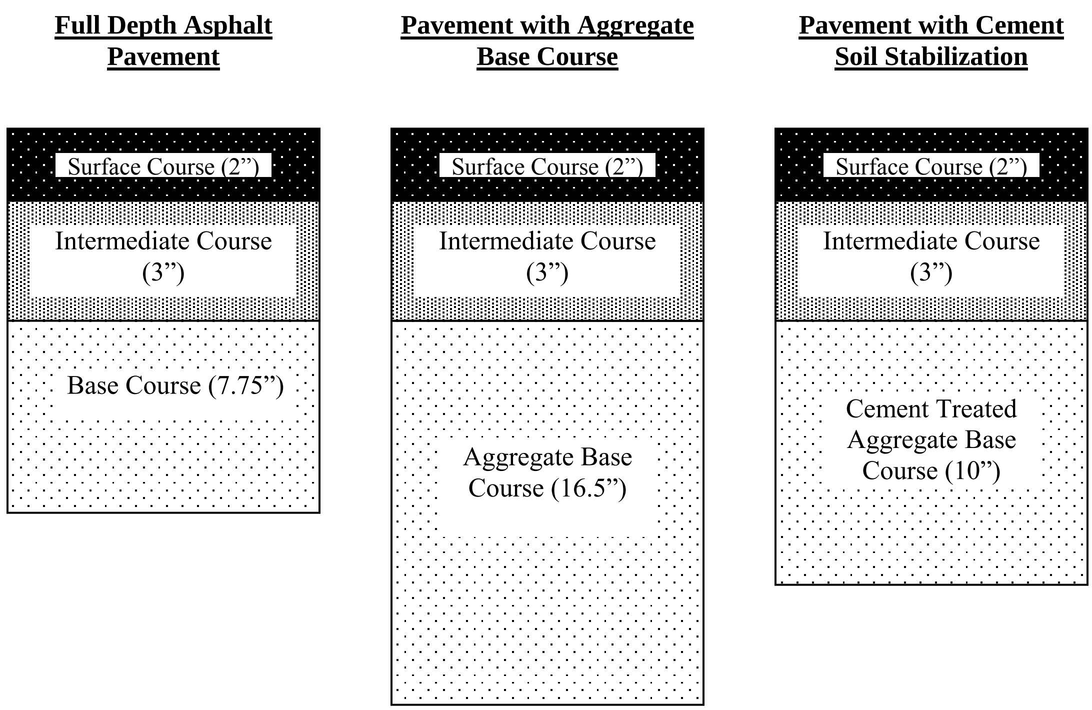


Chart N- 6

Pavement Design for Zone B

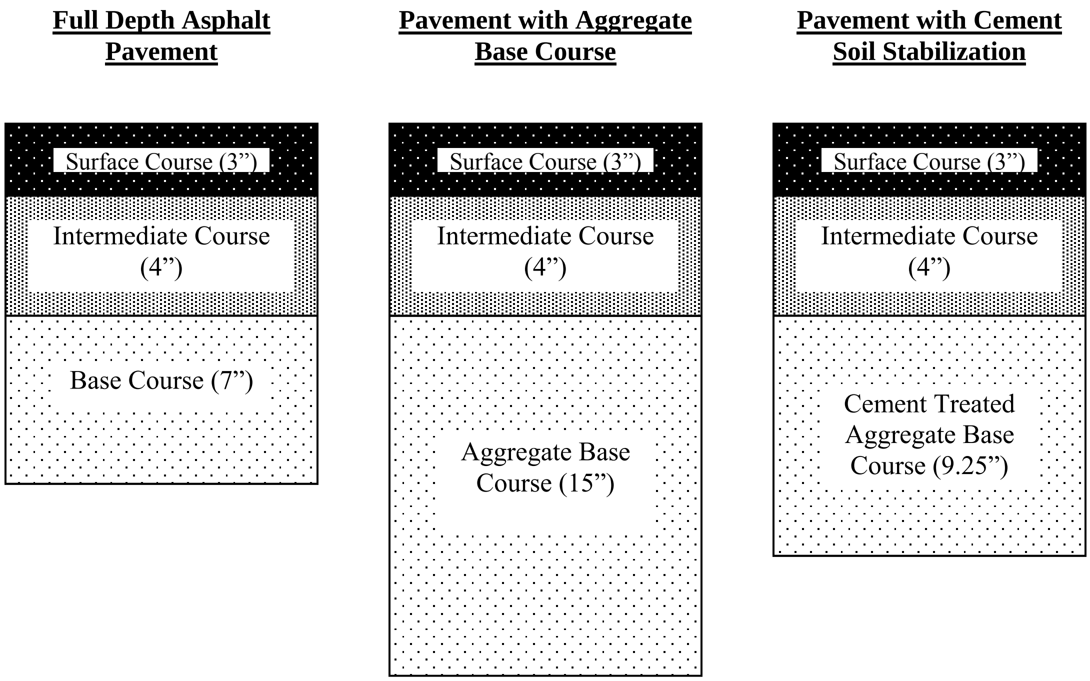


Chart N- 7
Pavement Design for Zone C