Development of Typical Truck Trip Profiles for Rural and Urban North Carolina

NCDOT Project HWY 2007-05

by

George F. List, Ph.D., P.E.
Professor

John R. Stone, Ph.D.
Professor

Alixandra Demers, Ph.D.
Research Assistant Professor

Department of Civil, Construction, and Environmental Engineering
North Carolina State University

for

Pavement Management Unit
North Carolina Department of Transportation

September 2009

<table>
<tr><td>Report No.
FHWA/NC/2007-05</td><td>Government Accession No.</td><td>Recipient's Catalog No.</td></tr>
<tr><td colspan="2" rowspan="2">Title and Subtitle:
Development of Typical Truck Trip Profiles
for Rural and Urban North Carolina</td><td>Report Date
September 2009</td></tr>
<tr><td>Performing Organization Code</td></tr>
<tr><td colspan="2">Author(s)
G.F. List, J.R. Stone, A. Demers</td><td>Performing Organization Report No</td></tr>
<tr><td colspan="2" rowspan="2">Performing Organization Name and Address
Department of Civil, Construction & Environmental Engineering,
NC State University, Raleigh NC 27695-7908</td><td>Work Unit No. (TRAIS)</td></tr>
<tr><td>Contract or Grant No.</td></tr>
<tr><td colspan="2" rowspan="2">Sponsoring Agency Name and Address
North Carolina Department of Transportation
Research and Analysis Group
1549 Mail Service Center
Raleigh, North Carolina 27699</td><td>Type of Report and Period Covered
Final Report
July 1, 2006 - September 30, 2008</td></tr>
<tr><td>Sponsoring Agency Code
NCDOT Project HWY 2007-05</td></tr>
<tr><td colspan="3">Supplementary Notes:</td></tr>
<tr><td colspan="3">Abstract: The purpose of this project is to describe the character (profiles) of the truck traffic that travels a wide selection of highways in North Carolina. Such information can be used to evaluate a variety of issues in planning, design, operations and policy. The research approach used a variety of data sources including: NCDOT WIM data, LTPP data, special 48-hour classification counts at selected urban and rural highways (especially low volume State Route (SR) highways), all overweight truck permits for year 2006, and NC truck network model estimates validated at the $R^2 = 0.92$ level by 472 ground counts. Analysis of the data yielded the following products: (1) a review of current truck flow estimation processes in North Carolina; (2) tabular information regarding vehicle weights and distances traveled on specific road classes; (3) a database that includes truck traffic profiles for urban and rural areas by NC region, vehicle classifications, weights, trip lengths, and highway types; (4) permitted overweight truck traffic profiles on three major interstates; (5) frequency of use of permitted overweight trucks on the top 10 highways by functional classification; and (6) truck traffic on a wide selection of State Routes near truck generators. Overall the research provided valuable information for pavement design, transportation planning and policy. Key recommendations are (a) NC DOT needs to keep enhancing its truck network model; it is an excellent method way to estimate VMT for the state and forecast rural truck traffic. Relying on the 48-hour short counts, and statistical inference, is mandated and helpful. (b) NC DOT should continue its quality control efforts related to the WIM datasets. And (c) It would be highly advantageous if the overweight permitting database was more regimented in the way it records the routes used by overweight trucks. Using GIS methods would be very helpful to plan and evaluate overweight permitted routes.</td></tr>
<tr><td>Key Words
Truck traffic, transportation planning</td><td colspan="2">Distribution Statement</td></tr>
<tr><td>Security Classif. (of this report) Unclassified</td><td>Security Classif. (of this page) Unclassified</td><td>No. of Pages 187 | Price</td></tr>
</table>

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

Disclaimer

Preface

This report contains the results of the NC Department of Transportation research project *Development of Typical Truck Trip Profiles for Rural and Urban North Carolina* (HWY 2007-05). The goal of this project is to describe the character (profile) of the truck traffic that travels a wide selection of highways in North Carolina. Such information can be used to define and illuminate a variety of issues in planning, design, operations, and policy.

Chapter 1 of this report defines the NCDOT needs and issues related to the research problem and research objectives and challenges. Chapter 1 also reflects on similar research conducted elsewhere and describes likely research results and expectations in terms of graphical depictions of truck traffic profiles and flows.

Chapter 2 of this report provides a review of current relevant literature that defines the need and structure of truck traffic profiles. The emphasis of Chapter 2 is on a review of methodologies to develop truck traffic profiles.

Chapter 3 represents the initial phases of data collection. Available data sources are identified and compared to data requirements in order to assess what additional data must be obtained. Data issues are identified.

Chapter 4 includes a brief discussion of the research methodology which is then expanded upon in the following chapters. It includes a discussion of how three NCDOT projects related to truck flows were tied together followed by an overview of the research.

Chapter 5 covers the approach for determining truck traffic profiles that is currently applied by NCDOT. A discussion of data, methods, and performance measures is presented. Both typical truck traffic and overweight vehicles are mentioned.

Chapter 6 produces the first set of results – that of truck traffic vehicle miles traveled by region and highway functional class. It has a summary discussion of the NCDOT Truck Network Model (HWY 2006-09) project to guide the reader through the details of the modeling approach; how the network was created; how traffic flows were estimated, calibrated, and validated; and finally results and findings.

Chapter 7 draws on the results of the previous chapter as well as the NCDOT MEPDG Traffic Data Project (HWY 2008-11) to develop graphs of the gross vehicle weights impacting each region of NC.

Chapter 8 pulls on the data source of overweight permits to enable an understanding of where these vehicles most frequently travel. Three key corridors were examined (I-40, I-77, and I-95) as well as a more general look at one year of data for the entire state.

Chapter 9 extends the knowledge learned so far by concentrating on the traffic characteristics of NC state route (SR) roadways. Data were collected at 34 sites across the state and then compared to the weigh-in-motion station data to draw conclusions as to whether SR routes have higher or lower frequencies of trucks of classes 4 to 13.

Chapter 10 has a summary of the findings for this project followed by Chapter 11 which identifies the references used in this report. Finally, Chapter 12 is the appendices.

Acknowledgements

The NCSU research team would like to express its sincere gratitude to Kent Taylor of NCDOT for assisting us in collecting and organizing truck counts. We further want to thank undergraduate and graduate students who have assisted in a variety of capacities: undergraduate Civil Engineering student Donald Katz: UNC-CH graduate students Caitlin Boon, and Corey Bell; graduate Civil Engineering students Barath Paladugu, Ilhyoung Shin, Aditya N. Ramachandran, and Fatemeh Sayyadi. Finally, we express our appreciation to our 2007 summer intern from Switzerland, Christoph Knellsworth.

[This page has been intentionally left blank.]

Executive Summary

Problem

Truck flows are fundamentally a reflection of the need to move freight from points of supply to points of demand. Truck highway use patterns (e.g., truck miles by class of truck and highway) are then the outcome from moving commodities from origins to destinations using specific types of trucks across paths in the North Carolina highway network. Before this research project, what NCDOT knew about truck trip-making patterns was captured in documents like those submitted to the legislature regarding the impacts of overweight and/or oversized trucks. The reports describe estimates of truck vehicle miles traveled (VMT) by truck weight class and highway functional class statewide. However, accurate estimates of truck travel by highway classification in NC regions and counties is difficult and the subject of this research. The results of this research will support, for example, requests from the NC Legislature to provide information on the cost of overweight vehicles on the pavement system and the equity of overweight exemptions. Further, the results of this research will be helpful to plan for highway improvement projects, especially involving truck traffic. Such projects include pavement maintenance and design, bridge replacement and design, and truck traffic detours around highway projects. The results also support location of traffic sensors, weigh stations and enforcement activities.

Scope and Objectives

This project provides profiles of truck traffic throughout North Carolina based on data from many specific highway locations where there are truck traffic counters, weight sensors, and axle counters. Tables and charts for major North Carolina regions (Coastal, Piedmont, and Mountain as defined in Figure E-1) present truck counts, gross vehicle weights, and estimates of vehicle miles traveled by Federal Highway Administration (FHWA) vehicle class and highway functional classification. Data include several years - 2005, 2006, and 2007.

The principle objective of the research has been to improve NCDOT's understanding of how trucks are using the state highway system – overall and on a regional basis. These better truck trip profiles describe the extent to which heavy trucks in particular are using the state's various categories of highway, from rural secondary roads to urban interstates. The older profiles provide only a coarse sense of the annual truck traffic by vehicle class statewide, not by region or county or highway functional classification. Pavement and bridge engineers need a better sense of truck weights and axle spacing. Investment decision makers and planners need a better picture of truck volumes, trip distances, and weight distributions by highway class and route category. To help meet these needs, this project has created better truck traffic profiles, especially for heavy vehicles, and those that need permits.

Methodology

This research on NC truck traffic profiles advantageously used data from two other NCDOT research projects: the NC Truck Network Model project (HWY 2006-09) and the NC Truck Traffic Data for the AASHTO Mechanistic Empirical Pavement Design Guide (HWY 2008-11). It built a sophisticated picture of truck traffic in North Carolina. As illustrated in Figure E-2, the network project contributed truck vehicle miles traveled for NC regions and different highway types. The pavement design project provided detailed information on the gross vehicle weights (GVW) of the most common class 5 and class 9 trucks on urban, rural, and recreational highways; making possible the calculation of axle load distributions. The truck traffic profiles project team examined additional truck counts on minor state SR and NC routes to enhance the picture of NC truck traffic. In addition, it examined the use of North

Carolina highways by permitted overweight trucks. Specifically, the NC truck traffic profiles research developed three steps of successively refined "pictures" of truck flows in North Carolina by:

1. using current data from NCDOT including counts, Highway Pavement Management System (HPMS) data, and weight-in-motion (WIM) data;
2. developing a truck origin-destination matrix (as part of the truck network model) based on the previous picture and data acquired from the previously mentioned NCDOT projects; and
3. enriching the understanding of truck flows through examining overweight truck permit data and State Route classification counts.

The research team developed truck trip profiles overall for the state and its regions (Figure E-1). The profiles have been validated, verified, and calibrated against NCDOT and other truck traffic data. As described above, the sources employed are the results from the NCDOT NC Truck Network Model project, the NC Truck Traffic Data for the AASHTO Mechanistic Empirical Pavement Design Guide project, HPMS data, WIM data, overweight permits issued by NCDOT, NC Highway Patrol enforcement data, and SR route class count data. The final products of this research are profiles of the truck trip traffic patterns in North Carolina regions by highway type (urban, rural, recreational, and bypass).

In addition to developing data on standard FHWA heavy truck classes 5 through 13, this research has sharpened the understanding of flow patterns for overweight trucks that require special permits to travel on North Carolina highways.

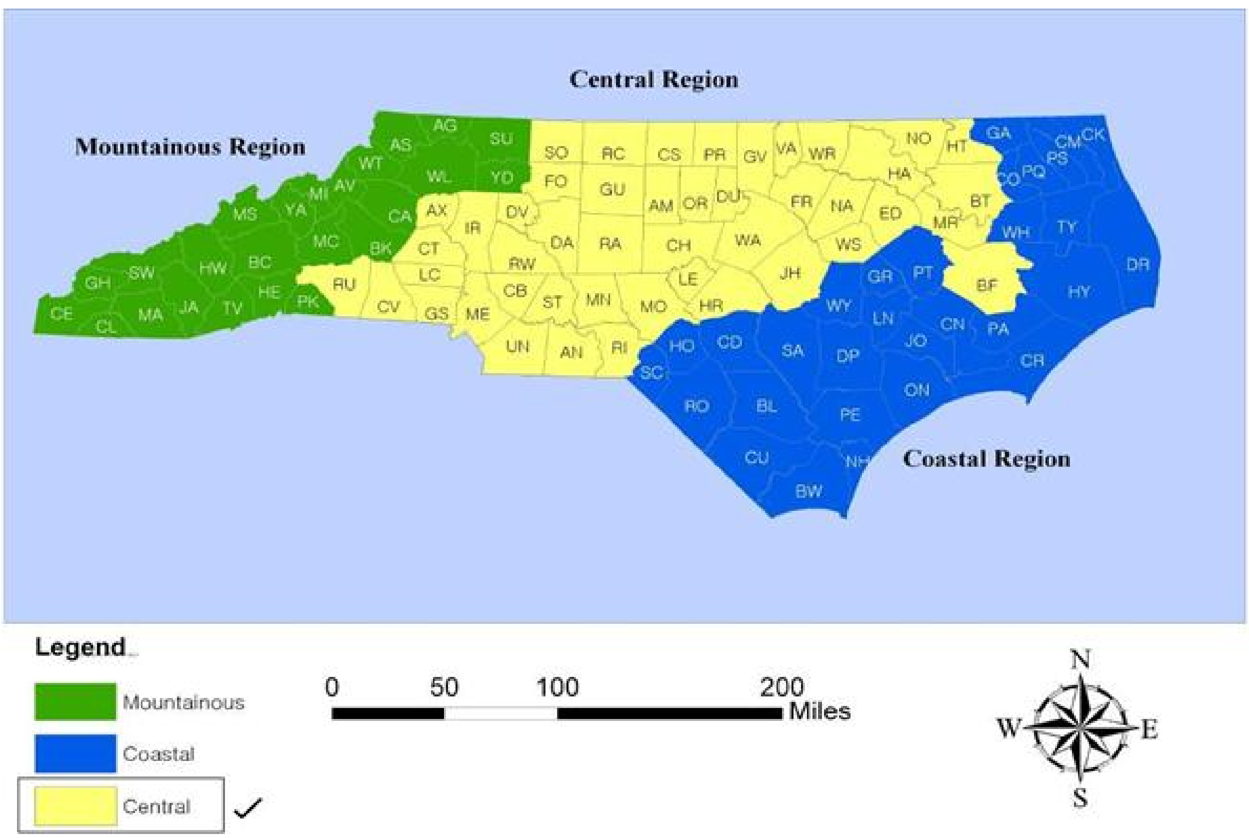


Figure E-1 NC Regions

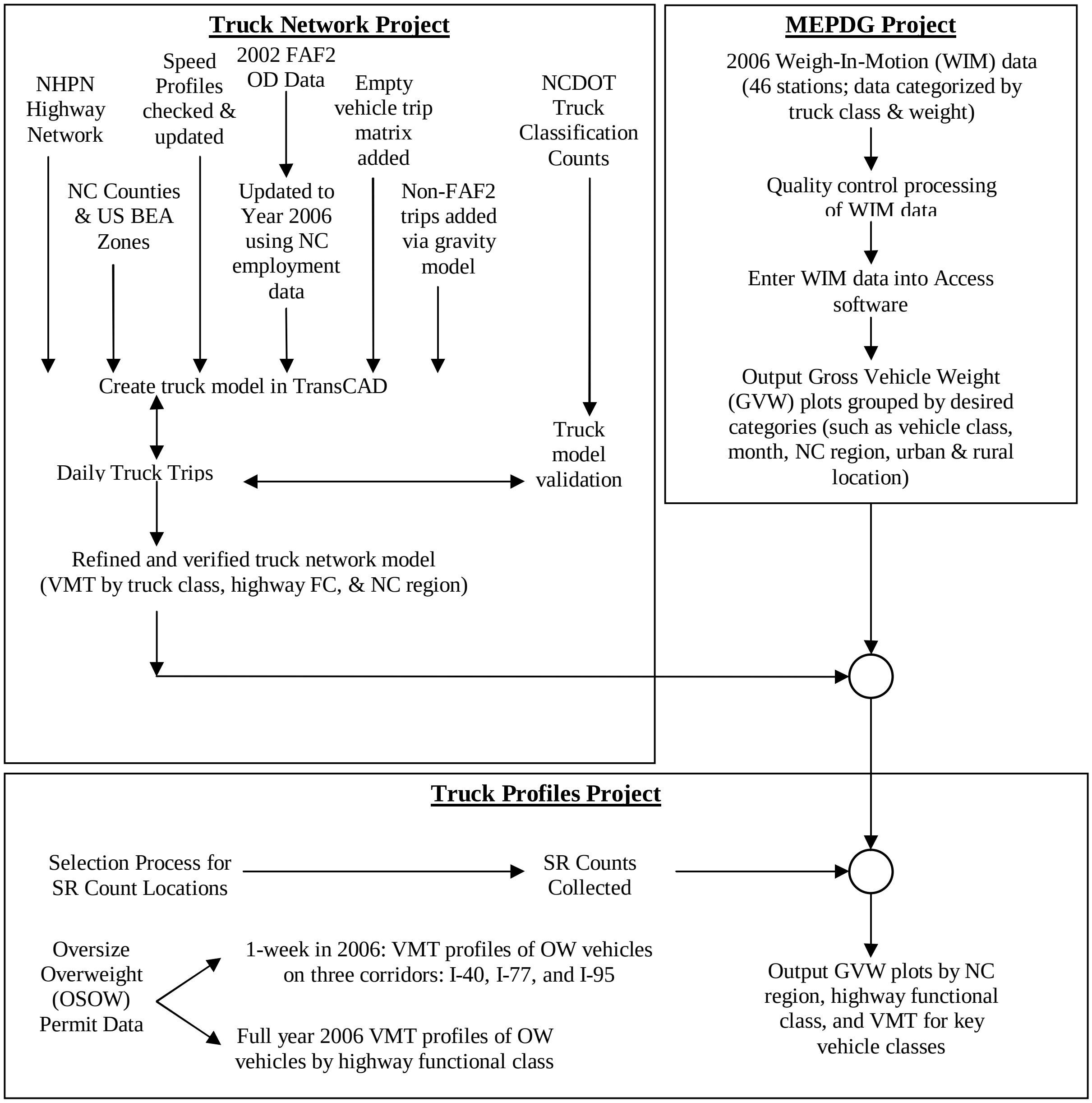


Figure E-2 Research Methodology for Developing NC Truck Traffic Profiles

Findings and Implications

Current NCDOT Traffic Profile Data

<u>VMT Data</u>

Tables E-1 and E-2 illustrate traditional statewide and county level VMT data that are developed by NCDOT. Further disaggregation of the summary data for Table E-1 is available for urban primary, secondary, and non-system facilities, and for rural primary, secondary, and non-system facilities. (See NCDOT Excel file \2005 DAILY VMT available from NCSU CCEE or the Road Inventory Section of the NCDOT GIS Unit.) A more detailed summary using the Table E-2 data is used to generate the HPMS report for FHWA. This summary is generated using a statewide sample that collects data using the 13-vehicle class scheme. Percentages displayed were carried over from 2004 according to the NCDOT Traffic Survey Unit (April 13, 2006). Annual updates, however, are routine. The originating document is Travel Activity by Vehicle Type_05.pdf, the standard report for HPMS data submitted for North Carolina. The HPMS report is an aggregation of the highway functional classifications and vehicle classes used in the spreadsheet (Tables E-3 and E-4). Both are statistically valid on a statewide basis only. They are applied to the statewide VMT totals to estimate travel by vehicle type. Some people use this data at a sub-statewide level as no other data are available. NCDOT does not generate county-level travel data by vehicle class. Subsequent research findings estimate regional-level travel by truck class based on a validated statewide truck model (Figure E-3 and Table E-5).

Statewide Average Vehicle Class Data

The NCDOT collects vehicle class counts on randomly selected HPMS segments for upper level functional classes and randomly selects segments from the universe data set for lower level functional classes to generate a statewide average of vehicle class distributions. The stations are selected by highway functional classification. Vehicles are categorized using the FHWA 13-vehicle class (VC) scheme. Data are collected for 48 hours at each station. The average 24-hour volume is generated for each station. These values are averaged and aggregated for each report. Table E-3 provides statewide averages for the complete set of highway functional classes (FC) using the FHWA class scheme as collected. Table E-4 is an aggregation of highway functional classification into functional systems and vehicle class into class groups as specified by FHWA for HPMS reporting.

Note that for Tables E-3 and E-4 only the local system data were updated in 2007. All other statistics are based on 2006 and 2005 counts – a procedure that meets FHWA HPMS reporting requirements. While the data collection procedures are adequate for statewide reporting requirements and statewide averages, biases may be introduced if applied at levels below the statewide level.

Table E-1 Statewide and County VMT Estimates for 2005

Source: Road Inventory Section of the NCDOT GIS Unit

NORTH CAROLINA PUBLIC ROADS VEHICLE MILES TRAVELED SUMMARY DATA AS OF JANUARY 1, 2006	Daily VMT (1,000)	Annual VMT (1,000)
ALAMANCE	3,667.55	1,338,655.75
ALEXANDER	688.48	251,295.20
ALLEGHANY	263.93	96,334.45
ANSON	907.16	331,113.40
ASHE	604.32	220,576.80
AVERY	553.48	202,020.20
BEAUFORT	1,174.88	428,831.20
BERTIE	870.63	317,779.95
BLADEN	1,205.29	439,930.85
BRUNSWICK	3,245.96	1,184,775.40
BUNCOMBE	6,279.20	2,291,908.00
BURKE	2,631.00	960,315.00
CABARRUS	4,134.77	1,509,191.05
CALDWELL	1,874.55	684,210.75
CAMDEN	333.30	121,654.50
CARTERET	1,737.88	634,326.20
CASWELL	617.39	225,347.35
CATAWBA	4,716.16	1,721,398.40
CHATHAM	1,863.30	680,104.50
CHEROKEE	756.85	276,250.25
CHOWAN	348.84	127,326.60
CLAY	270.19	98,619.35
CLEVELAND	2,671.78	975,199.70
COLUMBUS	2,056.96	750,790.40
CRAVEN	2,938.01	1,072,373.65
CUMBERLAND	7,982.30	2,913,539.50
CURRITUCK	956.59	349,155.35
DARE	1,471.31	537,028.15
DAVIDSON	4,334.01	1,581,913.65
DAVIE	1,369.47	499,856.55
DUPLIN	1,908.31	696,533.15
DURHAM	6,427.35	2,345,982.75
EDGECOMBE	1,624.81	593,055.65
FORSYTH	8,546.22	3,119,370.30
FRANKLIN	1,210.11	441,690.15
GASTON	5,431.86	1,982,628.90
GATES	334.13	121,957.45
GRAHAM	162.40	59,276.00
GRANVILLE	1,734.02	632,917.30
GREENE	625.68	228,373.20
GUILFORD	11,262.15	4,110,684.75
HALIFAX	1,917.23	699,788.95
HARNETT	2,436.99	889,501.35
HAYWOOD	2,387.29	871,360.85
HENDERSON	2,424.12	884,803.80
HERTFORD	608.65	222,157.25
HOKE	865.53	315,918.45
HYDE	179.23	65,418.95
IREDELL	5,016.21	1,830,916.65
JACKSON	1,354.77	494,491.05
JOHNSTON	5,130.28	1,872,552.20
JONES	539.33	196,855.45
LEE	1,636.44	597,300.60
LENOIR	1,755.71	640,834.15
LINCOLN	1,583.21	577,871.65
MACON	914.86	333,923.90
MADISON	550.50	200,932.50
MARTIN	908.23	331,503.95
MCDOWELL	1,670.15	609,604.75
MECKLENBURG	20,458.18	7,467,235.70
MITCHELL	368.48	134,495.20
MONTGOMERY	1,017.88	371,526.20
MOORE	2,157.67	787,549.55
NASH	3,772.58	1,376,991.70
NEWHANOVER	3,551.80	1,296,407.00
NORTHAMPTON	911.41	332,664.65
ONSLOW	3,413.92	1,246,080.80
ORANGE	3,732.90	1,362,508.50
PAMLICO	376.22	137,320.30
PASQUOTANK	761.22	277,845.30
PENDER	1,812.07	661,405.55
PERQUIMANS	411.72	150,277.80
PERSON	863.72	315,257.80
PITT	3,229.94	1,178,928.10
POLK	848.21	309,596.65
RANDOLPH	3,815.18	1,392,540.70
RICHMOND	1,390.15	507,404.75
ROBESON	4,552.91	1,661,812.15
ROCKINGHAM	2,482.35	906,057.75
ROWAN	3,662.15	1,336,684.75
RUTHERFORD	1,662.43	606,786.95
SAMPSON	2,017.77	736,486.05
SCOTLAND	1,126.42	411,143.30
STANLY	1,430.13	521,997.45
STOKES	996.81	363,835.65
SURRY	2,437.00	889,505.00
SWAIN	539.37	196,870.05
TRANSYLVANIA	800.81	292,295.65
TYRRELL	168.01	61,323.65
UNION	3,495.71	1,275,934.15
VANCE	1,360.71	496,659.15
WAKE	18,437.77	6,729,786.05
WARREN	642.32	234,446.80
WASHINGTON	480.35	175,327.75
WATAUGA	1,141.85	416,775.25
WAYNE	3,014.29	1,100,215.85
WILKES	1,807.74	659,825.10
WILSON	2,430.65	887,187.25
YADKIN	1,384.96	505,510.40
YANCEY	421.95	154,011.75
TOTAL	**243,059.02**	**88,716,542.30**

Table E-2 NCDOT 2005 Vehicle Class Percentages by FHWA Highway Functional Class and NCDOT Vehicle Classification

Source: NCDOT Traffic Survey Unit, NCDOT_2005 Vehicle Class Percentages by FC_FHWA Class.xls

Functional Classification	FC Code	Cycles	Cars	2A-4T	Buses	2A-SU	3A-SU	4A-SU	4A-ST	5A-ST	6A-ST	5A-MT	6A-MT	7A-MT
Rural Principal Arterial - Interstate	1	0.49%	56.93%	10.80%	1.06%	2.50%	1.56%	1.09%	4.79%	19.23%	0.48%	0.73%	0.24%	0.11%
Rural Principal Arterial - Other	2	0.40%	69.34%	15.79%	0.71%	2.80%	1.48%	0.25%	2.07%	6.67%	0.26%	0.16%	0.05%	0.04%
Rural Minor Arterial	6	0.49%	70.58%	17.23%	0.59%	3.19%	1.87%	0.27%	1.79%	3.69%	0.21%	0.05%	0.01%	0.02%
Rural Major Collector	7	0.36%	73.21%	17.52%	0.51%	3.01%	1.45%	0.24%	1.63%	1.84%	0.18%	0.02%	0.01%	0.02%
Rural Minor Collector	8	0.45%	74.00%	16.50%	0.65%	3.00%	1.55%	0.17%	1.75%	1.50%	0.30%	0.05%	0.02%	0.06%
Rural Local System	9	0.55%	71.93%	18.66%	0.51%	4.09%	1.06%	0.02%	1.54%	1.60%	0.05%	0.00%	0.00%	0.00%
Urban Principal Arterial - Interstate	11	0.36%	68.68%	12.84%	0.89%	2.12%	1.68%	0.42%	2.70%	9.29%	0.45%	0.36%	0.09%	0.10%
Urban Principal Arterial - Other Fways or Expways	12	0.33%	74.79%	13.97%	0.57%	2.48%	1.17%	0.42%	2.56%	3.42%	0.17%	0.07%	0.01%	0.03%
Urban Principal Arterial - Other	14	0.32%	76.64%	14.84%	0.46%	2.20%	1.30%	0.13%	1.66%	2.12%	0.21%	0.04%	0.01%	0.04%
Urban Minor Arterial	16	0.36%	79.35%	14.43%	0.47%	2.16%	1.08%	0.10%	1.26%	0.66%	0.11%	0.00%	0.00%	0.02%
Urban Collector	17	0.34%	81.15%	13.42%	0.43%	2.02%	1.12%	0.07%	0.99%	0.40%	0.05%	0.00%	0.00%	0.01%
Urban Local System	19	0.59%	75.56%	16.59%	0.82%	2.57%	1.73%	0.03%	0.95%	1.05%	0.10%	0.00%	0.00%	0.00%

2A-4T ~ 2 axle, 4 tires. Compare to FHWA classes
2A-SU ~ 2 axle, single unit. Compare to FHWA classes
4A-ST ~ 4 axle, single trailer. Compare to FHWA classes
5A-MT ~ 5 axle, multi trailer. Compare to FHWA classes

Table E-3 2007 Travel Activity by Vehicle Type with FHWA FC and VC

FC	Functional Classification	Samples	MC	Cars	2A4	Bus	2ASU	3ASU	4ASU	4AS	5AS	6AST	5AM	6AMT	7AMT
1	Rural Principal Arterial - Interstate	17	0.4%	59.0%	13.4%	1.1%	2.8%	0.5%	0.1%	1.9%	13.7%	0.8%	[illegible]	0.3%	0.2%
2	Rural Principal Arterial - Other	65	0.0%	65.7%	[illegible]	0.0%	[illegible]	[illegible]	[illegible]	1.4%	6.0%	0.0%	[illegible]	[illegible]	0.0%
6	Rural Minor Arterial	36	0.6%	65.3%	20.1%	0.9%	4.0%	[illegible]	[illegible]	1.3%	4.6%	0.2%	[illegible]	[illegible]	0.0%
7	Rural Major Collector	20	0.6%	72.1%	19.7%	0.5%	3.2%	[illegible]	[illegible]	0.8%	1.7%	0.1%	[illegible]	[illegible]	0.0%
8	Rural Minor Collector	[illegible]	0.7%	[illegible]	[illegible]	0.7%	4.1%	[illegible]	[illegible]	0.9%	1.2%	0.1%	[illegible]	[illegible]	0.0%
9	Rural Local System	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1.4%	1.1%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
11	Urban Principal Arterial - Interstate	21	0.5%	67.8%	14.1%	0.8%	2.7%	[illegible]	[illegible]	1.3%	[illegible]	0.3%	[illegible]	[illegible]	0.0%
12	Urban Principal Arterial - Other Freeways or Expressways	[illegible]	0.5%	[illegible]	6.2%	0.7%	2.0%	[illegible]	[illegible]	1.2%	5.9%	0.2%	[illegible]	[illegible]	0.0%
14	Urban Principal Arterial - Other	24	0.6%	74.4%	6.9%	0.5%	[illegible]	[illegible]	[illegible]	0.9%	[illegible]	[illegible]	[illegible]	[illegible]	0.0%
16	Urban Minor Arterial	21	0.6%	[illegible]	15.8%	0.6%	1.8%	[illegible]	[illegible]	0.6%	[illegible]	0.1%	[illegible]	[illegible]	0.0%
17	Urban Collector	14	0.0%	[illegible]	16.2%	0.5%	2.6%	0.5%	[illegible]	0.1%	0.2%	0.0%	[illegible]	[illegible]	0.0%
19	Urban Local System	14	[illegible]	72.4%	[illegible]	[illegible]	[illegible]	0.9%	[illegible]	[illegible]	[illegible]	[illegible]	0.0%	[illegible]	[illegible]

Table E-4 2007 HPMS Travel Activity by Vehicle Type (for HPMS reporting)

FC	Functional System	Samples	MC	Cars	Light Trucks	Buses	Single Unit	Multi-Unit	Total
RURAL									
1	Interstate	17	0.4%	59.0%	13.4%	1.1%	3.6%	22.5%	100.0%
2, 6	Other Arterial	101	0.8%	66.6%	19.1%	0.8%	4.9%	7.7%	100.0%
7, 8, 9	Other Rural	72	0.8%	69.0%	21.1%	1.1%	5.7%	2.2%	100.0%
URBAN									
11	Interstate	21	0.5%	67.8%	14.1%	0.8%	3.8%	13.0%	100.0%
12, 14, 16	Other Arterial	58	0.6%	75.0%	16.4%	0.6%	3.8%	3.7%	100.0%
17, 19	Other Urban	28	0.9%	75.4%	17.3%	1.4%	4.0%	1.0%	100.0%

Regional VMT Estimates by Highway Functional Type and Vehicle Classifications 5 and 9 (Chapter 6)

This research extends the traditional data collected by NCDOT (Tables E-3 and E-4) by using a validated statewide truck traffic network model developed as part of the NCDOT-NCSU research project *NC Truck Network Model.* A summary thematic map of total truck traffic volumes resulting from this statewide model is shown in Figure E-3.

This model applies the NCDOT statewide estimates of VMT to estimates of truck traffic by vehicle class and highway type to develop regional estimates of VMT as described by Table E-5. The statewide truck traffic model and the resulting regional VMT estimates were validated with 470 truck class counts throughout the state. These estimates for VMT by class and region should not be further disaggregated by county without additional traffic counts and further analysis. The results should be very useful to quickly gauge the amount of travel by NC region by vehicle classes 5 and 9, as well as total truck traffic. There are clear implications for highway design and maintenance, as well as funding.

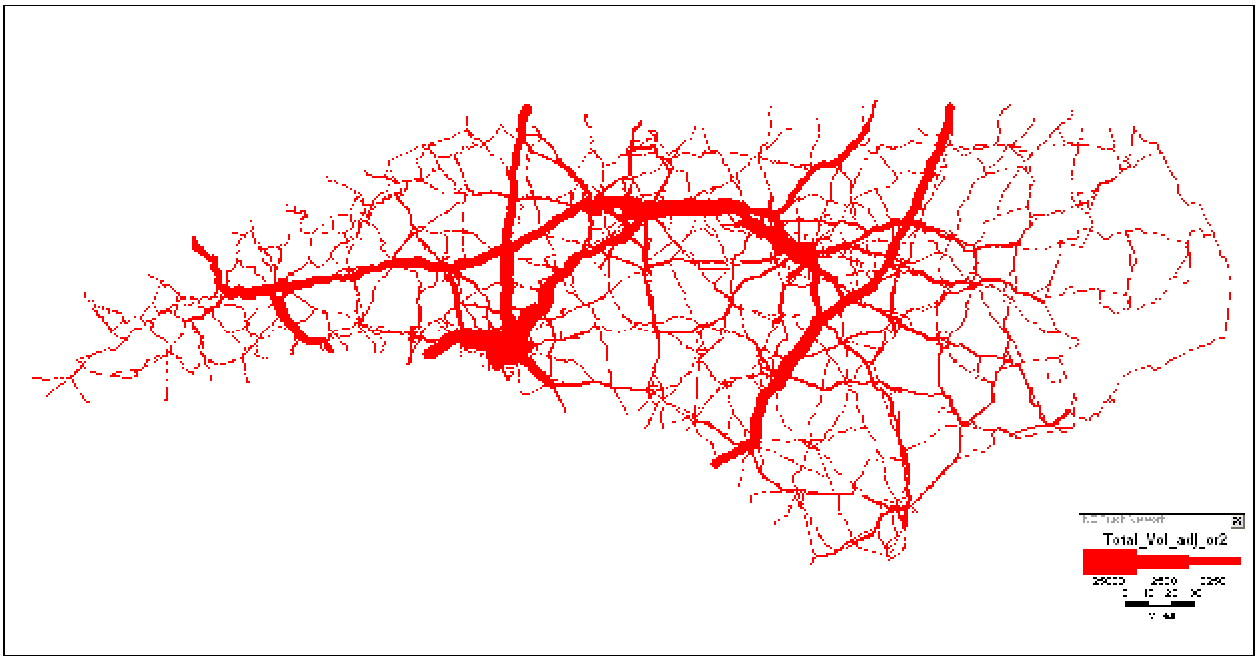


Figure E-3 Year 2006 Total Truck Traffic Estimates on the NC Highway Network
Source: NC Truck Network Model, 2008

Vehicle class 5 (box trucks) and vehicle class 9 (tractor trailers) are the most common truck types. Knowing their traffic profiles on various highways in urban and regional settings is important for pavement design and highway improvement planning. For this research project, NCDOT was particularly interested in average GVW truck traffic profiles of classes 5 and 9 in urban and rural settings in the three regions - mountains, central (or piedmont), and coastal. NCDOT was also interested in the class 5 and 9 profiles on several mountain and coastal recreational routes and on I-95. The results are displayed in Table E-6 and described in detail in Chapter 7. These results can quickly provide an estimate of the relative use of regional, urban and rural highways by the two major truck types 5 and 9. Appropriate implications for highway design, pavement design, and fund allocation may be drawn by NCDOT officials. The figures as illustrated in Table E-6 give a useful visual comparison of the relative GVW distributions by vehicle class and location.

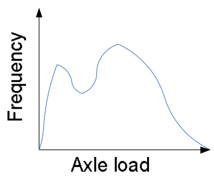
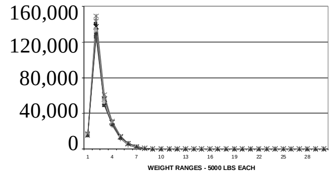
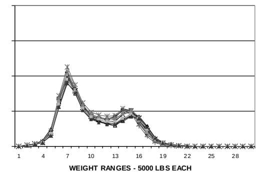
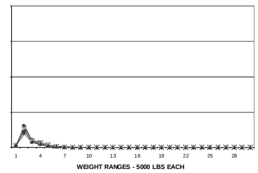
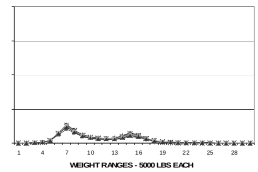
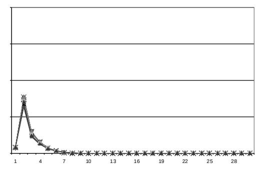
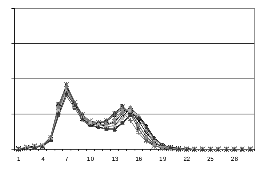
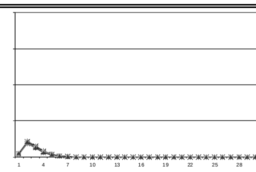
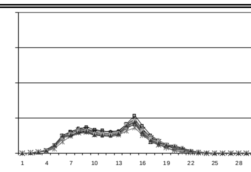
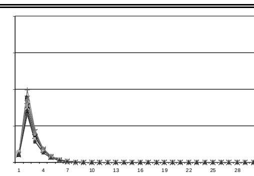
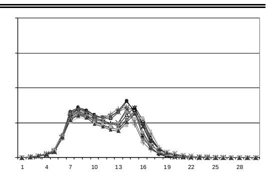
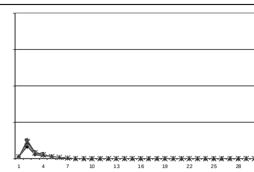
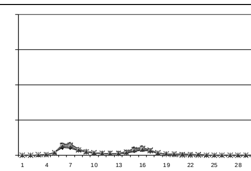
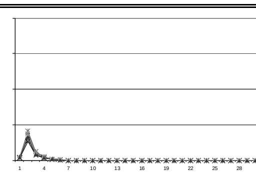
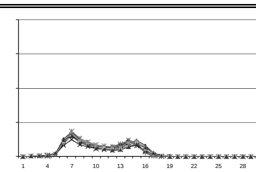
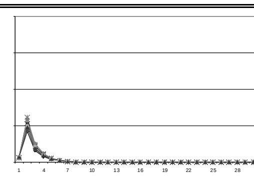
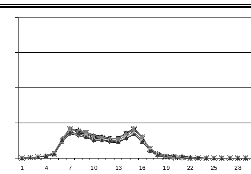
Table E-5 NC Truck Network Model Estimated VMT for Base Year 2006
(after post-model processing using NCDOT-provided VMT classification data)

FFC	Functional Classification	Regional Total Truck VMT			Sub Total
		Central	Coastal	Mountain	
1	Rural Principal Arterial - Interstate	3,677,480	1,006,310	1,273,040	5,956,830
2	Rural Principal Arterial - Other	2,077,461	1,399,812	591,434	4,068,707
6	Rural Minor Arterial	1,288,281	669,308	279,991	2,237,580
7	Rural Major Collector	78,887	97,839	38,607	215,333
8	Rural Minor Collector	41,579	25,949	1,712	69,240
9	Rural Local System	73,825	52,097	58,252	184,175
11	Urban Principal Arterial - Interstate	3,114,324	116,599	539,434	3,770,358
12	Urban Principal Arterial - Other Freeways or Expressways	691,733	95,363	32,131	819,227
14	Urban Principal Arterial - Other	1,193,520	391,234	97,605	1,682,359
16	Urban Minor Arterial	42,002	11,692	3,066	56,760
17	Urban Collector	3,756	3,147	322	7,225
19	Urban Local System	1,728	11,216	1,089	14,033
	Centroid Connector	1,544,950	358,678	296,605	2,200,233
	Sub Total	**13,829,527**	**4,239,245**	**3,213,288**	**21,282,059**

FFC	Functional Classification	Regional Truck VMT for Type 5 (2ASU)			Sub Total	%
		Central	Coastal	Mountain		
1	Rural Principal Arterial - Interstate	383,455	104,929	132,741	621,125	10.4%
2	Rural Principal Arterial - Other	511,069	344,363	145,497	1,000,928	24.6%
6	Rural Minor Arterial	411,671	213,878	89,471	715,019	32.0%
7	Rural Major Collector	33,584	41,652	16,436	91,671	42.6%
8	Rural Minor Collector	20,925	13,059	862	34,846	50.3%
9	Rural Local System	38,040	26,844	30,016	94,900	51.5%
11	Urban Principal Arterial - Interstate	485,948	18,194	84,171	588,313	15.6%
12	Urban Principal Arterial - Other Freeways or Expressways	162,278	22,372	7,538	192,188	23.5%
14	Urban Principal Arterial - Other	426,786	139,900	34,902	601,588	35.8%
16	Urban Minor Arterial	21,343	5,941	1,558	28,842	50.8%
17	Urban Collector	2,078	1,741	178	3,998	55.3%
19	Urban Local System	774	5,022	487	6,284	44.8%
	Centroid Connector	772,475	179,339	148,302	1,100,116	50.0%
	Sub Total	**3,270,425**	**1,117,234**	**692,159**	**5,079,819**	**23.9%**

FFC	Functional Classification	Regional Truck VMT for Type 9 (5AST)			Sub Total	%
		Central	Coastal	Mountain		
1	Rural Principal Arterial - Interstate	2,524,497	690,807	873,910	4,089,214	68.6%
2	Rural Principal Arterial - Other	962,701	648,677	274,072	1,885,451	46.3%
6	Rural Minor Arterial	477,263	247,955	103,727	828,945	37.0%
7	Rural Major Collector	18,094	22,441	8,855	49,390	22.9%
8	Rural Minor Collector	6,289	3,925	259	10,472	15.1%
9	Rural Local System	5,157	3,639	4,069	12,865	7.0%
11	Urban Principal Arterial - Interstate	1,939,545	72,616	335,950	2,348,111	62.3%
12	Urban Principal Arterial - Other Freeways or Expressways	340,494	46,941	15,816	403,251	49.2%
14	Urban Principal Arterial - Other	374,542	122,774	30,630	527,946	31.4%
16	Urban Minor Arterial	5,062	1,409	369	6,841	12.1%
17	Urban Collector	197	165	17	379	5.2%
19	Urban Local System	137	890	86	1,114	7.9%
	Centroid Connector	108,146	25,107	20,762	154,016	7.0%
	Sub Total	**6,762,125**	**1,887,346**	**1,668,523**	**10,317,994**	**48.5%**

Table E-6 Weight Distribution of Truck Types and North Carolina Highway Type

<table>
<tr><th>FHWA Truck Class</th><th></th><th></th><th>Class 5</th><th>Class 9</th></tr>
<tr><td rowspan="8">Weight Distribution/ Volume Level by Truck Type by NC Region and Urban or Rural Classification
</td><td>Urban</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Rural</td><td>Coastal</td><td></td><td></td></tr>
<tr><td>Central</td><td></td><td></td></tr>
<tr><td>I-95</td><td></td><td></td><td></td></tr>
<tr><td rowspan="2">Rural & Recreational</td><td>Mountains</td><td></td><td></td></tr>
<tr><td>Coastal</td><td></td><td></td></tr>
<tr><td>Urban & Some Recreational</td><td></td><td></td><td></td></tr>
<tr><td>Asheville Urban & Recreational</td><td></td><td></td><td></td></tr>
</table>

Note: All vertical scales are the same as shown in the top left graph. Low = 0, High = 160,000.

Summary Statistics for Overweight Permitted Truck Data

The database for permitted overweight trucks for August 21-25, 2006, can be used to identify critical highways segments. This data can serve as a test for a larger database for one year.

The data for this analysis comes from the NCDOT Oversize and Overweight (OS/OW) Permitting Unit. The OS/OW Permitting Unit processes approximately 300,000 permits each year, allowing overweight trucks to legally travel through the state. The rationale for permitting overweight trucks to use highways in North Carolina is that certain industry products and machinery cannot be broken down into conventional 80,000 pound truck loads. Each approved permit contains a record of the origin and destination of the truck's route, the registered and gross vehicle weight of the truck, its number of axles, and its permitted route. Roughly one-third of the permits issued are for overweight trucks while two-thirds are issued for oversize trucks. This analysis is concerned only with overweight trucks stratified into five different weight classes. Overweight trucks are the most damaging vehicles on NC roadways because of the exponential relationship between damage and vehicle weight.

The dataset is a sample of 2,234 overweight permits issued during the given week of August 20, 2006. The dataset contains overweight data by origin county, destination county, path in narrative format, gross vehicle weight, and axle weight (Axle weight and axle load are used interchangeably throughout the document). One permit usually represents one trip; however, some permits indicate that a return trip would be taken during the same week.

The analysis involved two phases: (1) identification of the highways most frequently used by overweight trucks during the sample five-day week of data (Table E-7) and (2) development of overweight truck traffic profiles on North Carolina interstate highways (Figures E-4, E-5 and E-6).

Table E-7 Highways Most Frequently Used by Overweight Trucks, August 21-25, 2006

Rank	Interstate Highways		NC Highways		US Highways		SR Roads	
	Road	Freq	Road	Freq	Road	Freq	Road	Freq
1	I-40	1,337	NC 16	160	US 74	419	SR 1101	100
2	I-85	908	NC 24	150	US 17	304	SR 1714	47
3	I-95	410	NC 87	100	US 1	277	SR 2029	40
4	I-77	400	NC 49	97	US 64	274	SR 4450	40
5	I-26	162	NC 55	75	US 70	271	SR 1007	35
6	I-440	143	NC 54	73	US 421	234	SR 1554	34
7	I-485	140	NC 150	71	US 117	178	SR 1010	31
8	I-40/85	101	NC 66	70	US 52	52	SR 1117	29
9	I-540	64	NC 211	54	US 220	147	SR 1002	27
10	I-40/440	62	NC 132	47	US 321	120	SR 1392	27

Source: Shin, NCSU MCE project, 2008
Note: The SR results in the table do not distinguish different SRs by County. The results represent statewide frequencies for the same SR #.

Table E-7 summarizes the number of times a permitted overweight truck uses ("touches") a segment of any length of the respective highway during the sample week. The frequencies (Freq) are the number of times an overweight truck made use of the highway, for whatever distance was required. For example, I-40 (when it exists by itself) was used 1,337 times for at least the length of one interchange-to-interchange segment. The portion of I-40 overlapped by I-85 was used 101times. I-95 was used 410 times, and Figure E-5 shows that the average length of use was high as reflected by vehicle miles traveled.

To check the results of the sample August 2006 week, an analysis was conducted of all permitted overweight truck data for the year 2006. Table E-8 displays the results which demonstrate that the sample week frequency results are highly correlated (0.99) to the annual frequencies of highway use. Thus, the sample week data may be used to illustrate the traffic profiles of permitted overweight trucks on North Carolina highways instead of using the much larger, full-year database.

Overall, Table E-9 shows the relative number of permitted overweight trucks broken down by weight category.

The overall top five highways by type are given by Figure E-7.

Table E-8 Comparison Table of Representative Roads and Use Frequencies (corr = 0.99)

Road	a year	a week	Road	a year	a week
I-40	69,927	1,337	US 74	21,763	419
I-85	42,960	908	US 1	11,772	277
I-77	21,322	400	US 17	13,195	304
I-95	21,007	410	US 64	15,009	274
I-26	10,287	162	US 421	12,186	234
I-440	9,037	143	US 220	7,245	147
I-485	8,858	140	US 321	5,047	120
I-40/85	5,803	101	NC 16	6,050	160
I-40/440	3,791	62	NC 24	7,585	150
I-540	3,524	64	NC 87	5,446	100
US 70	17,763	271	NC 49	3,422	97
			NC 66	3,264	70
			NC 54	4,192	53
			SR 2029	2,302	40
			SR 4450	2,262	40
			SR 1002	2,169	27
			SR 1101	1,501	100

Table E-9 Annual Number of Permitted Trucks by Weight Category (2006)

Weight category	Number of trucks	%
Under 94,500 lbs.	42,471	36%
94,501 ~ 108,000 lbs.	8,177	7%
108,001 ~ 122,000 lbs.	34,923	30%
122,001 ~ 132,000 lbs.	28,750	24%
Over 132,000 lbs.	4,092	3%
Sum	118,413	100%

Source: NCDOT 2006 OSOW Permit Data, OSOW_Permit_Data_062907.zip

Interstate Highway Truck Traffic Profiles for Overweight Permitted Trucks (Chapter 8)

The validated sample week's data can be confidently used to develop the permitted overweight truck traffic profiles of Interstates I-40, I-95, and I-77 (Figures E-4 to E-6). To compile the data necessary for mapping overweight trucks that traveled on I-40, I-95, and I-77 the following steps were taken. One week of data (2,234 trucks) was culled for records that show permitted overweight trucks traveling on any segment of all highways in NC. Only records for I-40, I-95, and I-77 were selected. An Excel worksheet representing each interchange-to-interchange segment for each interstate was created and used to plot data along segments used. Any amount of travel along the interstate was recorded by entering the gross vehicle weight (GVW) of the truck. Graphs depicting the total number of trucks traveling in each direction were stratified by weight class as shown in Figures E-4 to E-6.

Comparisons of the figures for I-95, I-40, and I-77 demonstrate the following:

- The maximum, weekly-permitted, overweight truck traffic on I-95, I-40, and I-77 goes as high as 250 vehicles per five-day week depending on the milepost.
- I-95 has the largest average weekly permitted truck use at about 200 vehicles, while I-40 and I-77 average approximately 170 and 150, respectively.
- Actual overweight truck traffic varies significantly depending on NC region and intersecting Interstate highways. For example, on I-77, the overweight truck traffic drops by 60 percent between the South Carolina line and I-40; and I-40 overweight truck traffic is significantly higher in the central region than in the mountainous or coastal regions.
- The most frequent permitted overweight categories are 108,000 – 122,000 pounds and 122,000-132,000 pounds.

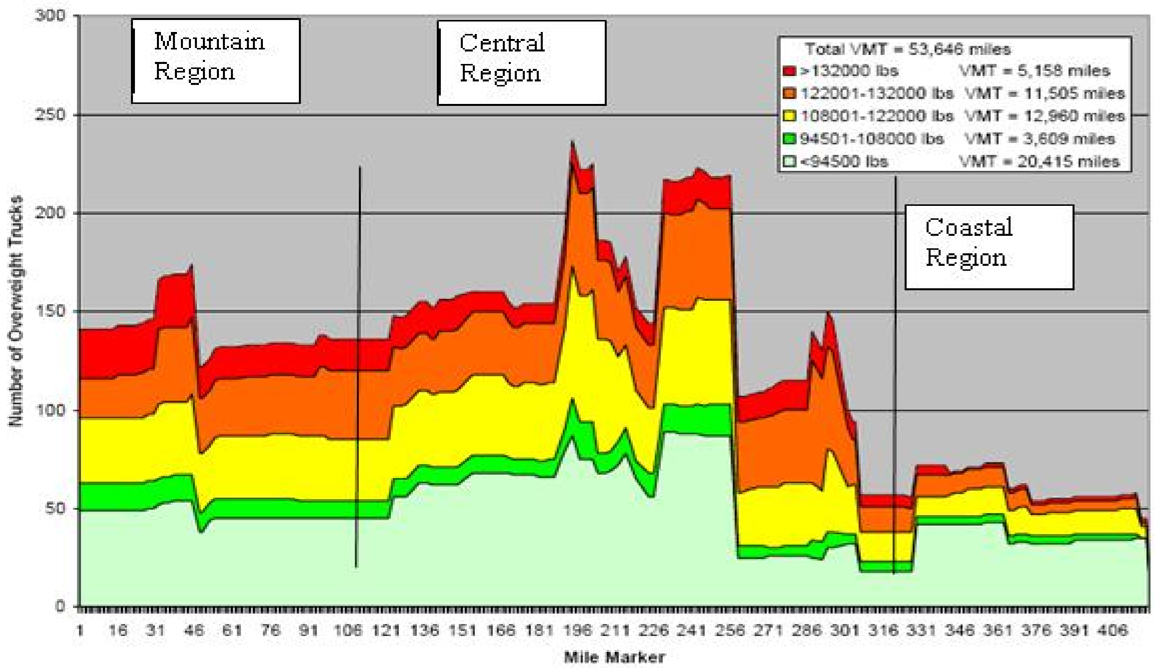


Figure E-4 I-40 Weight Distribution of Permitted Overweight Trucks (August 21-25, 2006) Milepost 0 < Mountains < 119 (119 miles), Milepost 119 < Central region < 341 (222 miles), Milepost 341 < Coastal region < 420 (79 miles), Source: Katz, NCSU REU Project, 2007.

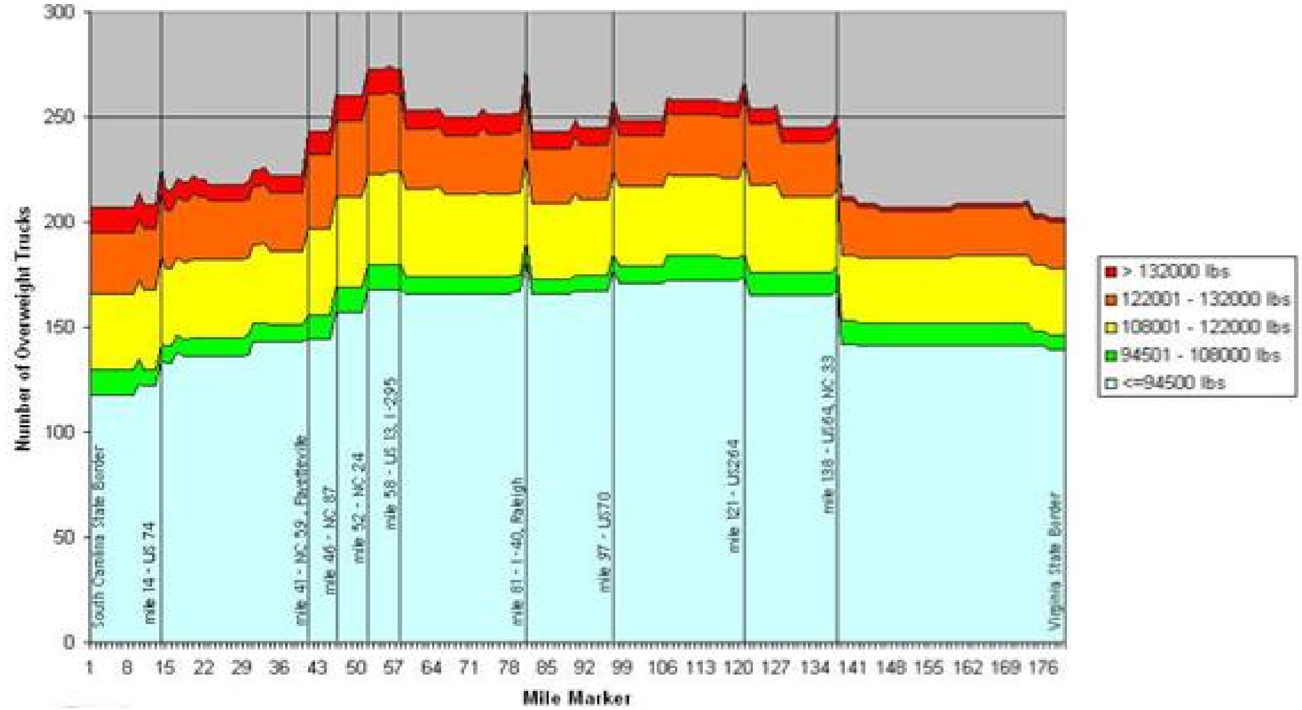


Figure E-5 I-95 Weight Distribution of Overweight Trucks (August 21-25, 2006)
Source: Bell, NCSU CE 501 Term Paper, Fall 2007.

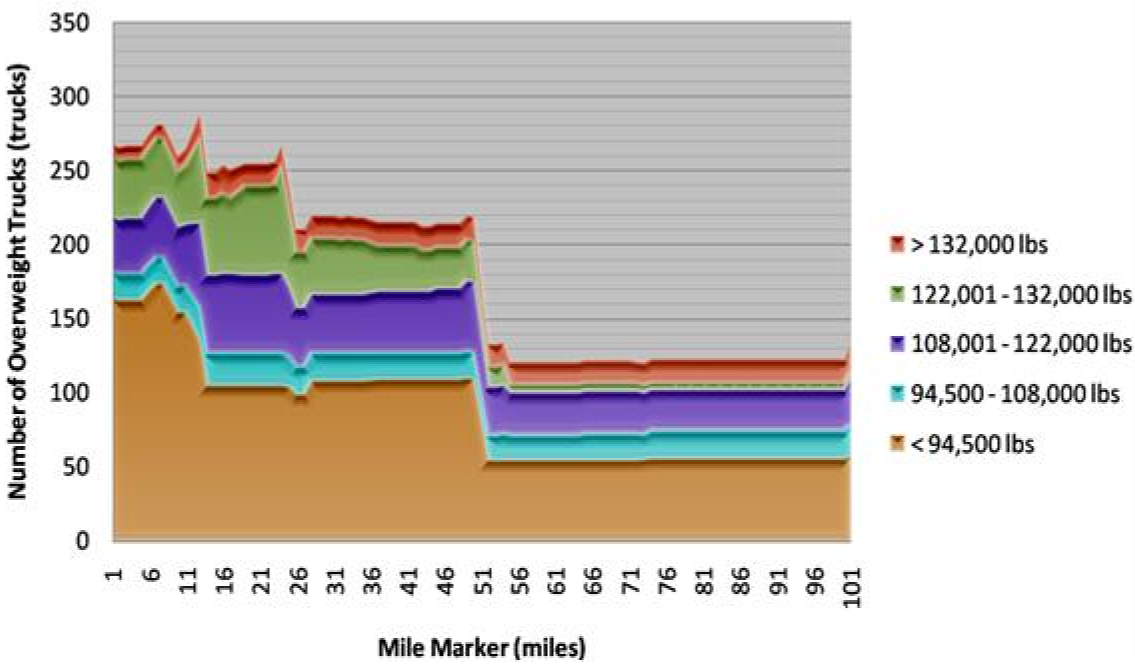
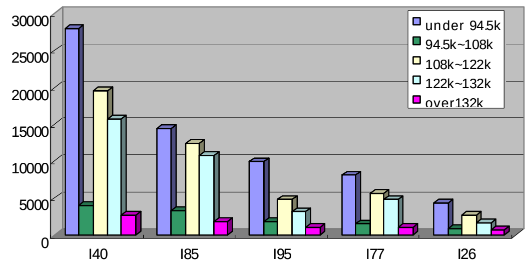
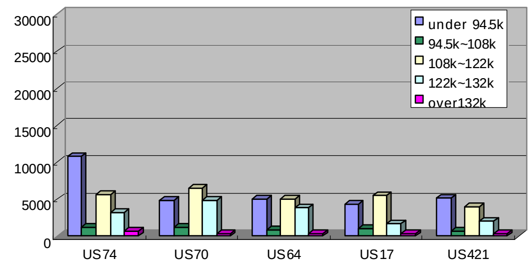


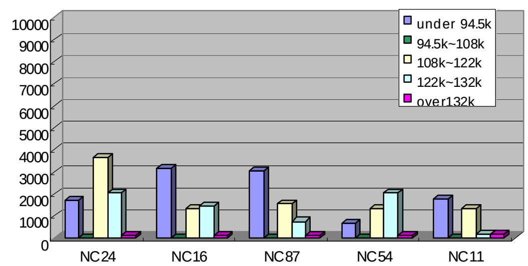
Figure E-6 I-77 Weight Distribution of Overweight Trucks (August 21-25, 2006)
Milepost 0 South Carolina line; milepost 2 I-485; milepost 13 I-85; milepost 50 I-40, milepost 101 Virginia line. Source: Boon, NCSU CE 501 Term Paper, Fall 2007.



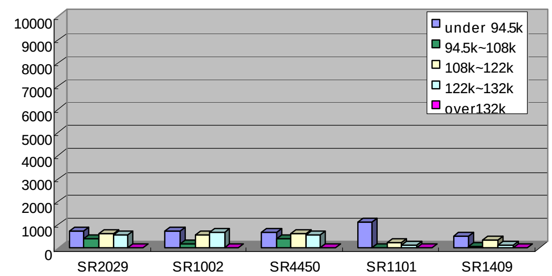
Interstate Highways



US Highways



NC Highways



SR Roads

Figure E-7 Top 5 Chart by Highway Type. Source: Shin, MCE Project 2007.
Note: The SR results in the table do not distinguish different SRs by County. The results represent statewide frequencies for the same SR #.

Use of State Routes (Chapter 9)

State routes are like "county roads" in many other states. For example, SR 1608, called Wilco Boulevard (South), in Wilson, NC (Wilson County) is located just east of US 301 and runs along the southwest side of a major industrial park. It sees significant truck traffic going to and from the tenants of the park.

Figure E-8 SR 1608, Wilson County, Wilson, NC

There are more than 50,000 miles of State Routes in North Carolina. Each county has many SR's using local names, but the SR # is often re-used by other counties (unlike NC or US #s). Local road names distinguish the different SR's with the same #.

Thirty (30) representative SRs were selected from among 105 candidates identified by Division Engineers; data were collected at 29 of these sites as well as 5 bypass routes for a total of 34 sites. The classification counts from these sites are shown in Table E-10. SRs were selected if they were near areas of high truck traffic, and not near one another. A truck traffic proxy was estimated for 65,000 of the 250,000 employers in North Carolina because they were likely to be generating more than two truck trips per day. Each establishment was located on a map and then the truck trip measure for a given SR was the sum of the truck trips generated within 5-miles of the highway. The state routes selected maximized the total truck trips covered and minimized the extent to which the 65,000 employers were double-counted in the total. The locations were distributed geographically based on six regional categories: Rural-Mountain, Urban-Mountain, Rural-Central, Urban-Central, and Rural-Coastal, and Urban-Coastal. Five count locations were selected for each.

Important observations are that:

- The percent trucks on these state routes (last column of Table E-10) is typical of rural minor arterials nationwide but in excess of rural collectors.
- The percentage of class 5 vehicles (2-axle, 6-tire single unit trucks) is comparable to that of rural collectors, but higher than rural minor arterials or the NC WIM sites.
- The percentage of class 9 vehicles (5-axle single trailer trucks) is less than that for rural minor arterials but higher than rural collectors or the NC WIM sites.
- The ADTs are typical for rural highways, with the maximum being 12,893 vehicles per day.
- The truck percentage for some of these roads is very high. For location 28, it is 45.8%; for location #15, it is 35.7%.
- 40% of the sites have a truck percentage in excess of 10%.
- 10% of the sites have a truck percentage over 25%.
- Most of the large truck volumes are for single unit trucks, and within that cluster, FHWA class 5.[1]
- Six sites (18%) have multiple-unit truck volumes greater than 200 trucks per day (12, 13, 20, 21, 22, and 31); the predominant truck type is FHWA Class 9; and for four of them, there are also large single-unit-truck volumes (20, 21, 22, 31).

[1] This is not unexpected, but it is interesting that intuition is consistent with reality.

Table E-10 ADT Breakdowns for the State Route Locations

LOCATION DESCRIPTION				ADT			ADT by Class														
LOC #	COUNTY	ROUTE	LOCATION	PV (1-3)	SU (4-7)	MU (8-13)	1	2	3	4	5	6	7	8	9	10	11	12	13	Total	PctTrk
1	DARE	SR 1217	W OF US 158	10312	477	84	94	7450	2768	36	393	45	3	71	12	1	0	0	0	10873	5.2%
2	PASQUOTANK	SR 1101	S OF NC 344	5375	203	68	31	4008	1336	29	145	27	2	35	33	0	0	0	0	5646	4.8%
3	WILSON	SR 1608	E OF US 301	2438	208	186	3	1865	570	26	107	70	5	28	134	19	0	0	5	2832	13.9%
4	CARTERET	SR 1147	S OF US 70	2470	151	28	12	1708	750	9	131	10	1	21	6	1	0	0	0	2649	6.8%
5	DUPLIN	SR 1501	E OF NC 403	1724	71	174	4	1394	326	16	40	13	2	12	159	2	0	0	1	1969	12.4%
6	SAMPSON	SR 1134	N OF NC 903	698	48	37	3	516	179	9	31	8	0	6	31	0	0	0	0	783	10.9%
7	ONSLOW	SR 1227	S OF US 258/NC 24	2697	311	159	14	2010	673	31	87	177	16	13	113	27	1	1	4	3167	14.8%
8	ONSLOW	SR 1518	E OF US 17	1945	137	76	12	1408	525	14	109	13	1	29	45	2	0	0	0	2158	9.9%
9	PENDER	SR 1520	N OF NC 210	902	55	27	9	760	133	10	30	13	2	4	20	2	0	0	1	984	8.3%
10	GRANVILLE	SR 1728	S OF US 15	3160	105	46	12	2585	563	18	60	23	4	20	22	4	0	0	0	3311	4.6%
11	ROBESON	SR 1005	N OF SR 1958	2720	150	78	24	2135	561	11	74	57	8	23	53	2	0	0	0	2948	7.7%
12	ALAMANCE	SR 2321	N OF SR 1136	3091	184	311	40	2346	705	14	135	31	4	32	269	9	0	0	1	3586	13.8%
13	ALAMANCE	SR 2326	E OF SR 2321	1641	134	364	18	1202	421	12	101	21	0	22	331	11	0	0	0	2139	23.3%
14	GUILFORD	SR 2133	E OF SR 2016	6340	354	162	39	5090	1211	77	207	47	23	74	71	14	0	0	3	6856	7.5%
15	RANDOLPH	SR 1595	N OF SR 1558	6671	280	196	70	5349	1252	54	194	32	0	69	118	2	6	0	1	7147	6.7%
16	HOKE	SR 1406	W OF SR 1412	2914	121	31	15	2316	583	36	62	22	1	22	7	1	0	0	1	3066	5.0%
17	DAVIDSON	SR 2024	E OF SR 2123	646	235	123	12	522	112	1	27	177	30	6	97	20	0	0	0	1004	35.7%
18	UNION	SR 1501	S OF POPLIN RD	9944	414	144	68	7938	1938	34	284	89	7	56	81	7	0	0	0	10502	5.3%
19	CABARRUS	SR 1002	N OF NC 152	5588	247	74	18	4478	1092	31	193	17	6	29	44	1	0	0	0	5909	5.4%
20	CABARRUS	SR 1394	E OF SR 1305	12019	656	218	44	9710	2265	87	434	113	22	83	125	8	1	0	1	12893	6.8%
21	MECKLENBURG	SR 1625	S OF I-85	6022	606	384	61	4558	1403	108	366	109	23	102	243	19	12	5	3	7012	14.1%
22	MECKLENBURG	SR 1601	N OF DILLING FARM RD	5641	338	338	49	4473	1119	60	188	87	3	83	245	8	0	0	2	6317	10.7%
23	CALDWELL	SR 1310	W OF SR 1392	5011	472	129	74	3968	969	48	213	200	11	34	91	3	0	0	1	5612	10.7%
24	YADKIN	SR 1510	S OF SR 1508	918	40	65	11	705	202	4	32	4	0	12	8	1	43	0	1	1023	10.3%
25	GASTON	SR 1307	N OF I 85	8750	291	141	73	7277	1400	37	223	28	3	55	82	4	0	0	0	9182	4.7%
26	IREDELL	SR 1005	S OF SR 1629	4435	211	105	50	3552	833	21	161	28	1	47	54	4	0	0	0	4751	6.7%
27	IREDELL	SR 1006	E OF SR 1753	2556	125	20	25	2067	464	31	82	12	0	12	6	2	0	0	0	2701	5.4%
28	BUNCOMBE	SR 1718	E OF PATTI LANE	574	348	137	21	381	172	26	54	207	61	12	96	26	0	0	3	1059	45.8%
29	McDOWELL	SR 1246	W OF LYTLE MOUNTAIN RD	683	37	95	17	483	183	5	28	4	0	8	70	12	0	1	4	815	16.2%
30	MITCHELL	SR 1121	S OF HALLTOWN RD	1669	99	23	19	1313	337	7	77	15	0	10	12	1	0	0	0	1791	6.8%
31	RUTHERFORD	SR 2169	S OF US 74 A	9166	422	457	107	7495	1564	56	277	86	3	74	373	6	3	0	1	10045	8.8%
32	CHEROKEE	SR 1537	S OF SR 1544	471	156	13	13	302	156	2	29	124	1	6	4	2	0	0	1	640	26.4%
33	HENDERSON	SR 1006	N OF SR 1513	7917	431	128	98	6336	1483	58	207	136	30	56	53	15	0	0	4	8476	6.6%
34	TRANSYLVANIA	SR 1540	S OF SR 1504	3873	227	48	26	2893	954	12	179	32	4	29	16	2	0	0	1	4148	6.6%

1 Motorcycles
2 Passenger Cars
3 Other 2-axle, 4-tire SUVs
4 Buses
5 2-axle, 6-tire SUTs
6 3-axle SUTs
7 4+ axle SUTs
8 <=4-axle STTs
9 5-axle STTs
10 6+ axle STTs
11 <=5-axle MTTs
12 6-axle MTTs
13 7+ axle MTTs

A percentage breakdown of truck volumes by FHWA Vehicle Type, compared with nearby WIM stations, shows that the State Routes have more vehicles at lower truck classes and fewer at the higher ones. This is true for all but one of the SRs shown in Figure E-9. There is one, however, SR 1501 in Calypso, NC (Duplin County) that sees more vehicles in FHWA class 9 than do the corresponding WIM sites. It happens to be adjacent to a major industrial complex. While this does not tell a story about differences in the axle load distributions, it clearly indicates that there are more trucks of lower vehicle classes on the State Routes than for the comparable WIM sites, with the most significant differences being the percent of vehicles in FHWA classes 5 (more) and 9 (fewer).

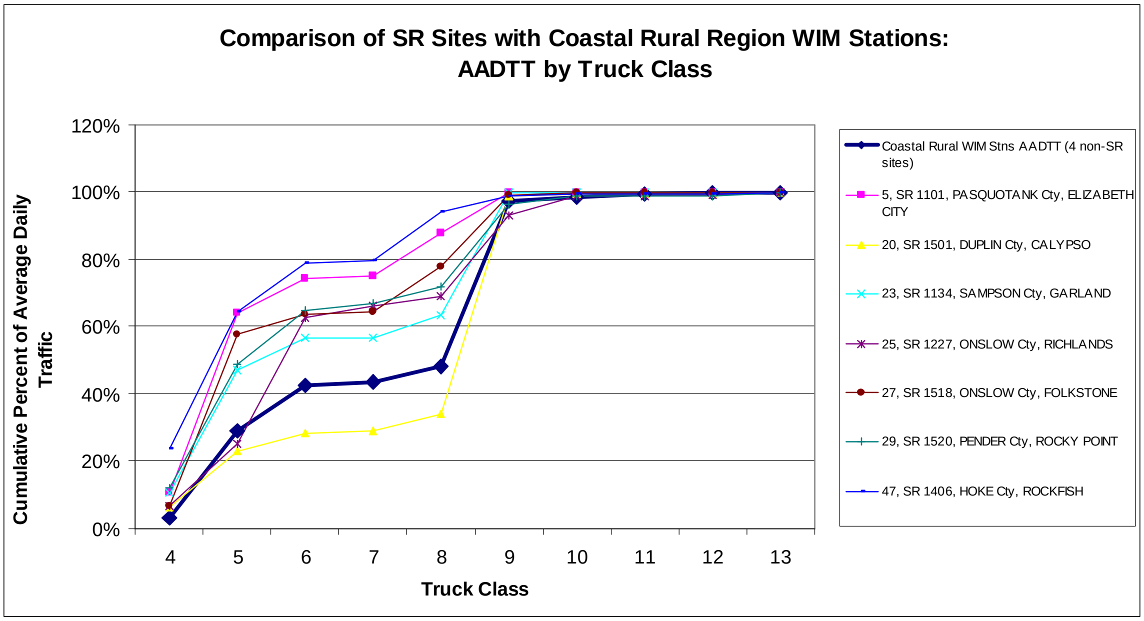


Figure E-9 Coastal, Rural State Routes

An analysis of the axle load distributions for these sites is a very important objective, but difficult to do since those distributions do not exist. However, if one assumes that the distribution of axle configurations and axle load distributions for the WIM sites being used in the MEPDG project[2] are reasonably representative of the axle load distributions for the State Routes, then one can do a preliminary analysis.

The basic conclusions are that:

- The State Routes almost always have axle load distributions that involve lighter axle weights than the WIM sites. This is illustrated in Figure E-10.
- However, many of the State Routes have axle weight distributions that come close to matching or exceeding those observed for the WIM stations.
- Two State Routes were found to have axle load distributions that might involve more, heavier axle loads than the WIM sites. They are:[3]
    - o SR 1501 in Calypso, NC (Duplin County), in the Coastal Rural Region (actually shown in Figure E-10), which is near a manufacturing plant; and

[2] Forty-two (42) WIM stations were used to approximate the axle load distributions at the SR sites.
[3] NC DOT might want to check the axle load distributions on these two State Routes to see if the distributions really do exceed WIM station observations.

- o SR 1246, McDowell County, Old Fort, in the Mountain Rural Region, which is near a commercial area.

- Coastal Rural WIMs are not SR types. In general, there only a couple SR WIMs

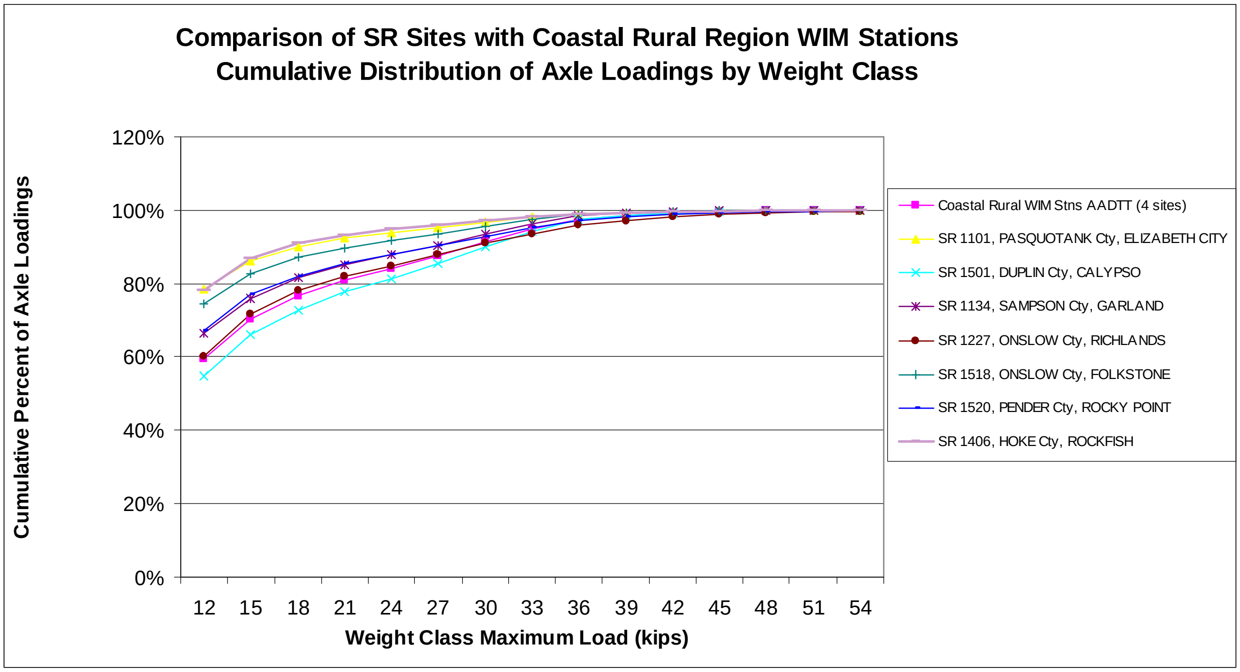


Figure E-10 Coastal, Rural State Routes

The conclusions/recommendations from the analysis are:

- There are state routes where the truck traffic is considerable. NCDOT does not regularly monitor high truck volume state routes. The data collected was a sampling for the purpose of the research. If funding and resources are available, periodic data for other SR routes could also be available in the future.

- The 34 sites studied have truck traffic percentages typical nationwide of rural minor arterials, but higher than rural collectors.

- The state routes sampled see higher percentages of trucks in Classes 4-8 and smaller percentages in Classes 9-13, except Class 10 (6+ axle single trailer trucks). This trend holds true across all the state routes regardless of where they are located.

- The method by which the initial 30 representative SR sites were chosen worked very well for this research. NCDOT collected data at 29 of the sites plus 5 bypass sites for a total of 34. With only a couple of exceptions, the data identified highways with heavy truck flows. NCDOT is developing class monitoring coverage at the local FC level based on random sampling. This approach avoids a bias towards routes with heavy truck flows, and is acceptable for HPMS reporting purposes. The authors recognize that the NCDOT is struggling to meet mandated class monitoring requirements. However, data collection such as this for SR and other routes is helpful to the state for special consideration such as statewide logistics planning and traffic management which are tightly tied to the economic development of North Carolina.

- Many of the State Routes have axle weight distributions that come close to matching those observed for the WIM stations.

Overall Summary

The purpose of this project was to describe the character (profile) of the truck traffic that travels a wide selection of highways in North Carolina. Such information supports a variety of issues in planning, design, operations, and policy. For example, knowing truck traffic volumes, size, and weight affects highway lane design, pavement design, structure design, and location of traffic sensors and weigh stations. Such information also helps to enforce weight limits on highways and bridges.

The project used a variety of data sources to develop these descriptions, including: NCDOT weigh-in-motion (WIM) data from 42 stations, 48-hour traffic counts at hundreds of urban and rural highways locations, and special counts for carefully selected State Route (SR) highways with higher truck volumes.

Besides creating statewide summaries of vehicle miles traveled, the project used a statewide truck network model to develop estimates of total truck vehicle miles traveled (VMT) by region (mountain, central, and coastal) and highway functional classification. Since class 5 and class 9 trucks are the most numerous trucks, VMT for those two classes were also developed. Such information is usually only available from expensive proprietary data.

Using the inventory of NCDOT weight-in-motion sensors, truck traffic profiles for class 5 and class 9 trucks were developed by gross vehicle weight, vehicle class, highway functional classification, and urban and rural locations. Special profiles for class 5 recreational vehicles in the mountains and class 9 trucks on I-95 were also prepared.

Because of their impact on pavement conditions, overweight trucks were studied intensely. A one-week sample of permitted movements in August 2006 allowed profiles by weight and distance traveled on I-40, I-95, and I-77. The top ten US, NC, and SR routes with the highest permitted overweight truck traffic were also identified.

Another focus was State Routes with higher truck volumes. It was found that these facilities tend to see more class 5 trucks and fewer class 9 trucks, and they have axle loading distributions which are slightly lower than, but not significantly different from, those of the WIM stations. Hence, it is wise for NC DOT to be monitoring the conditions of these highways, and making pavement investments that prepare them for heavy truck use.

Products of the project include: (1) a review of current truck flow estimation processes in North Carolina; (2) tabular information regarding vehicle weights and distances traveled on specific road classes; (3) a database that includes truck traffic profiles for urban and rural areas by NC region, vehicle classifications, weights, trip lengths, and highway types; (4) permitted overweight truck traffic profiles on three major interstates; (5) frequency of use of permitted overweight trucks on the top 10 highways by functional classification; and (6) truck traffic on a wide selection of State Routes near truck generators.

Findings

Perhaps foremost, many estimates of truck activity were developed. Data from 42 WIM stations were used to prepare weight and axle loading distributions to help refine pavement design parameters and assess overweight vehicle pavement impacts. Moreover, estimates of commodities moving on North Carolina highways were prepared for four basic commodities. The NCDOT commodity method was expanded to a prototype method for more commodities; however, none of the methods reliably provide commodity flows by highway, highway functional class, sub-region or length of typical trip.

VMT estimates by region were developed from a network analysis. The results were categorized in various ways: VMT by region and VMT by highway functional class, region, and vehicle class. The results compared favorably with prior NCDOT estimates. The estimates of vehicle miles traveled were developed using the truck traffic network model created in the HWY 2006-09 project. The model has a base year 2006 using the National Planning Highway Network (NHPN), the FHWA FAF2 OD dataset, and adjustments for short-haul truck traffic including empties. The model yielded an R^2 of 0.93 when ground counts of truck traffic were compared with the model estimates.

Network flow maps for truck traffic were developed. Truck traffic flow assignments on the network detailed likely truck routing patterns from county traffic analysis zone (TAZ) origins to county TAZ destinations assuming shortest paths are taken by the drivers. There were also some external path itineraries demonstrated to locations outside of NC.

It was estimated that the total truck VMT for 2006 was 21,282,059. The heavily urbanized Central region had the highest VMT of 13,829,527. By highway class, the highest VMT in this region (3,677,480) was on the rural principal arterials (Interstates), suggesting intense travel between the cities. VMTs of 4,239,245 and 3,213,288 were found for the Coastal and Mountain regions, respectively. Vehicle class 5 had a VMT of 5,079,819 across the state and Class 9 was more than double this value. As expected, VMTs on the Interstates for Class 9 were much higher than those of all other roads studied. These results should assist the Pavement Management Unit at NCDOT with gauging the volume of traffic crossing various road types in the three major regions of the state.

Gross Vehicle Weight (GVW) distributions were developed by region by highway functional type using the WIM station data. The highest truck volumes are on the urban WIM stations; however, the majority of Class 9 trucks at those locations are empty or near empty. The reverse trend, of predominantly loaded trucks, is observed for the I-95 WIM stations. This same trend, to a lesser degree, was observed on the rural and recreational routes in the Mountain region. Slight seasonal differences can be observed,[4] but the overall trends are quite consistent. Across all of the regions, Class 9 shows two predominant peaks corresponding with empty and almost-full loadings; at 35,000 and 75,000 pounds, respectively. For Class 5, there is a single peak for all regions at 10,000 pounds; again, the empty weight of a typical truck.

For overweight trucks, the spreadsheet analysis, while preliminary, provides insightful graphical representations of where the traffic is high along a given route. Further, it can rank highways by functional class and the amount of permitted overweight truck traffic carried. Such information may be used by planners and designers of highway, pavement and bridges to provide important overload weights and frequencies of those loads. The information may also be used by enforcement officials to plan enforcement strategies targeted at unpermitted overweight trucks. Moreover, the information may be used to demonstrate the degree to which overweight trucks use North Carolina highways and contribute

[4] See the task reports associated with the HWY 2008-11 project (*NC Truck Traffic Data for the FHWA Mechanistic Empirical Pavement Design Guide*).

their fair share or not to highway maintenance costs. The analysis also demonstrated that the overweight truck traffic on North Carolina highways appears to be relatively constant throughout the year and that one week's data may be used instead of an entire year's data.

The State Route analysis generally revealed that:

- There are state routes where the truck traffic is considerable. These state routes should continue to be monitored in the future.
- The 34 sites studied have truck traffic percentages typical nationwide of rural minor arterials, but higher than rural collectors.
- The state routes sampled see higher percentages of trucks in Classes 4-8 and smaller percentages in Classes 9-13, except Class 10 (6+ axle single trailer trucks). This trend holds true across all the state routes regardless of where they are located.
- The method by which the initial 30 representative sites were chosen worked very well.[5] With only a couple of exceptions, it identified highways with heavy truck flows. NCDOT should continue to use this procedure in the future to select additional state routes to add to the three-year classification count cycle.

Recommendations

Estimating Truck VMT. NCDOT should enhance its truck network model. It is the best current technique for disaggregating truck VMT to sub state levels. NCDOT 48-hour short counts, and statistical inference develop statewide truck VMT estimates which comply with HPMS requirements. However, these methods statistically are not appropriate for disaggregating truck VMT to sub state levels. The NCDOT truck network model is the best current method is the best current method to develop sub state truck VMT estimates. In the near term NCDOT will develop a statewide coverage for vehicle class monitoring that will allow direct calculation of truck VMT for higher order FC to any geographic level. NCDOT will continue to use a sampling process (statistical inference) for the lower order FC for the purposes of HPMS. In the long term when truck-based GPS transponders and data become available to public agencies, the need for model estimates, short counts, and statistical inferences of truck VMT will be reduced and augmented

- Make the model sensitive to commodity data. Make it possible to explicitly examine and capture the relationships between spatial representations of commodity flows (or bundled commodity flows) and the head-haul, loaded truck moves.
- Create a way to estimate empty back-haul trips. Very different from auto trips, truck trips involve deliveries followed by repositioning moves which are often done empty. Understanding the interplay between these two, and being able to model them conjunctively is important to higher quality truck flow estimates.
- Study the truck traffic with the non-truck traffic in the background. Ensure the truck model can speak to issues like truck percentages on links and the total volumes on links, especially in congested areas. Allow for capacity-constrained traffic assignment in congested areas.
- Make the truck model sensitive to volume-speed relationships. Give the model an ability to recognize that speeds decline as volumes increase.

[5] With the team able to collect data at 29 of the sites plus 5 bypass sites for a total of 34.

- Incorporate more detail about local truck trips. Develop ways to estimate local truck traffic and assign it to the network.

WIM Data Quality Control. NCDOT should continue its quality control efforts related to the WIM datasets (as developed in research project HWY 2008-11). Better WIM data translates into more intelligent pavement design decisions and practices. We believe that NCDOT perform these activities as frequently as its funding allows and collects the best quality data within the funding limits placed upon them. It's not an issue with process, it's a resource issue. It may be also be advisable to look for alternate database management systems like Oracle or Microsoft SQL Server that have better abilities to store, analyze, and process the huge amounts of WIM data. Funding to support more consistent equipment calibration and maintenance will also go a long way in providing better quality data for analysis.

Overweight Trucks. It would be highly advantageous if the permitting database was more regimented in the way it records the routes used by overweight trucks. A GIS-based approach, akin to the route specification capabilities of Google-Maps, would be outstanding. The person specifying the route could point, click, and drag the path line to the route to be employed and the underlying software could codify the resulting sequence of network links employed so that the path data could be mined for analysis.

[This page has been intentionally left blank.]

Table of Contents

Table of Figures

Table of Tables

[This page has been intentionally left blank.]

1. Introduction

Efficient freight transportation is critical to a healthy economy for North Carolina. Trucking, in particular, provides a vital and reliable mode of transporting regional and intra-regional goods movements in NC and beyond (Figure 1-1). On the other hand, the growth in truck flows (Figure 1-2) has significantly contributed to traffic congestion, vehicle emissions, and pavement and bridge damage. In addition large truck crashes also kill more than 100 people a week in the U.S. according to safety groups (www.trucksafety.org). In 2005, North Carolina ranked 19th in the U.S. in terms of number of people killed in truck crashes per 100,000 population (FARS 2007). To allow more informed transportation planning, pavement and bridge design, and maintenance activities, tracking truck flow patterns becomes an ongoing need for NCDOT. Since the effect of truck loads on pavement and bridge performance increases exponentially with truck weight (Figure 1-3), it is important to quantify the cost of heavy and overweight trucks to the NC roads system as a whole. Accurate information on truck weight distributions can assist NCDOT transportation planners and engineers to estimate the cost of early failure of the NC road system due to heavy and overweight trucks, and accordingly determine equitable fee structures and weight law enforcement.

Developing a reliable profile of truck trip flows is difficult in its own right, because of proprietary issues, competition between trucking companies, and truckers who do not comply with NC regulations. With limited data availability, existing data sources on truck traffic use different survey methodologies and truck classification schemes. To meet the above challenges, the authors of this research examine truck flow patterns for urban and rural NC and construct a clearer picture of how different trucks (especially overweight trucks) use NC interstate, primary, and secondary routes. The research team systematically integrates available freight commodity databases, truck classification counts, and truck class and weight measurements from weigh-in-motion (WIM) stations.

Products of the project include: (1) a discussion of current truck flows in North Carolina; (2) tabular information regarding vehicle weights and distances traveled on specific road classes; (3) a database that includes truck traffic profiles for urban and rural areas by NC region, vehicle classifications, weights, trip lengths, and highway types; (4) permitted overweight truck traffic profiles on three major interstates; (5) frequency of use of permitted overweight trucks on the top 10 highways by functional classification; and (6) truck traffic on a wide selection of State Routes (SR's) near truck generators.

Background

According to North Carolina State Statute Chapter 136, the NCDOT must maintain a safe and efficient highway system. To that end, managers and engineers must consider the impacts of future truck traffic on particular pavement and structure designs and the impacts of truck traffic on the overall condition of the entire state highway system. Current methods of collecting and forecasting truck traffic profiles can provide coarse estimates of annual truck traffic by vehicle class for the whole NC road system as shown in Table 1-1. Statewide vehicle percentages in Table 1-1 may be reliably applied to statewide VMT totals to estimate statewide travel by vehicle class and by facility type. However, sub-area travel in counties and in mountain, central, and coastal regions cannot be calculated reliably from Table 1-1 because statistically valid sub-area travel data by vehicle class are unavailable at NCDOT.[6] Furthermore, existing methods do not estimate the number of overweight vehicles or truck trip distance profiles by vehicle class, highway facility type, or sub-area. Weigh stations, WIM stations, and classification counts only measure a small

[6] Some professionals, however, do make county estimates using these statewide data.

proportion of trucks, and the small sample size may lead to biased estimates of traffic volumes (but not necessarily axle load spectra) when recorded data are extrapolated to adjacent sites (Lu 2002). Thus, the NCDOT needs better truck flow data than are currently available from state and federal sources.

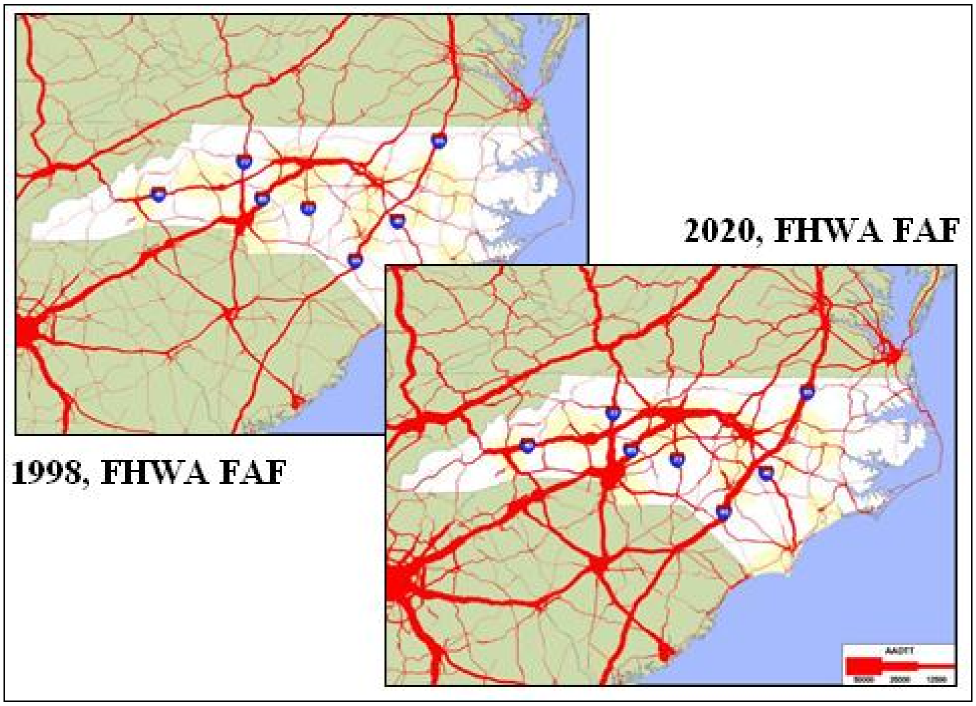


Figure 1-1 Past and Future North Carolina Truck Traffic

Source: Lambert, FHWA Freight Forecasting Framework, 2000.

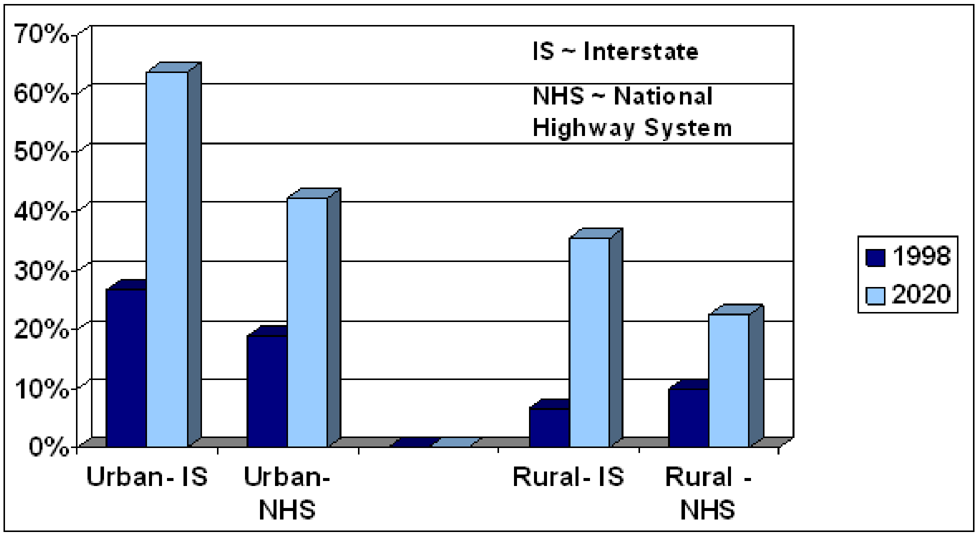


Figure 1-2 Percentage of U.S. Segments with 10,000 Trucks/Day or More

Source: Lambert, FHWA Freight Forecasting Framework, 2000.

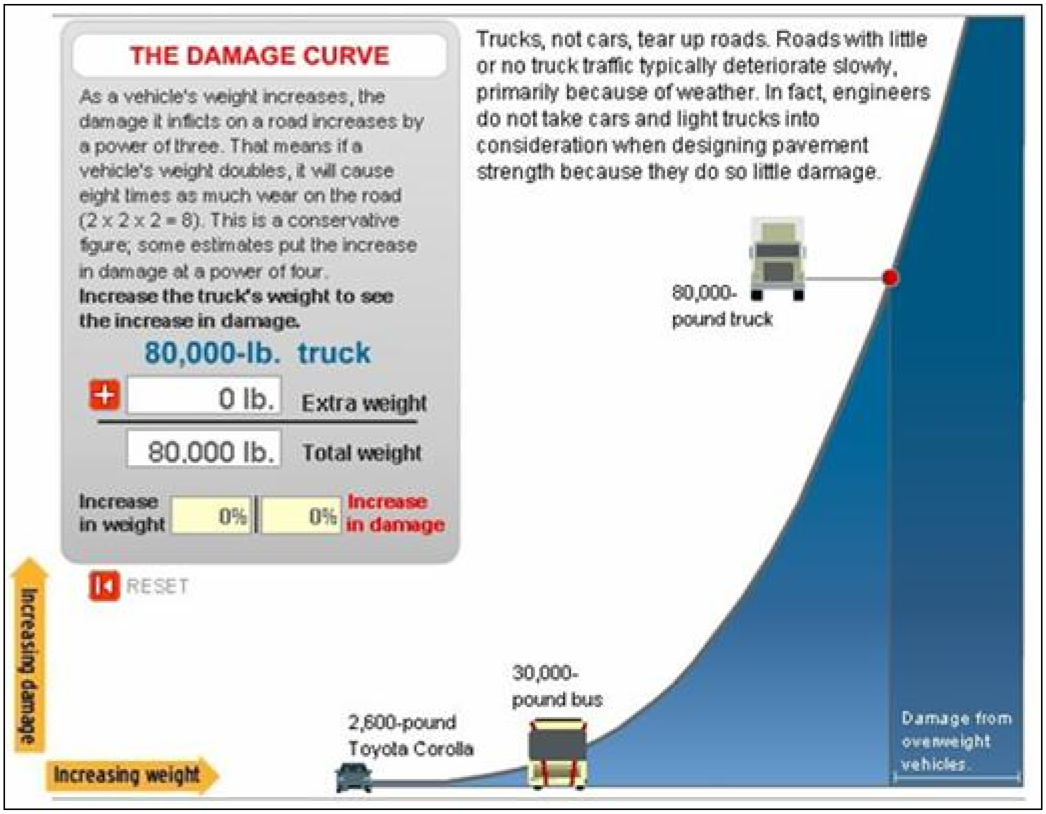


Figure 1-3 The Damage Curve

Source: Corley-Lay, NCDOT; News & Observer, 2005.

Table 1-1 North Carolina Vehicle Activity by Vehicle Type

FUNCTIONAL SYSTEM	PERCENT OF TRAVEL						
	MOTOR-CYCLES [OP-TIONAL]	PASSENGER CARS [2 AXLE, 4 TIRE]	LIGHT TRUCKS [OTHER 2 AXLE, 4 TIRE]	BUSES	SINGLE-UNIT TRUCKS	COMBINATION TRUCKS	TOTAL
RURAL							
INTERSTATE	0.5	56.8	10.8	1.1	5.2	25.6	100.0
OTHER ARTERIAL	0.4	69.9	16.4	0.7	4.9	7.7	100.0
OTHER RURAL	0.4	73.5	17.1	0.6	4.7	3.7	100.0
URBAN							
INTERSTATE	0.4	68.6	12.9	0.9	4.2	13.0	100.0
OTHER ARTERIAL	0.3	77.4	14.6	0.5	3.6	3.6	100.0
OTHER URBAN	0.4	79.9	14.1	0.5	3.5	1.6	100.0

Source: Taylor, NCDOT HPMS Data, 2005.

In the current NCDOT practice, there are two approaches for analyzing the impact of overweight trucks and axle weight exemptions. The first commodity-based approach aims to convert the quantity of major commodities to the total weight of commodities and then to the number of typical trucks, by assuming each commodity is carried by a single truck type with constant (e.g. maximum) truck loads with/without exemption (Chapter 5). The second approach utilizes weight distribution data from weigh-in-motion or static weigh stations to develop truckload and axle load distribution estimates for each road category that corresponds to a typical pavement design (Chapter 5). The truck flow loading pattern information calculated from these two approaches can be further used in the standard pavement design procedure to estimate the life cycle of pavement and the corresponding economic value of overweight truck permission and regulations. Similar methods that are augmented by NCDOT overweight truck permit data apply to bridges.

In principle, these two approaches provide rapid analyses for quantifying the marginal system-wide cost due to the overweight trucks and axle weight exemptions (NC General Statute 20-118). However, several simplifying assumptions in the above methods can be further relaxed to take into account more realism and to provide more accurate estimates. NC field crop commodities, for instance, could be carried by several truck types depending on which markets (e.g. local, regional or interstate) that agricultural products target. Furthermore, the average truck loads for different trip classes could be considerably different. Interstate goods movements, in general, are more likely to be served by heavy duty trucks that are typically fully loaded, and local goods are more likely carried by urban medium trucks that travel multiple trips during a day, while some of trips could be empty or half-loaded (Caltrans 2001). On the other hand, traffic flow patterns and axle weight distributions could vary significantly at different geographic regions and for different truck classifications (Figure 1-4 and Chapter 7). The situation is further complicated by heavily-loaded construction trucks in local and regional traffic (Chapter 8). Thus, it is necessary to synthesize commodity-based analysis results, truck weight data, and overweight truck permit data to construct accurate estimates on traffic volume and truck weight distributions on typical roadway sections (Chapter 8).

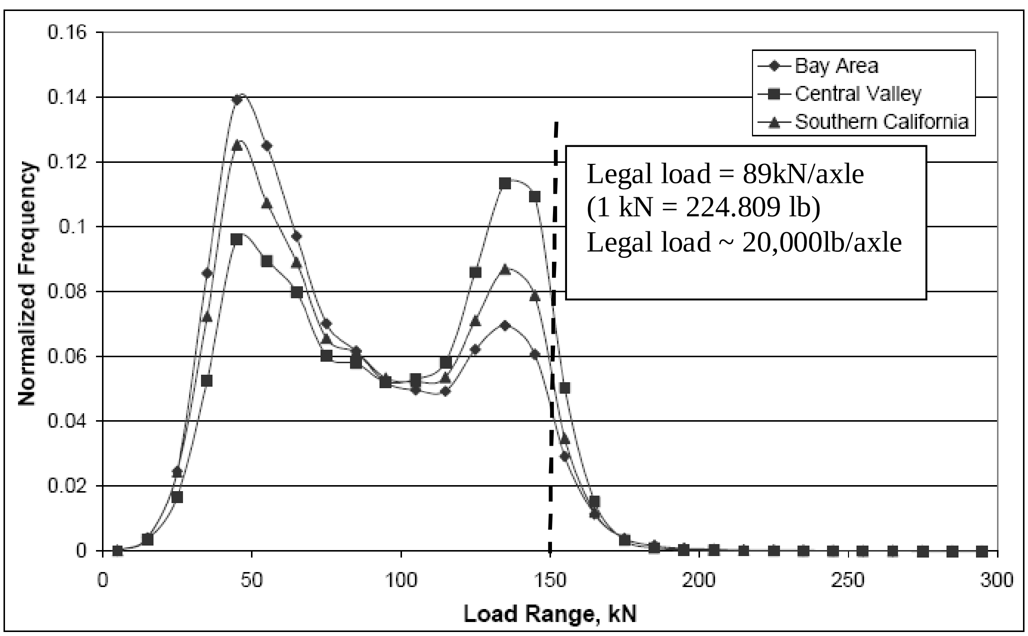


Figure 1-4 Tandem Axle Load Spectra in Three California Regions (Lu 2003)

Problem Definition

Truck flows are fundamentally a reflection of the need to move freight from points of supply to points of demand (Figure 1-5). The facility use patterns (e.g., truck miles by type of highway) are then the outcome from moving commodities from origins and destinations using specific types of trucks across paths in a network.

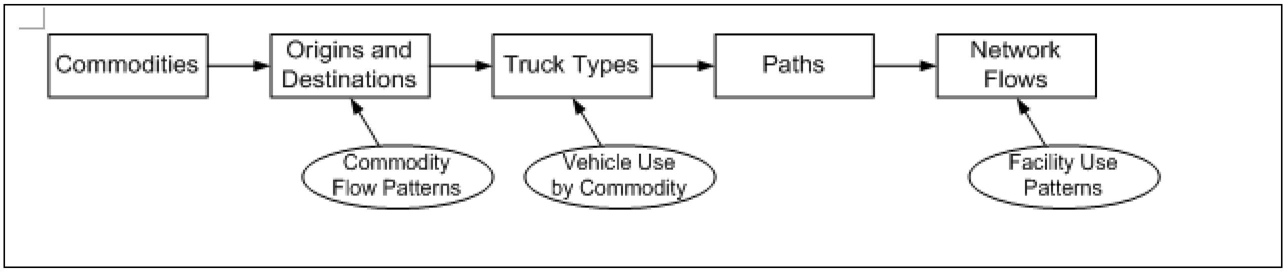


Figure 1-5 Truck Flows

Information like that shown in Table 1-2 and Table 1-3 can be developed by summarizing the network flows by facility type. If all the trucks and commodities had radio frequency identification (RFID) tags, that included weight information, and all the major network links had tag readers, this would be an easy task. Since that is not the case, the facility use information has to be estimated (synthesized) with techniques like statistical inference using truck traffic classification and weight counts at specific North Carolina highway locations (Chapter 5, Chapter 7, and NCDOT Research Project HWY 2008-11) and with flow estimation using truck traffic network modeling (Chapter 6 and NCDOT Research Project HWY 2006-09).

If statistical inference is employed, inferences are made for un-instrumented links based on instrumented links (*P*% of the flow on facility *x* passes over facility *y*). The HPMS, WIM and similar observations become the flow rates pertaining to the facilities where they were collected and they become the basis for estimating flow rates for nearby, un-instrumented links. Some kind of logic is needed to create those inferences. If "nothing" is known about the flow patterns of trucks that cross the instrumented link, statistical inference can be fairly difficult to do (NCDOT Research Project HWY 2008-11). Supplementary counts on nearby links, especially secondary roads, can help (Chapter 9). Such supplementary counts were taken on many links for this project and related projects, and the results will be applied to develop NC truck traffic profiles and flows at specific locations, for highway functional classifications, and for NC regions.

If flow estimation from truck network modeling is employed, a synthesized origin-destination (OD) trip matrix may used to estimate the link-specific flows. From these flows as in Tables 1.2 and 1.3, the highway-class-specific observations are derived. Origins and destinations are established, say, based on economic activity; and the OD flows by truck type are estimated using commodity flow data (e.g., the Reebie data, FHWA FAF2 data) and other sources (e.g., permits, roadside interviews, and carrier interviews). The observations from the HPMS, WIM other sources become validation checks to ensure that the estimated OD flows are consistent with what is observable in the field. Specifically in this research a truck network model (Chapter 6) was developed in NCDOT Research Project HWY 2006-09 using FAF2 data and validation counts from hundreds of locations. The network model will help estimate truck traffic vehicle miles travelled by truck class, highway functional classification and NC region.

What NCDOT presently knows about truck trip making patterns is captured in the documents like those submitted to the legislature regarding the impacts of overweight trucks (Corley-Lay 2005). Truck vehicle miles traveled are described by truck weight class and highway functional class in various regions of the state. As the NCDOT project description (NCDOT PV 710, 2005) indicates, "…the NC Legislature recently requested that NCDOT provide information on the cost of overweight vehicles to our pavement system and further, the cost of existing weight exemptions. It was possible to estimate the number of overweight vehicles and the change in pavement life they would cause to various pavement classes." The results of this research will further define with additional detail the types of information requested by the legislature.

Table 1-2 Vehicle Miles Traveled by Truck Class, NC Region, and Highway Classification

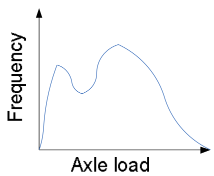
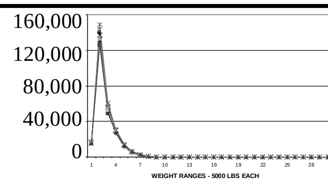
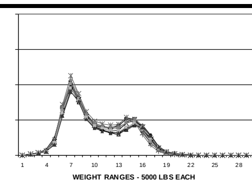
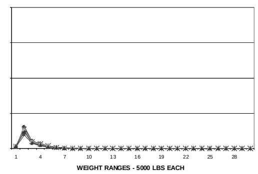
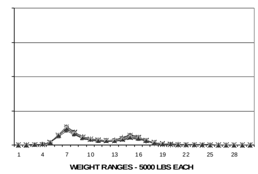
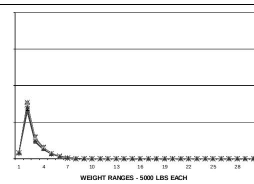
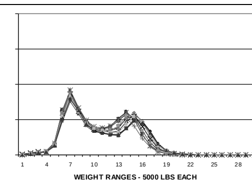
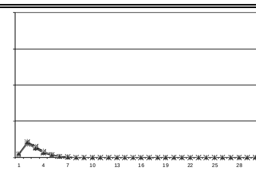
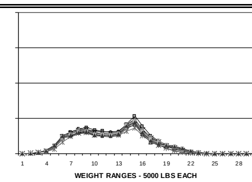
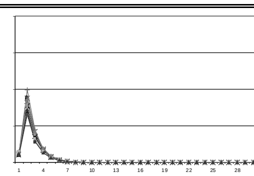
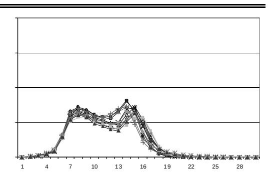
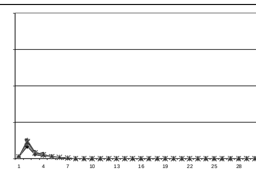
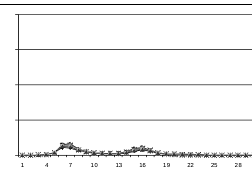
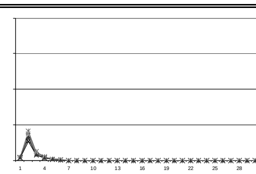
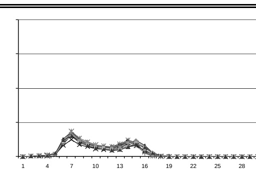
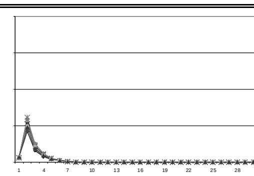
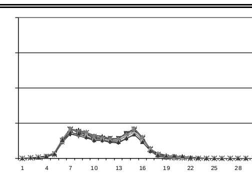
FHWA Truck Class	Distance Traveled/Volume Level by Truck Type by NC Region and Urban or Rural Classification					
	Mt, Central or Coastal Interstate Routes		Mt, Central or Coastal Primary Routes		Mt, Central or Coastal Secondary Routes	
	Rural	Urban	Rural	Urban	Rural	Urban
Class 5 Duals						
…						
Class 8 TTST						
…						
Class 11 TWIN						
…						
Class 13						

*See Chapter 6.

Unanswered questions remain, however. As the NCDOT project description says, "… to address the cost of the overweight or exempted vehicles, you need to know the length of their trips on Interstate, primary roads and secondary roads for both rural and urban cases" as represented by Table 1-2.

Generating information like that for Tables 1.1 to 1.3 is the purpose of this project. To cite the project description, "Information on the nature of truck traffic, specifically the length of travel on various roadway classes by various vehicle classifications …. is needed in order to quantify truck impacts to the pavement system. This information may also be helpful to planners." More specifically, "It is anticipated that the final product will be both a database and a table of current values. This table might include vehicle class, rural vs. urban, and number of miles in each road category in the typical trip."

Table 1-3 Weight Distribution of Truck Types and North Carolina Highway Types

FHWA Truck Class			Class 5	Class 9
Weight Distribution/ Volume Level by Truck Type by NC Region and Urban or Rural Classification 	**Urban**			
	Rural	Coastal		
		Central		
	I-95			
	Rural & Recreational	Mountains		
		Coastal		
	Urban & Some Recreational			
	Asheville Urban & Recreational			

Note: All vertical scales are the same as shown in the top left graph. Low = 0, High = 160,000.

Research Objectives

The research has two primary objectives: (1) develop a picture of facility use by truck type and facility type for various regions of the state, and (2) create truck traffic profiles for specific highways and highway types, especially rarely examined State Routes. The two research objectives are inter-related and depend on similar tasks.

Pavement engineers need annual truck vehicle miles traveled by vehicle class and facility type including trucks that receive exemptions from regulated weight restrictions and trucks that ignore weight restrictions. To meet their needs, this research aims to:

- Synthesize commodity flow data, truck survey data and truck measurement data
- Provide estimates on truck volumes and weight distribution by classification and route category
- Facilitate a better understanding of the truck trip flow pattern in NC
- Inform and support broad policy decisions in pavement design

Research Challenges

The project addresses the modeling challenges by inferring useful and reliable truck trip profiles for NCDOT. The research product will consider the specific requirements of pavement designers. As indicated by the commonly used ESAL calculation equation (Figure 1-3), the effect of traffic loads on pavement damage increases exponentially with the size of the load. Thus, the focus in this research should be on how to provide better estimation accuracy for heavy weight truck flows, and how to verify and improve the knowledge of truck travel patterns and truck trips to design pavement for primary and secondary freeway facilities.

It should be remarked that the data coverage and detailed truck classification schemes in the available data sources do not match each other. Thus, it is important to develop a systematical data mining procedure that can discover information conflicts, identify knowledge gaps and further integrate different categories of data regarding commodity, truck volume, classification counts, and weight data.

Because statewide coverage counts and class counts do not have weight data and because truck weigh-in-motion (WIM) stations can only cover a small portion of links at the NC road system, the research aims to synthesize the two databases to improve truck volume and distance estimates. Moreover, this research plans to develop a procedure for identifying critical State Route (SR) locations which carry significant truck traffic and to add those truck counts to the research database. By making judicious decisions in data collection, estimation and analysis, the project strikes to create an excellent combination of both realism and estimation performance to support planning, design and decision making.

Summary

This chapter outlined the research problem with regard to the expected growth in truck traffic and potential damage to highway pavements. Data demonstrated the significant percentage of trucks that comprise the traffic composition, especially on Interstates. Data further demonstrate how a small but significant number of trucks are likely over weight. The chapter discussed research objectives and challenges. Introduced also were the current NCDOT commodity-based method and data used to analyze the cost impact of trucks. Truck loading pattern analysis and pavement design based on WIM data were discussed. Overall the chapter presented the basic definitions and expectations for what truck traffic profiles are and what will be developed in the course of the research.

Subsequent chapters of this technical report refine and amplify the research efforts, the methodology for this research, and its results. The literature review in Chapter 2 discusses recent research efforts that pertain to NC truck traffic profiles analysis. Available data resources are summarized in Chapter 3. Chapter 4 summarizes the overall research methodology, and Chapter 5 outlines the current NCDOT methodology for developing truck traffic profiles. An innovative prototype statewide truck traffic network model is described by Chapter 6. Chapter 7 describes detailed truck traffic profiles for truck classes 5 and 9 for urban, rural and recreational highways in NC regions (mountain, central and coastal). Permitted overweight truck traffic profiles are described by Chapter 8. Chapter 9 extends the research to State Routes (SR's). And Chapter 10 presents conclusions and recommendations based on the research.

[This page has been intentionally left blank.]

2. Literature Review

Recognizing the interdisciplinary nature of the problem of developing truck traffic profiles for North Carolina, this chapter first discusses the classification of truck trip profiles (patterns) in different application areas. This discussion is followed by a brief review on existing truck spatial pattern estimation models in the field of freight transportation planning. The focus of the literature review is on two truck flow pattern studies conducted in California. The first study estimated the truck movement patterns in California for traffic emission analysis purposes, by utilizing commodity databases, roadside intercept survey data and limited truck count data (SCAG 2002). The second study examined the annual and seasonal patterns of truck axle load distributions according to data from 100 WIM stations in California (Lu 2003).

Classification of Truck Trip Profiles (Patterns)

Besides the FHWA classifications (Figure 2-1) and the NCDOT vehicle classification scheme (Table 2-1) trucks can be classified by other criteria, depending on specific needs of application areas. In particular, structural design uses ESAL or load spectra (Figure 1-4) as standard measures for quantifying the amount of damage vehicles do to the pavement. In emissions related traffic impact analysis, gross vehicle weight is the major concern because it determines the engine power and vehicle structural design. In transportation planning applications, trucks are converted to passenger car equivalents (PCE) to consider truck size and roadway geometric characteristics.

The classification of commodity flow patterns involves a number of interrelated characteristics. For instance, one can classify commodity flows in terms of spatial features, such as long-haul, inter-regional, local, and developing area. Another classification method used in Washington State considers trucks that serve (a) major statewide and interstate truck travel; (b) primarily intercity freight movements, and regional hauling; (c) farm to market routes and regional commerce; (d) suburban industrial activity, as well as (e) primarily local goods movement and specialized products. Using an extensive survey protocol about 100 individuals conducted personal interviews with truck drivers at 28 locations to determine truck traffic origins and destinations in the State of Washington. About 24,000 observations defined origins and destinations in over 400 Washington communities. Of particular interest were the following types of results: number of truck trips originating or ending at Washington ports, trips originating inside and outside the State, trucks coming from or going to Canada, and the most heavily used highways.

In contrast to the Washington State classification, NCDOT is particularly interested in truck flow patterns classified according to the NC regional geotechnical regions for pavement design (coastal, central and mountain – Figure 2-2), urban and rural highways, highway type (Interstate, US, NC and SR), and FHWA vehicle classes 5 – 13 which include NCDOT classes Dual and TTST (Table 2-1). Estimating truck origins and destinations is not a goal for this project, but rather NC Truck Traffic Profiles as the project title states. However, truck origins and destinations are valuable as well as the routes they travel in order to enumerate which and how frequently specific roadway sections are traveled. Origin-destination and path information is a product of the NC Truck Networks project (HWY 2006-09), and it is also available for overweight permitted vehicles from the NCDOT Oversize-Overweight Permitting Unit. Obtaining expensive origin-destination data from surveys like the State of Washington study is beyond the scope of this research.

This NC Truck Traffic Profiles project aims to develop truck traffic profiles of the following characteristics:

- counts of trucks on a sample of highways by functional classification (urban and rural, interstate, recreational, primary, and secondary)
- truck vehicle miles traveled on selected highways by NC region
- typical gross vehicle weight by truck class

To the extent the data are available this research project will identify these profiles for the following NC regions:
- Mountain Urban; Mountain Rural
- Piedmont/Central Urban; Piedmont/Central Rural
- Coastal Urban; Coastal Rural

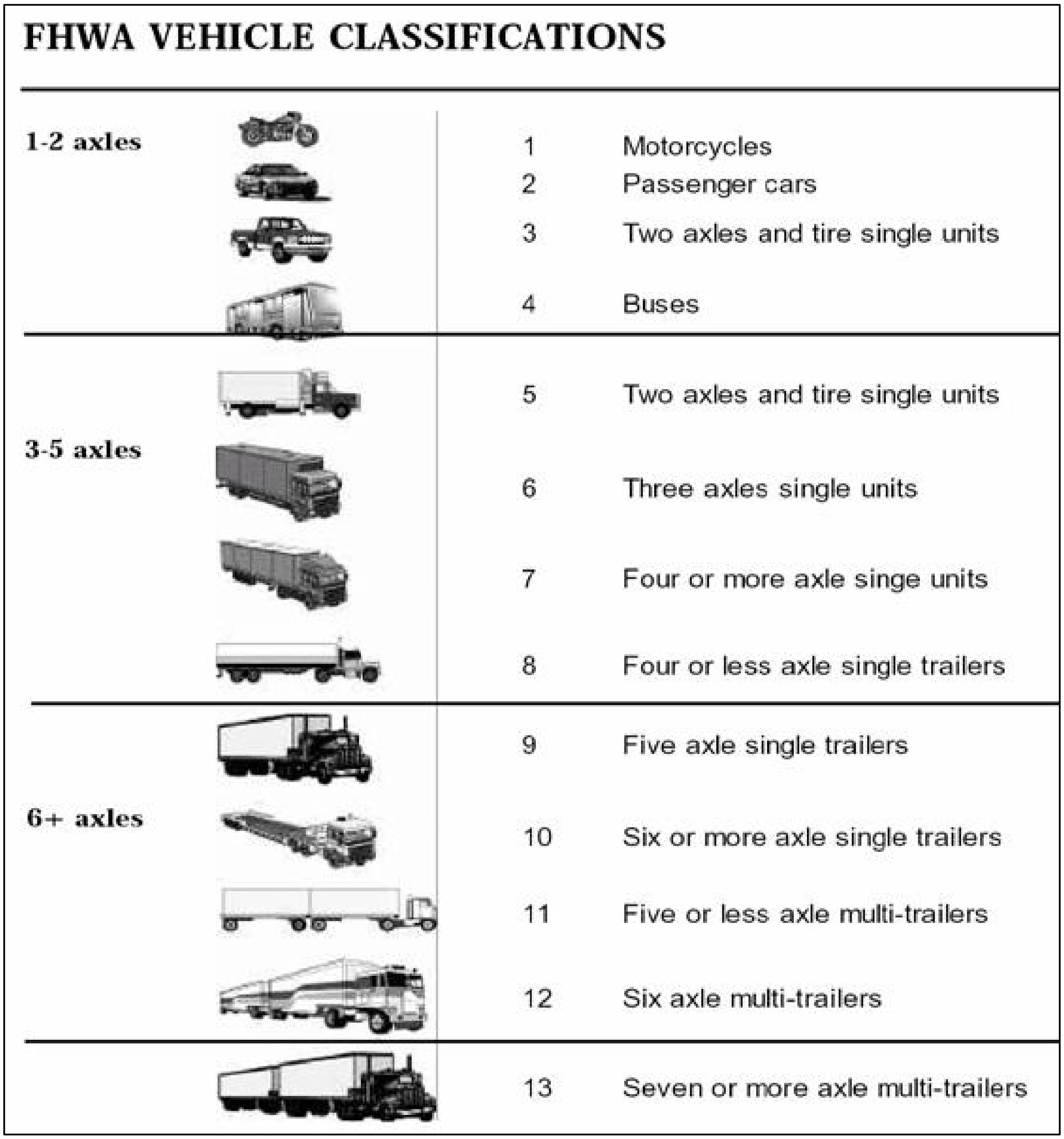


Figure 2-1 FHWA Vehicle Classifications (source FHWA)

Table 2-1 NCDOT and FHWA Vehicle Classifications (Stone 2004)

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								

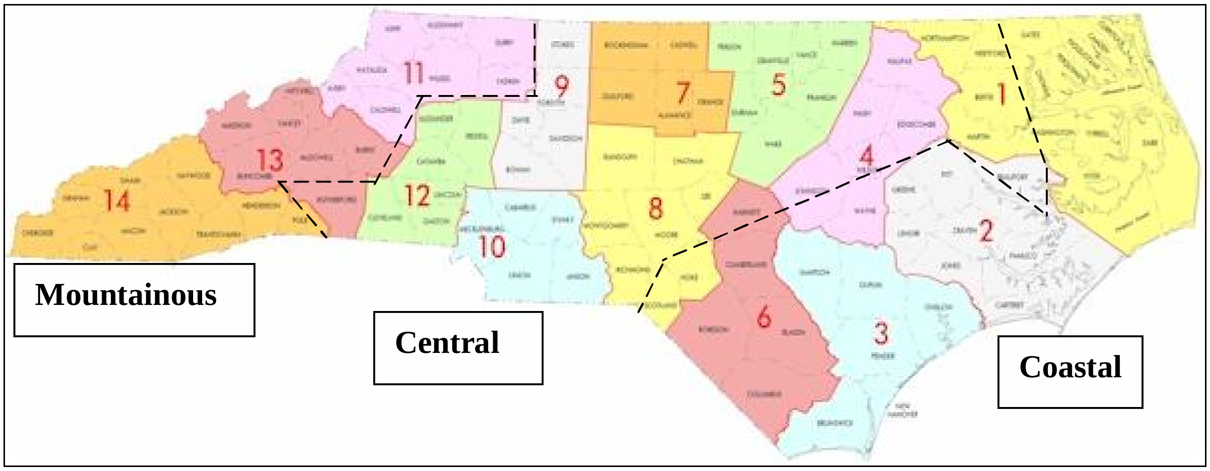


Figure 2-2 NC Regions for Pavement Design with NC Counties and NCDOT Divisions

Current NCDOT Methods for Estimating Truck Traffic Profiles

As presented in Chapter 1 current methods of collecting and forecasting truck traffic profiles provide coarse estimates of annual truck traffic by vehicle class for the whole NC road system as shown in Table 1-1. Statewide vehicle percentages in Table 1-1 may be reliably applied to statewide VMT totals (Chapter 5) to estimate statewide travel by vehicle class and by facility type. However, sub-area travel in counties and the mountain, central and coastal regions cannot be calculated from Table 1-1. because sub-area travel by vehicle class is unavailable at NCDOT. Furthermore, existing methods do not aggregate the number of and distance traveled by overweight vehicles by facility type, and current methods do not estimate truck trip distance profiles by vehicle class, highway facility type, or sub-area. Weigh stations, WIM stations and classification counts only measure a small proportion of trucks, and the small sample size may lead to biased estimates of traffic volumes (but not necessarily axle load spectra) when recorded data are extrapolated to adjacent sites (Lu 2002). Thus, the NCDOT needs better truck profile estimation methods and more and better truck flow data than are currently available from state and federal sources.

NCDOT is particularly interested in vehicle impacts due to axle loads. In the current NCDOT practice, there are two approaches for analyzing the impact of vehicle weight including overweight trucks and axle weight exemptions. The first commodity-based approach, as briefly mentioned in Chapter 1, converts the quantity of major commodities to the total weight of commodities and then to the number of typical trucks, by assuming each commodity is carried by a single truck type with constant (e.g. maximum) truck loads with/without exemption (Chapter 5). Axle loads may be determined by assuming a particular distribution of vehicle classes carrying the commodity (typically FHWA class 9 trucks with 5 axles and single trailers). The second approach utilizes weight distribution data from weigh-in-motion or static weigh stations to develop truckload and axle load distribution estimates for each road category that corresponds to a typical pavement design (Chapter 5). The truck flow loading pattern information calculated from these two approaches can be further used in the standard pavement design procedure to estimate the life cycle of pavement and the corresponding economic value of overweight truck permission and regulations. Similar methods that are augmented by NCDOT overweight truck permit data apply to bridges.

In principle, these two approaches provide rapid analyses for quantifying the marginal system-wide cost due to the overweight trucks and axle weight exemptions (NC General Statute 20-118). However, several simplifying assumptions in the above methods can be further relaxed to take into account more realism and to provide more accurate estimates. NC field crop commodities, for instance, could be carried by several truck types depending on which markets (e.g. local, regional or interstate) that agricultural products target. Furthermore, the average truck loads for different trip classes could be considerably different. Interstate goods movements, in general, are more likely to be served by heavy duty trucks that are typically fully loaded, and local goods are more likely carried by urban medium trucks that travel multiple trips during a day, while some of trips could be empty or half-loaded (Caltrans 2001). On the other hand, traffic flow patterns and axle weight distributions could vary significantly at different geographic regions and for different truck classifications (Figure 1-4). The situation is further complicated by heavily loaded construction trucks in local and regional traffic. Thus, it is necessary to synthesize commodity-based analysis results, truck weight and permit data, and truck survey samples to construct accurate estimates on traffic volume and truck weight distributions on typical roadway sections.

Truck Profile Estimation Models

To estimate freight demand spatial patterns including truck profiles, existing freight transportation demand models can be grouped into commodity-based and trip-based approaches.

Commodity-Based Models

Commodity-based models focus on commodity generation, commodity distribution, mode split and trip assignment. The commodity-based approach first analytically generates and distributes or acquires sampled region-to-region, state-to-state, or county-to-county tonnage flows from a proprietary source like Global Insight or from extensive driver surveys like those described above for the State of Washington. Second, the commodity-based approach allocates the commodities to the different transportation modes (e.g. truck, rail, water). Third, the commodity approach converts tonnage to the number of truck trips based on a payload factor (Chapter 5) and assigns the truck trips to a state or regional network. The *Freight Forecasting Framework* model (Tang 2006) is a commodity-based model.

A variation of the four-step framework bypasses the trip generation, distribution and mode choice steps. It uses synthesized county-to-county origin-destination (OD) commodity-based truck trip data such as those available from the FAF model. Truck trip assignments for a state highway network can be determined from the synthesized FAF OD matrix using a US highway network (like the National Highway Planning Network), a traffic analysis zone (TAZ) model based on counties, and separately generated short-haul truck traffic as in NCDOT Project HWY 2006-09, *NC Truck Network Model* (Stone and Mei 2007).

Vehicle-Based and Trip-Based Approaches

The vehicle-based or trip-based approach typically estimates the number of trips according to socio-economic data, (particularly industry type and employment) and land use characteristics, as well as trip survey data. The trip-based approach can be fully integrated into the traditional four-step traffic demand analysis framework, which includes trip generation, trip distribution and trip assignment. The *Quick*

Response Freight Forecasting Method developed by Horowitz (2003) is an example vehicle-based method that applies short cut methods and parameters to avoid costly surveys and data gathering.

An important example of the vehicle-based method combined with the commodity flow method, is the *Southern California Association of Governments Goods Movement Truck Count Study* (SCAG 2002). The goal of the SCAG study was to develop a regional heavy-duty truck travel demand model for evaluating the impact of truck emissions in southern California. The study focused on two different groups of truck flows: external flows and internal flows. A commodity flow database was used to estimate truck trip generation and distribution, while traditional trip-based methods were used to estimate truck trip generation and distribution inside the study area. By using the commodity flow technique for modeling external traffic flows, the study was able to systematically utilize different data sources such as total tonnage volume data at external cordons, aggregated commodity distributions, estimated origin-destination patterns, and payload conversion factors. This study also utilized intercept survey data to estimate gross truck weight distributions and verify external routing assumptions used in the model. However, the SCAG staff recognized the limitations of borrowing a variety of databases and that it would be desirable to collect additional data to validate commodity flows, OD patterns, payload factors, time of day factors, trip generation rates and gravity model parameters. Considering resource restrictions the staff concentrated on classification counts and external station intercept surveys.

Recommendations from the SCAG vehicle classification count and survey analysis include the following activities which have value for NCDOT and this project:

- Establish a regular regional truck count program to support modeling and planning studies.
- Coordinate with local transportation count programs.
- Conduct in-depth classification counts on arterials on selected screenlines.
- Conduct specialized speed studies (important for emissions and safety).
- Classify trucks by number of axles (consistent and accurate), gross vehicle weight (over 10,000 pounds), and the FHWA scheme for trucks (vehicle configuration, length, and body type).

Besides the SCAG model other freight origin-destination demand estimation models have been proposed to utilize truck classification counts available from State DOTs. For instance, List and Turnquist (1994) presented an optimization model to estimate different truck flow patterns with multiple vehicle classes. Sherali et al. (1994) presented a linear programming model with a simple route choice component. To model multi-mode multi-product freight transportation equilibrium, Crainic et al. (2001) proposed a bi-level freight OD demand estimation model, where the upper level is a generalized least square estimator and the lower level is a system optimum traffic assignment model.

Another important report related to this project is *Truck Traffic Analysis using WIM Data in California* conducted by the University of California, Berkeley (Lu 2002). The project examined a California Department of Transportation (Caltrans) WIM database that included 100 WIM stations by axle type, region, rural versus urban locations, and distribution of truck types. As depicted in Figure 2-3, the WIM data showed a significant percentage of empty and half-loaded trucks, especially for single axle loads, while there was a small, but significant portion of the axle loads that are over the legal limit. In addition, axle load spectra were much higher at rural WIM stations compared to urban WIM stations. The study found that axle load spectra, as characterized by Load Spectra Coefficients (LSC) can generally be extrapolated for steering and single axles to adjacent sites. Differences in LSC for tandem and tridem axles were larger among adjacent sites, meaning that extrapolation to adjacent sites for design is more risky. The report also provided several recommendations for the use of the WIM database. Truck volume estimates and ESAL estimates contain significant numbers of errors or poor relation to actual traffic, based on comparison of pavement performance and traffic levels.

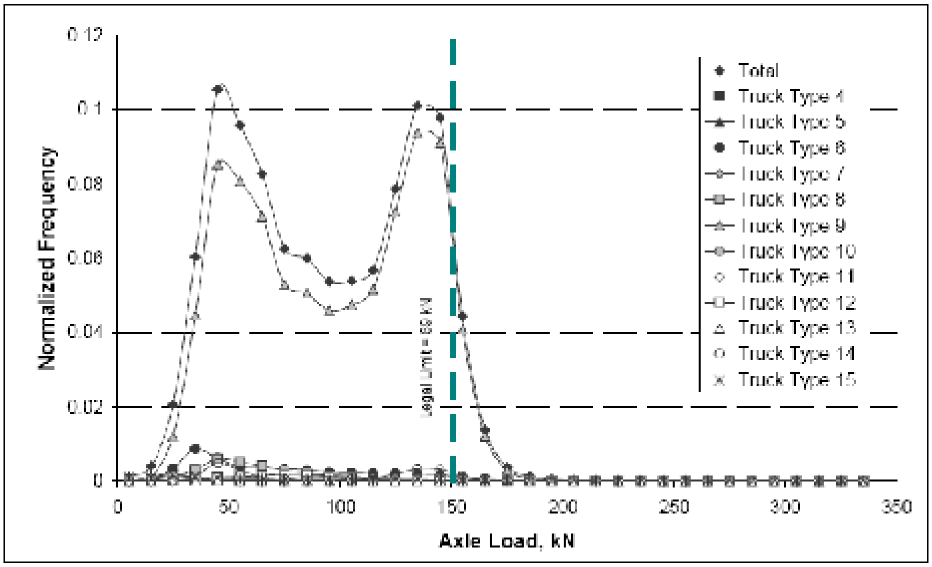


Figure 2-3 General Tandem Axle Load Spectra Across All Dates and Locations (Lu 2002)

However, the data in the WIM database appear to be of much higher quality than the data used for pavement design and management. The primary problem is estimation of truck traffic volumes and load spectra coefficients for locations that are not equipped with WIMs. The report recommended verifying the risk associated with errors in these estimation methods for different pavement types.

The findings and recommendations of the Lu (2002) study have particular resonance for this research on NC truck traffic profiles and the study (NCDOT HWY 2008-11) to determine traffic characteristics for the new AASHTO mechanistic empirical pavement design guidelines (NCHRP 538, 2005). For example, Figure 2-3 shows a composite picture of all trucks in California for all WIM locations for the 1991 – 2001 composite WIM databases. The report also shows similar profiles for individual WIM stations and for six California regions. The California regional profiles of truck type counts by axle weight are similar in nature to the profiles desired by NCDOT from this research - miles traveled by truck classes by highway class (Interstate, US, NC and SR) by urban/rural regions (mountains, Piedmont, and coast), relative frequencies of truck classes by axle load, and truck class frequencies by gross vehicle weight. In addition the California data, like the objectives of the NCDOT study, describe the entire range of truck weights including those under and over the legal limits. In contrast to the California study the NCDOT research will focus more on overweight trucks and their paths (routes) taken, as well as the other truck profile features. The emphasis of this research on overweight vehicles reflects current issues regarding highway safety, overweight exemptions, pavement design, and bridge maintenance (FARS 2004, Corley-Lay 2005, NC GS20-118, NCHRP 538, AASHTO).

Many other WIM data studies that address truck traffic profiles have occurred across the U.S. including Alaska, the New England states and Texas, to name a few states (Schomoyer 1998, Walters 1998, Qu 1997). These and other reports describe WIM data analyses for truck traffic related to pavement design and maintenance, traffic seasonality adjustments, clustering WIM stations, regional averages, and other important topics.

Summary

The literature review revealed that there are a variety of truck traffic classification schemes including the FHWA vehicle classification scheme based on vehicle design, gross vehicle weight, axle loadings, commodity flows in terms of geographic regions, number of long haul and short haul trips, origins and destinations, commodities carried, interstate and intrastate, oversize and/or overweight, permitted and illegal, and other measures. This NCDOT research will develop truck traffic profiles that classify truck miles and truck counts by truck class, weight, NC region, urban and rural highway location and highway type.

The literature review discusses two approaches at NCDOT used to evaluate the impact of truck weight and axle loads (Table 2-2). In the first method NCDOT determines statistically reliable vehicle miles traveled for each county and reliable statewide vehicle class percentages by facility type from traffic counts. The aggregate statewide vehicle class percentages, however, cannot be reliably allocated to counties or regions. Furthermore the county level vehicle miles traveled cannot be reliably allocated to highway classes or to commodity types carried. The second method focuses on pavement design using WIM traffic counts to measure axle loads by vehicle type. The method produces highway-specific section data. At this time the sparse WIM data cannot produce sub-area or regional estimates of vehicle miles traveled by vehicle class or highway type.

In other DOTs and research organizations two primary approaches for estimating truck traffic profiles are used: commodity-based models and vehicle or trip-based “4-step” models. Some models are a hybrid of these two approaches and use a variety of data sources taken both from the field (WIM station counts) and from synthetic databases (FAF). In general the methods are data intensive and involve network modeling and/or complex analysis. However, the results give reasonable pictures of truck activity by facility type, location, and vehicle class.

Table 2-2 Summary of Methods to Determine Truck Traffic Profiles

Method	Agency Use	Potential Use for This Project
Statewide vehicle class % and VMT	NCDOT	The research can use this method as a sum check on other methods. The methods cannot reliably disaggregate data to sub-regional and highway facility levels.
WIM and LTPP vehicle class counts and axle loads.	NCDOT	The research can use these pavement design databases and methods to determine site-specific truck loads by truck class. The data and methods do not provide sub-area or regional estimates for vehicle miles traveled by vehicle class or highway type.
Commodity-based models	NCDOT and other agencies	NCDOT uses statewide vehicle class and VMT data, commodity production data, and truck payload factors to estimate approximate commodity loads carried by trucks in NC. Other agencies (FHWA, SCAG and Caltrans) use complex supply-demand commodity-based methods that require extensive proprietary commodity flow data, truck driver surveys and/or synthetic databases. Current NCDOT research uses synthetic long-haul OD truck flow data and "4-step" estimates of short-haul truck trips to develop NC truck traffic network models. They will provide a systematic method for developing forecasts of truck traffic by facility type and location for this research on truck traffic profiles.
Vehicle or trip-based "4-step" models.	NCDOT and other agencies	The "4-step" method generates truck traffic flows by facility type and location on the network directly from socio-economic and other data. While used by other agencies, this approach will not likely be used during the truck traffic profiles project except to generate short-haul truck trips as noted above for the NCDOT truck network model research.

3. Data Resources

This chapter compares required data to available data for developing NC truck traffic profiles. Data needs are discussed depending on the nature of the profiles developed. Procedures for acquiring the necessary data are described. The combination of the methodologies presented in Chapters 2 and 4 and the data described in Chapter 3 support the methods and results developed in subsequent chapters.

Required Data

As discussed in Chapter 1 this research project has two primary objectives: (1) develop a picture of facility use by truck classification and facility functional class for various regions of the state, and (2) create site-specific truck traffic profiles for a broad sample of highway links emphasizing vehicle class, vehicle miles traveled by highway classification and region (Chapter 6), gross vehicle weight, and to the extent possible the number of axles, weight of each axle, and axle spacing. These axle data are the subject of the NCDOT MEPDG Truck Traffic Data project (HWY 2008-11) and are used to describe profiles for truck classes 5 and 9 (Chapter 7) and truck traffic on selected State Routes (Chapter 9). The two research objectives are inter-related and depend on similar tasks. The first objective addresses needs of pavement engineers and the second objective supports bridge engineers. The objectives of this NCDOT study address the entire range of truck weights including those under and over the legal limits. The task on overweight trucks (Chapter 8) and their paths (routes) reflects current NC issues regarding highway safety, overweight exemptions, and cost, as well as pavement design and bridge maintenance

Acquiring data and analyzing it to develop truck trip profiles is the purpose of this project. Citing the NCDOT project description, "Information on the nature of truck traffic, specifically the length of travel on various roadway classes by various vehicle classifications …. is needed in order to quantify truck impacts to the pavement system. This information may also be helpful to planners." More specifically, "It is anticipated that the final product will be both a database and a table of current values. This table might include vehicle class, rural vs. urban and number of miles in each road category in the typical trip."

A major challenge of the research will be to systematically integrate available NCDOT truck class counts, NC freight databases, truck surveys and truck weight measurements from weigh-in-motion (WIM) stations in order to construct a clearer picture of how different trucks (including overweight trucks) use NC interstate, primary, and secondary routes including bridges. Furthermore, the research will likely have to rely on Federal sources of data and the results of statewide and national truck network models to extend the NCDOT data and profile analysis to highway facilities that do not have vehicle classification counts. Thus, the research methodology will have to merge different data resources in order to uncover appropriate NC truck traffic patterns.

Available Data

Table 3-1, 3-2, and 3-3 respectively summarize available NCDOT and other NC agency data, Federal Highway Administration and other available federal agency data, and data from other sources Comments in the tables point out data sources, whether the NCSU research team acquired the data, and special attributes of the data.

Table 3-1 Available NCDOT and NC Agency Data

Data Set	Source	Status	Comments
NC Vehicle Classification Counts	NCDOT Traffic Survey Unit	Available April 2007	2006 update of HPMS class data. NCDOT 4-class scheme counts were collected on freeways only, were expanded to 24 hour estimates, and disaggregated to the FHWA 13 class scheme. All other counts were electronic 48 hour counts in the FHWA 13 class scheme averaged to ADT; FHWA 13-class expansion available. 48 hour weekday counts averaged to ADT. 724 stations including NC border crossings, screenlines, & county
Oversize/Overweight Permit Data	NCDOT OSOW Permit Unit	1 week of data for 20-24 Aug2006 on hand (Appendix D). 1 year of data available upon request.	Overweight data is a focus. Data includes: origin county, destination county, path in narrative format, GVW, axles. Analysis underway to determine Interstate, US, NC and SR highways with highest frequency of use by OW trucks.
WIM data	NCDOT Traffic Survey Unit	2006 data available upon request. May be part of 2006 update of HPMS (first item).	About 45 count stations on urban & rural Interstate & US routes in NC. Data is collected for all lanes and data captured is hourly FHWA vehicle class counts by lane for all classes and per vehicle records for trucks containing FHWA vehicle class, number of axles, axle spacings, axle weights, GVW, vehicle length, and speed.
Long Term Pavement Performance (LTPP) data for 2005	NCDOT for detailed data, FHWA for annual data	FHWA LTPP data on hand. NCDOT data available.	About 27 NC count stations in the 3 NC regions; this is a subset of WIM data - reported for LTPP study lanes only. Summaries are based on the study lanes only. FHWA 13-class scheme. FHWA data. averaged for day and year. Seasonal effects must be determined from NCDOT daily data. Vehicle counts, axle counts, and axle loads by direction and lane. Axle load distributions and cluster analysis results for the NC Piedmont region are available.
Turning movement counts identified by Duals and TTSTs at intersections near, for example, special generators	NCDOT Traffic Survey Unit	Some data available in digitized format (Access), some in paper format	Combine the turning movements into daily traffic by vehicle type to estimate total daily truck traffic for special generators.
2005 & 2006 summaries of VMT on NC roads	Road Inventory Section of the NCDOT GIS Unit	NCDOT, NCSU Archives	Daily & annual VMT by NC county
NC commodity annual tonnages and payload factors (1997)	NCDOT Pavement Design Unit (Corley-Lay)	NCDOT, NCSU Archives	NCDOT approach to determining NC truck profiles to estimate cost impacts.
NC employment locations & number of jobs (2005)	NC Employment Securities Commission	NCSU Archives	Excel spreadsheet and shapefile.

Overweight truck data and bridge impacts	NCDOT Structures Unit	Available upon request	Paper records.
DMV vehicle registration records	NC DMV	Available upon request	VIN yields GVW and body style.

Table 3-2 Federal Highway Administration and Other Federal Agency Data

Data Set	Source	Status	Comments
NC and US county to county long haul truck trips.	FHWA FAF2	Acquired, on-line.	Synthesized 2002 OD daily truck data used to load the NC truck network model.
Vehicle Inventory Use Survey (VIUS)	US Bureau of Transportation Statistics	2004 data acquired and on-line.	US BTS no longer updates the database. Data given statewide for NC: GVW, number of axles, body styles & vehicle length. Cannot disaggregate data to counties.
Vehicle Travel Information System (VTRIS)	USDOT, USBTS	On-line	WIM data summaries by year for NC and other states.
FHWA Freight Analysis Framework 2	FHWA	On-line. 1998 highway truck traffic available in graphic map format	2002 base year update underway.

Table 3-3 Other Sources of Data

Data Set	Source	Status	Comments
SCTG to STCC conversions	NCSU	On hand (Appendix B)	Helpful for commodity flow estimates.
Total NC Daily and Annual Truck Trips by STCG (1997)	NCSU	On hand (Appendix B)	Total truck loads of 43 commodity classes
Global Insight “Reebie” commodity flow data	Global Insight Transearch Inc.	Available for purchase (~$100,000 for NC)	Primary source of data for modeling commodity flows and truck trips.
Sub-regional and local traffic counts	Local DOTs and regional MPOs	Available upon request	Overall do not represent a statistically valid sample of sites, but could complement NCDOT data
External station surveys	Regional MPOs	Available upon request	Usual external station surveys address total through traffic, not the characteristics of truck traffic such as commodity groups, fraction loaded/empty, routes, Os and Ds.

Additional Data Needs

For this research according to NCDOT discussions the NC truck traffic should be categorized as follows:

- Mountain rural region (MtRR)
- Mountain urban region (MtUR)
- Piedmont/Central rural region (PCRR)
- Piedmont/Central urban region (PCUR)
- Coastal rural region (CRR)
- Coastal urban region (CUR)

NCDOT also requested that basic truck traffic profiles for each regional category should consist of at least the following:

- Vehicle miles traveled (VMT) by truck classification on each highway type (Interstate, Primary, Secondary or Interstate, US, NC and SR)
- Gross vehicle weight (GVW) and/or axle loading distributions by truck classification on each highway class (Interstate, Primary, Secondary or Interstate, US, NC and SR)

However, in mid-2007 NCDOT and the NCSU research team realized that the above details for truck traffic profiles were unrealistic given the available data, and NCDOT revised the research products to include the following specific data: gross vehicle weight (GVW) plots for class 5 and class 9 vehicles by NC region, by urban and rural area, and by recreational route; VMT estimates by NC region and highway type; and, to the extent possible, SR truck traffic profiles, as well as permitted overweight truck traffic profiles.

Other truck traffic profiles may be developed according to Lu (2003). Depending on the amount of available data they include the following:
- Generalized statewide axle load spectra and truck composition
- Generalized axle load spectra in different regions
- Axle load spectra at specific WIM sites
- Axle load spectra by season

The supporting data and the previous list of profiles are the topic of the NCDOT research project ***Traffic*** *Data for the MEPDG* (HWY 2008-11), and they will not be developed in this project. Some supporting data, however, will be used to develop State Route truck traffic profiles (Chapter 9).

Table 3-4 helps to summarize the available data versus the needed basic NCDOT truck traffic profile information. Shaded cells indicate the dataset that provides the truck traffic profile information.

The table shows that only the datasets for overweight truck permits and overweight trucks on bridges appear to deliver all the data necessary to develop the basic NC truck traffic profiles. However, the overweight permit data requires much post-processing to identify highway routes (paths) used. The VMT calculation is problematical because a narrative text string defines the route rather than GIS coordinates.

Excluding VTRIS, which is sampled WIM data, the next most complete datasets for basic NC truck profiles are provided by WIM and LTPP data. All necessary data appear available except for VMT, a significant objective of this research. VMT and ADTT by highway class and region, however, can be estimated from the NC truck network model, although vehicle class volumes by weight will not be.

The summary county VMT data and NC vehicle class percentages by highway functional classification provide validation sum total benchmarks for truck traffic profile results.

The remaining datasets appear insufficient to advance the development for NC truck traffic profiles.

The greatest data need is VMT which can be synthesized from the NC truck network model. The NC truck network model, however, does not directly provide VMT categorized by truck class, only generalized daily truck volumes. Furthermore, the NC truck network model does not provide GVW and axle data.

Data Issues

A variety of data issues exist including the following:

- Mismatch between truck network model estimates of aggregate truck volumes and disaggregate truck profile data needs, especially VMT by vehicle class.
- Data programming needs for the overweight data, and the need to link the results to GIS displays for ease of analysis.
- HPMS data and traffic classification counts are derived from 48-hour weekday counts on various days that may not address seasonal effects of truck traffic.
- The NC truck network model is based on synthesized county to county long haul truck flows that have been disaggregated by FHWA from much larger Commodity Flow Survey (CFS) districts. NC has only four CFS districts yet 100 counties.
- The NC truck network model provides total daily truck traffic volumes on network links and hence truck vehicle miles by specific highway route number, functional class, and location. The NC truck network model, however, does not directly discriminate by truck vehicle classification, weight or commodity.
- No statewide truck driver intercept surveys are readily available to define or provide validation checks on class counts, VMT, truck ODs and loadings.
- Static weight station data collected by the NC Highway Patrol is not archived and is not available.
- HPMS traffic samples are statistically valid statewide; however, on a regional basis the sample size is not. For example, a sample of 25 counts per grouping of highway functional class/region is statistically significant (small sample size). NCDOT maintains the 25 counts/category yet the Traffic Monitoring Guide is starting to group classes to reduce the traffic count workload on DOTs. Since the NCDOT HPMS data will provide data for different functional classes of roads in random areas of the state, requesting data to fill the data deficiencies is practical. There may be, for example, 11 Primary Road counts in the Coastal region, 7 Primary road counts in the Piedmont, and 7 in the West. Then in order to get 25 Primary counts per region from the original 25, requests should be made for an additional 14 from the Coastal region, 18 from the Piedmont, and 18 from the West. This would result in 50 more counts. Such a request may be unnecessary in that NCDOT expects to have up to 724 vehicle classification counts across NC, but the counts are not yet complete as of March 2007.

Chapter Summary, Findings, and Conclusion

This chapter described the available data and the data required for the project. Findings indicate that a variety of data from NCDOT and other sources are available to develop truck traffic profiles for North Carolina. However, important components of a complete picture of truck traffic are missing and must be synthesized or estimated. In particular VMT by sub-region, highway functional class, and vehicle classification must be estimated from the NC truck network model. Relatively little information is available on vehicle origins and destinations by route and weight and vehicle class except for permitted overweight trucks. Available weight data are available are for site specific WIM stations on US and Interstate routes. No weight data are available for secondary highways except as documented on overweight truck permits.

As a result of these findings for available versus required data, an innovative methodology must be developed to describe NC truck traffic profiles more fully. The following chapter shows how the data are used in the research methodology to accomplish the objectives of the research.

Table 3-4 Comparison of Available Datasets to Information Required for NC Truck Traffic Profiles

Dataset	MtRR	MtUR	PCRR	PCUR	CRR	CUR	VMT	Trk Class Counts	Hwy Class	GVW	Axles
NC class counts HPMS for 2006											
Overweight permit data +											
WIM data +											
LTPP data											
Turning movements at special generators											
VMT summary by Co. +											
NC vehicle class % by 12 urban & rural hwy functional classes +											
NC annual commodities											
NC employment											
Overweight data for bridges +											
DMV registration records (not used)											
NC county to county truck traffic (FAF2 2002 ODs & NC Truck Network Model)											
VIUS 2004 +											
VTRIS											
FAF2 Model*											
Reebie data (n.a.)											
Local counts											
Local external surveys											

n.a. ~ not available

+ Dataset added this project

* Disaggregated by NCSU and run in NCSU Truck Network Model

4. Research Methodology

This chapter describes the relationship of the NC Truck Traffic Profiles project (HWY 2007-05) with two other important NCDOT research projects: NC Truck Network Model (HWY 2006-09) and Traffic Data for the Mechanistic Empirical Pavement Design Guide (MEPDG) (HWY 2008-11). A summary for each project is given below.

NC Truck Network Model (HWY 2006-09)

This research developed a validated prototype truck traffic network model for North Carolina (Figure 4-1 and Chapter 6). The model traffic analysis zones include all counties and metropolitan areas of North Carolina and major economic areas throughout the U.S. The network is based on the National Highway Planning Network and it includes Interstates, US Highways, and a few secondary roads. Data from 724 class counts were provided for this project for validation; 470 were identified as being on the developed network. The North Carolina network attributes include highway type, speed, and terrain. The 2006 base year long-haul truck data originates from the FHWA Freight Analysis Forecasting origin-destination data for North Carolina including origins and destinations outside North Carolina. Short haul traffic and back haul truck traffic are generated using simplified trip generations rates and adjustments to the FAF data. Base year 2006 truck traffic estimates for North Carolina are validated by over 470 truck traffic counts throughout the state. The network model estimates only ADTT (average daily truck traffic), not total vehicle traffic including automobiles. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, the current network model does not have a capacity-constrained traffic assignment feature. The network is sensitive to input speed but not to traffic volumes on the highway. Consequently any network changes for scenario testing have to be expressed in terms of speed changes to the network links affected.

MEPDG Traffic Data Project (HWY 2008-11)

The research (Figure 4-1), which will finish in 2010, inventoried existing NCDOT vehicle class count data, methods and equipment, and it compared NCDOT data resources to MEPDG requirements. Simulation studies guided the selection of MEPDG-sensitive traffic data and traffic count locations based on the results of traffic data clustering and seasonal analysis of vehicle classifications and truck axle loadings. Research results will develop datasets and sampling plans for Levels 1, 2, and 3 MEPDG requirements. Level 1 uses project specific traffic inputs, Level 2 uses regionally averaged traffic inputs, and Level 3 uses statewide average traffic inputs.. The anticipated products of the research will be recommendations for locating new sites for vehicle class counts and vehicle load spectra, strategies for effectively using existing classification counters and deploying new traffic counters, and methods to cluster traffic counter sites in order to efficiently capture seasonal traffic adjustment factors. Other results of the research will include methods to forecast truck growth for MEPDG traffic input, and implementation strategies for expanding the NCDOT traffic count program to meet the requirements of the MEPDG.

Figure 4-1 illustrates the relationships of these two projects to this research on NC Truck Traffic Profiles (HWY 2007-05).

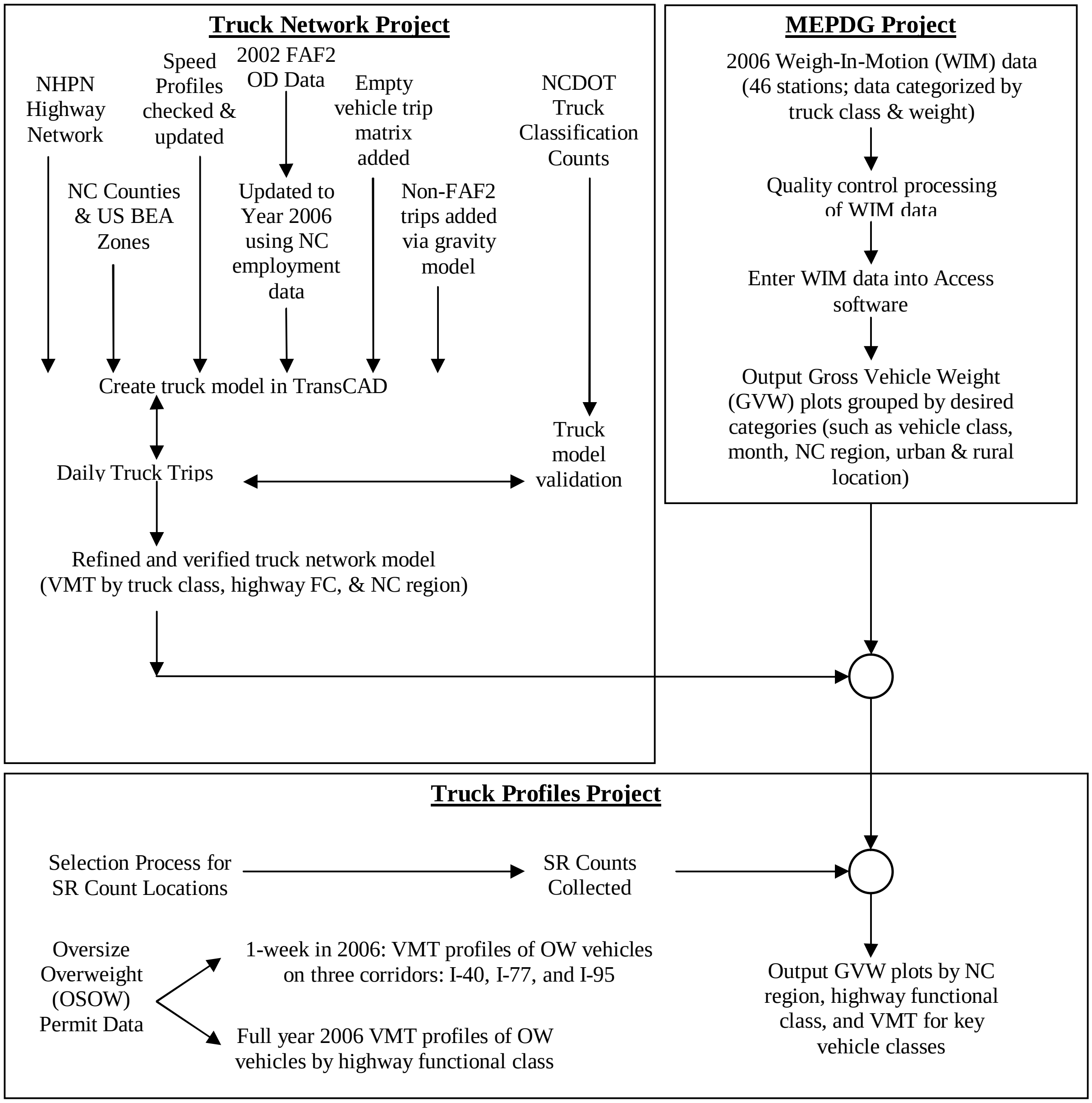


Figure 4-1 Research Methodology for Developing NC Truck Traffic Profiles

NC Truck Traffic Profiles (HWY 2007-05)

The purpose of the Truck Traffic Profiles project is to describe the character (profiles) of the truck traffic that travels a wide selection of highways in North Carolina. Such information supports a variety of issues in planning, design, operations and policy. For example, knowing truck traffic volumes, size and weight affects highway lane design, location of traffic sensors, and weight stations. Such information also helps to enforce weight limits on highways and bridges. As shown in Figure 4-1 the research approach uses a variety of data sources including: NCDOT weight-in-motion (WIM) data from about 50 stations, 48-hour traffic counts at hundreds of selected urban and rural highways. Special counts were taken on carefully selected SRs with higher truck volumes to fill in information gaps for those highways. Because of their impact on pavement condition, overweight trucks were a particular focus of this research. All overweight truck permits for year 2006 were examined to describe overweight truck traffic profiles (including truck traffic by weight and distance traveled on North Carolina Interstates. Using the inventory of NCDOT traffic counters and sensors, approximations to truck traffic profiles for trucks weighing less than 80,000 pounds or overweight trucks can be developed to describe truck traffic by gross vehicle weight, vehicle class, highway functional classification, urban and rural locations, and counties. What is missing, however, is information that is usually proprietary, i.e., truck manifest information including the origins and destinations of the trips, truck types, truck weights, and commodities carried. Samples of such proprietary information (cleaned of company identification) are available, but very expensive, and they were not used in this research. To overcome this data deficiency the research relied on the prototype truck network model developed in HWY 2006-09 (Figure 4-1 and Chapter 6). The validated truck network model provided independent estimates of truck traffic by gross vehicle weight, vehicle class, highway functional classification, urban and rural locations, and counties – estimates that can be compared to the estimates developed by NCDOT with samples of traffic counts and weights across NCDOT. The functionality of the prototype truck network model also provides a first step toward identifying typical truck traffic trips by origin, destination, and distance traveled by highway functional class and vehicle type (Chapter 6). However, the truck model estimates fall short of the ideal knowledge that could be provided by proprietary company manifest data or purchased survey summaries of manifest data.

Research Overview

Subsequent chapters carry out the methodology depicted in Figure 4-1.

Chapter 5 summarizes the current NCDOT methods for collecting truck traffic volume and weight information and current methods for developing statewide and county level estimates of annual average truck traffic (AADTT) and vehicle miles traveled (VMT) statewide and by county. Chapter 5 also categorizes AADTT and VMT by truck type and highway functional class. It describes how WIM stations provide vehicle weights by vehicle type to further define truck traffic profiles. Chapter 5 discusses the current NCDOT approach to adding commodity information to truck travel to support licensing and permitting policy. An extension to this approach is provided.

Chapter 6 describes the development of the prototype Truck Network Model for North Carolina (Figure 4-1). Results from the model estimate truck traffic profiles by AADTT and VMT by highway functional classification and sub-region. These results can be independently compared to the estimates provided by NCDOT using conventional sampling methods. Preliminary truck traffic flow assignments on the network also described likely truck routing patterns from county TAZ origins to county TAZ destinations assuming shortest paths are taken by the drivers. There are also some external path itineraries demonstrated to locations outside NC. The truck traffic network model represents another step toward complete vehicle-path information using sampled data and model estimates of the interactions of vehicles, the network, and the attributes of the network.

Chapter 7 represents the application of the MEPDG project and WIM station data analysis procedures to the NC Truck Traffic Profiles project (Figure 4-1). While GVW plots for all WIM stations for all vehicles classes and highway functional classifications could have been developed, the NCDOT Pavement Management Unit only recommended plots for vehicle classes 5 and 9 only to illustrate the majority of truck traffic. To further simplify the analysis and number of GVW plot combinations, NCDOT recommended that all urban WIM stations be grouped and that the remaining rural WIM stations be grouped by NC region – mountainous, central and coastal. During the analysis further categories became apparent - one for I-95 truck traffic and one for urban recreational traffic in Asheville. The results of this

GVW analysis for ubiquitous class 5 and class 9 trucks complement the statewide truck traffic estimates produced using the NC truck network model (Chapter 6).

Chapter 8 develops typical overweight truck trip profiles for North Carolina Interstates 40, 77 and 95 (I-40, I-77 and I-95). The profiles rely on NC overweight truck permit data from NCDOT for August 21-25, 2006. Statistical testing showed that the results for one week can be reliably expanded to one year. The resulting permitted overweight truck traffic profiles describe the distribution of weight by mile marker for I-40, I-77 and I-95 across North Carolina. Most heavily traveled segments are easily identified by graphic images. The analysis also gives the overall most used highway segments traveled by overweight trucks. To date, the overweight truck profiles represent the most complete picture of typical truck trips by origin, destination, route, counties traversed, distance traveled, and weight carried. Commodity information is not indicated.

Chapter 9 helps to complete the North Carolina picture of truck traffic profiles. As indicated by Chapter 7 there is virtually no vehicle weight data available on State Routes (SRs). WIM stations are primarily located on Interstates and US routes. Yet, traffic counts and the experiences of NCDOT pavement engineers demonstrate that significant truck traffic, which may be overweight, occurs on secondary highways. Thus, particular tasks of this research focused on SR routes throughout the state. Potentially active truck routes were identified in each region - mountains, central and coastal – and a statistically valid sample of locations was identified for truck class counts. Statistical methods were also used to infer the truck weights on SR routes from WIM data on Interstate and US routes. Results are described in Chapter 9.

To summarize, Chapters 5, 6, 7, 8, and 9 implement the methodology illustrated by Figure 4-1. The methodology draws on available data and current methods at NCDOT to describe truck traffic profiles statewide, by sub-region and by highway functional class. The profiles typically include AADTT, VMT, and truck vehicle type. Current profiles developed by NCDOT do not include typical truck trip information such as origins, destinations, commodities carried and distance carried by highway route number. Thus, the research provides prototype methods and applications for developing truck trip information for trucks in general using a statewide truck network model and for permitted overweight trucks by using permit data. New approaches are explored for including commodity information and for extending truck traffic profiles to SR routes.

Chapter 10 reviews research findings, states recommendation, and discusses avenues for technology transfer.

5. Current NCDOT Approach for Determining Truck Traffic Profiles

This chapter presents examples of data summaries used by NCDOT to characterize truck traffic across the state of North Carolina. The purpose of the data summaries prepared by NCDOT is to improve understanding of the manner in which trucks are using the state highway system. The formats of the summaries (which are usually spreadsheets and accompanying charts) describe how trucks by vehicle classification use highways overall, on a county basis, and by highway functional class. The units of measurement are annual average daily truck traffic (AADTT) and vehicle miles traveled (VMT). Except for the relatively limited number of site specific Interstate and U.S. route locations for 46 weigh-in-motion (WIM) stations, other important categorizations for the truck traffic by weight and by highway route number are not developed in the current NCDOT approach. Commodities carried by trip, by route, vehicle miles, and vehicle class would also be valuable for planning and policy decisions, however, proprietary commodity information is beyond reach of most departments of transportation. Subsequent chapters in this report provide prototype methods for improved truck traffic profiles categorizations. For example, TransCAD truck VMT estimates by highway functional classification by county and region are described in the next chapter, and other chapters describe the extent to which heavy trucks are using the state's various categories of highway, from rural secondary roads to urban interstates.

Introduction

The NCDOT description for this research project is: "Information on the nature of truck traffic, specifically the length of travel on various roadway functional classes by various vehicle classifications … is needed in order to quantify truck impacts to the pavement system. This information may also be helpful to planners." Also knowing such information, especially for overweight vehicles, will be helpful to policy makers who set licensing and permit costs for vehicles. Again citing the NCDOT description for this research project, "It is anticipated that the final product (of this research) will be both a database and a table of current values. This table might include vehicle class, rural vs. urban, and number of miles in each road category in the typical trip."

Currently NCDOT uses several approaches (Table 5-1) to describe truck traffic profiles in terms of VMT, AADTT, truck weight and axle loads. Thousands of 48-hour traffic counts statewide provide a coarse estimate of the annual truck traffic AADTT and VMT by vehicle class statewide, by county, and by urban and rural highway functional classification. Detailed weight-in-motion (WIM) station counts give detailed minute by minute vehicle counts and axle weight information at 46 Interstate and US highway locations (Figures 5-1 to 5-3). And WIM counts combined with commodity payload information allow rough estimates of heavy weight loads on North Carolina's highways. However, precise information is not available to track truck trips by commodity, by weight by typical trip lengths, and by highways used.

Additional details on the three current NCDOT methods to establish truck traffic profiles are given in subsequent paragraphs.

Table 5-1 Current NCDOT Methods to Determine Truck Traffic Profiles

Method: Results	Comments
Traffic counts: statewide and county level VMT and statewide vehicle class percentage.	Hundreds of 48-hour traffic counts give statistically reliable estimates of VMT for each county and estimates of statewide vehicle class percentages. The results measure traffic by facility type. The county level VMT cannot be reliably allocated to highway functional type. The statewide class percentages cannot be reliably disaggregated to counties and regions.
WIM station counts: vehicle class counts and axle loads.	Data collected are continuous hourly vehicle class counts of all traffic and per vehicle records for trucks including axle spacing and axle weight measurements.
Commodity-based methods: commodity loads by truck using WIM data	NCDOT uses statewide vehicle class and VMT data, commodity production data, and truck payload factors to estimate approximate commodity loads carried by trucks in NC.

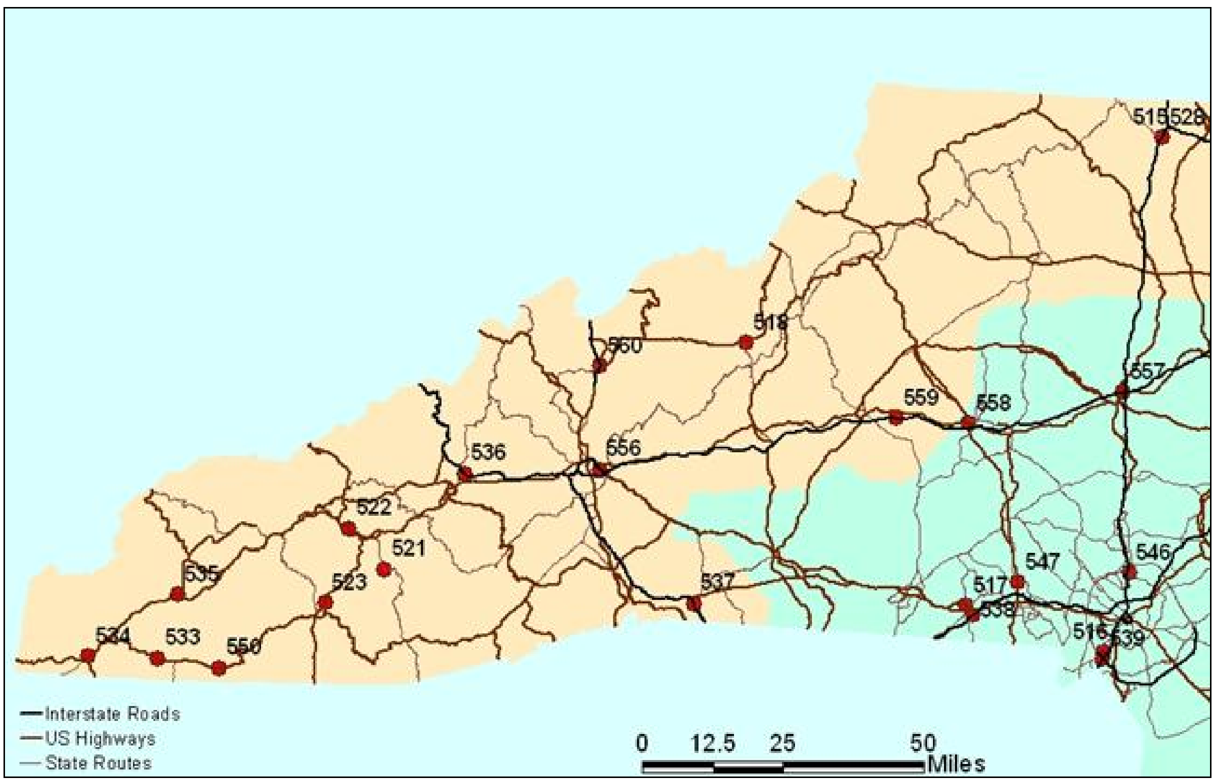


Figure 5-1 WIM Stations in the Mountainous Region

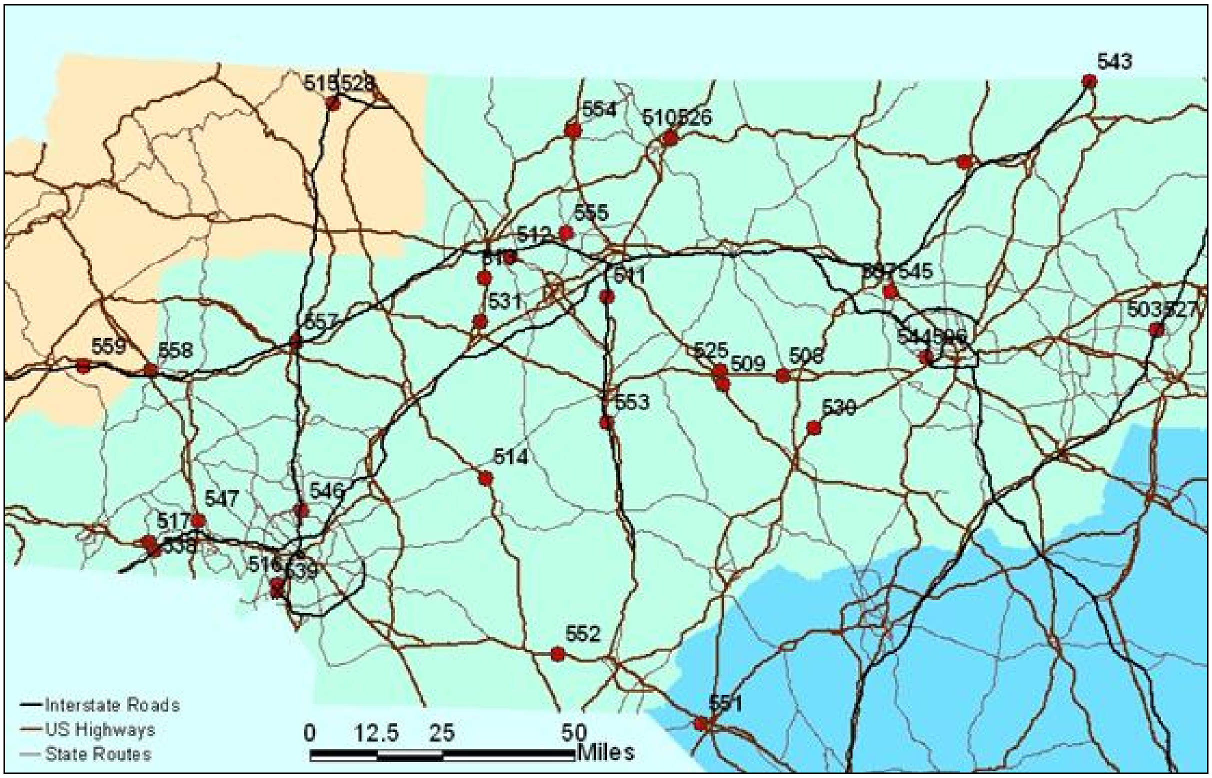


Figure 5-2 WIM Stations in the Central Region

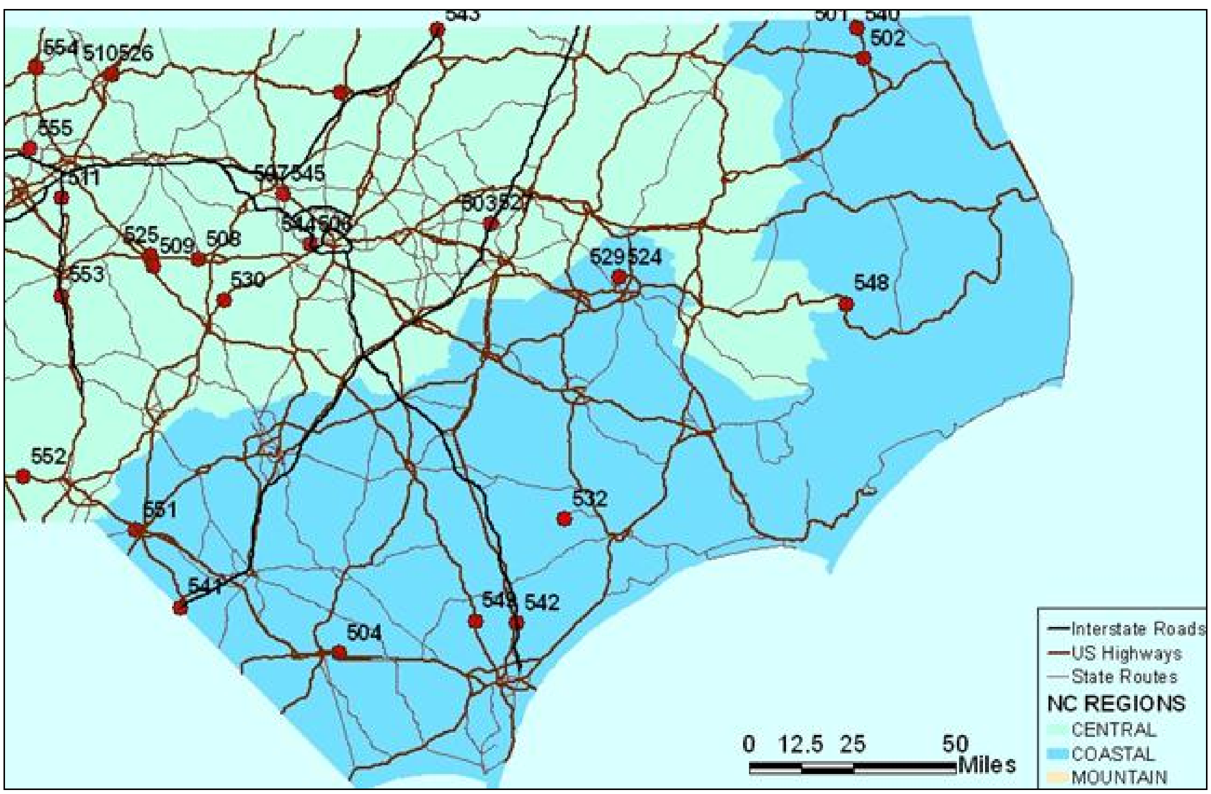


Figure 5-3 WIM Stations in the Coastal Region

Current NCDOT Methods

Vehicle Miles Traveled on North Carolina Highways

The approach to estimating VMT focuses on sampling truck traffic throughout the State and estimating county level truck traffic measured by daily and annual VMT by highway functional class. The approach relies on 48-hour truck classification counts on samples of each highway functional classification in each county, and then the samples are factored up proportional to the number of miles of highways in each functional class. County and regional VMT by vehicle class and highway functional classification are disaggregations of the statewide estimate.

NCDOT follows standard practice for its various counting programs as defined by the ***FHWA Traffic Monitoring Guide.*** NCDOT reports the results of the traffic count programs to FHWA annually. The FHWA Highway Pavement Monitoring System (HPMS) is an important traffic count program the results of which can be applied to develop truck traffic profiles by North Carolina county, highway functional class, and urban and rural highway segment type.

Appendix F (page F-4) of the ***HPMS Field Manual*** (2005) describes procedures for determining VMT by county and the other categories listed above. Quoting from the manual:

> Estimates of Daily Vehicle-Miles of Travel (DVMT) can be developed by direct computation for the Interstate, other principal arterials, and other NHS [National Highway System] sections and by expansion of the HPMS standard sample on a functional system basis for other systems. This is done by multiplying the standard sample section AADT by the section length and by the standard sample expansion factor and summing the result to the HPMS stratification level desired (functional system, total rural, etc.); the HPMS software will perform these calculations by functional system. Since HPMS standard sample expansion procedures are based on the ratio of universe to sample mileage, mileage totals at any stratification level should be exact. A comprehensive count program, good count practices, a well-distributed HPMS standard sample, and appropriate AADT estimation techniques will result in highly reliable DVMT estimates.

Note that the NCDOT Traffic Survey Unit volume counts are factored from raw counts to estimates of annual average daily traffic (AADT), not AADTT (truck traffic)

Using the data from its extensive statewide 48-hour coverage count program and from its 365-24-7 Automatic Traffic Recorder (ATR) program, NCDOT can apply appropriate annualizing factors to convert 48-hour coverage counts from ADTT to AADTT and to convert DVMT to annual VMT estimates.

The details of the NCDOT process is as follows.

> Truck VMT: Traffic Survey collects volume counts at approximately 25,000 volume monitoring stations annually. These counts are seasonally factored to current year AADT. Monitoring stations that are off-cycle (there is a two year cycle) have previous AADTs growth factored to current year AADT (approximately 15,000 stations) for a total of 40,000 AADTs. Monitored segments have DVMT calculated directly (whether being sampled or a coverage). A FC with full coverage has DVMT calculated for all segments which are then summed. Estimation of DVMT on all highways for sampled FC is generated by applying an expansion factor based on total mileage and monitored mileage to sampled DVMT. This expansion process is sub-stratified by volume group for each FC sampled.

Vehicle Distribution: NCDOT collects class counts at approximately 200 class sampling stations annually to perform a partial update for estimating statewide average vehicle distributions by FC (full update on a three year cycle as per HPMS requirements). These are averages based on class ADT from all samples without any weighting.

Statewide Vehicle Class VMT: Applying vehicle distributions by FC to statewide VMT by FC generates statewide VMT by FC by VC. VMT can be generated by the HPMS functional systems and vehicle groups or using the base statistics (sampling is based on this level of detail) of highway FC and FHWA VC. Both are statistically valid.

Table 5-2 displays daily and annual VMT examples for conventional NCDOT statewide traffic profiles by North Carolina county. Other categorizations like Table 5-3 break out total traffic VMT and truck traffic VMT by highway functional class, urban and rural highway segment type, and NC region. Sampled coverage counts also identify the travel activity by percentage vehicle type and FHWA urban/rural highway functional class as shown in Table 5-4 (for 2005) and Table 5-5 (for 2007).

The four tables (Table 5-2, 5-3, 5-4, and 5-5) demonstrate that current NCDOT procedures provide a first realization of the purpose for this research project, that is to provide "…information on the nature of truck traffic, specifically the length of travel by roadway functional classes by vehicle classifications…". However, NCDOT footnotes its data for VMT and vehicle class in Table 5-2, 5-3, 5-4 and 5-5 by saying "…statewide averages (are) based on HPMS reporting requirements and bias may be introduced if applied at levels (regions, counties, and highway classes) below the statewide level". By extension, the estimated county level VMT cannot be reliably allocated to county level highway classes or to commodity types carried.

Table 5-2 State Summary Daily and Annual VMT Estimates by County, 2005

VMT SUMMARY			VMT SUMMARY			VMT SUMMARY		
DATA AS OF JAN 1, 2006			DATA AS OF JAN 1, 2006			DATA AS OF JAN 1, 2006		
	Daily VMT (1,000)	Annual VMT (1,000)		Daily VMT (1,000)	Annual VMT (1,000)		Daily VMT (1,000)	Annual VMT (1,000)
ALAMANCE	3,668	1,338,656	DUPLIN	1,908	696,533	NEWHANOVER	3,552	1,296,407
ALEXANDER	688	251,295	DURHAM	6,427	2,345,983	NORTHAMPTON	911	332,665
ALLEGHANY	264	96,334	EDGECOMB	1,625	593,056	ONSLOW	3,414	1,246,081
ANSON	907	331,113	FORSYTH	8,546	3,119,370	ORANGE	3,733	1,362,509
ASHE	604	220,577	FRANKLIN	1,210	441,690	PAMLICO	376	137,320
AVERY	553	202,020	GASTON	5,432	1,982,629	PASQUOTANK	761	277,845
BEAUFORT	1,175	428,831	GATES	334	121,957	PENDER	1,812	661,406
BERTIE	871	317,780	GRAHAM	162	59,276	PERQUIMANS	412	150,278
BLADEN	1,205	439,931	GRANVILLE	1,734	632,917	PERSON	864	315,258
BRUNSWICK	3,246	1,184,775	GREENE	626	228,373	PITT	3,230	1,178,928
BUNCOMBE	6,279	2,291,908	GUILFORD	11,262	4,110,685	POLK	848	309,597
BURKE	2,631	960,315	HALIFAX	1,917	699,789	RANDOLPH	3,815	1,392,541
CABARRUS	4,135	1,509,191	HARNETT	2,437	889,501	RICHMOND	1,390	507,405
CALDWELL	1,875	684,211	HAYWOOD	2,387	871,361	ROBESON	4,553	1,661,812
CAMDEN	333	121,655	HENDERSON	2,424	884,804	ROCKINGHAM	2,482	906,058
CARTERET	1,738	634,326	HERTFORD	609	222,157	ROWAN	3,662	1,336,685
CASWELL	617	225,347	HOKE	866	315,918	RUTHERFORD	1,662	606,787
CATAWBA	4,716	1,721,398	HYDE	179	65,419	SAMPSON	2,018	736,486
CHATHAM	1,863	680,105	IREDELL	5,016	1,830,917	SCOTLAND	1,126	411,143
CHEROKEE	757	276,250	JACKSON	1,355	494,491	STANLY	1,430	521,997
CHOWAN	349	127,327	JOHNSTON	5,130	1,872,552	STOKES	997	363,836
CLAY	270	98,619	JONES	539	196,855	SURRY	2,437	889,505
CLEVELAND	2,672	975,200	LEE	1,636	597,301	SWAIN	539	196,870
COLUMBUS	2,057	750,790	LENOIR	1,756	640,834	TRANSYLVANIA	801	292,296
CRAVEN	2,938	1,072,374	LINCOLN	1,583	577,872	TYRRELL	168	61,324
CUMBERLAND	7,982	2,913,540	MACON	915	333,924	UNION	3,496	1,275,934
CURRITUCK	957	349,155	MADISON	551	200,933	VANCE	1,361	496,659
DARE	1,471	537,028	MARTIN	908	331,504	WAKE	18,438	6,729,786
DAVIDSON	4,334	1,581,914	MCDOWELL	1,670	609,605	WARREN	642	234,447
DAVIE	1,369	499,857	MECKLENBU	20,458	7,467,236	WASHINGTON	480	175,328
DUPLIN	1,908	696,533	MITCHELL	368	134,495	WATAUGA	1,142	416,775
DURHAM	6,427	2,345,983	MONTGOME	1,018	371,526	WAYNE	3,014	1,100,216
EDGECOMBE	1,625	593,056	MOORE	2,158	787,550	WILKES	1,808	659,825
FORSYTH	8,546	3,119,370	NASH	3,773	1,376,992	WILSON	2,431	887,187
						YADKIN	1,385	505,510
						YANCEY	422	154,012
						TOTAL	**243,059**	**88,716,542**

Source: Road Inventory Section of the NCDOT GIS Unit, 2005 Daily VMT.xls

Table 5-3 Total and Truck Traffic by NC Region and Highway Functional Class, 2005

DAILY ALL VEHICLE MILES TRAVELED (1,000) at NC RURAL/URBAN ROADS

Ru/Ur	NC DOT DV Class	FCLASS_DES	DAILY VEHICLE MILES TRAVELED (1,000)			
			MOUNTAIN	CENTRAL	COASTAL	Sum
Rural	01	1 Rural Principal Arterial - Interstate	2852.32	10877.26	3094.13	16823.71
	02	3 Rural Principal Arterial - Other	4018.51	11602.66	7412.55	23033.72
	06	4 Rural Minor Arterial	3448.95	8057.44	4379.02	15885.41
	07	6 Rural Major Collector	3516.8	13440.52	9184.04	26141.36
	08	7 Rural Minor Collector	1257.19	5670.46	2615.84	9543.49
	09	8 Rural Local	2316.66	7511.97	5111.77	14940.4
		Sum	17410.43	57160.31	31797.35	106368.09
Urban	11	1 Urban Principal Arterial - Interstate	5126.67	31860.6	1310.22	38297.49
	12	2 Urban Principal Arterial - Freeways and Expressw	1189.88	10347.6	1525.95	13063.43
	14	5 Urban Principal Arterial - Other	3529.95	20782.1	9552.48	33864.53
	16	6 Urban Minor Arterial	2945.3	20288.9	5138.85	28373.05
	17	7 Urban Collector	1028.39	8089.95	1686.12	10804.46
	19	8 Urban Local	1217.36	8680.58	2390.03	12287.97
		Sum	15037.55	100049.73	21603.65	136690.93
Total			32447.98	157210.04	53401	243059.02

DAILY Truck MILES TRAVELED (1,000) at NC RURAL/URBAN ROADS

Ru/Ur	NC DOT DV Class	FCLASS_DES	DAILY VEHICLE MILES TRAVELED (1,000)			
			MOUNTAIN	CENTRAL	COASTAL	Sum
Rural	01	1 Rural Principal Arterial - Interstate	876.56	3342.76	950.88	5170.20
	02	3 Rural Principal Arterial - Other	553.41	1597.85	1020.81	3172.07
	06	4 Rural Minor Arterial	382.82	894.34	486.05	1763.20
	07	6 Rural Major Collector	295.46	1129.18	771.58	2196.21
	08	7 Rural Minor Collector	105.55	476.06	219.61	801.22
	09	8 Rural Local	193.45	627.27	426.84	1247.56
		Sum	2407.24	8067.45	3875.77	14350.47
Urban	11	1 Urban Principal Arterial - Interstate	883.24	5489.03	225.73	6598.00
	12	2 Urban Principal Arterial - Freeways and Expressw	123.05	1070.06	157.80	1350.91
	14	5 Urban Principal Arterial - Other	273.07	1607.67	738.97	2619.71
	16	6 Urban Minor Arterial	158.97	1095.04	277.36	1531.37
	17	7 Urban Collector	47.93	377.01	78.58	503.51
	19	8 Urban Local	78.35	558.70	153.83	790.88
		Sum	1564.60	10197.53	1632.26	13394.38
Total			3971.84	18264.98	5508.03	27744.85

Source: Road Inventory Section of the NCDOT GIS Unit, 2005 Daily VMT.xls

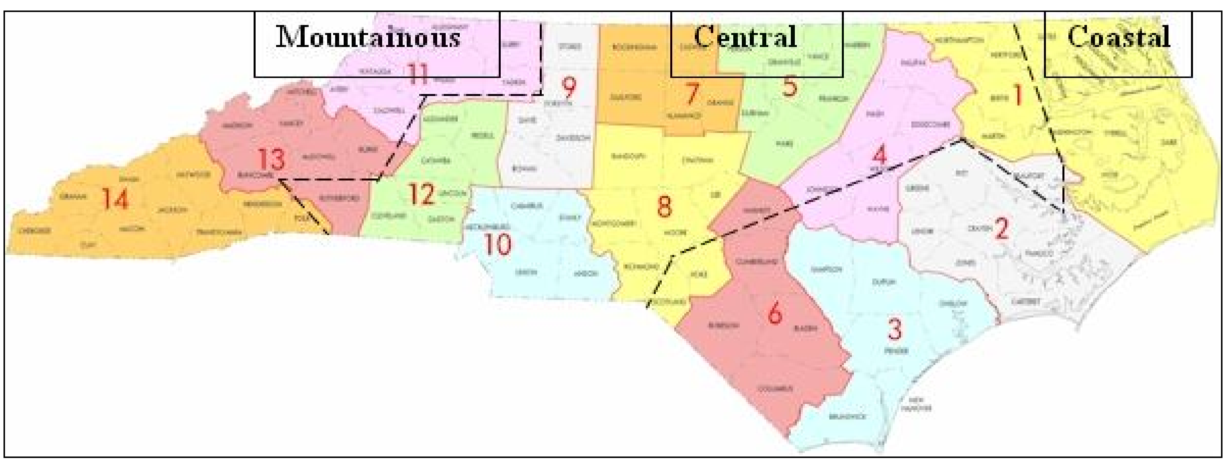


Figure 5-4 NC Regions for Pavement Design with NC Counties and NCDOT Divisions

Table 5-4 Travel Activity by Vehicle Type and FHWA Highway Functional Class, 2005

Functional Classification	FC Code	Cycles	Cars	2A-4T	Buses	2A-SU	3A-SU	4A-SU	4A-ST	5A-ST	6A-ST	5A-MT	6A-MT	7A-MT
Rural Principal Arterial - Interstate	1	0.49%	56.93%	10.80%	1.06%	2.50%	1.56%	1.09%	4.79%	19.23%	0.48%	0.73%	0.24%	0.11%
Rural Principal Arterial - Other	2	0.40%	69.34%	15.79%	0.71%	2.80%	1.48%	0.25%	2.07%	6.67%	0.26%	0.16%	0.05%	0.04%
Rural Minor Arterial	6	0.49%	70.58%	17.23%	0.59%	3.19%	1.87%	0.27%	1.79%	3.69%	0.21%	0.05%	0.01%	0.02%
Rural Major Collector	7	0.36%	73.21%	17.52%	0.51%	3.01%	1.45%	0.24%	1.63%	1.84%	0.18%	0.02%	0.01%	0.02%
Rural Minor Collector	8	0.45%	74.00%	16.50%	0.65%	3.00%	1.55%	0.17%	1.75%	1.50%	0.30%	0.05%	0.02%	0.06%
Rural Local System	9	0.55%	71.93%	18.66%	0.51%	4.09%	1.06%	0.02%	1.54%	1.60%	0.05%	0.00%	0.00%	0.00%
Urban Principal Arterial - Interstate	11	0.36%	68.68%	12.84%	0.89%	2.12%	1.68%	0.42%	2.70%	9.29%	0.45%	0.36%	0.09%	0.10%
Urban Principal Arterial - Other Fways or Expways	12	0.33%	74.79%	13.97%	0.57%	2.48%	1.17%	0.42%	2.56%	3.42%	0.17%	0.07%	0.01%	0.03%
Urban Principal Arterial - Other	14	0.32%	76.64%	14.84%	0.46%	2.20%	1.30%	0.13%	1.66%	2.12%	0.21%	0.04%	0.01%	0.04%
Urban Minor Arterial	16	0.36%	79.35%	14.43%	0.47%	2.16%	1.08%	0.10%	1.26%	0.66%	0.11%	0.00%	0.00%	0.02%
Urban Collector	17	0.34%	81.15%	13.42%	0.43%	2.02%	1.12%	0.07%	0.99%	0.40%	0.05%	0.00%	0.00%	0.01%
Urban Local System	19	0.59%	75.56%	16.59%	0.82%	2.57%	1.73%	0.03%	0.95%	1.05%	0.10%	0.00%	0.00%	0.00%

2A-4T ~ 2 axle, 4 tires. Compare to FHWA classes
2A-SU ~ 2 axle, single unit. Compare to FHWA classes
4A-ST ~ 4 axle, single trailer. Compare to FHWA classes
5A-MT ~ 5 axle, multi trailer. Compare to FHWA classes

Source: NCDOT Traffic Survey Unit

Table 5-5 Travel Activity by Vehicle Type and FHWA Highway Functional Class, 2007

2007 Travel Activity by Vehicle Type with FHWA FC and VC (as collected)

FC	Functional Classification	Samples	MC	Cars	2A4T	Bus	2ASU	3ASU	4ASU	4AST	5AST	6AST	5AMT	6AMT	7AMT
1	Rural Principal Arterial - Interstate	17	0.4%	59.0%	13.4%	1.1%	2.8%	0.8%	0.1%	1.9%	18.7%	0.8%	0.6%	0.3%	0.2%
2	Rural Principal Arterial - Other	69	0.8%	66.5%	18.7%	0.8%	3.4%	1.2%	0.1%	1.4%	6.5%	0.3%	0.2%	0.1%	0.0%
6	Rural Minor Arterial	32	0.6%	66.8%	20.1%	0.9%	4.0%	1.3%	0.1%	1.3%	4.6%	0.2%	0.0%	0.0%	0.0%
7	Rural Major Collector	20	0.6%	72.1%	19.7%	0.5%	3.2%	1.1%	0.1%	0.8%	1.7%	0.1%	0.0%	0.0%	0.0%
8	Rural Minor Collector	25	0.7%	70.8%	20.4%	0.7%	4.1%	1.1%	0.1%	0.9%	1.2%	0.1%	0.0%	0.0%	0.0%
9	Rural Local System	27	1.1%	65.1%	22.7%	1.9%	5.7%	1.4%	0.1%	1.0%	0.8%	0.1%	0.0%	0.0%	0.0%
11	Urban Principal Arterial - Interstate	21	0.5%	67.8%	14.1%	0.8%	2.7%	1.0%	0.0%	1.3%	11.0%	0.3%	0.3%	0.1%	0.0%
12	Urban Principal Arterial - Fwys or Exwys	13	0.5%	71.3%	16.2%	0.7%	2.8%	1.0%	0.1%	1.2%	5.9%	0.2%	0.1%	0.0%	0.0%
14	Urban Principal Arterial - Other	24	0.6%	74.4%	16.9%	0.5%	2.9%	0.9%	0.1%	0.9%	2.5%	0.2%	0.0%	0.0%	0.0%
16	Urban Minor Arterial	21	0.6%	78.1%	15.8%	0.6%	2.8%	0.7%	0.1%	0.6%	0.7%	0.1%	0.0%	0.0%	0.0%
17	Urban Collector	14	0.8%	78.3%	16.2%	0.5%	2.6%	0.9%	0.0%	0.4%	0.2%	0.0%	0.0%	0.0%	0.0%
19	Urban Local System	14	1.0%	72.4%	18.4%	2.3%	3.6%	0.9%	0.0%	0.5%	0.6%	0.1%	0.0%	0.0%	0.0%

2007 HPMS Travel Activity by Vehicle Type (for HPMS reporting)

FC	Functional System	Samples	MC	Cars	Light Trucks	Buses	Single Unit	Multi-Unit	Total
	RURAL								
1	Interstate	17	0.4%	59.0%	13.4%	1.1%	3.6%	22.5%	100.0%
2, 6	Other Arterial	101	0.8%	66.6%	19.1%	0.8%	4.9%	7.7%	100.0%
7, 8, 9	Other Rural	72	0.8%	69.0%	21.1%	1.1%	5.7%	2.2%	100.0%
	URBAN								
11	Interstate	21	0.5%	67.8%	14.1%	0.8%	3.8%	13.0%	100.0%
12, 14, 16	Other Arterial	58	0.6%	75.0%	16.4%	0.6%	3.8%	3.7%	100.0%
17, 19	Other Urban	28	0.9%	75.4%	17.3%	1.4%	4.0%	1.0%	100.0%

Source: NCDOT Traffic Survey Unit

WIM Station Vehicle Counts and Axle Loads for Traffic Moving on North Carolina Highways

WIM station data support pavement design with precise vehicle class counts and measurements of axle loads by vehicle type. The method produces highway-specific section data for 46 Interstate and US highways (Figures 5-1 to 5-3). The approach cannot produce sub-area or regional estimates of vehicle miles traveled by vehicle class or highway type; the results for a specific WIM location cannot easily transfer to other locations; and there are only a couple of WIM stations on NC or SR highways to give truck traffic profiles for those lower level facilities.

WIM station data are thoroughly investigated in NCDOT Project HWY 2008-11 *Traffic Data for the Mechanistic Empirical Pavement Design Guide (MEPDG)*. The MEPDG project and this Truck Traffic Profiles project have different objectives but both projects rely on similar datasets. A principle objective of the MEPDG project is to develop methods to analyze WIM data including profiles of gross vehicle weight (GVW) by vehicle class and profiles of average daily truck traffic (ADTT) volume by month and day of the week (MDOW). The MEPDG research objective also supports this research project concerning truck traffic profiles. Additional objectives of the MEPDG project develop procedures to correlate site specific WIM data to other highway sections for the purpose of pavement design. Extensive manual and automated computer methods clean the massive amounts of WIM data before developing truck traffic profiles with Excel, Microsoft Access and other tools from the NCDOT Traffic Survey Unit and the NC State University Department of Civil, Construction, and Environmental Engineering. The detailed methods for establishing the profiles are described in the MEPDG project documentation.

The NCDOT and NCSU WIM analysis tools use the WIM data to develop a variety of truck traffic profiles that are necessary for highway planning and pavement design. Typical truck traffic profiles include tables of data and graphic plots of vehicle classes, truck weights, and axle loads passing WIM station. Figures 5-5 to 5-7 illustrate summary vehicle class plots for WIM station 371805 (legacy station number 508) on US 64 near the intersection of US15-501 in Pittsboro. The figures show the usual preponderance of class 5 and class 9 trucks, and their fairly constant distribution throughout the year. Chapter 7 in this report explores class 5 and class 9 trucks in more depth and their regional, urban, and rural class profiles. The apparent spikes in seasonal variations of classes 10, 11 and 13 can be probably be ignored because of the overall low traffic in these classes and the exaggeration caused by normalizing (dividing) by small numbers.

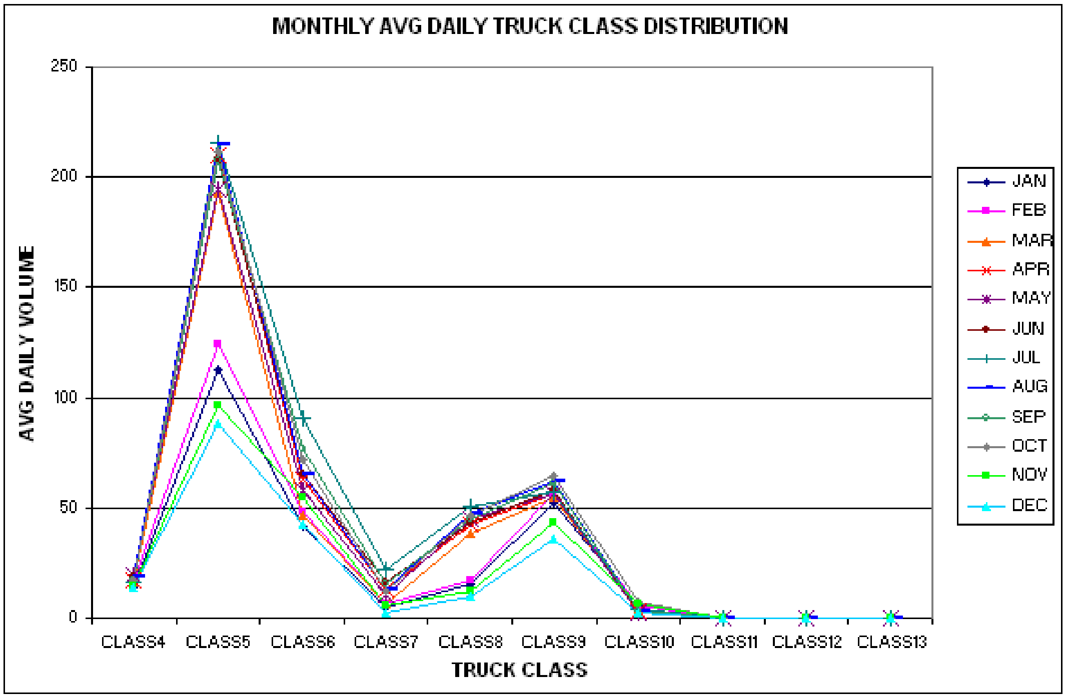


Figure 5-5 Monthly Average Daily Class Distribution, WIM 371805 (508) on US 64 near US15-501

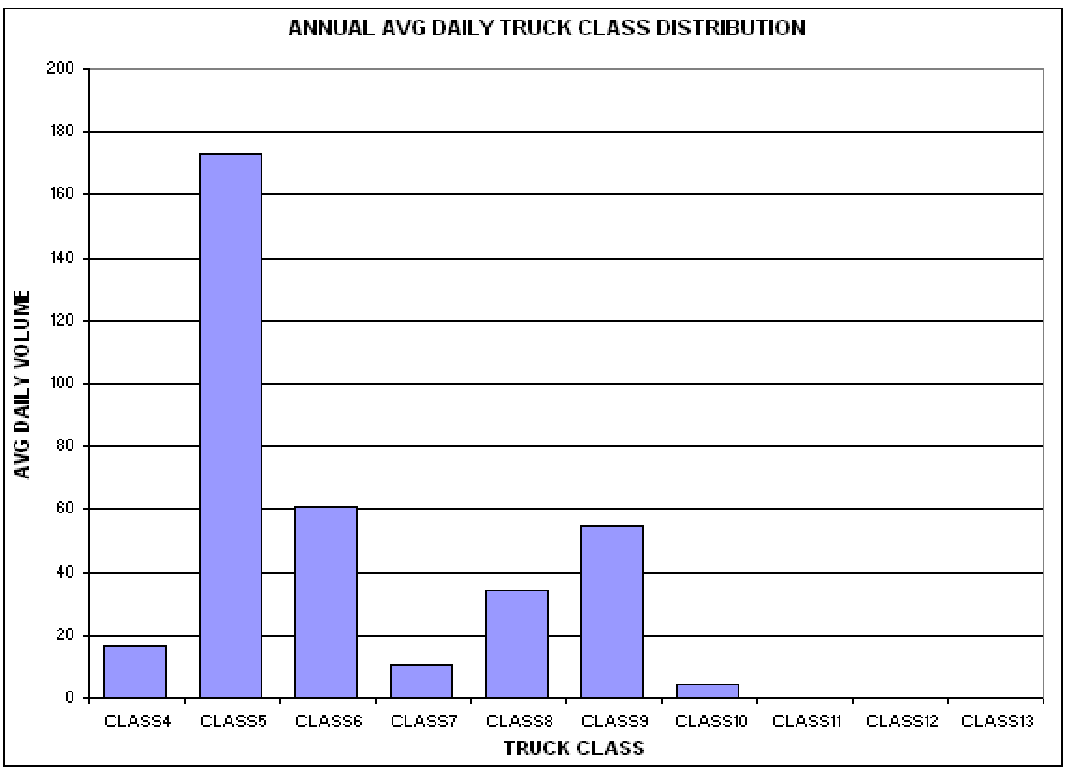


Figure 5-6 Annual Average Daily Class Distribution, WIM 371805 (508), US 64 near US15-501

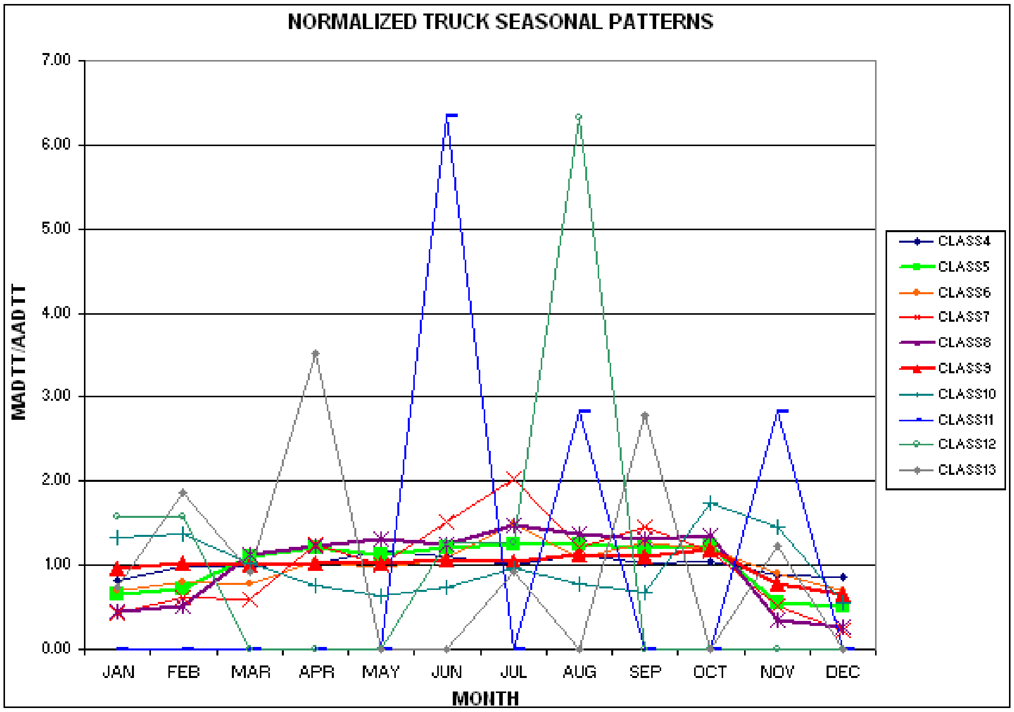


Figure 5-7 Seasonal Truck Traffic Patterns, WIM 371805 (508), US 64 near US15-501

Figure 5-8 illustrates summary weight profiles that are particularly important in pavement design, bridge design, and enforcement of overweight permitting regulations. Figure 5-8 illustrates the monthly GVW frequency distribution for the often encountered class 9 trucks. The two peaks in Figure 5-8 are typical profiles and represent unloaded and loaded class 9 trucks. It is noted that a number of the trucks weigh over the legal limit of 80,000 pounds GVW.

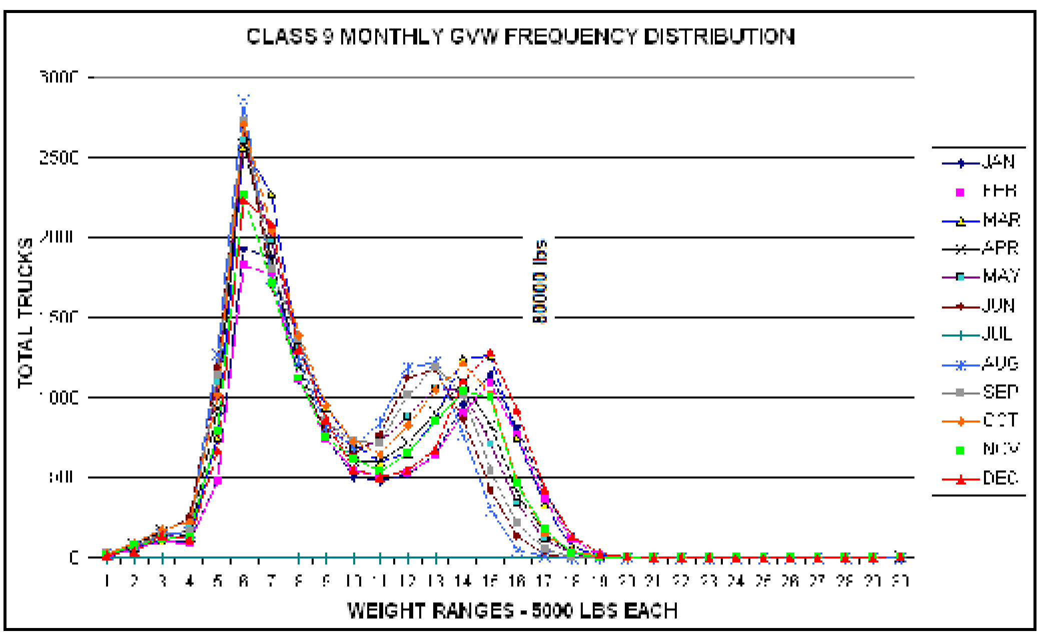


Figure 5-8 Class 9 GVW Distribution, WIM 371805 (508), US 64 near US15-501

Figures 5-9 to 5-12 show important truck axle load frequency diagrams for WIM station 371805 that are used in pavement design. The diagrams are categorized by single, tandem, tridem, and quad axle loads by vehicle class. The purpose of having more axles is to distribute the weight of heavy loads. Axle load limits depend on the type of axle (single, tandem, tridem and quad) and the distance between the extremes of any group of two or more consecutive axles. Regardless of the distance between groups of axles, the maximum loads for axle groups are:

Single axles:	20,000 pounds
Tandem axles:	38,000 pounds

The maximum allowable GVW is 80,000 pounds unless a special permit costing $200 annually is acquired. Precise load limits by axle group spacing and exemptions are defined by ***NC Laws Relating to Commercial Vehicles*** as detailed by the Internet link and Tables 5-6 and 5-7.
www.ncdot.org/doh/operations/dp_chief_eng/maintenance/permits/docs/NorthCarolinaLaws.pdf

Figures 5-9 to 5-12 show that the vast majority of vehicles passing WIM station 71805 have axle weights at or below the maximum legal limit of about 20,000 pounds per axle. A more precise interpretation of the figures to determine overweight vehicles requires examination of axle loads by axle spacing (Table 5-6) and axle group definitions (Table 5-7).

In summary, the WIM truck traffic profiles are accurate for the specific highway sections where the weight and class data are measured. The WIM data, however, measure only a small proportion of all trucks moving in North Carolina, and the small sample size at 46 WIMs compared thousands of miles of North Carolina highway will lead to biased estimates of truck class volumes and overweight vehicles (but not axle load spectra according to Lu, 2002) if the data are extrapolated to other sites, highway facility types, counties or regions. Thus, NCDOT needs more WIM truck traffic equipment and resulting data than are currently available. Never-the-less, WIM data alone are insufficient to provide "…vehicle class, rural vs. urban, and number of miles in each road category in the typical (truck) trip…" as requested by NCDOT. Thus, new analytical methods and models for processing WIM data in concert with the more ubiquitous 48-hour traffic count and class data are needed. Examples of such new methods will be presented in Chapters 6, 7, and 8.

Overweight Vehicles on North Carolina Highways

In the current NCDOT practice, there are two approaches for analyzing the impact of overweight trucks and axle weight exemptions. The commodity-based approach aims to convert the quantity of major commodities to the total weight of commodities and then to the number of typical trucks, by assuming each commodity is carried by a single truck type with constant (e.g. maximum) truck loads with/without exemption (Corley-Lay, 2004). The second approach utilizes weight distribution data from weigh-in-motion or static weigh stations to develop truckload and axle load distribution estimates for each road category that corresponds to a typical pavement design. The truck flow loading pattern information calculated from these two approaches can be further used in the MEPDG design procedure to estimate the life cycle of pavement and the corresponding economic value of overweight truck permits and vehicle exemptions from permits.

Table 5-6 Maximum Weights for Axle Groups by Distance between Axle Groups

Distance Between Axles*	Maximum Weight in Pounds for any Group of Two or More Consecutive Axles					
	2 Axles	3 Axles	4 Axles	5 Axles	6 Axles	7 Axles
4	38000					
5	38000					
6	38000					
7	38000					
8 or less	38000	38000				
more than 8	38000	42000				
9	39000	42500				
10	40000	43500				
11		44000				
12		45000	50000			
13		45500	50500			
14		46500	51500			
15		47000	52000			
16		48000	52500	58000		
17		48500	53500	58500		
18		49500	54000	59000		
19		50000	54500	60000		
20		51000	55500	60500	66000	
21		51500	56000	61000	66500	
22		52500	56500	61500	67000	
23		53000	57500	62500	68000	
24		54000	58000	63000	68500	74000
25		54500	58500	63500	69000	74500
26		55500	59500	64000	69500	75000
27		56000	60000	65000	70000	75500
28		57000	60500	65500	71000	76500
29		57500	61500	66000	71500	77000
30		58500	62000**	66500	72000	77500
31		59000	62500**	67500	72500	78000
32		60000	63500**	68000	73000	78500
33			64000**	68500	74000	79000
34			64500**	69000	74500	80000
35			65500**	70000	75000	
36			66000**	70500	75500	
37			66500**	71000	76000	
38			67500**	72000	77000	
39			68000	72500	77500	
40			68500	73000	78000	
41			69500	73500	78500	
42			70000	74000	79000	
43			70500	75000	80000	
44			71500	75500		
45			72000	76000		
46			72500	76500		
47			73500	77500		
48			74000	78000		
49			74500	78500		
50			75500	79000		
51			76000	80000		
52			76500			
53			77500			
54			78000			
55			78500			
56			79500			
57			80000			

*Distance in Feet Between the Extremes of any Group of Two or More Consecutive Axles.

**See exception in G.S. 20-118(c)(1).

Source:
www.ncdot.org/doh/operations/dp_chief_eng/maintenance/permits/docs/NorthCarolinaLaws.pdf

Table 5-7 Axle Group Definitions

Group	Span (in)				
Axle Count	**24-39**	**40-96**	**97-150**	**118-192**	**193+**
1	Single	Single	Single	Single	Single
2	Single-2	Tandem	2 Singles	2 Singles	2 Singles
3		Tandem-3	Tridem	Tridem	2 or 3 groups
4		Tandem-4	Tridem-4*	Quad	Quad to 288
5		Tandem-5	Tridem-5*	Quad-5	Quad to 384
6			Tridem-6*	Quad-6	Quad to 480
Adjacent axles with a spacing > 96 can not be placed in a same group					
* Quad groups takes precedence over these groups for spans >= 118					

Source: Stone et al., Development of Traffic Data Input Resources for MEPDG, 2009

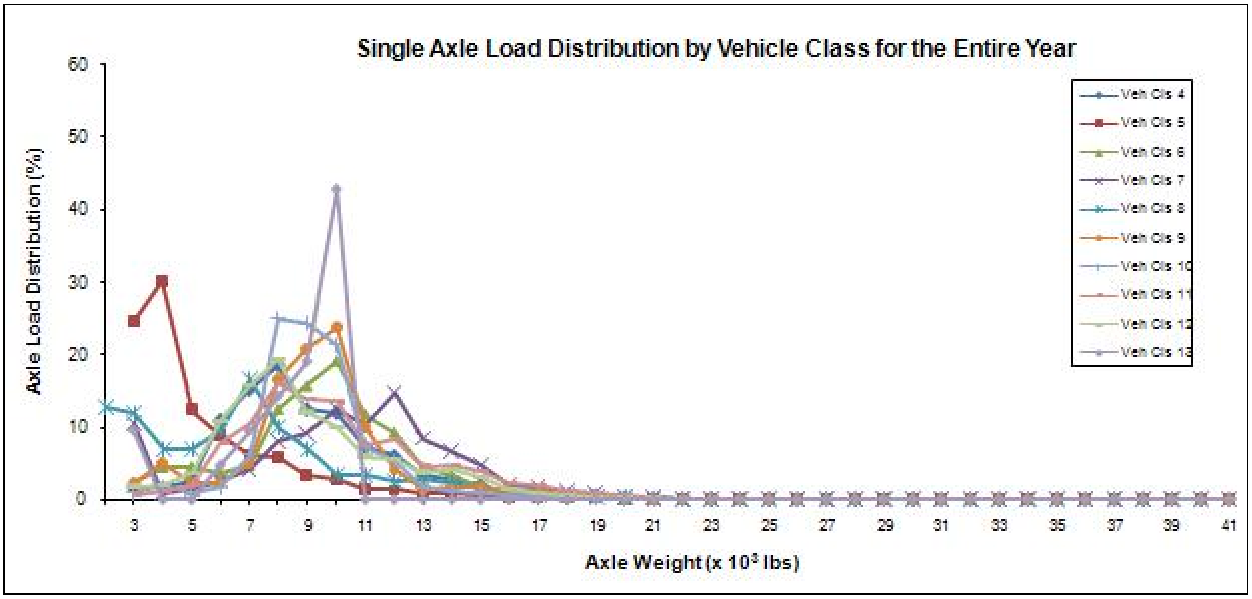


Figure 5-9 Single Axle Load Frequency Diagram, WIM 371805, US 64 near US15-501

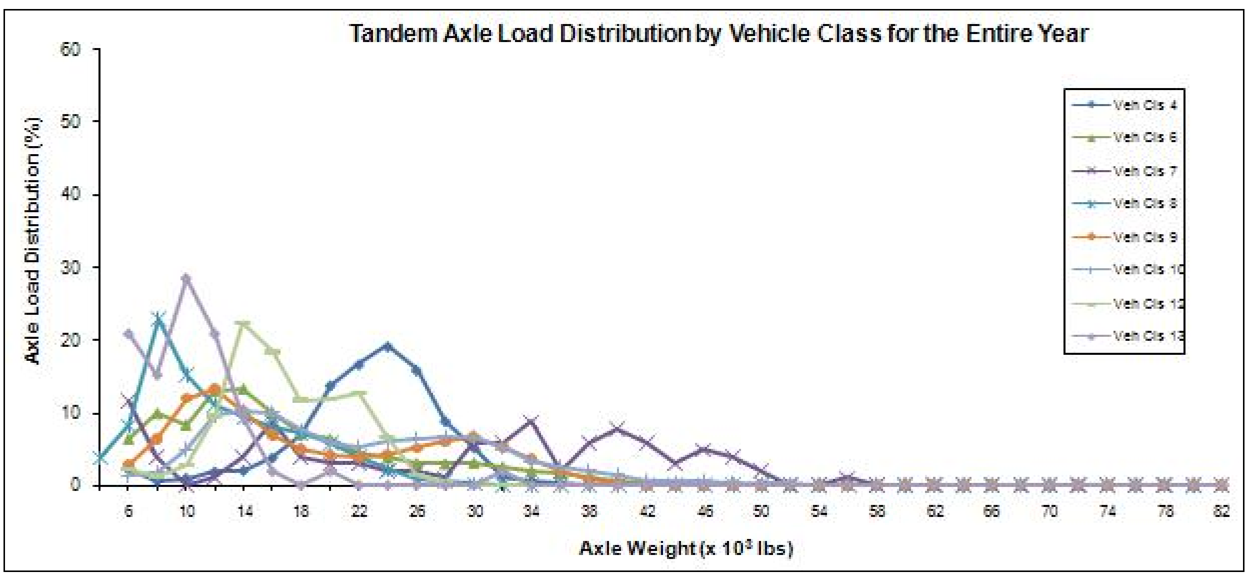


Figure 5-10 Tandem Axle Load Frequency Diagram, WIM 371805, US 64 near US15-501

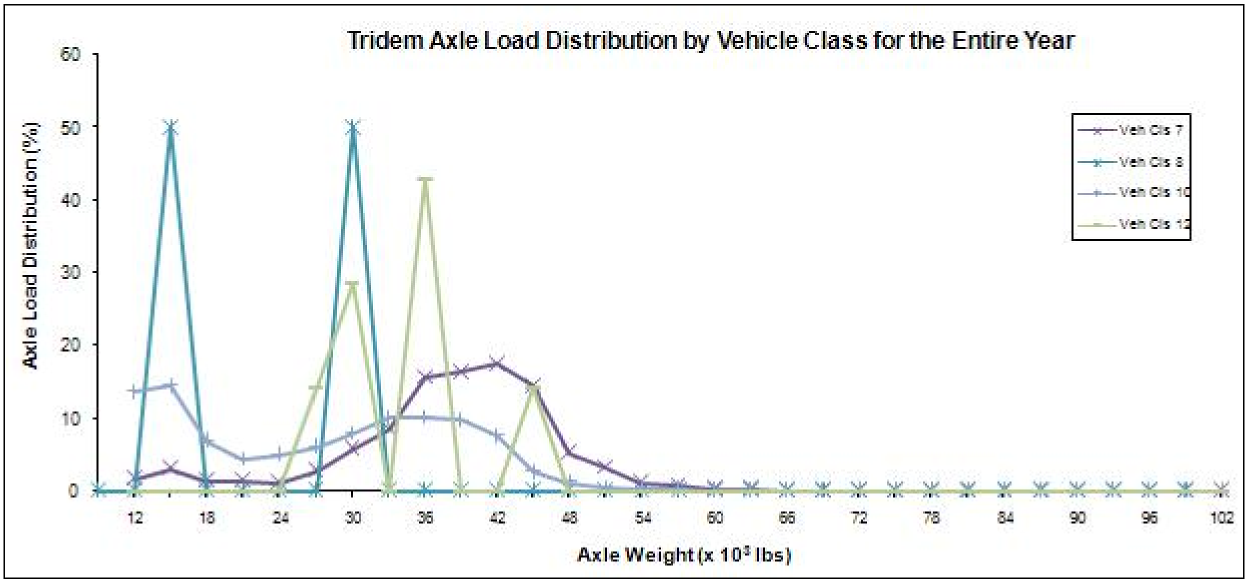


Figure 5-11 Tridem Axle Load Frequency Diagram, WIM 371805, US 64 near US15-501

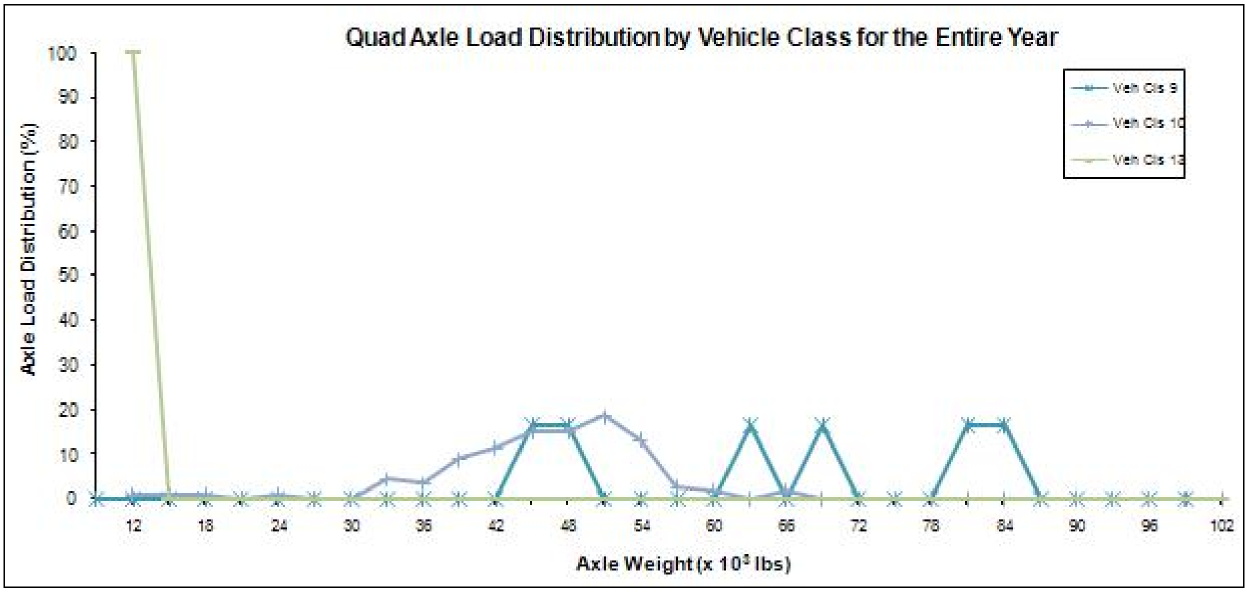


Figure 5-12 Quad Axle Load Frequency Diagram, WIM 371805, US 64 near US15-501

In principle, these two approaches (the Corley-Lay method and the WIM method) for estimating the impacts of overweight trucks allow rapid analyses for quantifying the marginal system-wide cost due to the overweight trucks and axle weight exemptions (NC General Statute 20-118). However, several simplifying assumptions in the above methods can be further relaxed to take into account more realism and to provide more accurate estimates. NC field crop commodities, for instance, could be carried by several truck types depending on which markets (e.g. local, regional or interstate) that agricultural products target. Furthermore, the average truck loads for different trip classes could be considerably different. Interstate goods movements, in general, are more likely to be served by heavy duty trucks that are typically fully loaded, and local goods are more likely carried by urban medium trucks that travel multiple trips during a day, while some of trips could be empty or half-loaded (Caltrans, 2001). On the other hand, traffic flow patterns and axle weight distributions could vary significantly at different geographic regions and for different truck classifications (Chapter 7). The situation is further complicated by heavily loaded construction trucks in local and regional traffic. Thus, a new approach is necessary to synthesize commodity-based analysis results, truck weight and permit data and truck survey samples to construct accurate estimates on traffic volume and truck weight distributions on typical roadway sections.

While fully developing such a new approach is beyond the scope of this research, the following first-step prototype analysis is offered. The method uses an expanded selection of commodities from what Corley-Lay considered, and it uses data available from national sources.

Prototype Commodity-based Approach for Heavily Loaded Vehicles

The NCDOT commodity-based approach aims to convert the quantity of major commodities to the total weight of commodities and then to the number of typical trucks by assuming each commodity is carried by a single truck type with constant (e.g. maximum) truck loads with/without exemption. Corley-Lay in her study on *Impact of Overweight trucks and Overweight Exemptions in North Carolina* (2002) considered the impact of the following commodities:

Agricultural Crops
Timber
Crushed Stone
Sand and Aggregate

By analyzing and expanding her results to all commodity categories, the number of heavy trucks that carry commodities in North Carolina may be determined if given the results of (1) a commodity flow survey such as available from the US Bureau of Transportation Statistics Commodity Flow Survey (CFS 1997, the latest available data) or (2) a synthesized commodity flow matrix such as that available from the FHWA FAF model.

1. Agricultural Crops: The summary of North Carolina Annual Crop Estimates was obtained from the NC Dept. of Agriculture and Consumer Services web site. The summary of the estimates was utilized for production of major NC crops. The unit weights for each of the crops were found from the web sites of Georgia Farm Bureau and Penn State University. It was assumed that 3-axle trucks with 26 ft. axle spacing were used. The empty truck weight for this class of trucks is 27,500 lbs. The maximum gross weight for a vehicle was obtained from NC Laws related to commercial vehicles and was found to be 55,500 lbs. The number of truck trips were calculated based on this number as a fully loaded commercial truck.

2. Timber: The Round wood and Byproduct loads were considered separately for the usage of NC roads in 2001. It was assumed that 5-axle trucks with a distance between axles of 51 ft. were used. The empty truck weight for this category was found to be 32,500 lbs. The maximum gross

weight for a vehicle was obtained from the NC Laws related to commercial vehicles and was found to be 80,000 lbs.

3. Crushed Stone: The summary of road usage by the distribution of crushes stone in North Carolina in 2002 was considered for the study. The empty truck weights of the trucks typically used for transporting crushed stone was assumed as 22,500 lbs. The maximum gross weight for a vehicle as obtained from the NC Laws related to commercial vehicles was 57,500 lbs.

4. Sand and Aggregates: The truck classes used for transporting sand aggregates were similar to the trucks used to transport crushed stone. Thus, the empty truck weight was assumed to be 22,500 lbs. and the gross weight was taken as 57,500 lbs.

The data available from the study by Corley-Lay were thus summarized to find the total trips using the following equation:

Total Trips = [Total Wt. (lbs)] / [Gross Wt. Limit – Empty Truck Wt.]

The payload factors were then calculated using the equation:

Payload factor = [Total Wt. (Tons)] / [Total Trips]

The payload factors thus obtained for Crops, Timber, Crushed Stone, Sand and Aggregates are summarized in Table 5-8.

Table 5-8 Payload Factors for Crops, Timber, Crushed Stone, Sand and Aggregates

Commodity	Total Wt. (lbs)	Total Wt. (Tons)	Empty Truck Wt. (lbs)	Gross Wt. Limit (lbs)	Total Trips	Payload Factors (Tons/Truck)
Crops	19046112600	8639171	27500	55500	680218	12.7
Timber	50721251416	23006800	32500	80000	1067816	21.5
Crushed Stone	138670876024	62900000	22500	57500	3962025	15.9
Sand&Aggregates	22046244201	10014000	22500	57500	629893	15.9

The interest now is to expand the results of Corley-Lay to other commodities listed under the Standard Classification of Transported Goods (SCTG). Similar commodities were assumed to have similar payload factors. Thus, the payloads for commodities classified under SCTG 03 (Other agricultural products), 06 (Milled grain products) and 09 (Tobacco) were approximated as 12.7 as they are similar to 'crops'. By the same reasoning, the payloads for categories SCTG 10 (Building Stone), 11 (Natural Sands) and 12 (Gravel and Crushed Stone) were approximated to 15.9 and the payloads for SCTG 25 (Logs and other Wood) and 26 (Wood products) were approximated to 21.5. The next step is to find the payloads for the other commodity classes listed under STCG. The sum average of the payload factors used by the other states for commodities classified under STCC is calculated. Then, a correspondence is drawn between the STCC classes and STCG classes to find the payloads of the commodities of interest in the STCG classification. Each commodity class in STCG was studied to relate it to an STCC class. For example, SCTG classes 01 (Live Animals and Fish) and 05 (Meat, Fish and Sea food) were related to STCC 09 (Fresh fish or marine products); SCTG 07 (Other prepared food, fats, oils) was related to STCC 20 (Food or kindred products). Similar analysis was carried out for all the commodities and Table 5-9 was generated to show the correspondence between the STCG and STCC classifications. Some classes, however, did not fall under any category of STCG.

Table 5-10, a table of payload factors and the annual commodity truck trips by STCG classification, was thus generated using the correspondence table. The commodity flows were converted into truck trips using the payload factors and the mode split value of 87.2% as obtained from CFS, 1997 using the following equation:

Truck Trips = [Tons (000)*1000] / [Payload] * (0.872)
(Total loaded truck trips in 1997)

The truck trips thus obtained were the total loaded trucks in the year 1997. The empty truck trips percentages were obtained from Dr. Corley-lay. These percentages were used to find the total number of trucks (empty + loaded) in North Carolina in 1997. The total annual truckloads were divided by 312 (6 days per week multiplied by 52 weeks) to obtain average daily truck loads. The estimated daily truck trips for North Carolina are shown in Table 5-11. (Check: Table 5-10 expanding Table 5-11 by 365 or 360 gives much less than Table 5-10 values.)

The heavy truck profile information calculated from this approach can be further used in the standard pavement design procedure to estimate the life cycle of pavement and the corresponding economic value of overweight truck permits and exemptions.

Chapter Summary

NCDOT uses 48-hour class counts to estimate vehicle travel statewide by highway functional class and vehicle type. Estimates are also made for sub-regions and counties, though the results are not reliable. Data from 46 WIM stations give detailed weight and axle loading information that helps define pavement design parameters and overweight vehicle pavement impacts. Estimates of commodities moving on North Carolina highways are also made for four basic commodities. The NCDOT commodity method was expanded to a prototype method for more commodities; however, none of the methods reliably provide commodity flows by highway, highway functional class, sub-region or length of typical trip. Subsequent chapters of this report will address those shortcomings by using:

- TransCAD estimates of VMT by county and NC region,
- Gross vehicle weight (GVW) profiles by selected truck vehicle class, NC region, highway functional class, and urban/rural facility location, and
- Permitted overweight truck traffic AADTT on selected North Carolina Interstates, US highways, and NC and SR highways.

Table 5-9 Correspondence between SCTG and STCC

SCTG Code	Commodity Description	Corresponding STCC Code
1	Live animals and live fish	9
2	Cereal grains	1
3	Other agricultural products	1
4	Animal feed and products of animal origin, n.e.c.	-
5	Meat, fish, seafood, and their preparations	9
6	Milled grain products & preparations & bakery products	1
7	Other prepared foodstuffs and fats and oils	20
8	Alcoholic beverages	-
9	Tobacco products	21
10	Monumental or building stone	-
11	Natural sands	-
12	Gravel and crushed stone	-
13	Nonmetallic minerals n.e.c.	14
14	Metallic ores and concentrates	10
15	Coal	11
17	Gasoline and aviation turbine fuel	13
18	Fuel oils	13
19	Coal and petroleum products, n.e.c.	29
20	Basic chemicals	28
21	Pharmaceutical products	29
22	Fertilizers	28
23	Chemical products and preparations, n.e.c.	28
24	Plastics and rubber	30
25	Logs and other wood in the rough	24
26	Wood products	24
27	Pulp, newsprint, paper, and paperboard	26
28	Paper or paperboard articles	26
29	Printed products	27
30	Textiles, leather, and articles of textiles or leather	22
31	Nonmetallic mineral products	14
32	Base metal in primary or semi-finished forms	33
33	Articles of base metal	33
34	Machinery	35
35	Electronic / electrical equipment/office equipment	36
36	Motorized and other vehicles (including parts)	37
37	Transportation equipment, n.e.c.	37
38	Precision instruments and apparatus	38
39	Furniture, mattresses and supports, lamps and fittings	25
40	Miscellaneous manufactured products	39
41	Waste and scrap	-
43	Mixed freight	-
--	Commodity unknown	-

Table 5-10 NC Payload Factors and Annual Truck Trips by 2-Digit STCG Classification

STCG	Commodity Description	Tons(000)	Payload	Truck Trips (1997)
1	Live animals and live fish	-	16	15309868
2	Cereal grains	2105	12.7	-
3	Other agricultural products	3547	12.7	144532
4	Animal feed and products of animal origin, n.e.c.	7534	-	-
5	Meat, fish, seafood, and their preparations	2821	16	410603
6	Milled grain products and preparations, and bakery products	1571	12.7	193694
7	Other prepared foodstuffs and fats and oils	11759	16	85620
8	Alcoholic beverages	1695	-	-
9	Tobacco products	2051	12.7	116381
10	Monumental or building stone	-	15.9	112483
11	Natural sands	12757	15.9	-
12	Gravel and crushed stone	77973	15.9	699629
13	Nonmetallic minerals n.e.c.	1967	25.8	2635367
14	Metallic ores and concentrates	-	25.8	66482
15	Coal	-	25.8	-
17	Gasoline and aviation turbine fuel	12823	17.8	-
18	Fuel oils	9649	17.8	628183
19	Coal and petroleum products, n.e.c.	5578	17.8	472693
20	Basic chemicals	3489	19.5	249437
21	Pharmaceutical products	2045	17.8	170922
22	Fertilizers	5319	19.5	91448
23	Chemical products and preparations, n.e.c.	1618	19.5	237855
24	Plastics and rubber	4653	10.5	134371
25	Logs and other wood in the rough	26405	21.5	188717
26	Wood products	22836	21.5	1070938
27	Pulp, newsprint, paper, and paperboard	4048	15.2	1310065
28	Paper or paperboard articles	2167	15.2	232227
29	Printed products	1496	15.2	124317
30	Textiles, leather, and articles of textiles or leather	7370	18	72473
31	Nonmetallic mineral products	22096	25.8	249095
32	Base metal in primary or semi-finished forms	3320	20	963386
33	Articles of base metal	2502	20	144752
34	Machinery	1481	17.2	126846
35	Electronic / electrical equipment/office equipment	1635	14.7	87853
36	Motorized and other vehicles (including parts)	1814	15	95048
37	Transportation equipment, n.e.c.	51	15	105454
38	Precision instruments and apparatus	36	17.3	2571
39	Furniture, mattresses and supports, lamps and fittings.	1588	11.3	2778
40	Miscellaneous manufactured products	3774	13	106518
41	Waste and scrap	2037	-	-
43	Mixed freight	2780	-	-
--	Commodity unknown	575	-	-
Total				26,642,606

Table 5-11 Total NC Daily Truck Trips by STCG

STCG	Commodity	Loaded Trucks	% Driven Empty	Total Trucks	Daily Trips
1	Live animals and live fish	15309868	22.9	19857156	63645
2	Cereal grains	-	22.9	-	-
3	Other agricultural products	144532	45.1	263265	844
4	Animal feed & products of animal origin n.e.c.	-	45.1	-	-
5	Meat, fish, seafood, and their preparations	410603	22.9	532559	1707
6	Milled grain products, preps & bakery products	193694	22.9	251224	805
7	Other prepared foodstuffs and fats and oils	85620	22.9	111050	356
8	Alcoholic beverages	-	45.1	-	-
9	Tobacco products	116381	45.1	211987	679
10	Monumental or building stone	112483	33.2	168387	540
11	Natural sands	-	33.2	-	-
12	Gravel and crushed stone	699629	33.2	1047349	3357
13	Nonmetallic minerals n.e.c.	2635367	40.3	4414349	14149
14	Metallic ores and concentrates	66482	40.3	111359	357
15	Coal	-	40.3	-	-
17	Gasoline and aviation turbine fuel	-	40.3	-	-
18	Fuel oils	628183	40.3	1052233	3373
19	Coal and petroleum products, n.e.c.	472693	40.3	791780	2538
20	Basic chemicals	249437	40.3	417817	1339
21	Pharmaceutical products	170922	35.6	265407	851
22	Fertilizers	91448	34.3	139191	446
23	Chemical products and preparations, n.e.c.	237855	34.3	362032	1160
24	Plastics and rubber	134371	34.3	204522	656
25	Logs and other wood in the rough	188717	45.1	343747	1102
26	Wood products	1070938	45.1	1950706	6252
27	Pulp, newsprint, paper, and paperboard	1310065	45.1	2386276	7648
28	Paper or paperboard articles	232227	24.1	305965	981
29	Printed products	124317	24.1	163791	525
30	Textiles, leather, & articles of textiles or leather	72473		-	-
31	Nonmetallic mineral products	249095	40.3	417244	1337
32	Base metal in primary or semi-finished forms	963386	40.3	1613711	5172
33	Articles of base metal	144752	40.3	242466	777
34	Machinery	126846	37	201342	645
35	Electronic / electrical equipment/office equipment	87853	25.9	118559	380
36	Motorized and other vehicles (including parts)	95048	24.1	125228	401
37	Transportation equipment, n.e.c.	105454	24.1	138938	445
38	Precision instruments and apparatus	2571	24.1	3387	11
39	Furniture, mattresses and supports, lamps and fittings	2778	25.9	3749	12
40	Miscellaneous manufactured products	106518	37	169076	542
Total					123032

6. Statewide Estimation of Truck Vehicle Miles Traveled (VMT)

As described in Chapter 5, NCDOT uses 48-hour class counts to develop statewide VMT and AADT by vehicle class. With caution, the statewide results may be used to develop estimates at the sub-regional and county levels and by highway functional classification. However, NCDOT cautions that the results may be biased.

Furthermore, NCDOT uses 48-hour and WIM station traffic counts to forecast truck traffic for individual highway projects by applying simple statistical procedures to current and historical truck traffic data. Even though this approach, considers important transportation system and network effects such as traffic diversion to competing routes and modes, inter-modal transfers, interstate versus intrastate truck traffic, and economic development in a forecast but any adjustments made are highly judgmental. For more effective consideration of alternative statewide highway projects these effects should be simulated with a network model that is analogous to the traditional “four-step” method used for urban and regional travel demand models. As part of the NC Truck Networks project (HWY 2006-09), such a truck flow model was created and validated. This chapter gives a summary of the data sources and procedures used to develop the model. A fully-detailed description of the model can be found in the final report for HWY 2006-09. Following the summary development of the truck network model is an assessment of the model and results pertinent to this research on truck profiles project. The results will illustrate how truck traffic VMT may be estimated at the regional and county levels by highway functional class and by vehicle classification. While the model is still in prototype form and does not treat overweight vehicles, it does illustrate how to overcome the shortcomings of the current NCDOT approaches of disaggregating truck VMT and AADTT from the statewide level to sub-regional levels by vehicle and highway class.

Model Approach

A network model for truck flows consists of three main components combined to create the picture: physical data, traffic analysis zones (TAZs), and vehicular data.

Physical Data

The research developed a calibrated and validated base year 2006 truck network model for North Carolina using TransCAD software. The network was based on the National Highway Planning Network (NHPN, http://www.fhwa.dot.gov/planning/nhpn/). The North Carolina network attributes include highway type, speed, and terrain (coastal, central and mountain regions). Included in the model are Interstate, US, NC, and some secondary road (SR) routes in North Carolina, and beyond North Carolina the network has US and Interstate routes to capture external traffic effects as far away as the West Coast, as well as surrounding neighboring states.

Regional Data

The traffic analysis zones (TAZs) include metro, county and Bureau of Economic Analysis areas (Figures 6-1 and 6-2). The TAZs are selected such that they cover the entire US concentrating more on North Carolina. Twelve urbanized counties representing Metrolina, the Triad, the Triangle and Wilmington were subdivided into 51 metro area TAZs which are the major contributors to truck traffic in North Carolina. The remaining 88 rural counties were TAZs. Along the border of North Carolina the neighboring states of Virginia, Tennessee, Georgia, and South Carolina had 42 buffer TAZs to facilitate truck traffic access to major US and Interstate routes. External TAZs based on Bureau of Economic Analysis (BEA) zones completed the regional dataset.

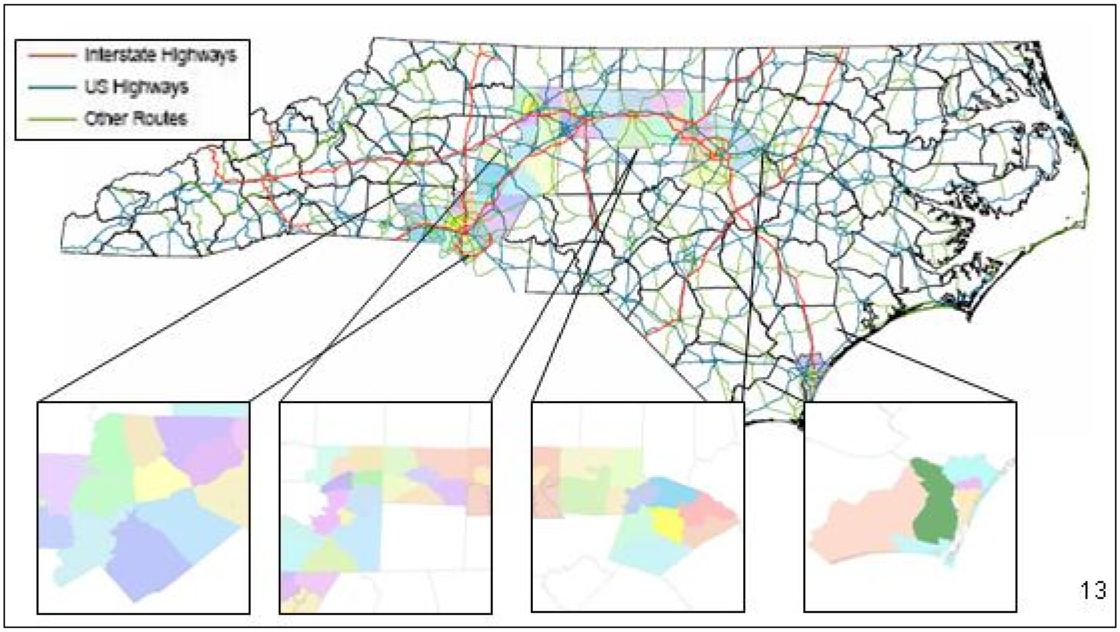


Figure 6-1 NC Truck Network and TAZs

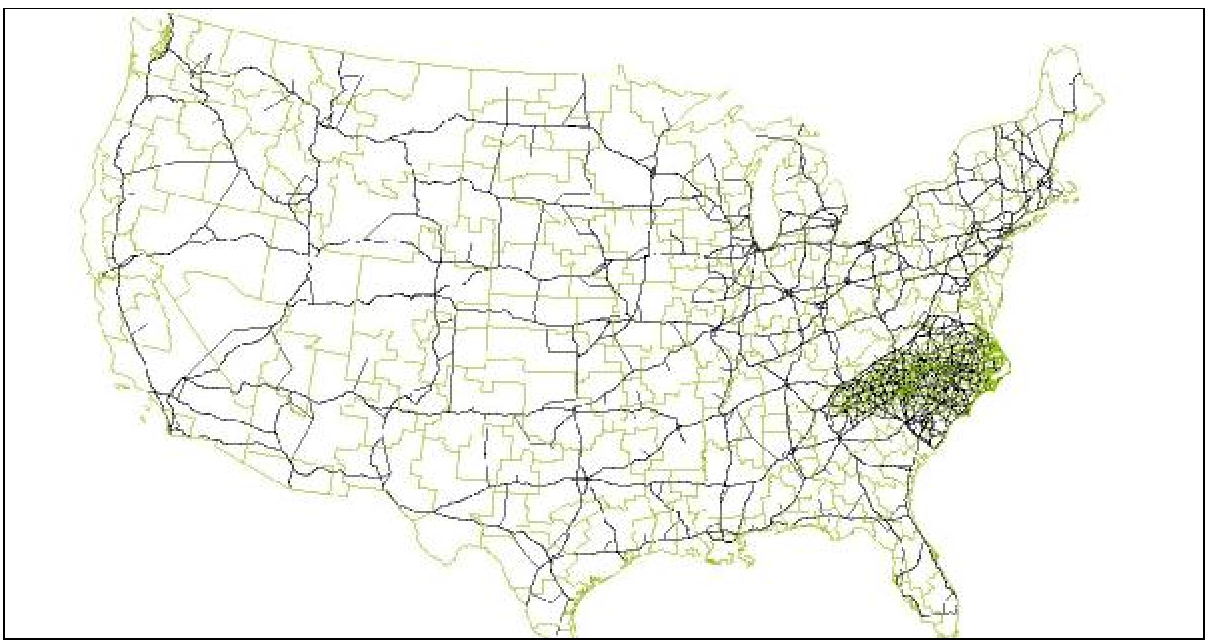


Figure 6-2 National Network and TAZs for the NC Truck Network Model

Vehicular Data

The model is based on available synthetic FAF2 US county-county OD annual average daily truck traffic (AADTT) flow data for long-haul truck trips and North Carolina employment data (NCESC, 2004) for short-haul truck trips. The FAF2 county-to-county OD AADTT flows are converted into TAZ-to-TAZ OD AADTT flows by disaggregating FAF2 OD flows for metro TAZs and aggregating county TAZ FAF2 flows for external BEA TAZs. County-to-county TAZ OD flows in North Carolina were disaggregated to small metro TAZs in the major metro areas. The external buffer area TAZ OD flows needed no adjustments.

The development of the NC truck network model relied on no-cost FHWA FAF2 trip matrix data representing long haul truck traffic between US and NC counties. The research demonstrated the feasibility of this approach when combined with NC truck traffic count data, VIUS data, NC employment data, national truck trip data, the National Highway Planning Network, and the NCDOT Universe File for highway characteristics. The approach did not use or have available the usual travel modeling survey data: NC truck trip rates by employment type, trip length distributions, time-of-day parameters, truck routing characteristics, and so forth. Empty trucks and back-haul trips were each assumed to represent 30% of the truck traffic, and local truck trips were based on national truck trip data. This hybrid, synthetic approach (combined with careful modeling skills) yielded a calibrated NC truck trip model that matched approximately 460 ground counts at an R^2 of 0.93 to meet FHWA validation guidelines. Compared to VIUS truck travel estimates, coastal, central and mountain region vehicle miles traveled were within +11.5%, +0.7%, and -5.7%, respectively, for an overall total VMT comparison of +1.9%.

The long haul truck data are based on the 2002 FHWA Freight Analysis Framework 2 origin-destination data for North Carolina including origins and destinations outside North Carolina. Since 2006 is base year for the NC truck traffic network model (the year the validation counts were taken), the 2002 FAF2 OD data had to be extrapolated to 2006. The extrapolation used exponential 2002 to 2006 growth factors based on the Gross Domestic Product for each BEA TAZ outside North Carolina. Inside North Carolina the exponential growth factors were based on county employment. A Fratar procedure carried out the calculations. Truck traffic that is not produced by FAF2 trips is mostly local short haul traffic, which is generated using a simplified statewide trip generation rate of 0.1 trips per employee per day. The resulting model estimates for base year 2006 truck traffic in North Carolina are well-validated by approximately 460 48-hour truck traffic counts throughout the state.

Network Development

To be consistent with FAF2 data and modeling efforts by FHWA the network model uses the 2002 version of the National Highway Planning Network (NHPN) for modeling the truck flows in North Carolina. NCDOT uses the National Highway System (NHS) which is very similar to the NHPN but has more local roads. However, this research uses NHPN as it is nationwide and it allows for extending the model across North Carolina. The NHPN consists of Interstate, US highways and ‘other’ routes. The density of NHPN is consistent with the geography of TAZs in the study area. The road network inside North Carolina consists of all the roads classified under NHPN including Interstates, US, and some NC and SR routes. Outside North Carolina, the network models Interstate highways to capture the traffic to and from external zones. Buffer counties in neighboring states around North Carolina allow for the transition in the road network from all NHPN roads inside North Carolina to Interstate and US highways outside North Carolina. All the NC routes at the state line are extended beyond the state using state routes in the neighboring states and connected to the nearest US or Interstate highway. This made sure there were no dead ends at the state line. All the US routes are terminated near the buffer boundary by appropriately connecting them to the nearest Interstate highway. Figure 6-1 illustrates the North Carolina network overlaid on the model TAZs, and Figure 6-2 shows how the NC truck network model extends to surrounding states and across the US.

Network Attributes: Link Functional Class, Link Speeds, Truck Average Speed

To assign reasonable travel speeds to highway links, federal functional classifications (FFC) of the links are required, which differentiate both functionality and area type of the road. If the link in NHPN has a value in the FCLASS field, use it directly; otherwise, use the combination of RUPOPU (NC area type, rural/urban population) and FUNCLS to impute FFC. Manual corrections were made later when unreasonable FFC values were found.

Speed limit data for Interstate and US routes outside North Carolina were not available, so assumptions were made:

- 55 mi/hr speed limit for trucks on US routes,
- 70 mi/hr speed limit for Interstate routes and all non-North Carolina routes, 35 mi/hr for all the North Carolina metro TAZs,
- 45 mi/hr for the centroid connectors in the buffer TAZs and North Carolina rural TAZs,
- 55 mi/hr for all centroid connectors in the US Bureau of Economic Analysis (BEA) zones.

This approach for setting link speeds is efficient and common practice in national networks that focus on a particular state. However, refinements and other approaches to setting link speed are of interest in future versions of the NC truck network model.

Table 6-1 Average Travel Speed Lookup Table for NC Truck Network Model

Average Travel Speed		2 lanes									3 lanes or more							
		speed limit (mph)									speed limit (mph)							
Terrain Type	Functional Class	<=20	25	30	35	40	45	50	55	60	30	35	40	45	55	60	65	70
1 (Flat)	1								59	62						60	69	70
	2		30	35	37	42	48	50	53	56	36	40	45	42	54	56	65	
	6		27	31	36	41	45	47	53	56	36	39	44	45	53	56	62	
	7	24	23	30	35	40	44	46	51		34	30	40	40	52	57	60	
	8	21	23	27	34	36	40	41	45		30	33	36	42	47	50		
	9	20	22	24	26	32	36	38	40		27	31	36	33	42	46		
2 (Rolling)	1								53	61						60	63	72
	2		20	31	35	40	45	49	54	59	30	39	44	40	50	50	60	
	6		33	29	34	39	47	47	49	58	33	38	43	45	50	56	61	
	7	22	25	20	30	30	42	46	40		31	33	41	45	49	54	59	
	8	20	22	26	31	34	39	42	44		28	32	36	40	44	49		
	9	20	22	24	20	32	35	37	40		25	29	31	33	40	40		
3 (Mountainous)	1								43	56						57	63	67
	2		29	31	34	36	39	44	49	54	32	39	40	45	49	56	59	
	6		24	28	33	36	38	42	45	53	31	35	39	44	48	53	57	
	7	21	20	27	32	34	37	39	40		30	34	30	40	47	51	53	
	8	19	21	24	30	31	35	38	40		27	31	36	33	42	46		
	9	17	20	22	26	26	32	35	37		26	27	31	34	37	42		

Average travel speed for all links in the network must be assumed for assigning trips using the multi-path stochastic assignment technique without capacity restraint. A speed lookup table (Table 6-1) was developed for assigning a reasonable average travel speed for each highway link based on the functional class, speed limit, number of lanes, and terrain type of the link – proven factors having significant impact on speeds. For rural roads, average speeds are pulled directly from the table. Urban road speeds were factored down from equivalent rural road speeds based on urban FFC. Values used for these factors are:

- FFC 11 & 12 (interstate freeways and expressways): 0.95
- FFC 14 (urban principal arterials): 0.8

- FFC 16 & 17 (urban minor arterials & collectors): 0.75
- FFC 19 (locals): 0.7

Traffic Flow Estimation

FAF2 is a synthesized nationwide origin-destination database and it ignores some local short haul truck trips; hence, the methodology includes a method to incorporate these trips. Productions and attractions of these trips are estimated based on North Carolina employment data. A gravity model is employed and calibrated to distribute short haul truck OD flows in North Carolina, and a network assignment of FAF2 ADTT OD flows and short haul ADTT OD flows is then performed using a multi-path stochastic assignment technique. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, capacity-constrained traffic assignment techniques, such as User Equilibrium, are not used. As a final step in the truck traffic flow estimation, empty truck trips were added to the trip matrix. Details of the procedure are documented in the final report for NCDOT HWY 2006-09.

Model Calibration

Model calibration was accomplished at three levels: system-wide, regional level, and link level. System-wide calibration was done to ensure that the model-estimated volumes and the trip length distribution agree with the observed ones within a reasonable range. Regional level calibration included a volume summary comparison at cordon lines and screen lines between modeled estimates and observed traffic counts. Link level calibration included checking and adjusting volumes on major facilities, such as I-85 and I-40, as well as other classifications of roads. VMT is another important index for model calibration and validation that was performed at both the system wide level and the regional level.

The model parameters were tweaked based on the validation results to obtain a validated 2006 North Carolina truck network model. A typical approach follows these steps:

- Conduct reasonableness checks at each stage of the modeling process, as well as after the assignment step.
- Check network development (density, coverage, discontinuities, and minimum paths), and TAZ development (coverage, number, and consistency of geography with network density).
- Balance trip generation productions and attractions, and verify average trip rate per employee.
- Adjust trip distribution gravity model parameters (trip length distributions, control total flow).
- Compare estimated traffic volumes from model traffic assignment to ground counts, screen line balances, and VMT.

Model Validation Using Truck Traffic Ground Count Data

Approximately 460 48-hour NC truck traffic counts collected by the NCDOT Traffic Survey Unit are used for the NC truck model validation. NCDOT conducted a statewide truck traffic count survey in 2006 and 2007 and collected truck trip classification counts at 724 locations across the state, as shown in Figure 6-3. Truck traffic was classified by truck type, which includes bus, 2-, 3-, and 4-axle single-unit, 4-, 5-, and 6-axle single-trailer, and 5-, 6-, and 7-axle multi-trailer. Of the 724 locations, 460 are on the highway links that are represented in the model network. These counts were used as a key element for model calibration and validation. As discussed in a previous paragraph, NC truck trip model matched the 460 ground counts at an R^2 of 0.93 (Figure 6-4). And compared to VIUS truck travel estimates, coastal, central and mountain region vehicle miles traveled were within +11.5%, +0.7%, and -5.7%, respectively, for an overall total VMT comparison of +1.9%.

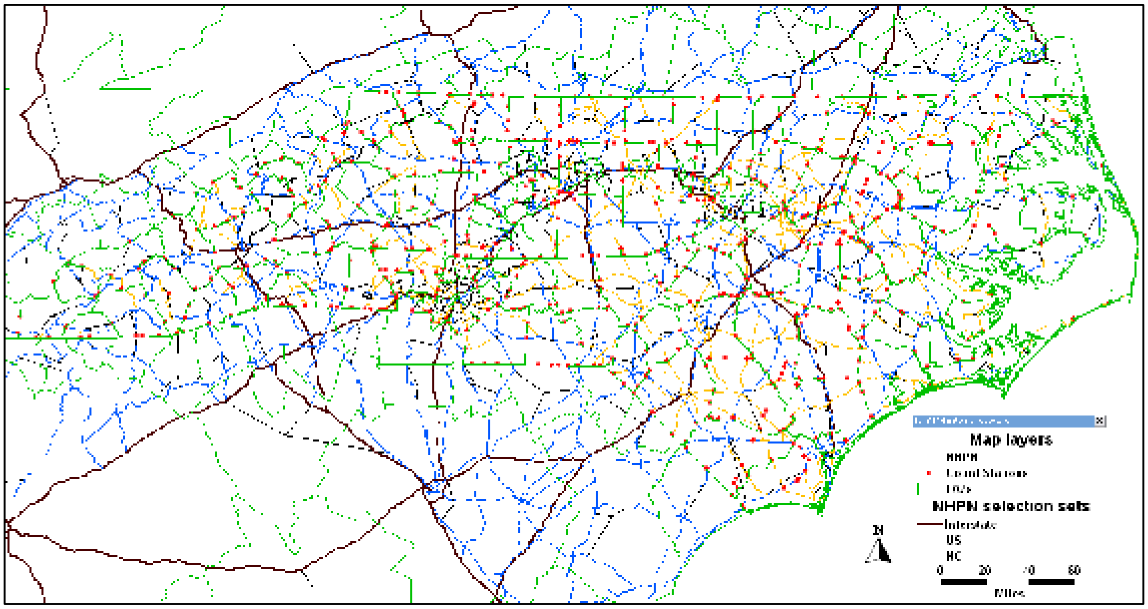


Figure 6-3 NCDOT Truck Count Locations

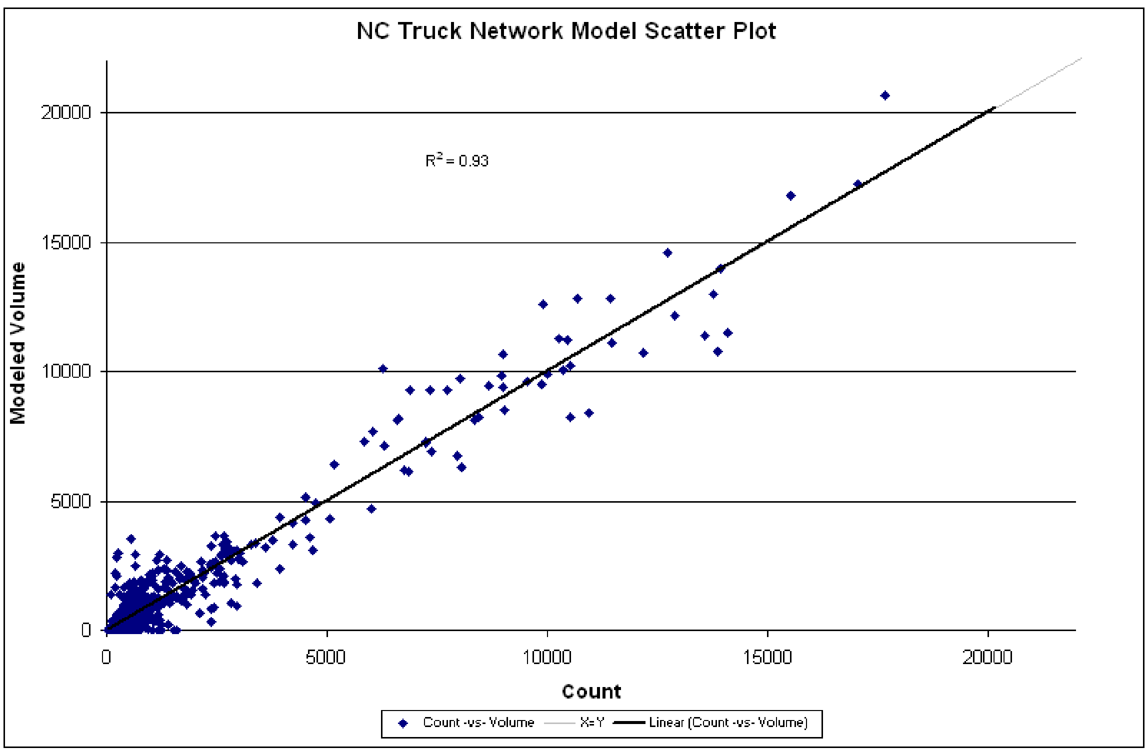


Figure 6-4 Model Validation

Model Results

After calibration and validation the truck-only model was run using stochastic multipath assignment. Figure 6-5 illustrates the relative magnitude of daily truck traffic on the North Carolina truck network model. As expected the major Interstates, especially in the Central region of the state, carry most of the truck traffic.

Of particular interest to this North Carolina Truck Traffic Profiles project the truck model was used to:

- Compare the relative magnitudes of North Carolina truck traffic VMT by region (mountains, central, and coastal) and by 12 highway functional classifications including urban and rural interstates, arterials, and local roads, and
- Identify the relative size of interstate truck flows from North Carolina to major interstate destinations.

These results are developed and discussed below.

Truck Traffic VMT by Region and Highway Functional Class

As discussed in the previous chapter, the North Carolina practice is to estimate VMT and AADTT based on vehicle classification counts throughout the state on a variety of highway functional classes. Then, knowing the DVMT of various highway types, a statewide estimate of the VMT by highway class and vehicle classification may be made. The statewide results may also be allocated to sub-regions and counties, though NCDOT cautions that the estimates may not be reliable. The North Carolina truck traffic network model of this Chapter offers an alternate approach.

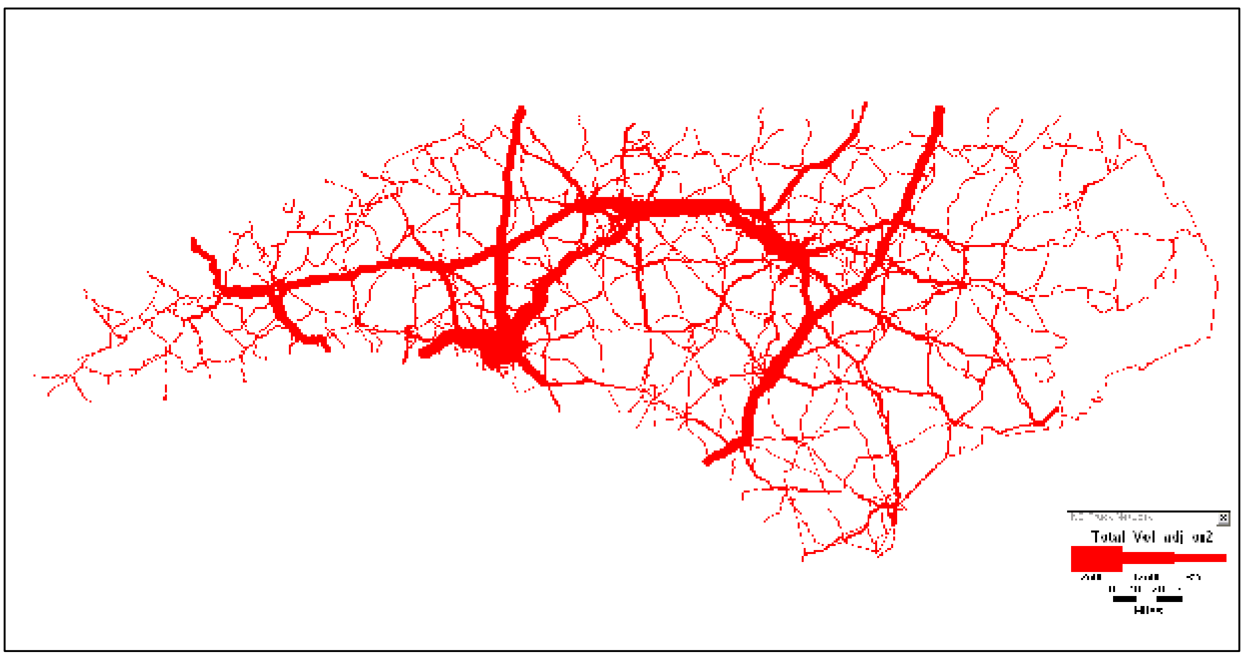


Figure 6-5 Model Results - Daily Truck Traffic Flows

The most complex step in creating truck VMT profiles is estimating the distances traveled by each truck. The truck network model provides that information directly from the GIS network model. (As discussed in Chapter 7, NCDOT only tracks truck distances for overweight and oversize permitted vehicles. Yet, the data is ambiguous data in the sense that a permit may be for multiple trips and there is no record of when the trips are completed or how many are completed as part of a particular permit.) More generally a further difficulty for total truck travel is determining over which types of roadways the vehicles are moving. Again, the truck network model provides that information. And a final difficulty is what type of truck is driven for a given trip. The truck class counts used for validating the truck network model give an estimate of what vehicles are used on what highways.

In other words, full path/route information is needed to estimate VMT by truck type and highway functional class. Much of this information could be obtained by purchasing proprietary and expensive data, such as the Global Insight Transearch dataset. Otherwise, much of it must be estimated based on available non-proprietary information. Therefore, as described in this chapter, a truck network model was developed in TransCAD and combined with multiple data sources to estimate truck vehicle-miles traveled (VMT).

VMT were derived from the NC truck network model including 4728 links of which 309 were local rural or urban roads taken from the NHPN network and the NCDOT Universe file. VMT is the product of number of vehicles on a highway link and the length of that link in miles after the model assigns truck traffic to all links. Knowing the percentage of the vehicle classes on the highway (Table 5-5) allows the VMT to be categorized by vehicle class. A regional or county VMT is simply the summation of the VMT's on all the road links in a region, and similarly the VMT of a collective highway functional classification is the summation of the VMT's on all the road links that belong to that classification. Applying the North Carolina truck network model in that regard, VMT's by region and highway functional classification were produced as show in Table 6-2. As can be seen from the table, the central region produces the most truck traffic (VMT) in the state - about 13.8 million vehicle miles daily. The coastal and mountain regions generate about 4.2 million and 3.2 million truck VMT daily, respectively. Assessed at the statewide level but broken down by highway functional class, rural interstate and other principal arterials are the facilities where the most truck VMT occurs. They amount to about 6 million VMT and 4 million VMT daily, respectively.

Derivation of VMT for truck types 5 and 9 by region and highway functional classification required information from NCDOT, as well as the truck network model. Due to the lack of region-specific truck type distribution on different types of highways, a statewide vehicle class distribution table provided by NCDOT was used to derive the VMT for truck types 5 and 9. The results are shown in Table 6-3 and Table 6-4. As a note, since the truck type distribution data are statewide averages, the numbers in the tables may have some bias as the distribution data are applied at a level below the statewide level. These two tables each also contain a column titled "%". This column indicates, statewide, what percent of the total VMT on a highway type is made by truck type 5 or 9. For example, truck type 5 accounts for about 10.4% of the total VMT on rural interstate highways (Table 6-3), while truck type 9 accounts for 68.6% (Table 6-4).

Table 6-5 shows how the model estimated Truck VMT compares to the NCDOT estimated Truck VMT. The basis of Table 6-5 NCDOT estimates for truck VMT is a statewide truck percentage of 11% (Table 5-3) applied to the total VMT for all vehicles. The total VMT for all vehicles for each county results from counting all vehicles on a randomized sample of links categorized by functional class and multiplying the average vehicle counts for a functional class by the highway miles for that functional class in the county. The VMT attributed to trucks must be developed as a percentage of the total VMT, preferably by individual vehicle class and highway functional class. For simplicity an unweighted statewide average truck percentage of 11% for all NC trucks operating on NC all highway functional classes was assumed based on NCDOT data (Table 5-3). Thus, Table 6-5 results for the NCDOT truck VMT estimates represent the aggregation of county total VMT by region with an 11% adjustment for trucks.

Both NCDOT truck VMT estimates and truck network model estimates are calculated independently, and they serve as checks on each other, the validity of the NCDOT sample VMT approach, and the validity of the network model. Note that the calculated un-weighted 11% statewide truck percentage varies over the nine truck vehicle classes and 12 highway functional classifications from less than 1% on urban facilities to nearly 20% on rural Interstates, for example, for tractor trailer 5-axle vehicles. Furthermore, the Interstate trucks which have the greatest percentage also travel the greatest distances. Thus, a weighted truck percentage may be greater than 11%. The NCDOT class counts for the 470+ count locations provide percent trucks by highway functional class, county and region, but that data has not been analyzed for 2006. The percentages will likely be similar to the 2005 averages presented in Chapter 5. The comparison of Table 6-5 NCDOT estimates to model estimates shows differences which should be investigated.

Ultimately the validation of the network model must show that the estimated model volumes compare within acceptable limits to actual truck traffic counts. NCDOT counted truck traffic at about 470 locations on all highway functional classes (Figure 6-2). The estimates compared to actual counts (Figure 6-4) varied somewhat depending on the highway functional class.

Given the functionality of a truck network model, preliminary steps toward estimating likely vehicle paths are feasible. Indeed, the model determined example shortest path routes between Wake County and other counties (Table 6-6) and Wake County and destinations beyond North Carolina (Table 6-7).

Table 6-2 VMT by Region and Highway Functional Classification

FFC	Functional Classification	Regional Total Truck VMT			Sub Total
		Central	Coastal	Mountain	
1	Rural Principal Arterial - Interstate	3,677,480	1,006,310	1,273,040	5,956,830
2	Rural Principal Arterial - Other	2,077,461	1,399,812	591,434	4,068,707
6	Rural Minor Arterial	1,288,281	669,308	279,991	2,237,580
7	Rural Major Collector	78,887	97,839	38,607	215,333
8	Rural Minor Collector	41,579	25,949	1,712	69,240
9	Rural Local System	73,825	52,097	58,252	184,175
11	Urban Principal Arterial - Interstate	3,114,324	116,599	539,434	3,770,358
12	Urban Principal Arterial - Other Freeways or Expressways	691,733	95,363	32,131	819,227
14	Urban Principal Arterial - Other	1,193,520	391,234	97,605	1,682,359
16	Urban Minor Arterial	42,002	11,692	3,066	56,760
17	Urban Collector	3,756	3,147	322	7,225
19	Urban Local System	1,728	11,216	1,089	14,033
	Centroid Connector	1,544,950	358,678	296,605	2,200,233
Sub Total		**13,829,527**	**4,239,245**	**3,213,288**	**21,282,059**

Table 6-3 Truck Type-5 VMT by Region and Highway Functional Classification

FFC	Functional Classification	Regional Truck VMT for Type 5 (2ASU)			Sub Total	%
		Central	Coastal	Mountain		
1	Rural Principal Arterial - Interstate	383,455	104,929	132,741	621,125	10.4%
2	Rural Principal Arterial - Other	511,069	344,363	145,497	1,000,928	24.6%
6	Rural Minor Arterial	411,671	213,878	89,471	715,019	32.0%
7	Rural Major Collector	33,584	41,652	16,436	91,671	42.6%
8	Rural Minor Collector	20,925	13,059	862	34,846	50.3%
9	Rural Local System	38,040	26,844	30,016	94,900	51.5%
11	Urban Principal Arterial - Interstate	485,948	18,194	84,171	588,313	15.6%
12	Urban Principal Arterial - Other Freeways or Expressways	162,278	22,372	7,538	192,188	23.5%
14	Urban Principal Arterial - Other	426,786	139,900	34,902	601,588	35.8%
16	Urban Minor Arterial	21,343	5,941	1,558	28,842	50.8%
17	Urban Collector	2,078	1,741	178	3,998	55.3%
19	Urban Local System	774	5,022	487	6,284	44.8%
	Centroid Connector	772,475	179,339	148,302	1,100,116	50.0%
Sub Total		**3,270,425**	**1,117,234**	**692,159**	**5,079,819**	**23.9%**

Table 6-4 Truck Type-9 VMT by Region and Highway Functional Classification

FFC	*Functional Classification*	Regional Truck VMT for Type 9 (5AST)			Sub Total	%
		Central	Coastal	Mountain		
1	Rural Principal Arterial - Interstate	2,524,497	690,807	873,910	4,089,214	68.6%
2	Rural Principal Arterial - Other	962,701	648,677	274,072	1,885,451	46.3%
6	Rural Minor Arterial	477,263	247,955	103,727	828,945	37.0%
7	Rural Major Collector	18,094	22,441	8,855	49,390	22.9%
8	Rural Minor Collector	6,289	3,925	259	10,472	15.1%
9	Rural Local System	5,157	3,639	4,069	12,865	7.0%
11	Urban Principal Arterial - Interstate	1,939,545	72,616	335,950	2,348,111	62.3%
12	Urban Principal Arterial - Other Freeways or Expressways	340,494	46,941	15,816	403,251	49.2%
14	Urban Principal Arterial - Other	374,542	122,774	30,630	527,946	31.4%
16	Urban Minor Arterial	5,062	1,409	369	6,841	12.1%
17	Urban Collector	197	165	17	379	5.2%
19	Urban Local System	137	890	86	1,114	7.9%
	Centroid Connector	108,146	25,107	20,762	154,016	7.0%
Sub Total		**6,762,125**	**1,887,346**	**1,668,523**	**10,317,994**	**48.5%**

Table 6-5 Model VMT Estimates Compared to NCDOT VMT Estimates

NC Region	Model Truck VMT	NCDOT Truck VMT
Central	13,829,527	18,264,980
Coastal	4,239,245	5,508,030
Mountain	3,213,288	3,971,840
Total	21,282,060	27,744,850

Table 6-6 Example Shortest Path Routes for NC

TAZ Origin	TAZ Destination	Shortest Path (Major routes)	Travel Time (Model, hrs)	Travel Time (Google, hrs)
Wake	New Hanover	I-440E, I-40E	2.0	2.2
Wake	Mecklenburg	I-40W, I-85S	2.4	2.7
Wake	Cherokee	I-40W, US-19S	5.3	5.1
Wake	Ashe	I-40W, US-421N, US-221N	3.6	3.6

Table 6-7 Example Shortest Path Routes for Trips Beyond NC

TAZ Origin	TAZ Destination	Shortest Path (Major routes)	Time (Estimated, hrs)	Time (Google, hrs)
Wake, NC	Dallas, Texas	I-40W, I-85S, I-20W	17.8	18.0
Wake, NC	Miami, Florida	I-40 E, I-95S	12.8	12.0
Wake, NC	Augusta, Maine	US-64E, I-95N	15.6	14.9
Wake, NC	San Francisco, CA	I-40W, I-5N	43.1	42.0

Findings

This chapter described a prototype truck traffic network model for base year 2006 using the National Planning Highway Network (NHPN), the FHWA FAF2 OD dataset and adjustments for short-haul truck traffic including empties. The model was calibrated and validated at an R^2 of 0.93 and was used, among other tasks, to estimate statewide vehicle miles traveled by the trucks on highways in North Carolina. These results were categorized in various ways: VMT by region; VMT by county; and VMT by highway functional class, region, and vehicle class. Comparisons to traditional VMT estimates from NCDOT were good.

The prototype truck network model demonstrated that it can be used to determine truck traffic profiles by sub-region, vehicle class, and highway functional classification. Preliminary truck traffic flow assignments on the network also described likely truck routing patterns from county TAZ origins to county TAZ destinations assuming shortest paths are taken by the drivers. There are also some external path itineraries demonstrated to locations outside NC.

The truck traffic network model represents another step toward complete vehicle-path information using sampled data and model estimates of the interactions of vehicles, the network, and the attributes of the network. Additional improvements in the prototype model are required to overcome such limitations as those which are listed below.

- Only ADTT (average daily truck traffic) is estimated for the network model, not total vehicle traffic including automobiles. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, the current network model is not built with a capacity-constrained traffic assignment feature.
- The network is sensitive to input speed, not to traffic volumes on the highway. Consequently any network changes for scenario testing have to be expressed in terms of speed changes to the network links affected. Thus, network improvements from adding lanes (capacity) will not make the model estimate different traffic volumes on the highway.
- Long haul truck traffic estimates depend on national estimates produced by the FHWA FAF2 data. Short haul truck traffic in North Carolina is estimated based on employment (0.1 truck trips/employee/day). This total average rate does not recognize individual NAICS categories of employment. The rate is close to the lower end of the rates reported for some U.S. cities. Because the rate is a state average, it does not explicitly reflect intense truck activity such as that experienced at trucking hubs. This limitation is due to the aggregation of truck activity locations into counties and metropolitan areas, since they serve as traffic analysis zones (TAZs) in this model.

The model has particular strengths in that it is a statewide model that can be used for:

- Simulating year 2006 truck flows in and across the state,
- Forecasting intercity / inter-region truck travel by highway functional class,
- Forecasting rural area truck traffic by region, and
- Other important truck traffic information that can be used by MPOs in the regional modeling process.

The primary objective of the truck network model research - to develop a base year truck network model for North Carolina – was accomplished. Furthermore, as described above, the prototype truck network model for North Carolina represents another step toward better descriptions of truck traffic profiles including descriptions of typical truck trips by highway and route chosen.

7. Development of GVW Plots for Urban and Rural Regions of North Carolina

Knowing the type of traffic by vehicle class by highway functional classification is critical to designing, maintaining and paying for North Carolina highway pavements. Such information is used by the NCDOT Pavement Management Unit to estimate pavement costs by NC region and highway functional classification. Thus, gross vehicle weight (GVW) plots by vehicle class and highway functional class are very important.

NCSU developed database procedures and NCDOT collected WIM station data during the NCDOT research project called NC Traffic Data for the Mechanistic Empirical Pavement Design Guide (NCDOT project HWY 2008-11). NCSU used the database procedures on the WIM data to develop GVW plots for urban and rural regions in North Carolina for this project. While GVW plots for all WIM stations for all vehicles classes and highway functional classifications could have been developed, the NCDOT Pavement Management Unit only recommended plots for vehicle classes 5 and 9 only to illustrate the majority of truck traffic. To further simplify the analysis and number of GVW plot combinations, NCDOT recommended that all urban WIM stations be grouped and that the remaining rural WIM stations be grouped by NC region – mountainous, central and coastal. During the analysis further categories became apparent - one for I-95 traffic and one for urban recreational traffic in Asheville. The results of this GVW analysis for class 5 and class 9 trucks complement the statewide truck traffic estimates produced using the NC truck network model (Chapter 6) developed by NCDOT research project HWY 2006-09.

Approach

Table 7-1 identifies the location of the WIM stations and the nature of the truck traffic (urban, rural, and recreational). All WIM stations are grouped as shown in Figure 7-1 and Figure 7-2. Figures 7-3 to 7-5 illustrate the location of WIM stations in North Carolina regions (mountainous, central and coastal).

The GVW plots for the urban and rural regions are obtained using the following procedure.

1. Quality Control is performed on the raw C (class) and W (weight) card data using the NCDOT QC Database.
2. GVW plots by vehicle class by WIM station are obtained by using the NCDOT WIM QC database, which in turn is connected to the WIM data in the WIM Processor database.
3. The groupings in Figure 7-1 were suggested by NCDOT Traffic Survey Unit personnel. In addition WIM stations 519, 520 and 556 in Asheville were classified as a special case to show class 5 and class 9 traffic on urban recreational routes. WIM 557 on I-40 in Statesville was also identified as an Urban WIM with some recreational features.
4. Data from the WIMs shown in Table 7-1 are processed.
5. Data from WIMs 507, 513, 514, 517, 518, 524, 526, 528, 532, 537, 538, 544 and, 550 were not processed for this project, but the data is available in the results for the MEPDG project HWY 2008-11.
6. Data from all WIMs are grouped according to Figure 7-1 and the plots shown in Table 7-3 are plotted in Excel. A total of 49 plots are generated for each WIM station group. Following the guidance from NCDOT only the most important plots for truck classes 5 and 9 are produced because these truck classes represent a majority of the truck traffic on highways. In addition,

summary class plots obtained from vehicle class data are also shown in this report. Thus, this report produces 24 examples of class 5 and class 9 plots.

All plots are available on the data CD which will be produced for this report. Figures 7-1 and 7-2 illustrate the class 5, class 9 and summary plots produced by region and urban/rural areas. The plots themselves are given in Figures 7-6 to 7- 29.

Low Weight Screening

The minimum gross vehicle weights for all classes of trucks are shown in Table 7-2. All weight records less than the weights shown in Table 7-2 have not been excluded from the GVW plot. This table is used for enforcement reporting only to exclude underweight trucks before generating statistics. This is not used in the QC process for MEPDG. It's a crude technique to quickly remove "suspect" vehicles before generating enforcement statistics. However, the Minimum GVW Check, a utility in the NCDOT WIM QC Database is used only if a significant issue occurs with low weight GVWs for a class. This is done last after both weight and class check reviews are completed.

As an example of low weight screening consider class 5 trucks. In general, class 5 vehicles are two-axle six-tired "box" trucks. Sometimes pick-up trucks and campers are misclassified as class 5 trucks (especially on recreational routes) which lead to a significant number of low weight records in the WIM database. However, the WIM Enforcement Minimum GVW QC checks flag low weight records less than 10,000 lbs. GVW as shown in Table 7-1.

Findings

In general, the class 5 and 9 GVW plots for all categories of WIM stations show expected trends. Plots for class 9 tend to have peaks at approximately 30,000 and 80,000 lbs corresponding to empty and fully loaded conditions respectively, which is reasonable. Class 5 plots tend to have a peak at about 15,000 lbs which is reasonable as well. However, the application of the minimum GVW rule for class vehicles results in the formation of a ski-slope rather than a peak and this is evident in all class 5 plots. The peak usually occurs at the very first data point as shown in all class 5 plots.

Although the data from the GVW plots showed expected trends, there were still some unexpected low weight values for both class 5 and class 9 truck classes. These weight records were excluded by the minimum GVW weight rule accessible through the NCSU WIM QC database. This is probably because of truck misclassifications as in the case of pick-up trucks and campers being misclassified as class 5 trucks.

These results may be used by highway planners and pavement designers to quickly determine typical truck traffic profiles in the various NC regions. The results provide insight into NC truck transportation flows.

Summary Findings

Although the WIM data was good in general, it may be helpful to collect more than one year of data to compare trends or to substitute missing or incomplete data. It is also recommended to apply all of the QC procedures in the NCSU WIM QC database in the specified order before plotting the GVW plots. In addition to applying quality control checks and an upgrade to Access 2003, it is also advisable to think ahead and look for alternate database solutions like Oracle or Microsoft SQL Server to store, analyze and process WIM data. Regular equipment calibration and maintenance will also go a long way in providing good quality data for analysis. In that regard, fine tuning of equipment to fix misclassifications, especially for recreational WIMs is highly desirable.

Table 7-1 WIM Stations in North Carolina, Source: NCDOT Traffic Survey Unit

SHRP	Nearest Town/City	Rt. Name	Type	Region
501	South Mills	US 17	Rural and Recreational	Coastal
502	Elizabeth City	US 17	Rural	Coastal
503	Rocky Mount	I-95	I-95 has a unique pattern - primarily recreational - It has its own ATR group	Central
504	Whiteville	US 74	Rural and Recreational	Coastal
508	Pittsboro	US 64	Rural	Central
509	Siler City	US 421	Rural	Central
511	Greensboro	US 220	Urban	Central
512	Winston Salem	US 311	Urban	Central
515	Mount Airy	I-77	Rural and Recreational	Mountain
516	Charlotte	SR 1138	Urban	Central
519	Oteen	I-40	Asheville Urban and Recreational	Mountain
520	Swannanoa	I-40	Asheville Urban and Recreational	Mountain
523	Franklin	US 23-441	Rural and Recreational	Mountain
525	Siler City	US 421	Rural	Central
527	Rocky Mount	I-95	Same as 503	Central
529	Greenville	US 264	Urban Loop/bypass	Coastal
530	Sanford	US 1	Rural	Central
531	Lexington	US 52	Rural	Central
539	Charlotte	I-77	Urban	Central
540	South Mills	US 17	Same as 501	Coastal
542	Rocky Point	I-40	Rural and Recreational	Coastal
545	Durham	NC 147	Urban	Central
546	Charlotte	NC 24	Urban	Central
547	Dallas	US 321	Urban	Central
548	Scranton	US 264	Rural	Coastal
549	Currie	US 421	Rural	Coastal
551	Laurinburg	US 74	Rural	Coastal
552	Lilesville	US 74	Rural	Central
553	Asheboro	US 220	Rural	Central
554	Madison	US 220	Rural	Central
555	Greensboro	NC 68	Urban	Central
556	Asheville	I-240	Asheville Urban and Recreational	Mountain
557	Statesville	I-40	Urban and some Recreational	Central
558	Hickory	US 321	Urban	Central
559	Valdese	I-40	Rural and Recreational	Mountain
560	Mars Hill	I-26	Rural and Recreational	Mountain
506	Raleigh	I-40	Urban	Central

SHRP	Nearest Town/City	Rt. Name	Type	Region
521	Cullowhee	NC 107	Rural and very Recreational	Mountain
522	Whittier	US 74-441	Rural and Recreational	Mountain
534	Murphy	US 64	Rural and Recreational	Mountain
535	Andrews	US 74	Rural and Recreational	Mountain
533	Hayesville	US 64	Rural and Recreational	Mountain
536	Clyde	I-40	Rural and Recreational	Mountain
510	Reidsville	US 29	Rural	Central
541	McDonald	I-95	I-95 has a unique pattern - Primarily Recreational - It has its own ATR group	Coastal
543	Wise	I-85	Rural	Central

Table 7-2 Minimum GVW for Trucks

Source: NCDOT Traffic Survey Unit

FHWA Vehicle Class	Minimum GVW (lbs)
4	12,000
5	10,000
6	12,000
7	12,000
8	16,000
9	22,000
10	22,000
11	22,000
12	22,000

Table 7-3 Plots Generated Using the NCDOT QC Database

Name	Obtained from	No. of Plots Generated
Weight Average Hourly Plots	W-Card Data	12
Weight GVW Plots	W-Card Data	10
Class Average Hourly Plots	C-Card Data	12
Average Daily Class Plots	C-Card Data	12
Summary Class Plots	C-Card Data	3

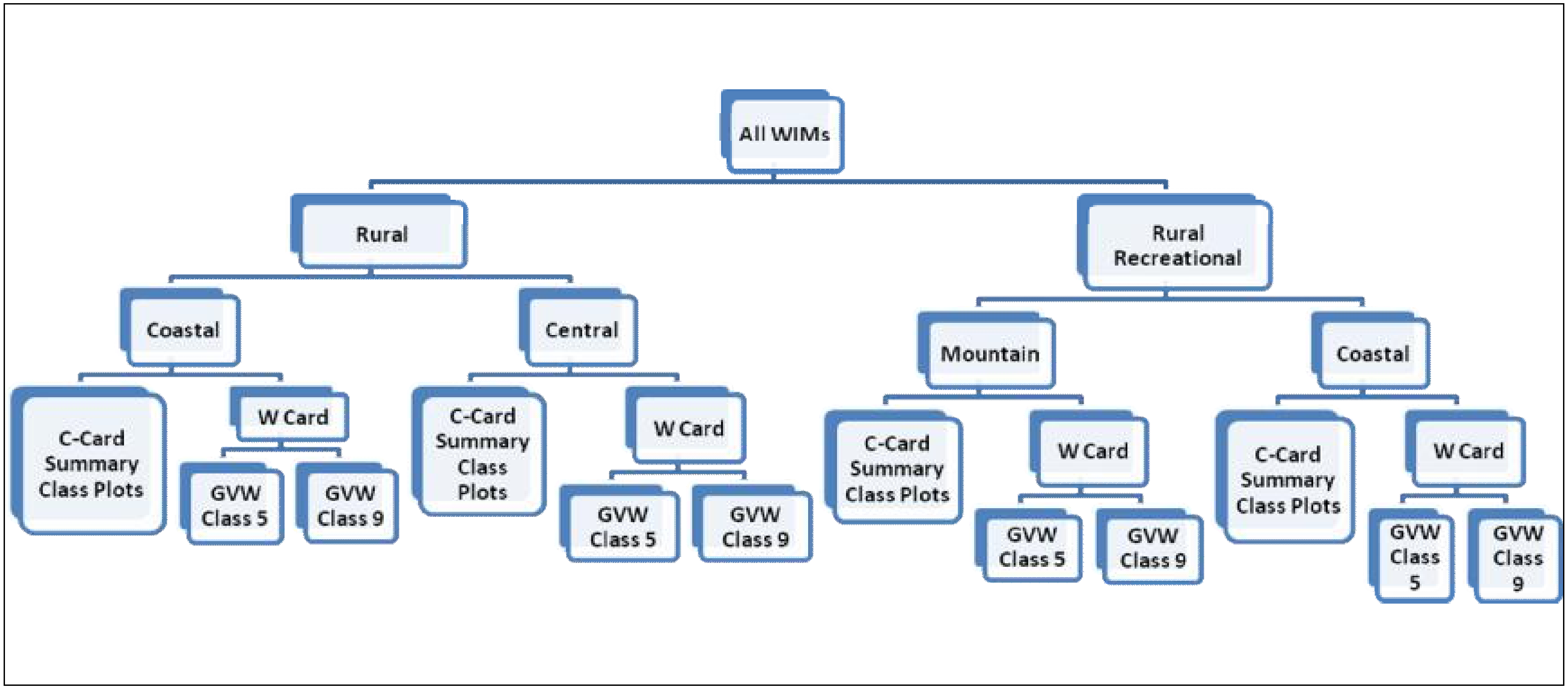


Figure 7-1 WIM Station Groups

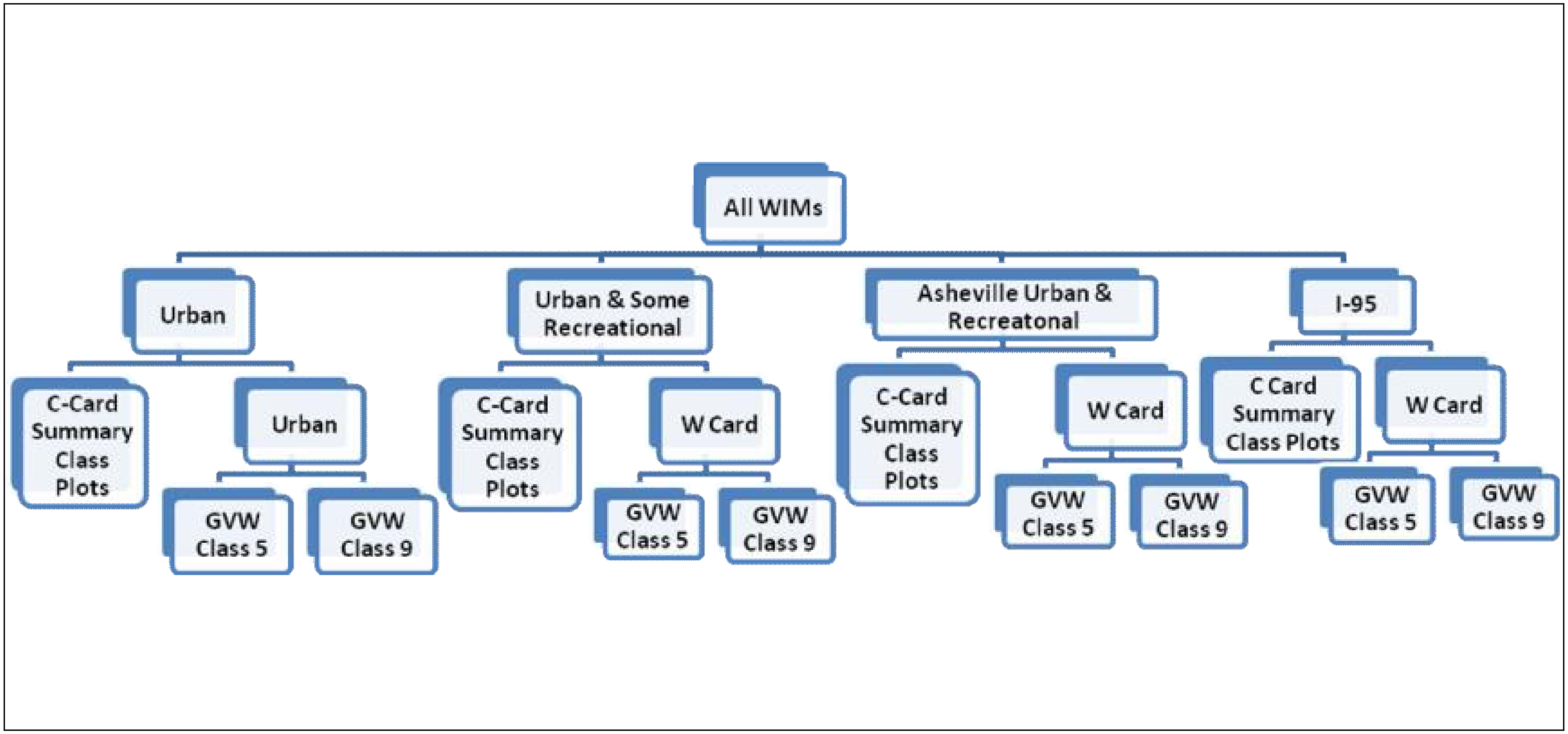


Figure 7-2 More WIM Station Groups

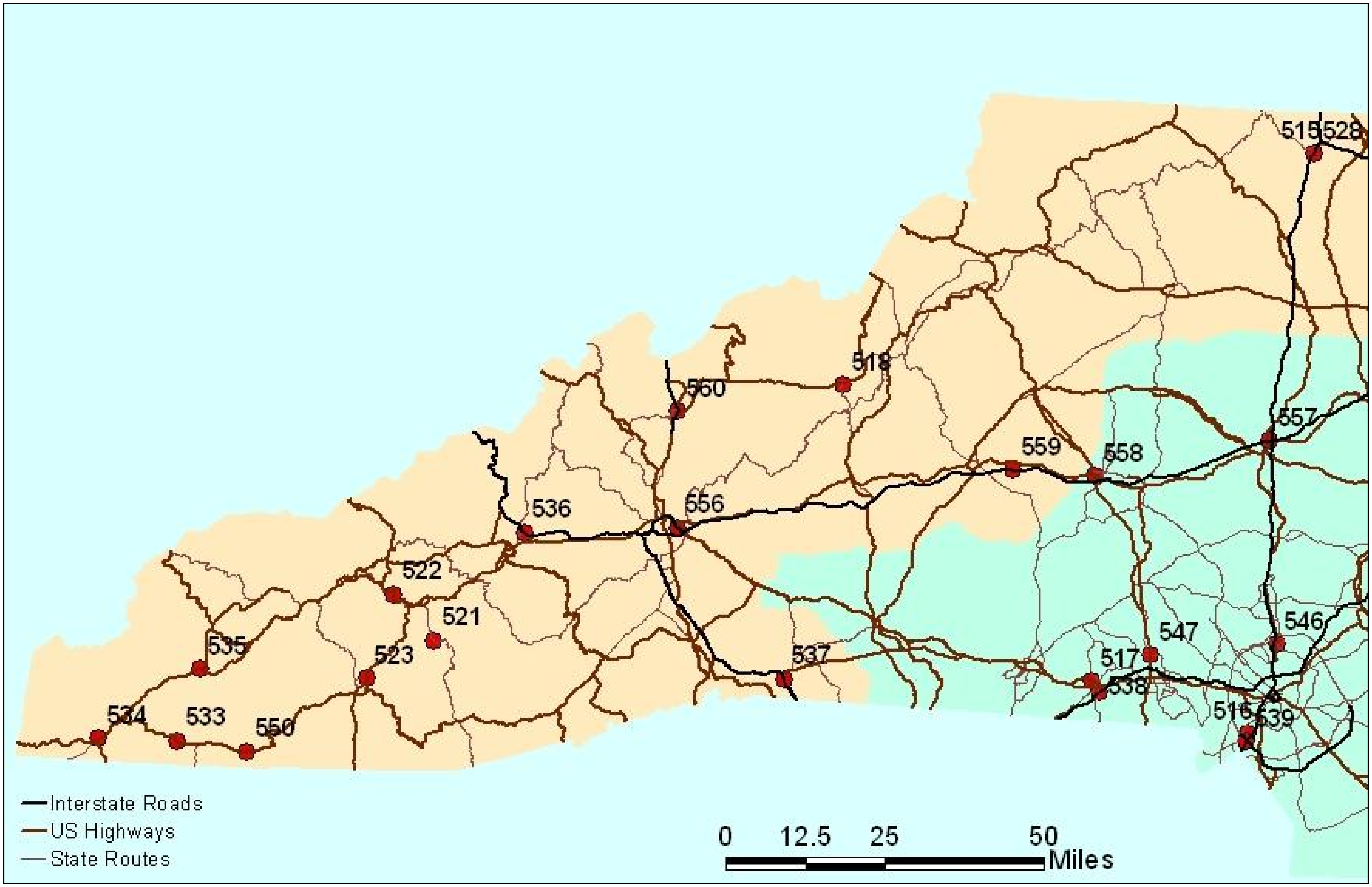


Figure 7-3 WIM Stations in the Mountainous Region of North Carolina

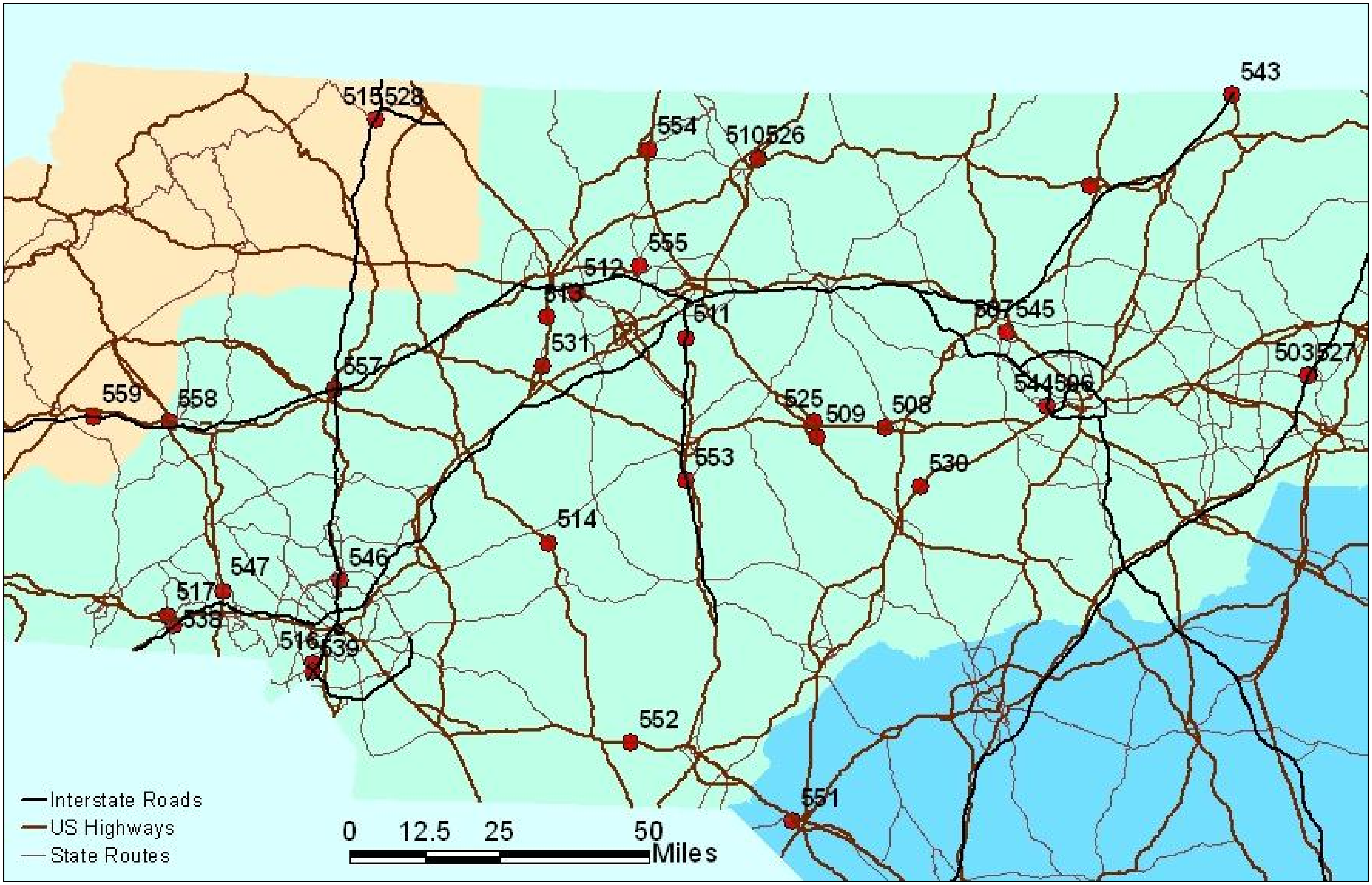


Figure 7-4 WIM Stations in the Piedmont Region of North Carolina

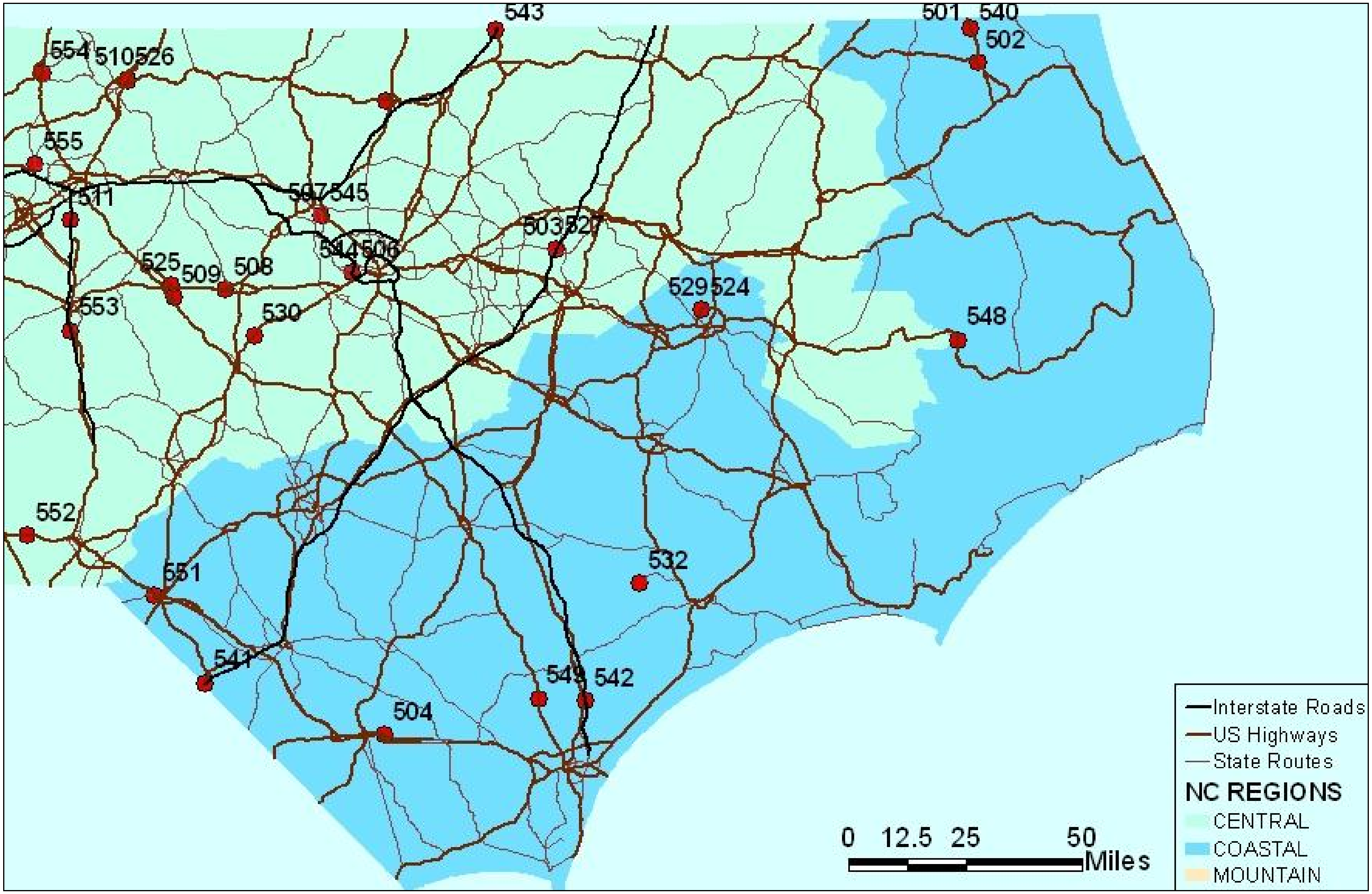


Figure 7-5 WIM Stations in the Coastal Region of North Carolina

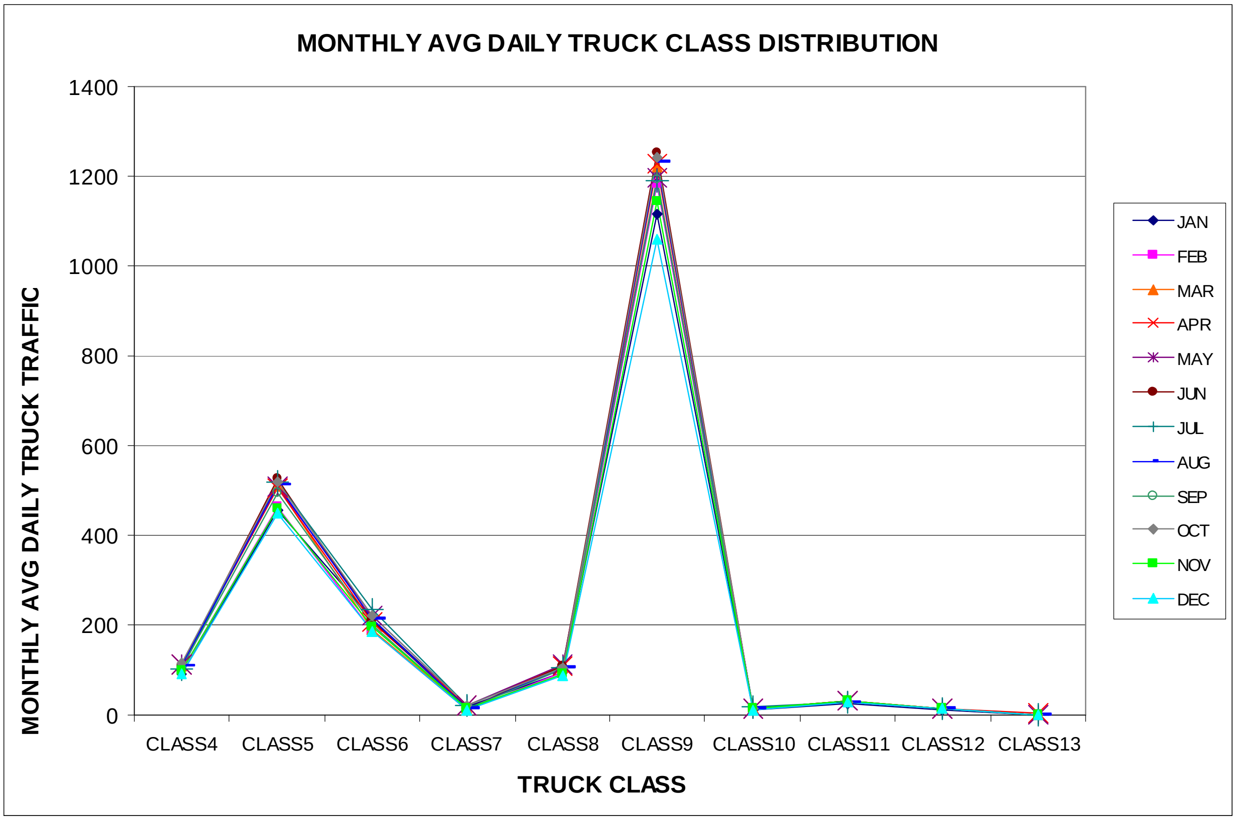


Figure 7-6 Rural Summary Class Plot for the NC Coastal Region

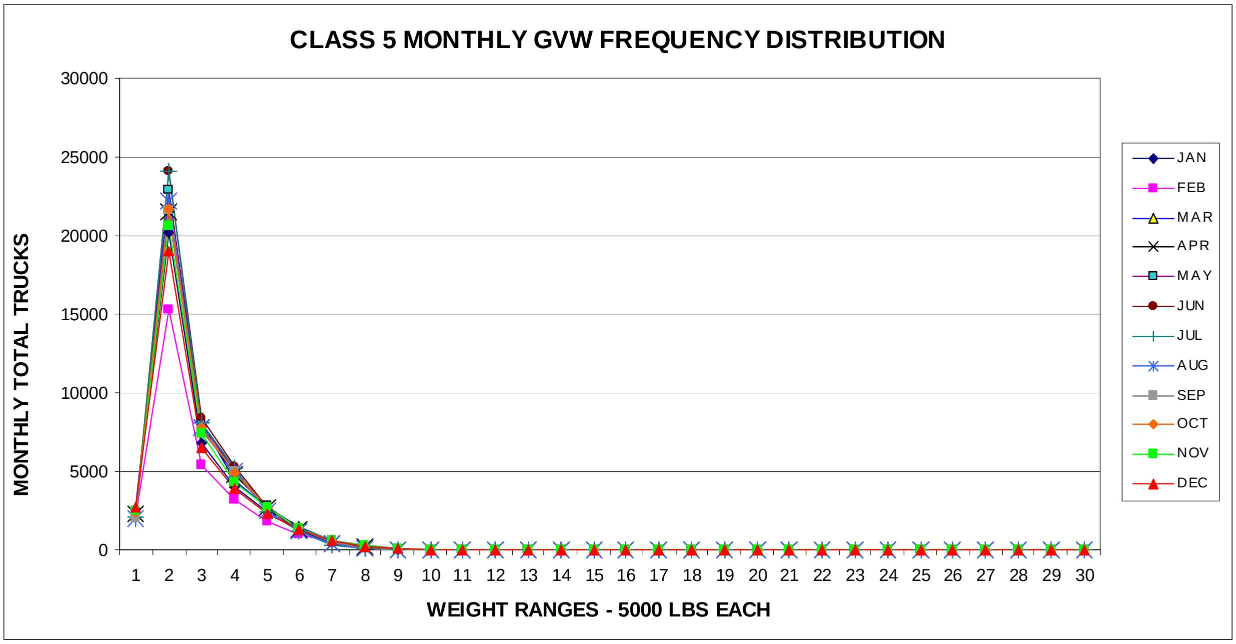


Figure 7-7 Rural Class 5 GVW Plot for the NC Coastal Region

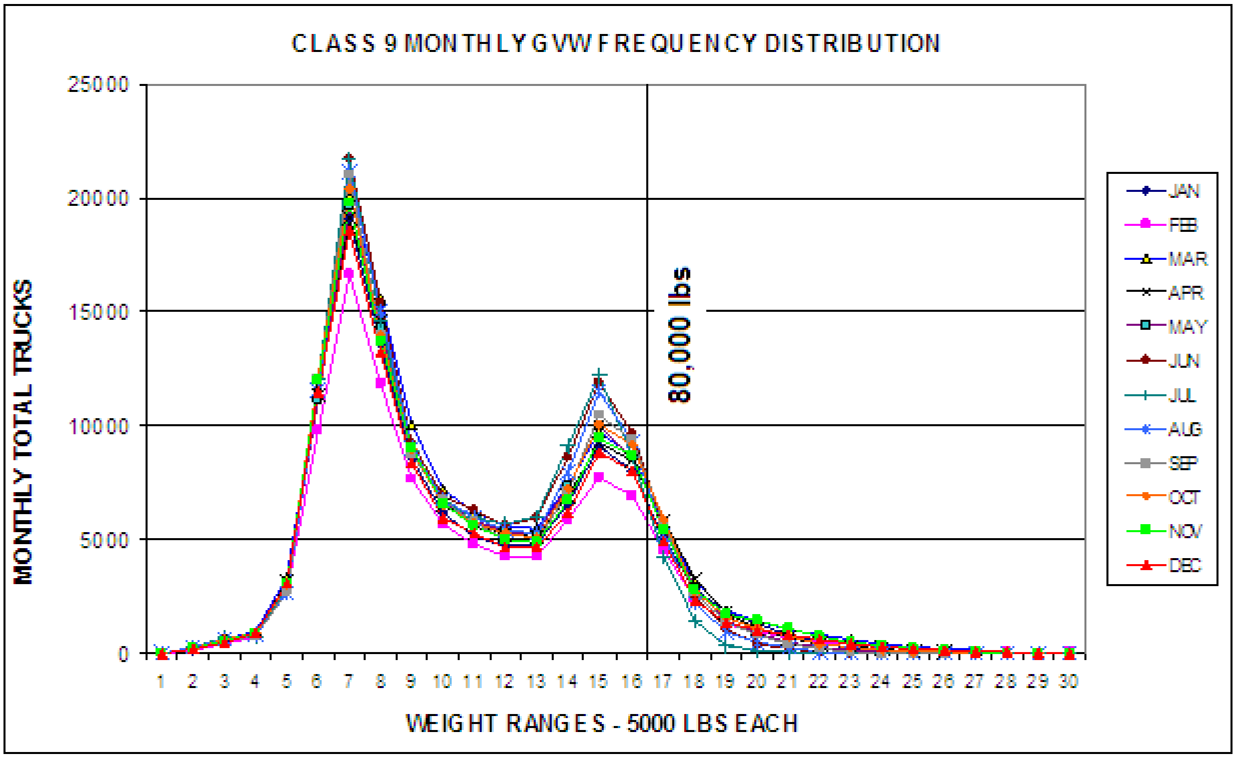


Figure 7-8 Rural Class 9 GVW Plot for the NC Coastal Region

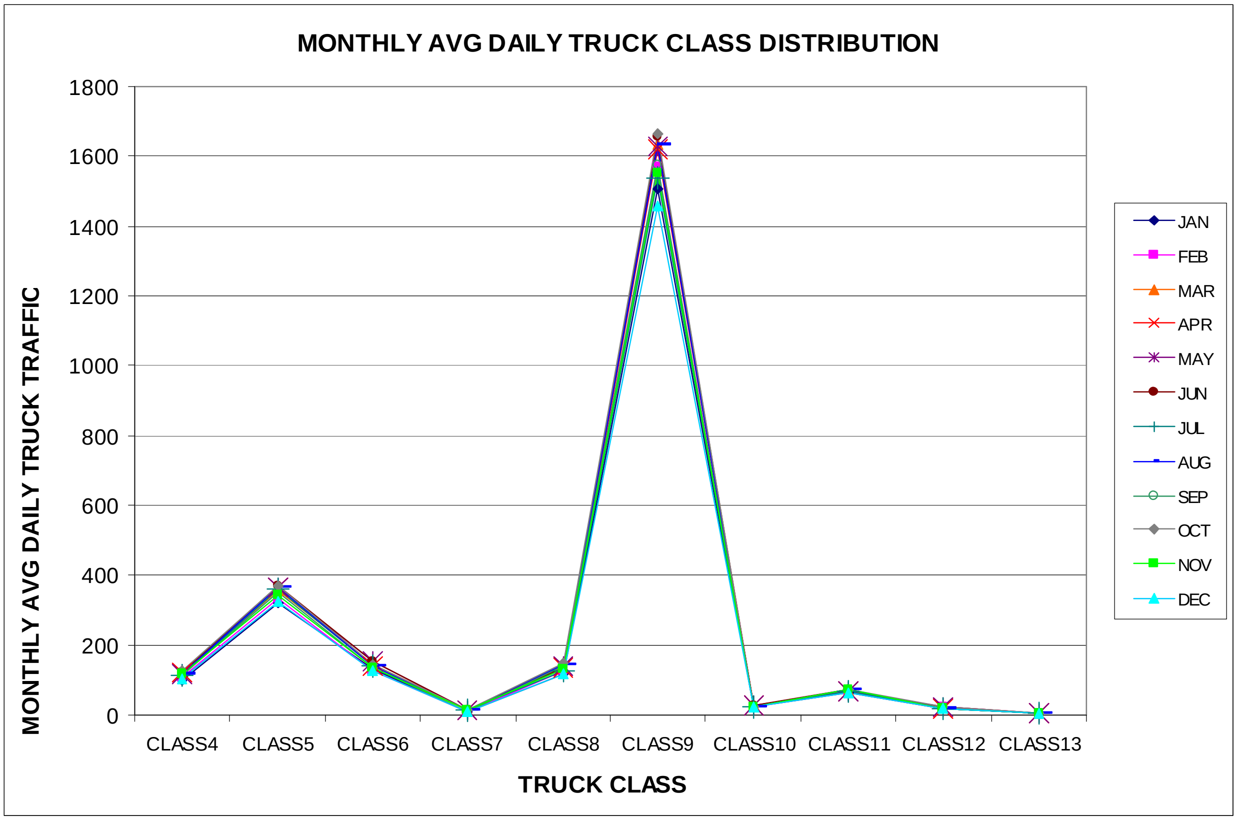


Figure 7-9 Rural Summary Class Plot for the NC Central Region

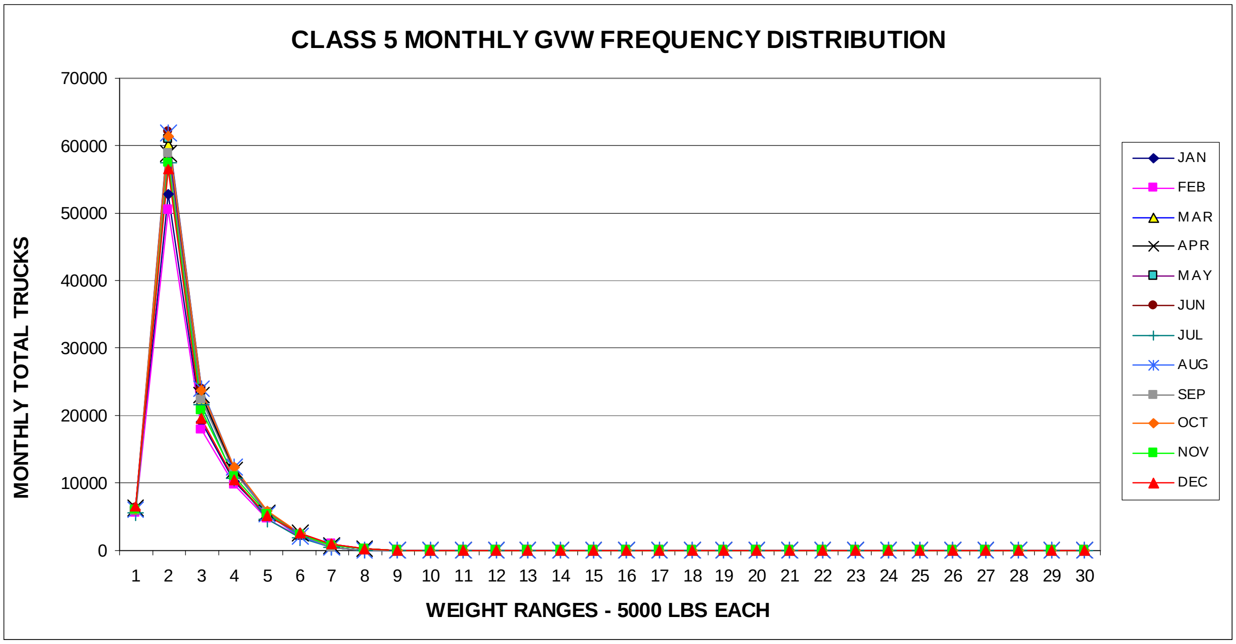


Figure 7-10 Rural Class 5 GVW Plot for the NC Central Region

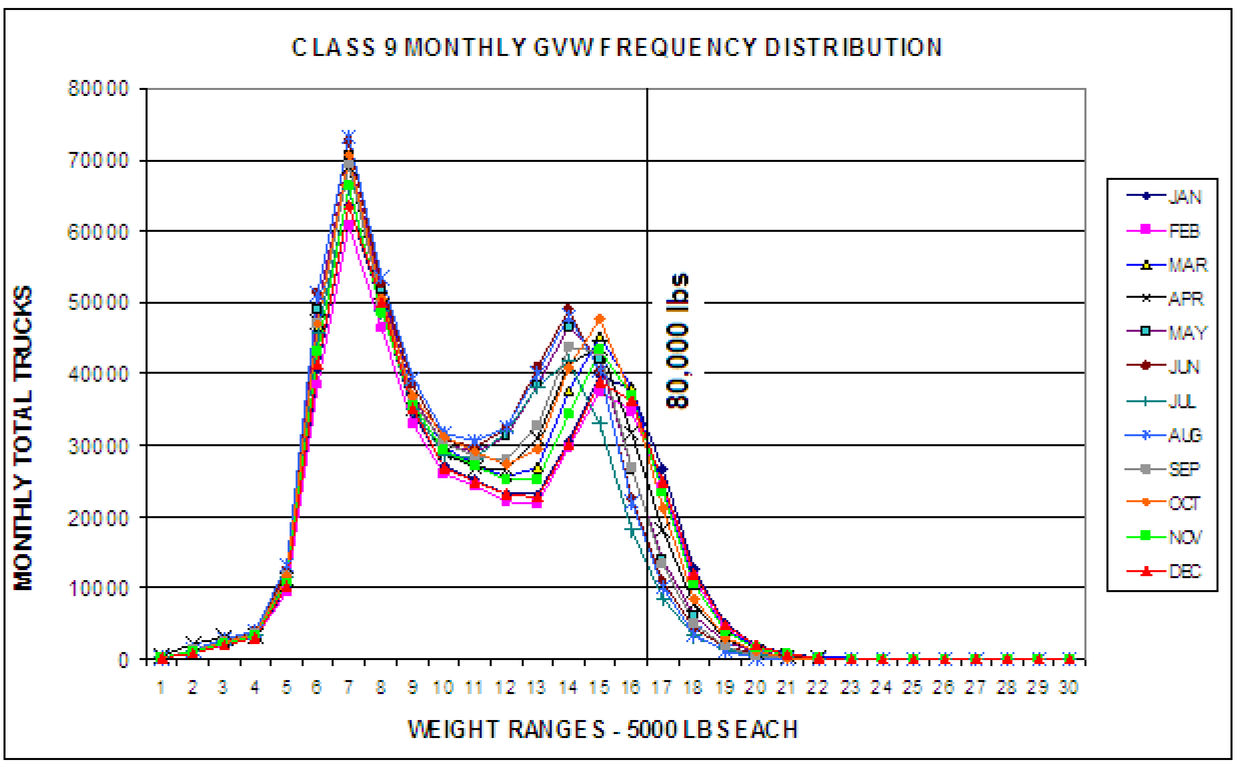


Figure 7-11 Rural Class 9 GVW Plot for the NC Central Region

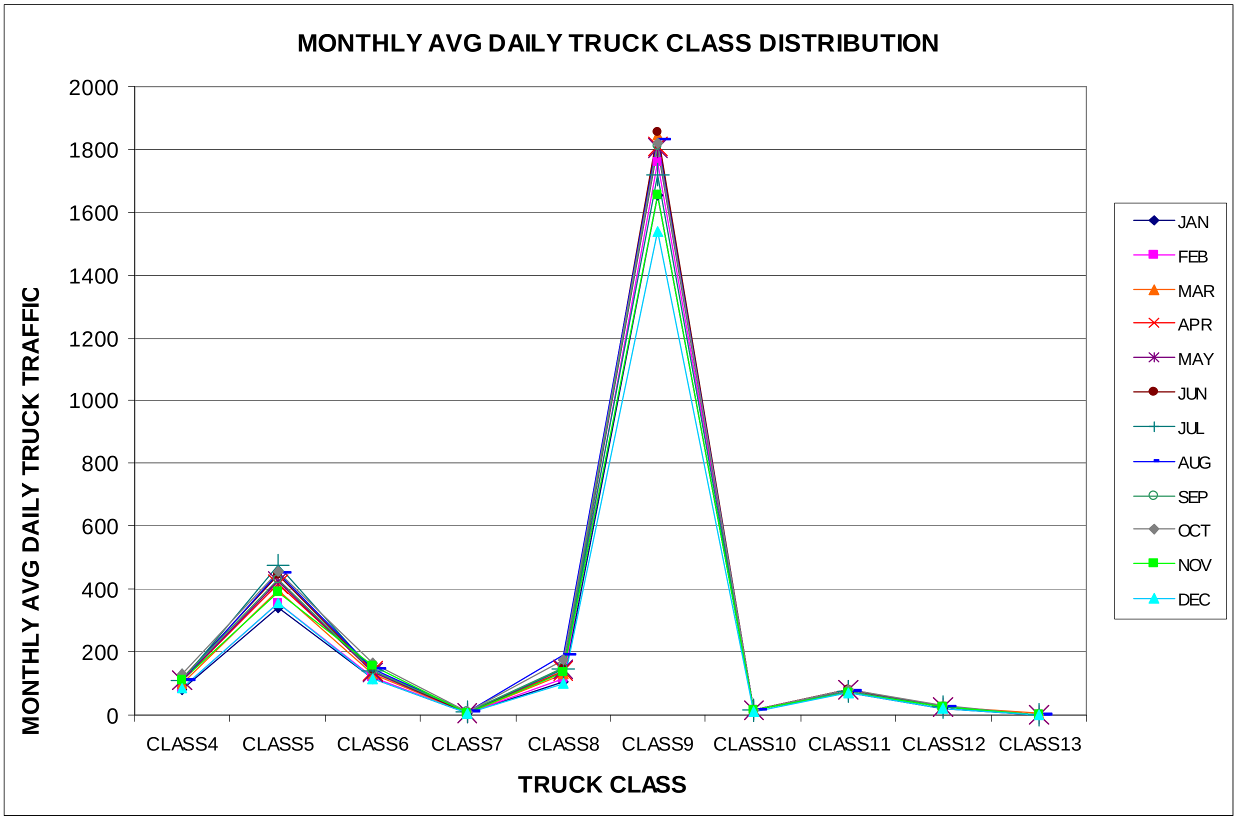


Figure 7-12 Rural Recreational Summary Class Plot for the NC Mountainous Region

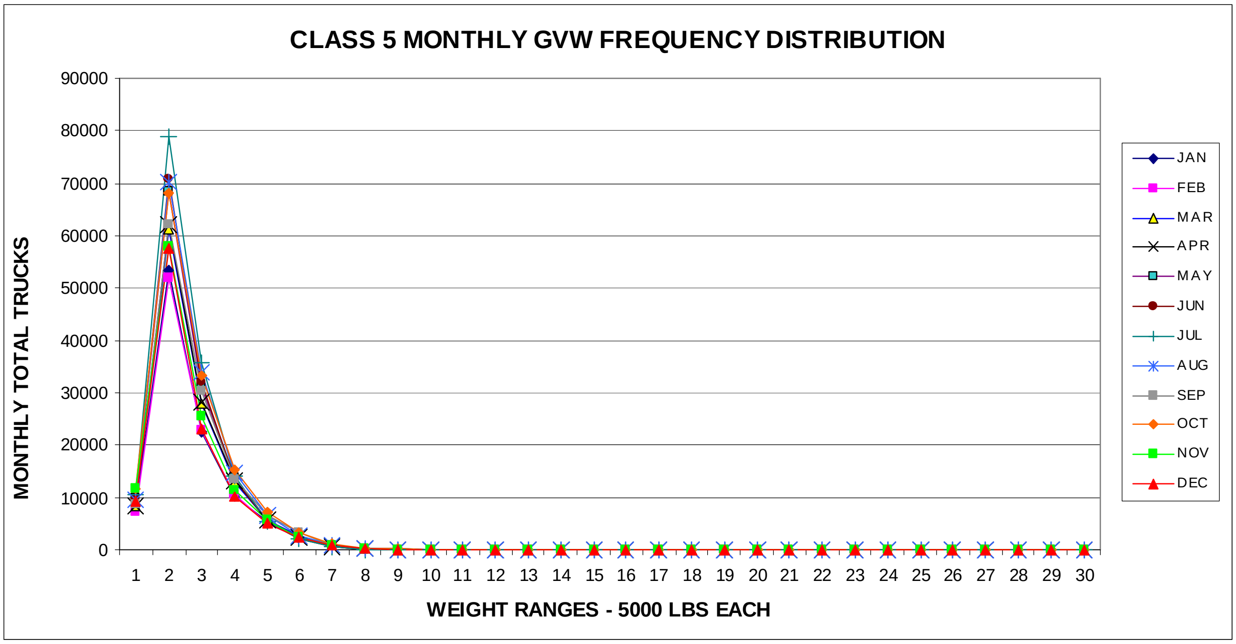


Figure 7-13 Rural Recreational Class 5 GVW Plot for the NC Mountainous Region

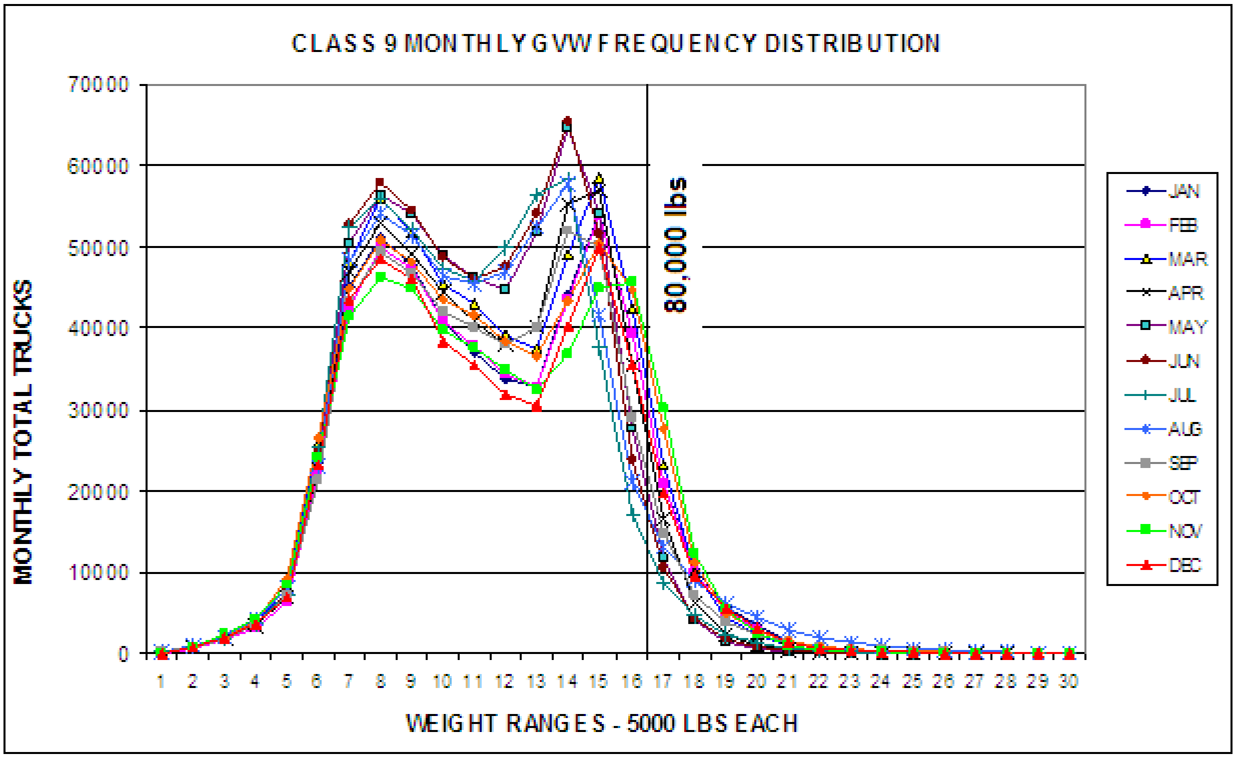


Figure 7-14 Rural Recreational Class 9 GVW Plot for the NC Mountainous Region

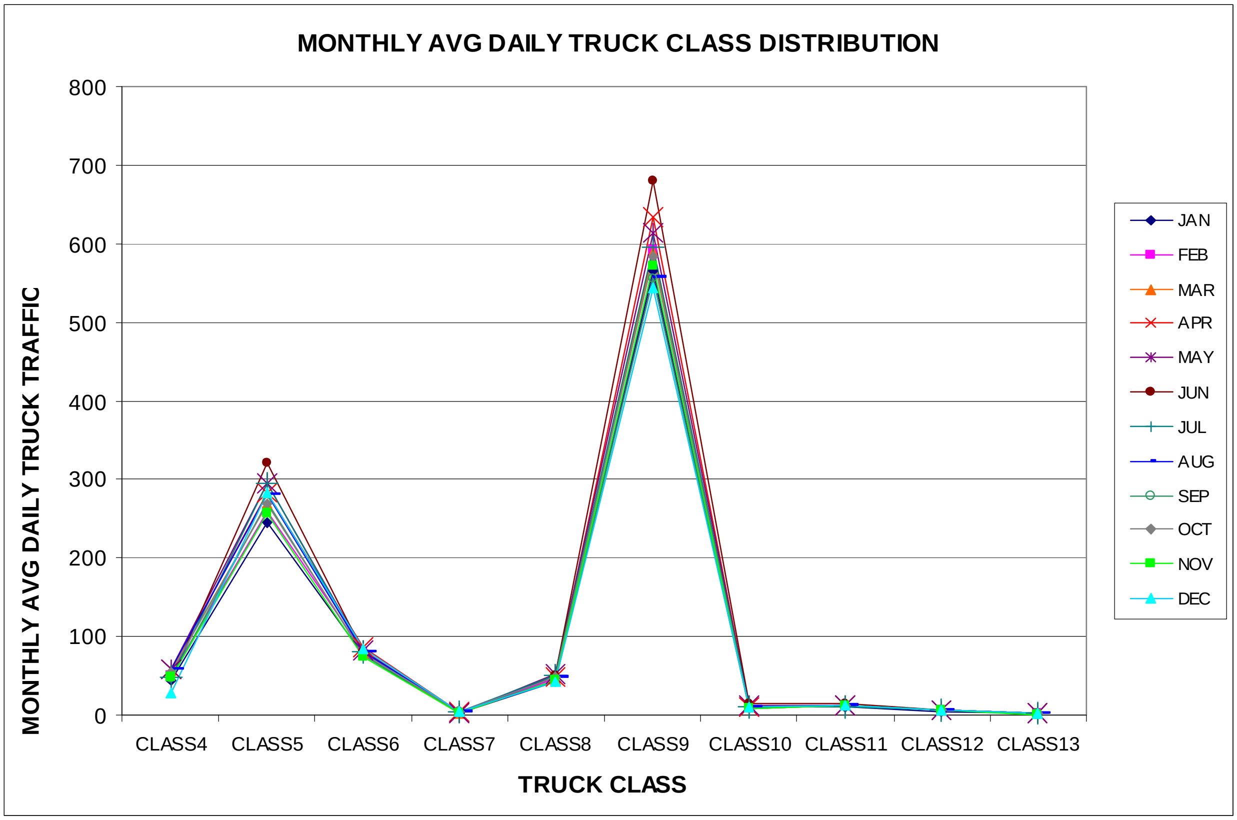


Figure 7-15 Rural Recreational Summary Class Plot for the NC Coastal Region

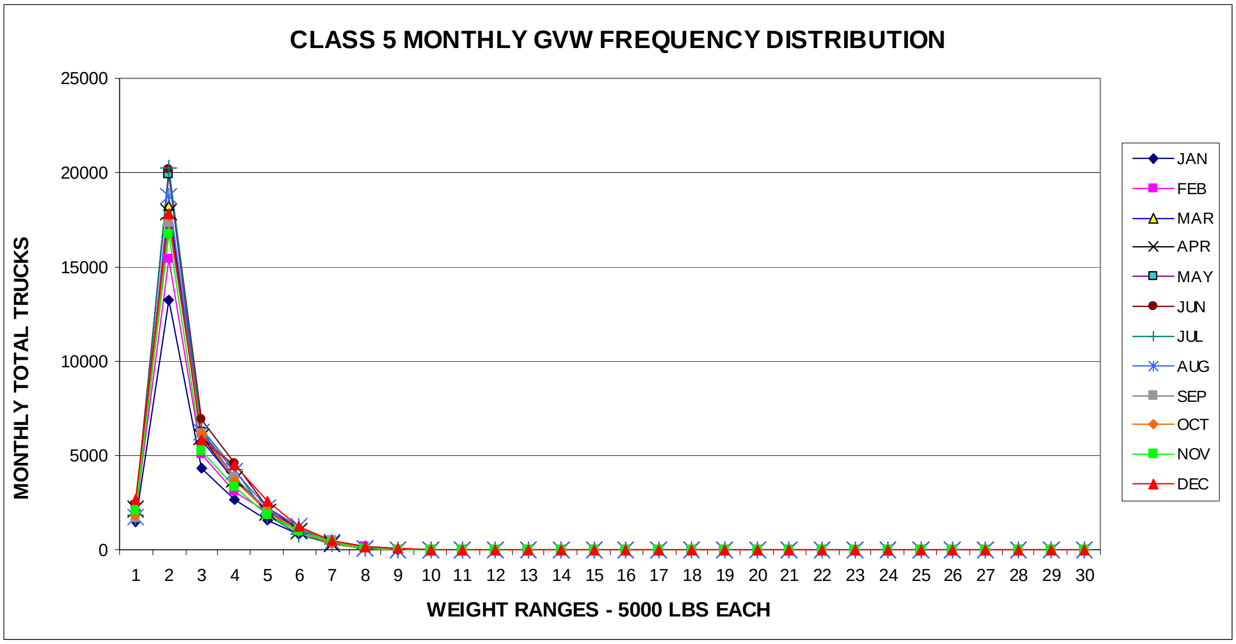


Figure 7-16 Rural Recreational Class 5 GVW Plot for the NC Coastal Region

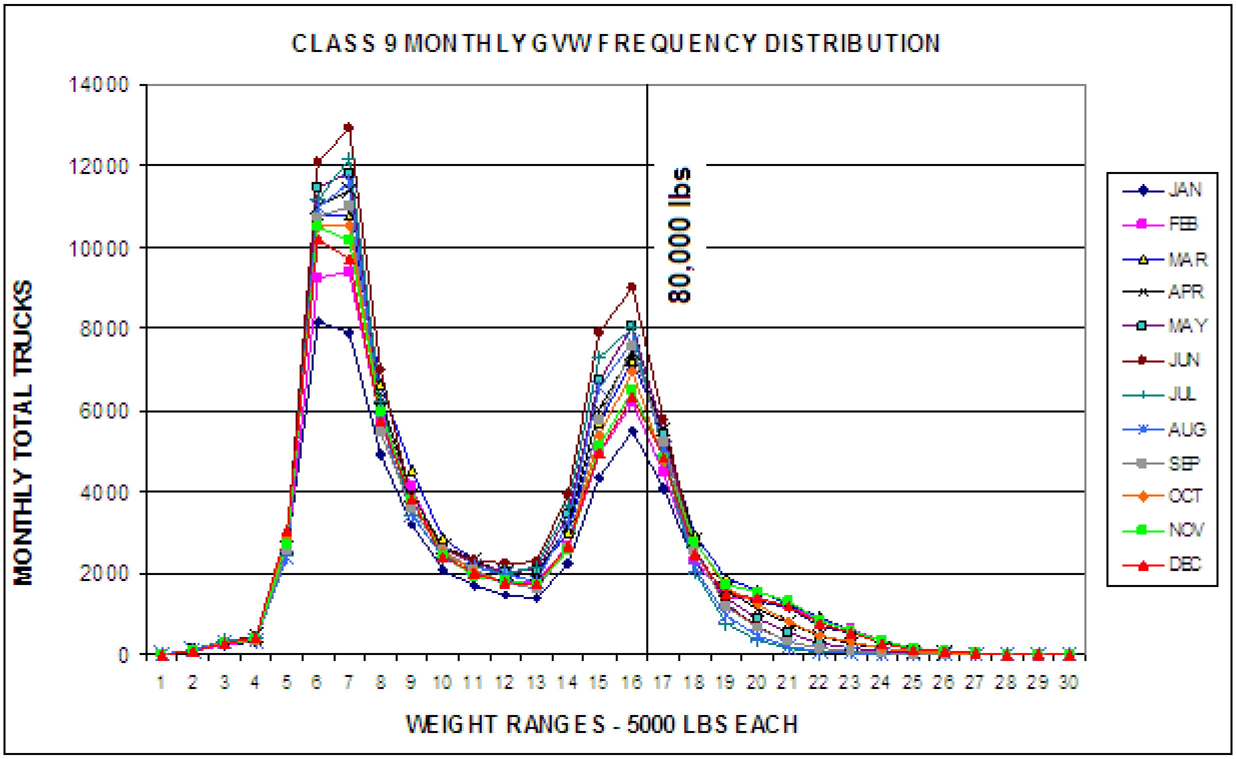


Figure 7-17 Rural Recreational Class 9 GVW Plot for the NC Coastal Region

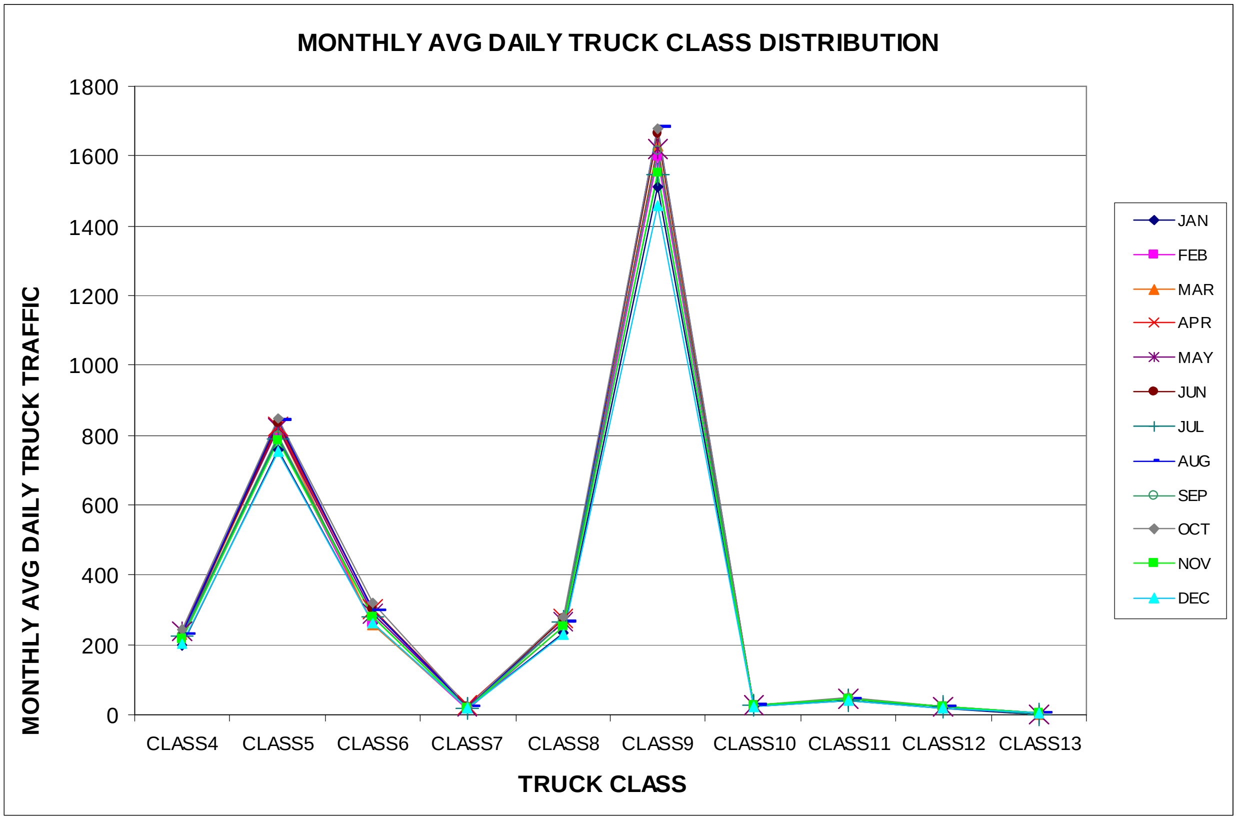


Figure 7-18 Summary Class Plot for all Urban WIMs

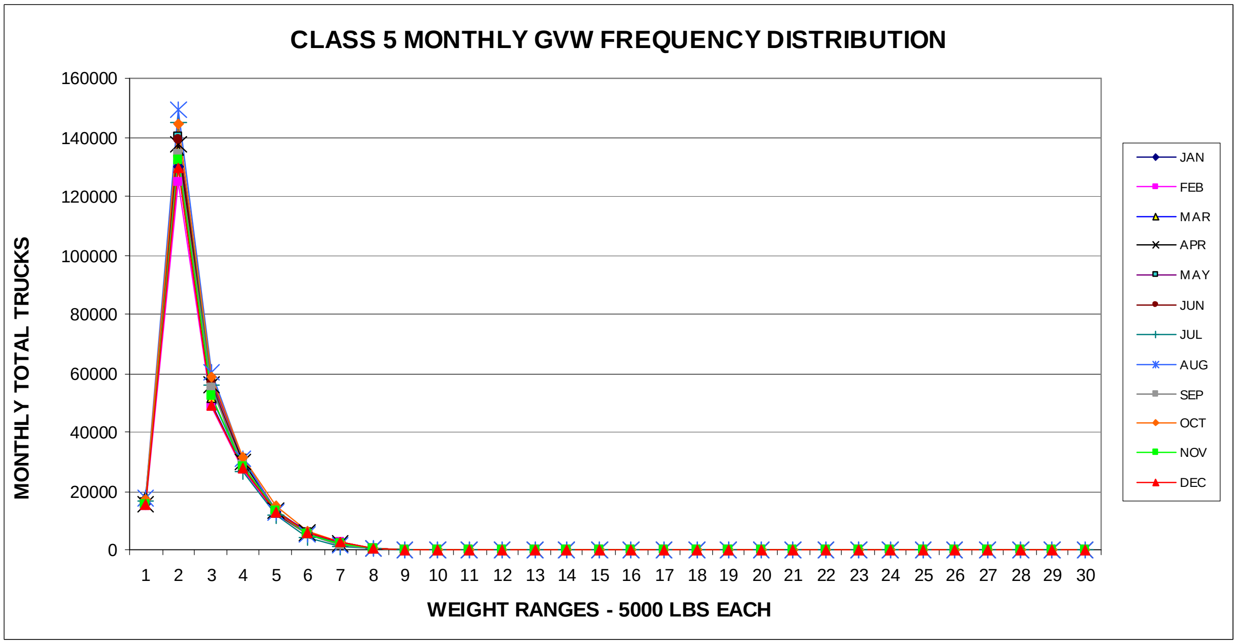


Figure 7-19 Class 5 GVW Plot for All Urban WIMs

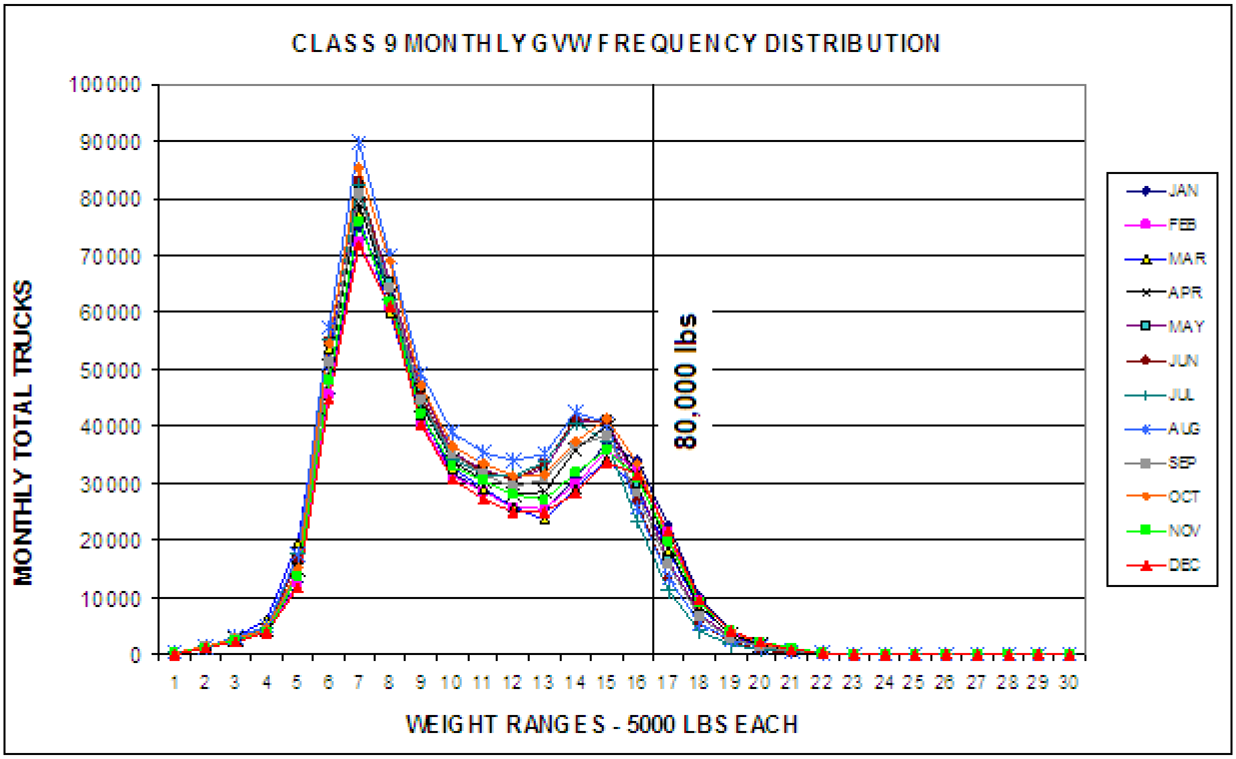


Figure 7-20 Class 9 GVW Plot for All Urban WIMs

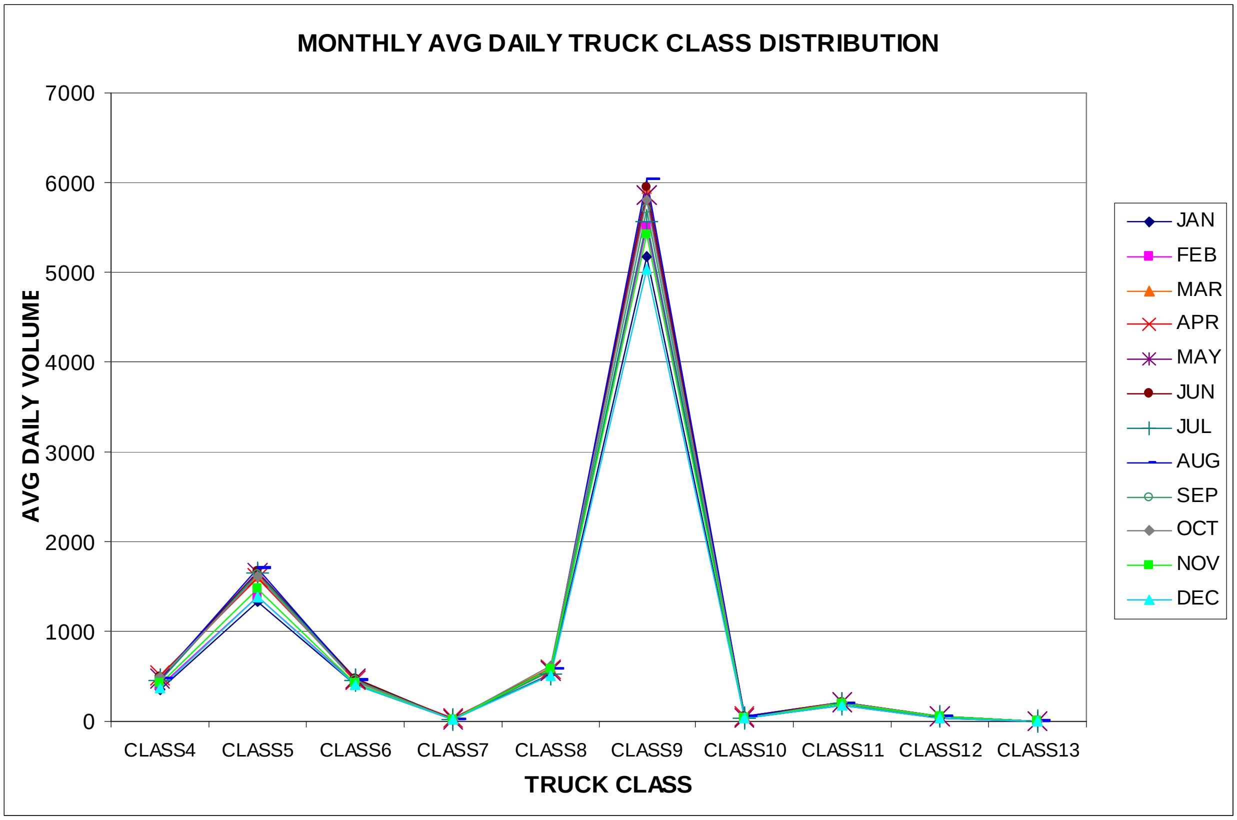


Figure 7-21 WIM 557 - Urban and Some Recreational Summary Class Plot

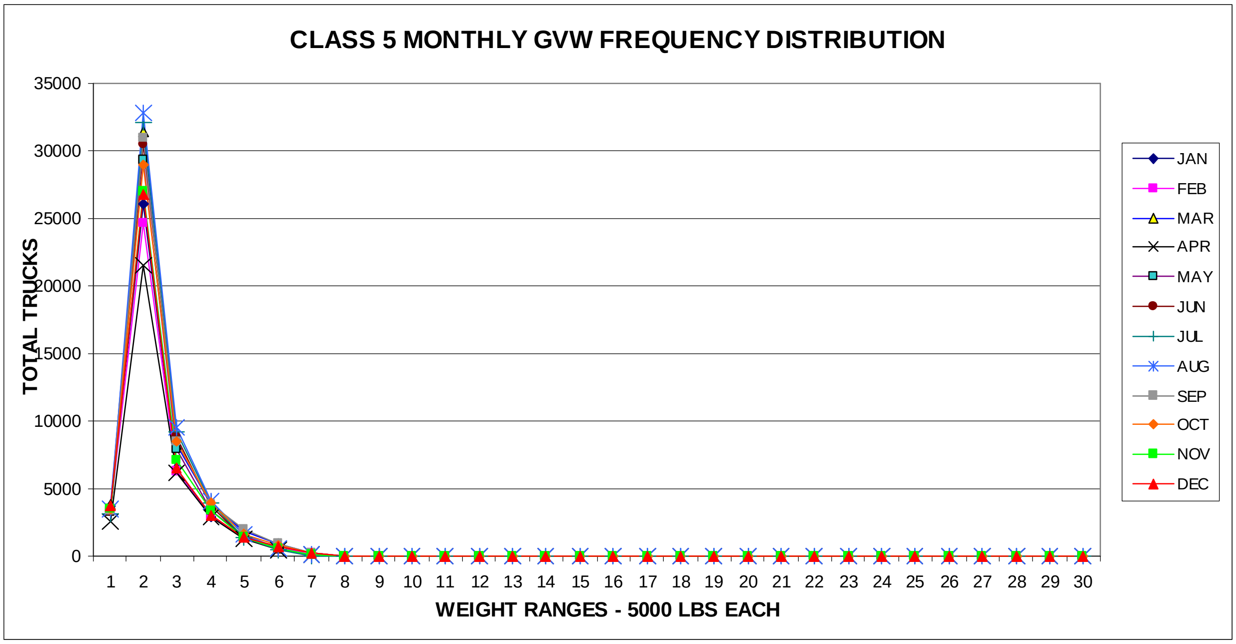


Figure 7-22 WIM 557 - Urban and Some Recreational Class 5 GVW Plots

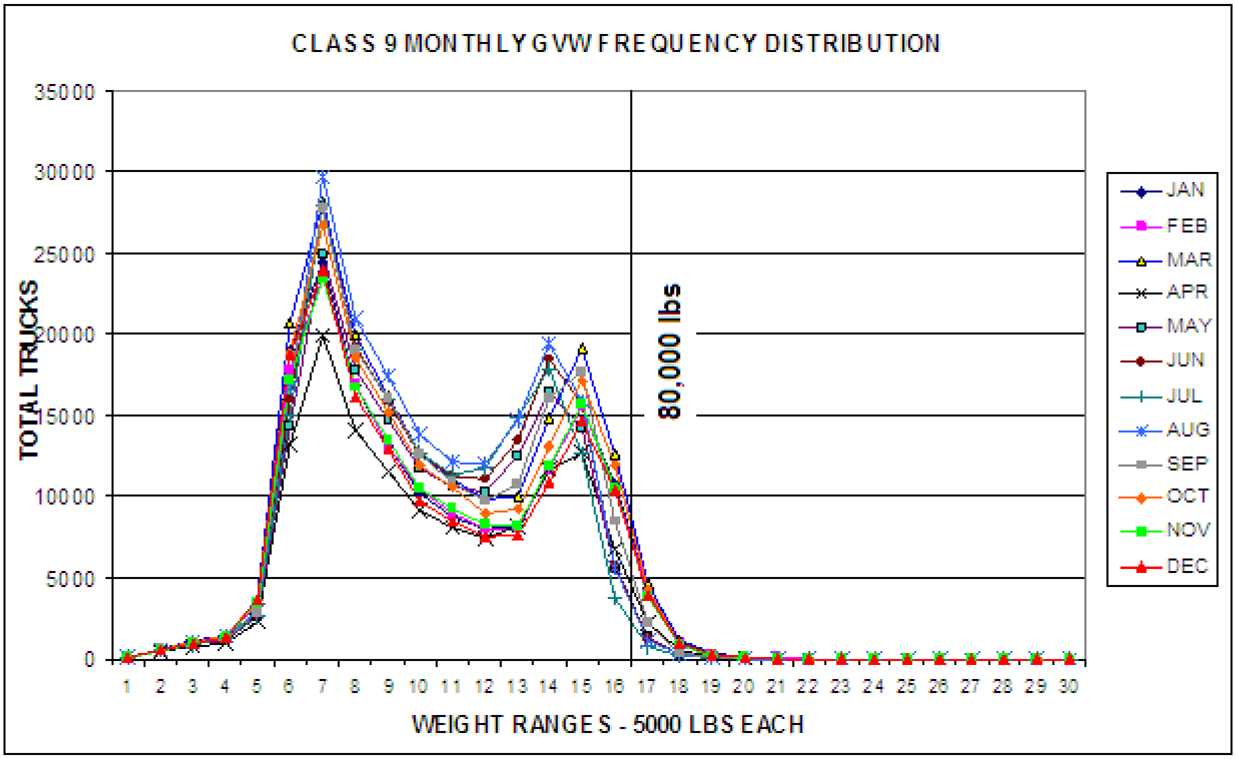


Figure 7-23 WIM 557 - Urban and Some Recreational Class 9 GVW Plots

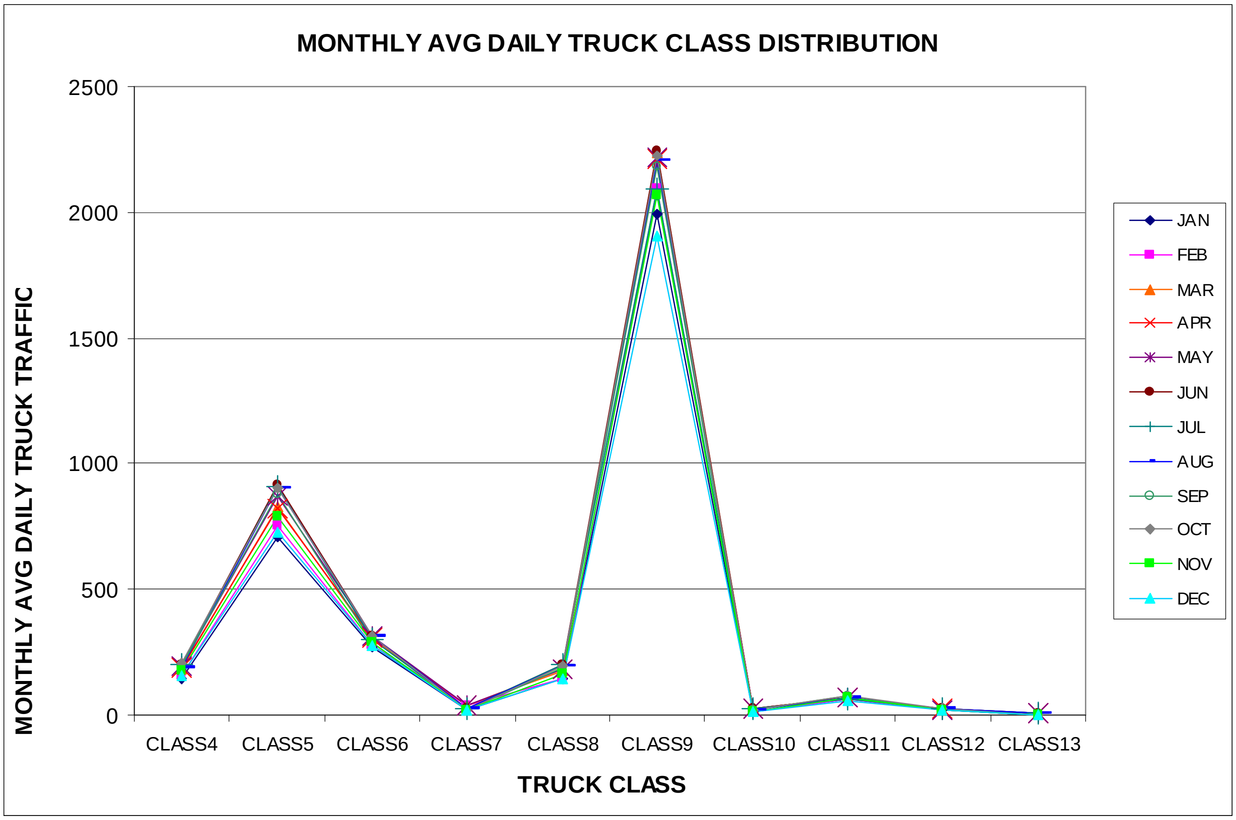


Figure 7-24 Asheville Urban and Recreational Summary Class Plot

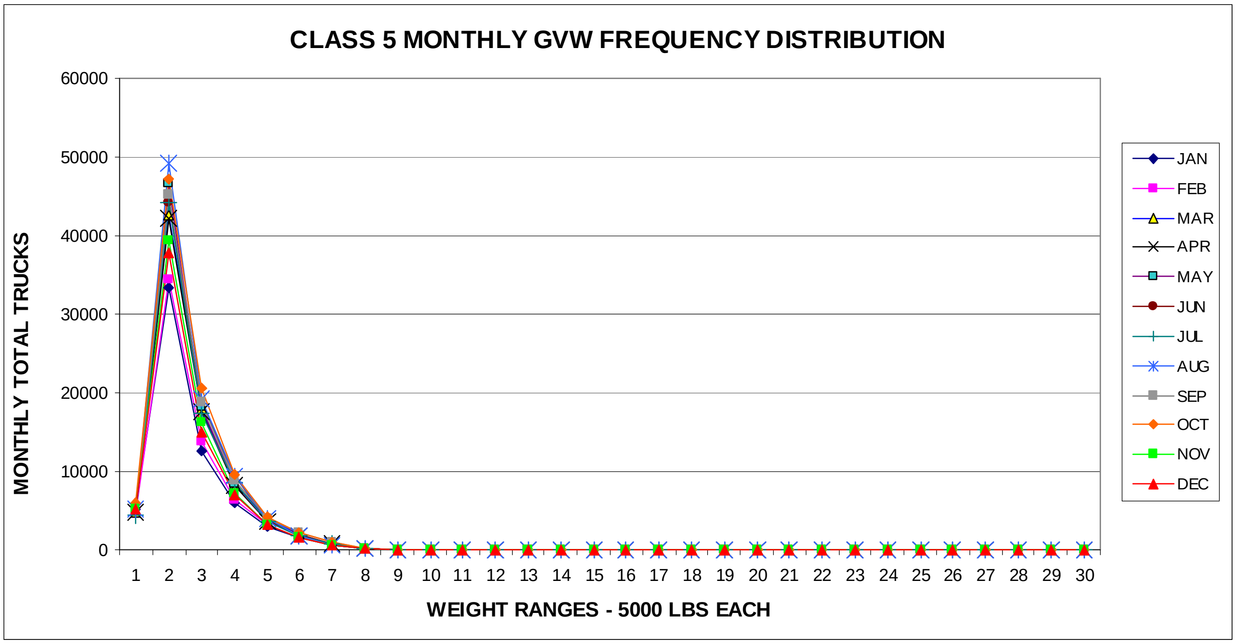


Figure 7-25 Asheville Urban and Recreational Class 5 GVW Plot

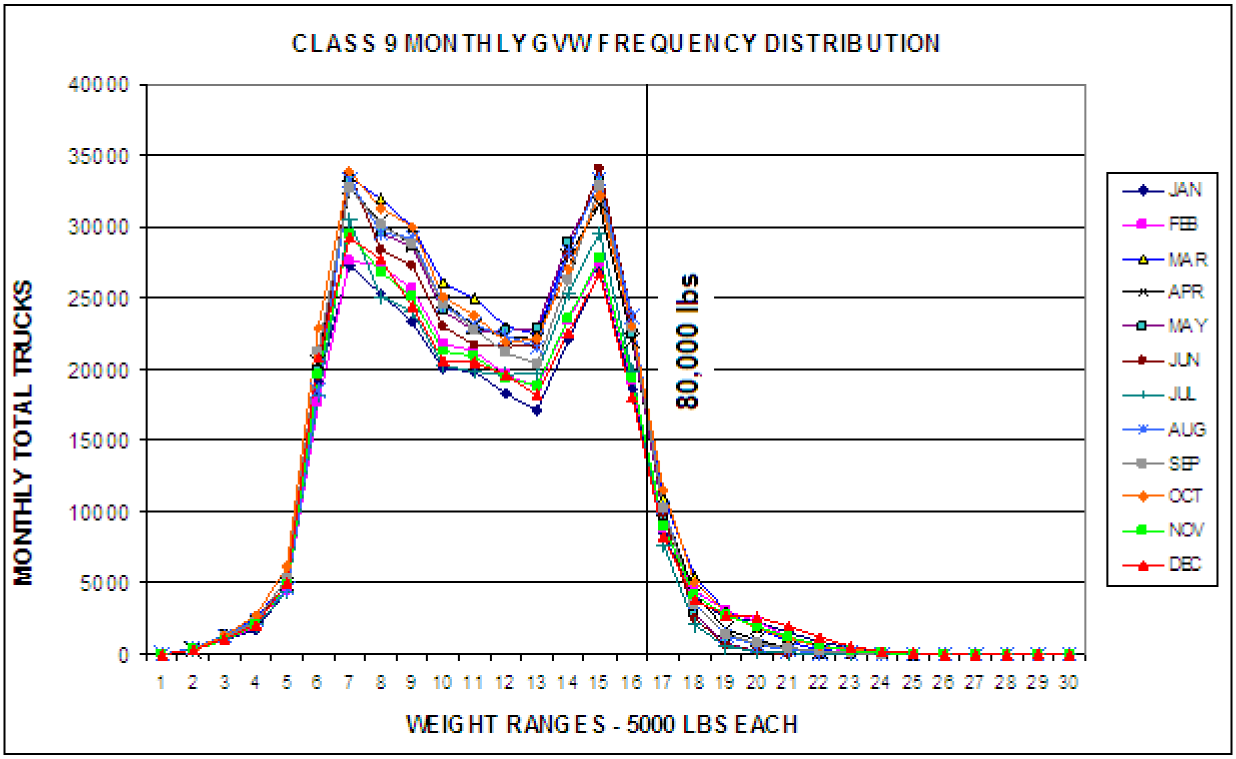


Figure 7-26 Asheville Urban and Recreational Class 9 GVW Plot

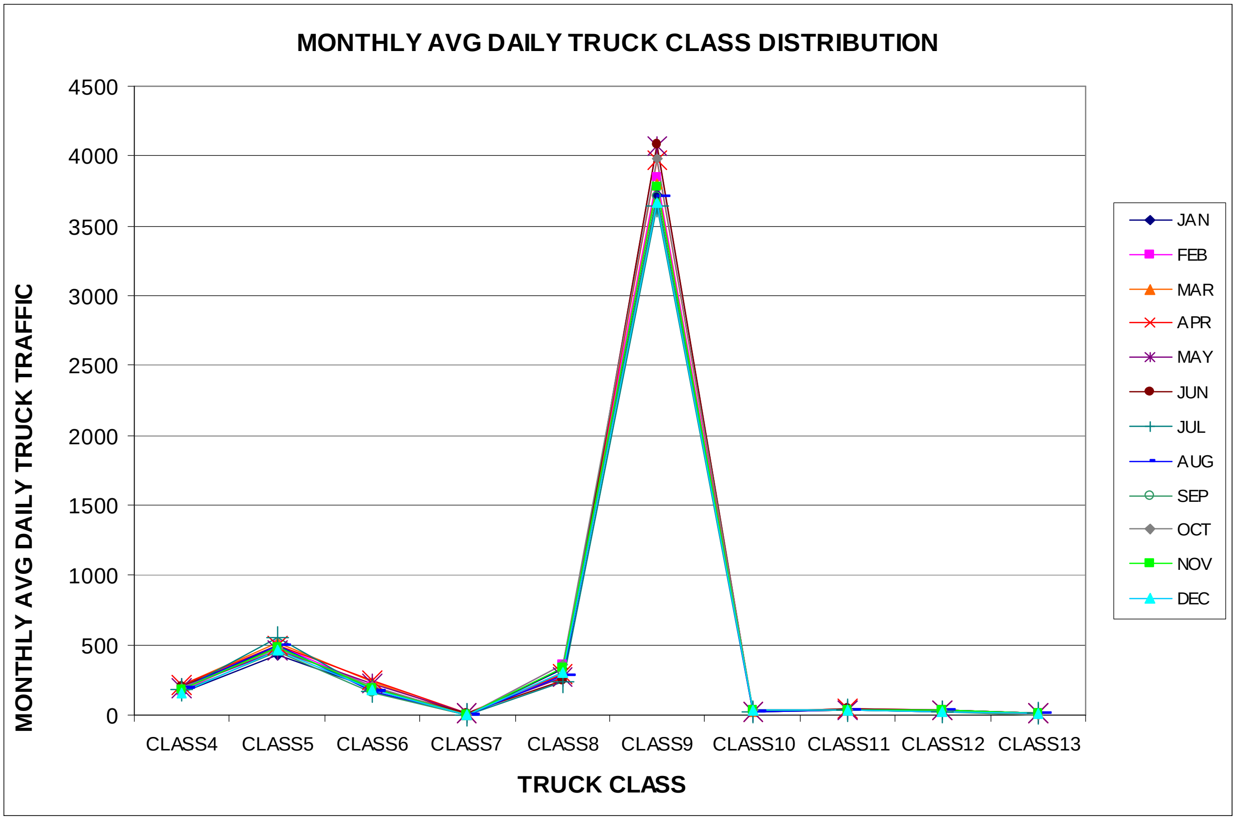


Figure 7-27 Summary Class Plot for all I-95 WIMs

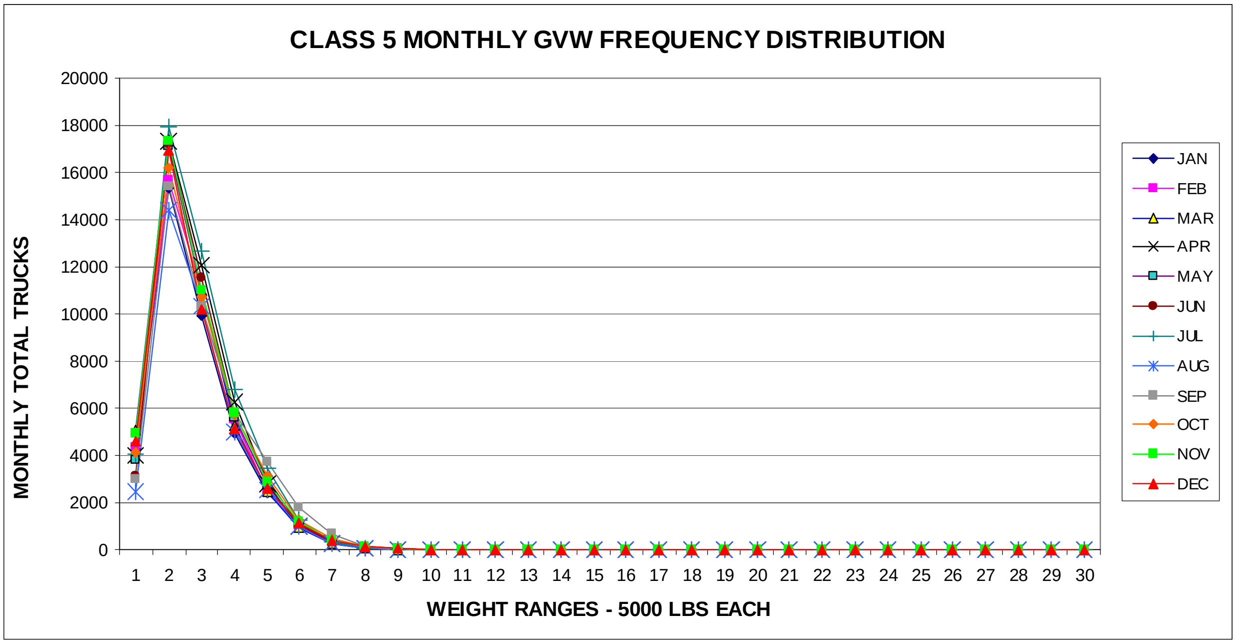


Figure 7-28 Class 5 GVW Plot for all I-95 WIMs

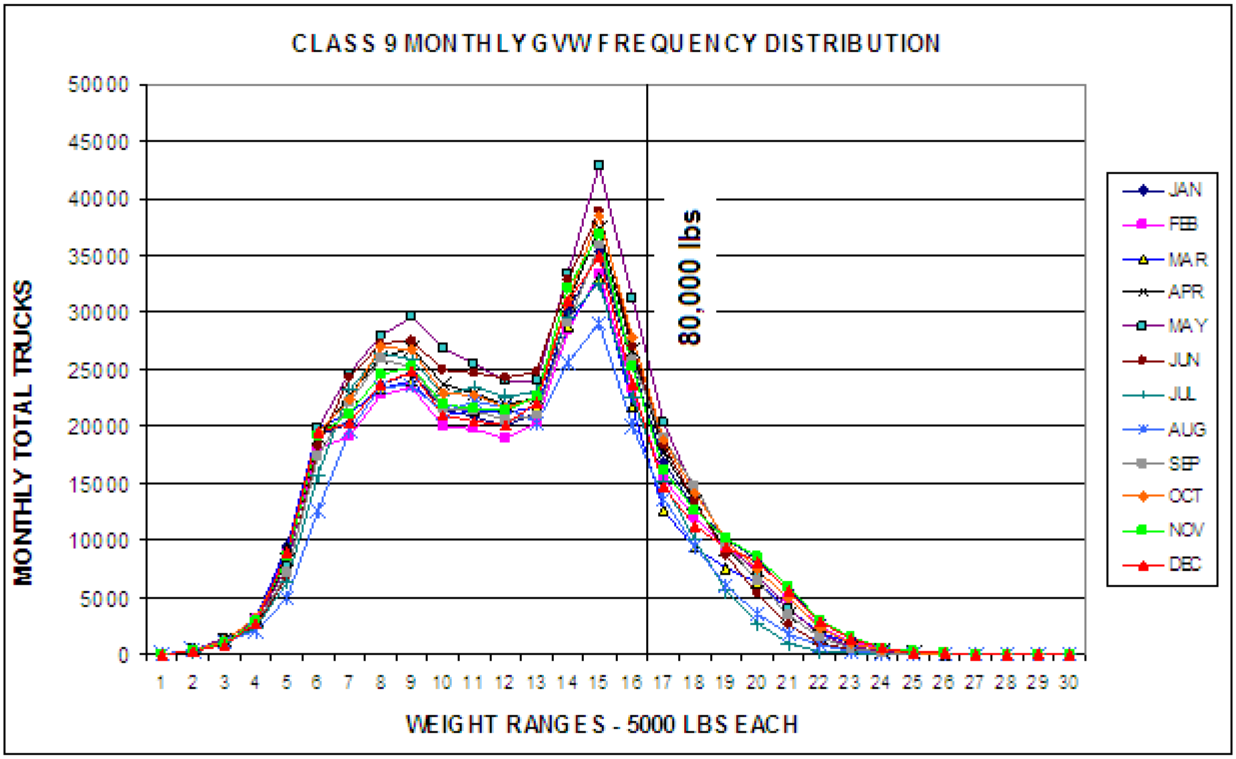


Figure 7-29 Class 9 GVW Plot for All I-95 WIMs

[This page has been intentionally left blank.]

8. Estimation of Overweight Truck Traffic Profiles

This chapter develops typical overweight truck trip profiles for North Carolina Interstates 40, 77 and 95 (I-40, I-77 and I-95). The results are based on the methods developed by Don Katz in the white paper "Development of Typical Truck Trip Profiles for Rural and Urban North Carolina" developed in conjunction with this research project. Katz focused on I-40. Subsequent analyses by Catlin Boon and Corey Bell applied Katz's method to I-77 and I-95, respectively. The studies used NC overweight truck permit data from NCDOT for August 21-25, 2006. The data indicated truck gross vehicle weight and route path. The resulting permitted overweight truck traffic profiles describe the distribution of weight by mile marker for I-40, I-77 and I-95 from border to border across North Carolina. Most heavily traveled segments are easily identified by graphic images. Such analysis and images, especially expanded to a year's time period, can show the most used highway segments traveled by overweight trucks. Overall results suggest that the proposed approach provides an accurate means to developing overweight truck trip profiles for NC highways.

Introduction

The impact of overweight trucks on the highways is a growing concern. Overweight trucks are defined as those exceeding 80,000 pounds gross vehicle weight (GVW) on Interstates and 90,000 pounds GVW on non-Interstate highways. If the loads are indivisible and exceed weight restrictions, drivers must apply for permits. The permitted overweight trucks are the subject of this chapter.

There is a need to establish the potential impact of overweight truck traffic on Interstate, US, NC and SR highways in North Carolina. As shown in the Figure 8-1, pavement damage increases exponentially with weight.

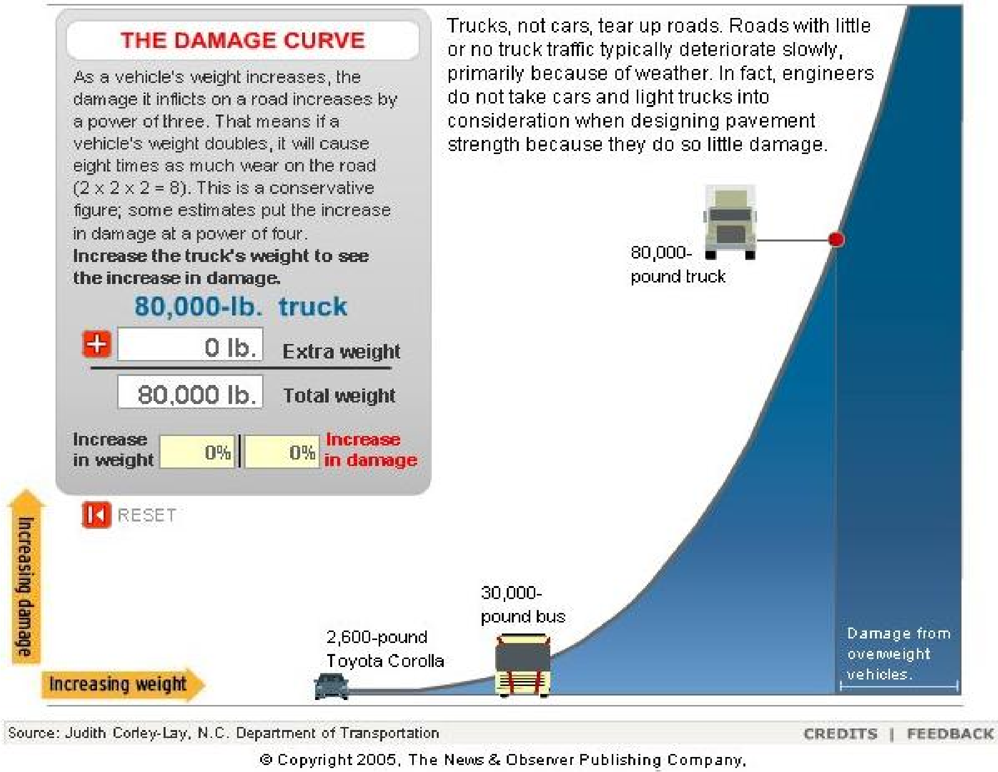


Figure 8-1 The Damage Curve

In order to prevent the damage problems caused by heavy trucks, engineers and policymakers need to understand where the heavy truck traffic occurs on the highways. Therefore, it is important to understand the extent to which heavy trucks use the state's highways. For example, investment decision makers and planners need a good picture of truck volumes, trip distances, and weight distributions by highway class, route (path), and geographic region. And pavement and bridge engineers need to evaluate where overweight truck traffic is most intense to quantify the magnitude of pavement damage caused by overweight trucks. To help meet these needs, this study aims to create better overweight truck profiles than currently used by the North Carolina Department of Transportation (NCDOT), based upon on year 2006 overweight truck permit data. Thus, the primary object of this study is to analyze the frequency and permit analysis and develop an overweight truck model. Developed profiles could be improved by incorporating directional traffic flow, and by extending data collection to better assess annual trends.

Most Heavily Used Highways by Permitted Overweight Trucks

The data for this analysis comes from the NCDOT Oversize and Overweight (OS/OW) Permitting Unit. The OS/OW Permitting Unit processes approximately 300,000 permits each year, allowing overweight trucks to legally travel throughout the state to carry needed goods and equipment to support the NC economy. Each approved permit contains a record of the origin and destination of the truck's route, the registered weight and the gross vehicle weight of the truck, its number of axles, and its permitted route. Roughly one-third of the permits issued are for OW trucks while two-thirds are issued for OS trucks. This analysis is concerned only with OW trucks stratified into five different weight classes. Overweight trucks are especially damaging to pavement because of the exponential relationship between damage and vehicle weight (Figure 8-1).

A database for August 21-25, 2006, permitted overweight trucks provided data to develop prototype spreadsheet methods to identify critical highways segments for Interstate and other highways in North Carolina. The research team examined more than 2000 permits and identified the top 10 roadway sections in NC most used by overweight permitted trucks (Table 8-1). The table represents highways most used by trucks with overweight permits issued during the week of August 21, 2006. The highways are categorized by Interstate, US route, NC route, and SR route. For example, 1,808 I-40 segments represent the summation of all the I-40 segments listed on the permits including segments identified as I-40, I-40B, I-240, I-440, I-540, I-40/I-85, etc. The table data represent one-way overweight truck trips on a highway where a one-way trip may use multiple segments of the same highway, as well as other highway segments. During the sample week there were 2,234 overweight permits issued. One permit usually represents one trip.

Analytical Method

In order to compile the data necessary for mapping solely overweight trucks that traveled on I-40, I-77 and I-95, the following steps were taken. One week of data (2,234 trucks) was combed for permit entries that registered truck travel on any segment along, for example I-95. An Excel worksheet representing each mile of and exit along I-95 was created and used to plot data along segments of used highway. Any amount of travel along the interstate was recorded in the worksheet with the gross vehicle weight (GVW) of each truck. For instance, consider the following truck's travel record on I-95:

SR1002	I540	I40	I40/440	I40	I95	US421	SR1719	SR1719

This record means that directly before entering I-95, the truck was traveling on I-40, and the truck traveled on I-95 until exiting at the US421 highway interchange. Therefore this truck's corresponding GVW would be recorded on the 'virtual highway' spreadsheet between the mile marker where the exit for I-40 occurs and the mile marker where the exit for highway US421 occurs. This process was completed for every truck with a record of traveling on I-95. A unique column was dedicated for every unique truck. However, one instance occurred where two columns were used for the same truck because the truck's journey was such that it traveled along the same portion of I-95 twice. The resulting spreadsheet in essence becomes a visual representation of overweight truck coverage along I-95. Every occupied cell can be thought of as metaphorical tire tracks. All of the rows are then aggregated based on truck weight class to come up with values for total trucks and weight stratified trucks per mile. The final outputs are shown in Figures representing I-40, I-77 and I-95 on subsequent pages.

Table 8-1 Most Frequently Used Highways by Overweight Trucks

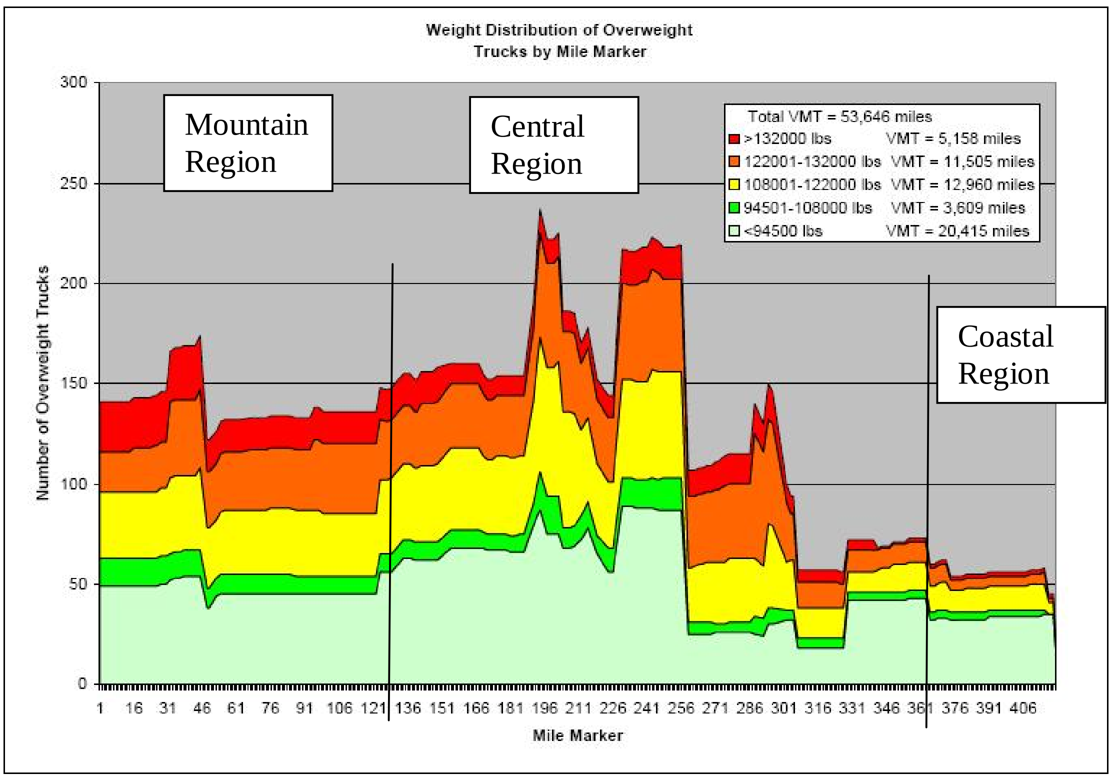
Most Frequently Used Highways by Overweight Trucks During the Week of 21 August 2006							
Hwy	Freq	Hwy	Freq	Hwy	Freq	Hwy	Freq
I-40	1808	US74	419	NC16	160	SR1101	100
I-85	1186	US17	304	NC24	150	SR1714	47
I-95	821	US1	277	NC87	100	SR2029	40
I-77	456	US64	274	NC49	97	SR4450	40
I-26	174	US70	271	NC55	75	SR1007	35
I-74	26	US421	234	NC54	73	SR1554	34
		US117	178	NC150	71	SR1010	31
		US52	152	NC66	70	SR1117	29
		US220*	151	NC211	54	SR1002	27
		US220	146	NC132	47	SR1392	27
		US321	120	NC68	45	SR1919	27

\Summary Table Freq Sorted & \NCSU Report – ver3.2a

I-40 Overweight Truck Traffic Profiles

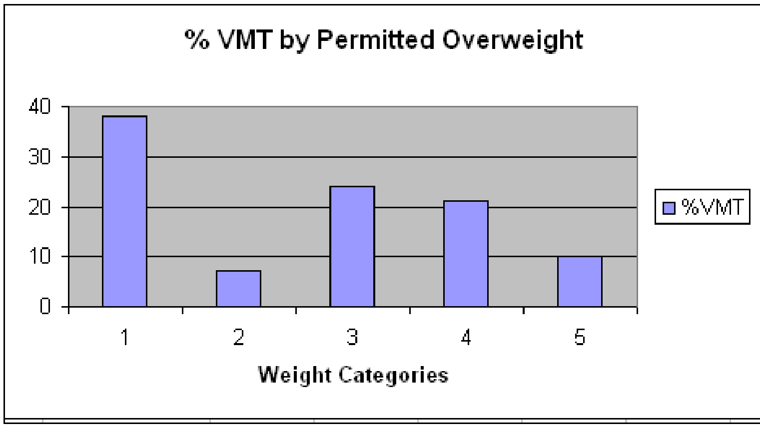
Inspection of the overweight truck traffic on I-40 yields the truck traffic profiles of Figures 8-2 and 8-3. Figure 8-2 displays the number of permitted overweigh vehicles traveling each segment of I-40 during the week of 21 August 2006. Wilmington is the eastern terminus of I-40 and has the highest milepost numbers. The vehicles are also classified according to weight categories. As expected, the results of Figure 8-3 show significantly higher overweight truck traffic in the Central Region compared to the Coastal and Mountain Regions. The peaks of truck activity represent interchange locations, an artifact of the analysis method, and the "tight" mile post scale of the figure. Figure 8-2 shows the VMT profile of overweight truck activity. Trucks weighing between 80,000 and 94,500 pounds account for about 40% of the I-40 VMT during the week of 21 August 2006 as a result of more vehicles, longer trips per vehicle or both. Trucks weighing between 108,000 pounds and 132,000 pounds account for another 40% of the I-40 VMT by overweight vehicles. Similar analyses may be accomplished for an entire year of 2006 or other year's data for overweight truck permits.

Table 8-2 is a sample of the oversize and overweight truck permit data available from the NCDOT Over Size-Over Weight Permit Unit. It provides explicit vehicle and route information by gross vehicle weight (GVW), axles, origin, destination and intermediate points. Data such as Table 8-2 are used for analyzing permitted truck traffic by vehicle class, weight, axle loadings, highway type, distance traveled, and NC region.



0 < Mountain Mile Markers < 119 (119 miles)
119 < Central Mile Markers < 341 (222 miles)
341 < Coastal Mile Markers < 420 (79 miles)

Figure 8-2 I-40 Permitted Overweight Truck Traffic Profile by Class & VMT (Aug 21-25, 2006)



Category	Weight	VMT	% VMT
1	< 94500	20415	38
2	94501 - 108000	3609	7
3	108001 - 122000	12960	24
4	122001 - 132000	11505	21
5	>132000	5158	10

Figure 8-3 I-40 VMT Profile Overweight Truck Traffic (August 21-25, 2006)

Findings for I-40 Permitted Overweight Truck Traffic

The example data set for one week in August 2006 served to develop prototype analysis software to determine the overweigh truck traffic profiles on three case study interstates (I-40, I-77 and I-95), as well as identify the most used highways by functional class (Figure 8-2). For I-40 it is very clear that the

Table 8-2 Sample Oversize / Overweight Data

	A	B	C	D	E	F	G	H	I	J	K
1	REGISTERED_WEIGHT	LOAD_DESC	TOTAL_AXLES	GVW	WIDTH	LENGTH	HEIGHT	RFROM	RTO	PATH	DATE_ENTERED
2	54000	MOBILE HOME - MULTI	2	-1	168	1260	170	CANDOR FAC	S C LINE	FROM A POINT ON NC211 IN CANDOR TO NC211 TO	20-Aug-06
3	54000	MOBILE HOME - DOUBLE	2	-1	168	1260	173	US64BUS (MFG) - US64BUS (MFG) AT	US701 - US701 AT CLINTON, NC	FROM A POINT ON US64BUS E TO US64BYP E TO I-95 S	20-Aug-06
4	54000	MOBILE HOME -	2	-1	168	1260	195	401 LILLINGTON	I-77 VA LINE	401 to 421 to 78 to 15/501 to 24/27 to 109 to moore 1186 to	20-Aug-06
5	54000	MOBILE HOME -	2	-1	168	1260	162	LAURINBURG NC	VIRGINIA LINE	FROM A POINT ON SCOTLAND COUNTY SR1622 TO	21-Aug-06
6	54000	MOBILE HOME -	2	-1	168	1260	162	NASH COUNTY	NEW HANOVER COUNTY	FROM POINT ON US64BUS W TO US64BYP E TO I-95 S TO	20-Aug-06
7	54000	MOBILE HOME -	2	-1	168	1260	191	70-"GOLDSBORO	401-LILLINGTON	FROM A POINT ON WAYNE CO US70 BYP TO US70 BYP TO	22-Aug-06
8	54000	MOBILE HOME -	2	-1	192	1260	172	CANDOR	CHARLOTTE	FROM A POINT ON NC211 TO US220 TO NC24/27 TO TROY	22-Aug-06
9	-1	SELF PROPELLED -	7	114520	118	818	162	GEORGIA STATE LINE NC-69	US64 NC	STARTING AT THE GEORGIA STATE LINE ON NC-69, US-	21-Aug-06
10	80000	CONSTRUCTION EQUIPMENT - EXCAVATOR	7	132000	125	960	167	CHARLOTTE, NC - 2023 JOHN CROSLAND	TN LINE	(REPUBLIC CRANE)JOHN CROSLAND JR DR TO GARY ST	21-Aug-06
11	80000	OTHER -COOLING HOUSE	5	112000	144	1188	162	SC LINE	CHARLOTTE NC	I-77 NORTH FROM THE SC LINE TO 77-TO 14320	21-Aug-06
12	54000	MOBILE HOME - DOUBLE	2	-1	168	1260	170	64 BUS NASHVILLE NC	CLEVELAND COUNTY 2008	FROM A POINT ON US64 BUS TO US64 WEST TO	20-Aug-06
13	54000	MOBILE HOME -	2	-1	168	1260	184	LAURINBURG	SOUTH CAROLINA LINE	FROM A POINT ON SCOTALND CO SR1622 TO SR1615 TO	21-Aug-06
14	30000	OTHER - BOAT	5	-1	154	720	155	VA	MOORESVILLE	77-277-77-21-EXIT 33-827 LANGTREE	21-Aug-06
15	30000	OTHER - BOAT	5	-1	154	720	155	VA	MOORESVILLE	77-277-77-21-EXIT 33-827 LANGTREE	21-Aug-06
16	80000	OTHER - MCNEILUS LE613 TRUCK	6	85000	102	816	162	WHITEVILLE NC	SC STATE LINE	From 1890 Pineloq Rd - byp 701 - 74 - I95	21-Aug-06
17	80000	OTHER -POWERBOAT	6	108000	167	1080	180	SC LINE	SC LINE	PLEASE CANCEL THIS APPLICATION	21-Aug-06
18	80000	STEEL -PANELS/STACKED	5	-1	102	1020	162	SC LINE	PISGAH FOREST NC	I20 WEST EAST - I285 NORTH- I85 NORTH-HWY 178 NORTH-	21-Aug-06
19	80000	CONSTRUCTION EQUIPMENT - LOADER	5	84000	120	900	168	SKYLAND, NC	TENNESSEE LINE	FROMA POINT ON US25 TO NC146 TO I-26 WEST TO I-40	22-Aug-06
20	54000	MOBILE HOME - DOUBLE	2	-1	168	1260	188	ROBBINS	OCEAN ISLE	FROM A POINT ON MOORE CO SR1477 TO NC24/27 EAST	21-Aug-06
21	65000	OTHER - 3 BOATS (NESTED)	5	-1	108	900	173	SC LINE	VA LINE	PLEASE CANCEL THIS APPLICATION	21-Aug-06
22	54000	OTHER - DORMERS END TO END	6	-1	120	720	162	R-ANELL FACTORY - R-ANELL FACTORY	SPRUCE PINE	from a point on nc 16 to nc 10/16 to us 321 bus to us 70 to us 70	21-Aug-06
23	54000	MOBILE HOME -	2	-1	168	1260	176	HOLMES FACTORY AT ROBBINS	DEALER BURLINGTON	FROM A POINT ON MOORE CO SR1477 TO NC705 NW TO	21-Aug-06
24	54000	OTHER - DORMERS E/E	6	-1	120	720	162	R-ANELL AT DENVER	VIRGINIA LINE	FROM A POINT ON NC16 IN DENVER TO NC150 NE TO	21-Aug-06
25	80000	OTHER -PIPE EXPANSION JOINTS	5	-1	152	864	162	ALEXIS	SOUTH CAROLINA	SR1820 - SR27 - SR275 - I85	21-Aug-06
26	80000	CONSTRUCTION EQUIPMENT - EXCAVATOR	7	122000	144	864	162	JEFFERSON-ASHE COUNTY	VA LINE	JCT OF US 221 & 16 IN ASHE COUNTY TO NC 16 NORTH TO	22-Aug-06
27	80000	OTHER -OFF ROAD TIRES STACKED	5	-1	126	900	162	EDENTON, NC	TN	COKE AVE-17-64-40	22-Aug-06
28	54999	MOBILE HOME -	2	-1	168	1260	188	SOUTH CAROLINA LINE	GOLDSBORO NC	GOLDSBORO NC	22-Aug-06
29	54000	OTHER -DORMERS - END TO END	5	-1	144	840	162	16 DENVER	I-85 VA LINE	FROM A POINT ON NC16 TO NC150 TO NC152 TO I-85	20-Aug-06
30	80000	FARM EQUIPMENT -JD 9200 TRACTOR	5	-1	126	840	162	SC LINE	VA LINE	I95	22-Aug-06
31	80000	CONSTRUCTION EQUIPMENT - LOADER	7	132000	143	948	166	SKYLAND,NC.	SC LINE	HENDERSONVILLE RD.-25-280-I26	21-Aug-06
32	80000	OTHER - ROOF TRUSSES/STACKED	5	-1	168	840	162	CABARRUS CO	MECK CO	SR1173 TO NC49 S TO I485 TO NC16 N TO SR4867 TO DEST	21-Aug-06
33	80000	STEEL - TANK	5	-1	114	720	162	SC LINE	AURORA, NC	I-95, 264E-17S-NC33-NC306 1530 NC306	21-Aug-06
34	25000	OTHER -FIBERGLASS POOL	4	-1	168	720	162	HARNETT COUNTY	WEDDINGTON, NC	FROM A POINT ON HARNETT CO SR1811 BUD HAWKINS RD	25-Aug-06
35	80000	CONSTRUCTION EQUIPMENT - CONCRETE PAVER	8	140000	140	960	165	TENNESSEE	SPENCER NC	I 26 - I 40 - 52 - I 85 TO JOB SITE ON I-85 AT MP 81	24-Aug-06
36	80000	CONSTRUCTION EQUIPMENT - EXCAVATOR	7	132000	144	864	161	VA LINE	JCT OF 88 & SR1131-ASHE COUNTY	NC18 SOUTH TO NC88 WEST TO DESTINATION AT JCT OF	22-Aug-06
37	80000	CONSTRUCTION EQUIPMENT - EXCAVATOR	6	12000	126	888	162	SC	VA	77	21-Aug-06
38	80000	STEEL - BEAMS (STACKED)	5	-1	102	960	162	GREENSBORO -	STALEY -	PLEASANT GARDEN ROAD - WILEY-LEWIS ROAD - 421 -	21-Aug-06
39	54000	MOBILE HOME -	2	-1	168	1260	195	LILLINGTON	GREENSBORO	FROM A POINT ON SR1257 TO SR1257 TO SR1302 S TO	22-Aug-06
40	80000	OTHER -WOOD GRINDER	6	108000	142	720	162	ROSE HILL	MONCURE	MOVE FROM A POINT ON US117 IN ROSE HILL TO US117 TO	25-Aug-06
41	26000	OTHER -FIBERGLASSSWIMMING POOL	5	-1	168	816	168	HARNETT CO.	VA BORDER	BUD HAWKINS RD. TO I-95 NORTH TO VA BORDER	25-Aug-06
42	80000	CONSTRUCTION EQUIPMENT - DUMP TRUCK	5	-1	119	876	162	SOUTH CAROLINA LINE	CHARLOTTE, NC (4600 NORTH I-85	I 85 - EX.41-SERVICE RD.	21-Aug-06
43	80000	OTHER -STEEL BEAMS	5	-1	102	972	162	ARDEN- 8 LOOP ROAD	SOUTH CAROLINA LINE	LOOP ROAD - I26	21-Aug-06
44	80000	SEALED SHIP CONTAINER -	5	-1	108	720	179	VA LINE	MEBANE	I-85, EXIT 152, TO: 1067 TROLLINGWOOD HAWFIELDS RD	21-Aug-06
45	80000	OTHER - 3 SWIMMING POOLS NESTED	5	-1	180	960	162	SC LINE AND I-77	VA LINE AND I-77	I-77	21-Aug-06
46	80000	OTHER - ELECTRIC SWITCH PLATE	5	-1	137	780	162	CHARLOTTE	SC STATE LINE	4045 HARGROVE AVE,US 29,I77	21-Aug-06
47	54000	MOBILE HOME -	2	-1	168	1260	197	SR1257 - SR1257 AT HARNETT	ALF HOOVER RD - ALF HOOVER RD AT	FROM A POINT ON HARNETT CO SR1257 TO SR1302 TO	22-Aug-06
48	54999	MOBILE OFFICE -	2	-1	144	1140	175	CHARLOTTE NC	CHARLOTTE NC	FROM A POINT ON US29/NC49/GRAHAM ST TO I277 TO I77	22-Aug-06
49	54999	MOBILE HOME -	2	-1	168	1260	181	STANLY COUNTY	PITT COUNTY	FROM A POINT ON US52 IN RICHFIELD TO US52 NORTH TO	21-Aug-06
50	54000	MOBILE HOME -	2	-1	168	1260	184	LILLINGTON	EDENTON	FROM A POINT ON US401 TO US401 TO US421 S TO DUNN	22-Aug-06
51	54000	MOBILE HOME -	2	-1	192	1260	191	CHARLOTTE	CHARLOTTE	FROM A POINT ON ACS/MCNINCH ST IN CHARLOTTE TO	21-Aug-06
52	54000	MOBILE HOME -	2	-1	192	1260	162	CHARLOTTE NC	CHARLOTTE NC	FROM A POINT ON CHARLOTTE ACS/MCNINCH TO	20-Aug-06
53	54000	MOBILE HOME -	2	-1	168	936	188	LINCOLN COUNTY	WATAUGA COUNTY	FROM A POINT ON NC16 TO NC16 NORTH TO NC10/16 TO	25-Aug-06
54	80000	STEEL - BEAMS - 5 PCS, 1 STACK	5	-1	102	936	162	SC LINE	VA LINE	I-77 N TO THE VA LINE	21-Aug-06
55	54000	OTHER - DORMERS - END TO END	6	-1	144	1080	162	NASH COUNTY	PITT COUNTY	FROM A POINT ON US64 BUS IN NASHVILLE TO US64 BUS	20-Aug-06
56	49000	MOBILE HOME -	7	-1	168	1260	186	VIRGINIA LINE	HALIFAX COUNTY	FROM THE VIRGINIA LINE ON US1 TO US301 TO US903 TO	21-Aug-06
57	80000	OTHER - WOODEN TRUSSES - (1 STACK)	5	-1	165	780	162	KINGS MOUNTAIN, NC	MECKLENBURG COUNTY	FROM A POINT ON CLEVELAND CO SR2036 TO US74 BUS	21-Aug-06
58	-1	SELF PROPELLED - MOBILE CRANE	6	108000	144	720	162	LINCOLIN COUNTY	SOUTH CAROLINA LINE	FROM A POINT ON LINCOLIN CITY PKWY EXT TO	23-Aug-06
59	80000	CONSTRUCTION EQUIPMENT - DRILL RIG	7	86000	120	894	162	SOUTH CAROLINA LINE	CHARLOTTE, NC	FROM THE SOUTH CAROLINA LINE ON I85 TO I85 NORTH	21-Aug-06
60	80000	OTHER - (6) ROOF PLATES 1 STACK	5	-1	120	900	162	TENNESSEE LINE	SEMORA NC	FROM THE TN LINE ON I40 EAST TO I40 BYP AT WINSTON	21-Aug-06
61	80000	OTHER - DAMPER CRATED	5	-1	164	840	162	TENNESSEE LINE	SOUTH CAROLINA LINE	I-26 EAST TO I-26/US19/23 SOUTH TO I-26/240 TO I-26	21-Aug-06
62	53380	SELF PROPELLED -CRANE	3	53380	102	510	162	ASHEVILLE NC	SOUTH CAROLINA LINE	FROM A POINT AT THE JCT OF US70 ANDUS25 TO US25	21-Aug-06
63	80000	STEEL - TANK EMPTY STAINLESS	5	-1	128	840	168	SC LINE	TN LINE	FROM THE SC LINE ON US25 TO US25 N TO I26 TO I40 W	21-Aug-06
64	80000	OTHER - MACHINE CENTER	6	102000	136	936	162	VIRGINIA LINE	SOUTH CAROLINA LINE	I95 SOUTH TO THE SC LINE	21-Aug-06
65	80000	OTHER -PRESS BRAKE	6	110000	108	900	162	TENNESSEE LINE	CONOVER NC	I-26 TO US19/23/I26 TO I240 TO I40 EAST TO CATAWBA	21-Aug-06
66	26000	OTHER -EMPTY PLASTIC TANKS END TO END	4	-1	142	780	162	VIRGINIA LINE	CHARLOTTE NC	FROM THE VIRGINIA LINE ON I77 TO I77 SOUTH TO NC49	21-Aug-06
67	54000	MOBILE HOME -	2	-1	168	1260	168	KINSTON	WILMINGTON	FROM A POINT NC11 IN KINSTON TO NC11 SOUTH TO	20-Aug-06
68	54000	MOBILE HOME -	2	-1	168	1260	169	NASHVILLE	SHALLOTTE	FROM A POINT ON US64 BUS TO US64 EAST TO I-95	20-Aug-06

central region of North Carolina is most heavily traveled by overweight trucks. The most frequent over weight range is 80,000 to 94,500 GVW representing about 40% of the overweight trucks. Nearly 50% of the overweight trucks weigh more than 108,000 pounds. Also, I-40 is the Interstate most heavily traveled by overweight trucks; then come I-85, I-95, I-77, I-26 and I-74. The most heavily traveled US, NC and SR highways were also identified in Table 8-1 for the week of August 21-25, 2006.

I-77 Permitted Overweight Truck Traffic Profiles

The August 21-25, 2006 data (Table 8-2) may be used for the I-77 overweight truck traffic profiles (Figure 8-3). The results of the analysis give truck gross vehicle weight distribution by mile marker for I-77 stretching from the South Carolina state-line (mile marker 1) to the Virginia state-line (mile marker 101). The data also provide the VMT estimates of Table 8-3.

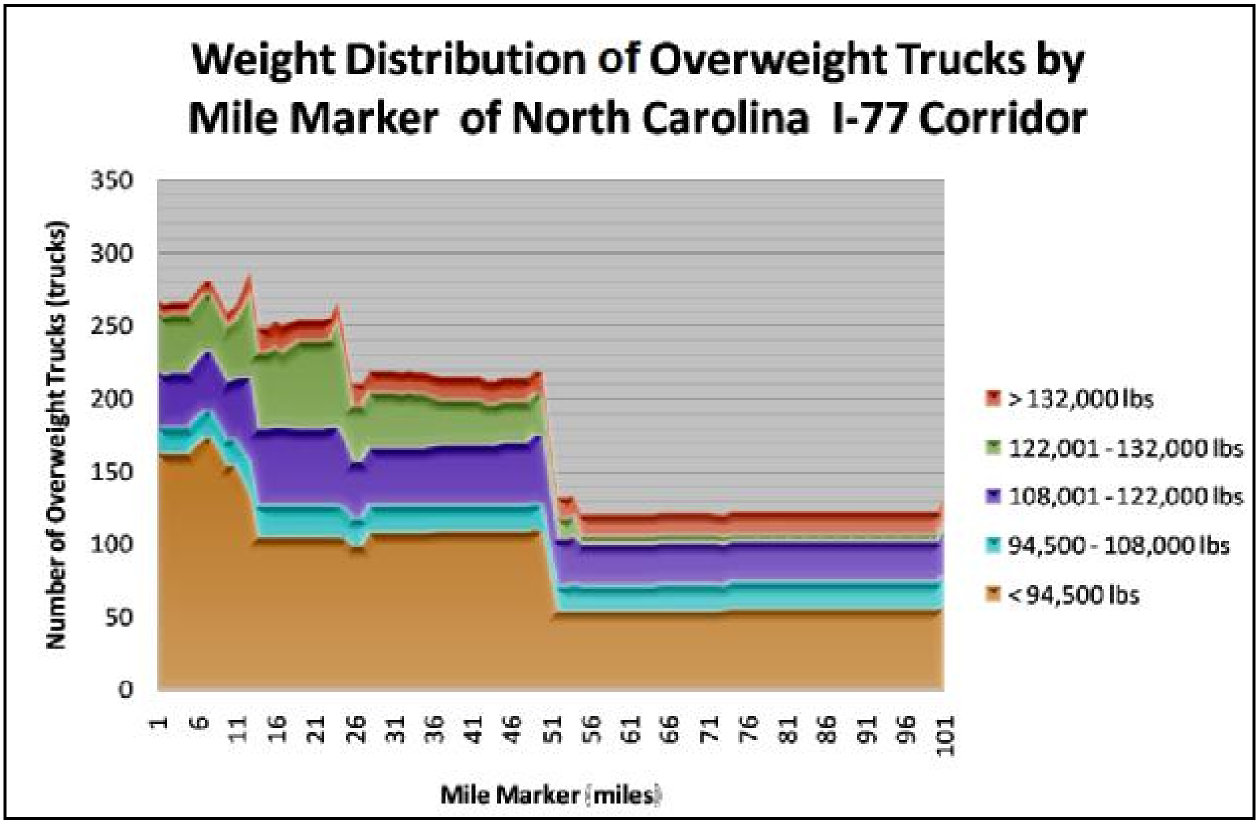
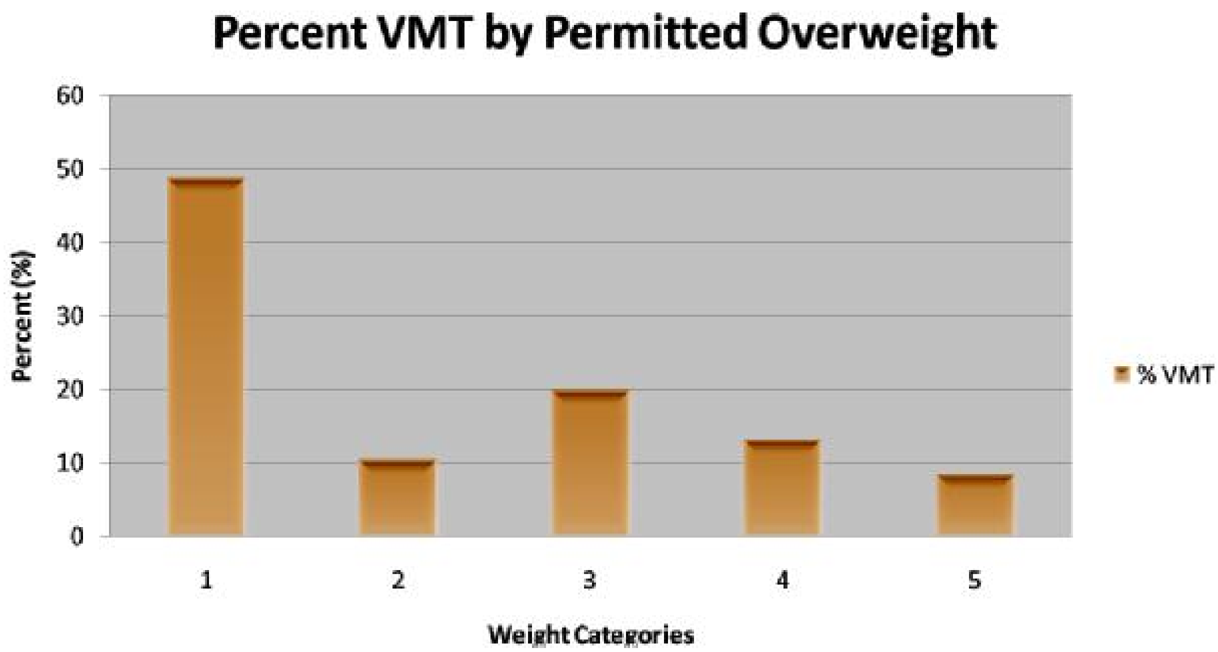


Figure 8-4 I-77 Overweight Truck Traffic Profile for August 21-25, 2006

Table 8-3 I-77 VMT Profile Overweight Truck Traffic for August 21-25, 2006

Category	Weight (lbs)	VMT	% VMT
1	80,001 < 94,500	8,894	48
2	94,500 - 108,000	1,899	10
3	108,001 - 122,000	3,602	20
4	122,001 - 132,000	2,373	13
5	> 132,000	1,512	8

Note: percents do not sum up to 100 due to rounding.



Overweight Categories: (1) 80,0001 – 94,5000; (2) 94,501-108,000; (3) 108,001-122,000; (4) 122,001,132,000; (5) >132,000 GVW

Figure 8-5 VMT% by Permitted Overweight Trucks on I-77 for August 21-25, 2006

Findings for I-77 Permitted Overweight Truck Traffic

Locations requiring special attention with respect to pavement construction and bridge design follow in order of decreasing priority based on the overweight I-77 truck traffic:

- The first 25 miles of I-77 from the South Carolina border to NC-73 interchange have the highest overweight truck traffic.
- The second 25 miles of I-77 from NC-73 interchange to I-40 interchange in Statesville have the second highest level of overweight truck traffic.
- After Statesville, (mile marker 51) where I-40 intersects I-77, the overweight truck traffic falls to about one-half its initial level at the South Carolina line.

Feeder routes and frequent destinations are identified below in decreasing order:

- NC-49,
- Lassalle Street in Charlotte,
- NC-73, and
- I-40

Furthermore, permitted overweight trucks between the weights of 80,000 – 94,500 pounds account for the majority of overweight truck VMT on I-77. Trucks between the weights of 108,001 – 122,000 pounds represent the next highest proportion of total VMT along the I-77 in North Carolina.

I-95 Permitted Overweight Truck Traffic Profiles

The same procedures used to determine the I-40 and I-77 permitted overweight truck traffic profiles were applied to the August dataset for I-95 between South Carolina (mile marker 1) and Virginia (mile marker 177). The results are shown in Figure 8-5. 369 individual trucks were recorded in the dataset as using I-95 at least once. While the total number of times that trucks physically traversed along I-95 was 409; this is higher than the total number of individual trucks that used the road due to some individual trucks exiting and reentering the highway, thus traveling along I-95 more than once.

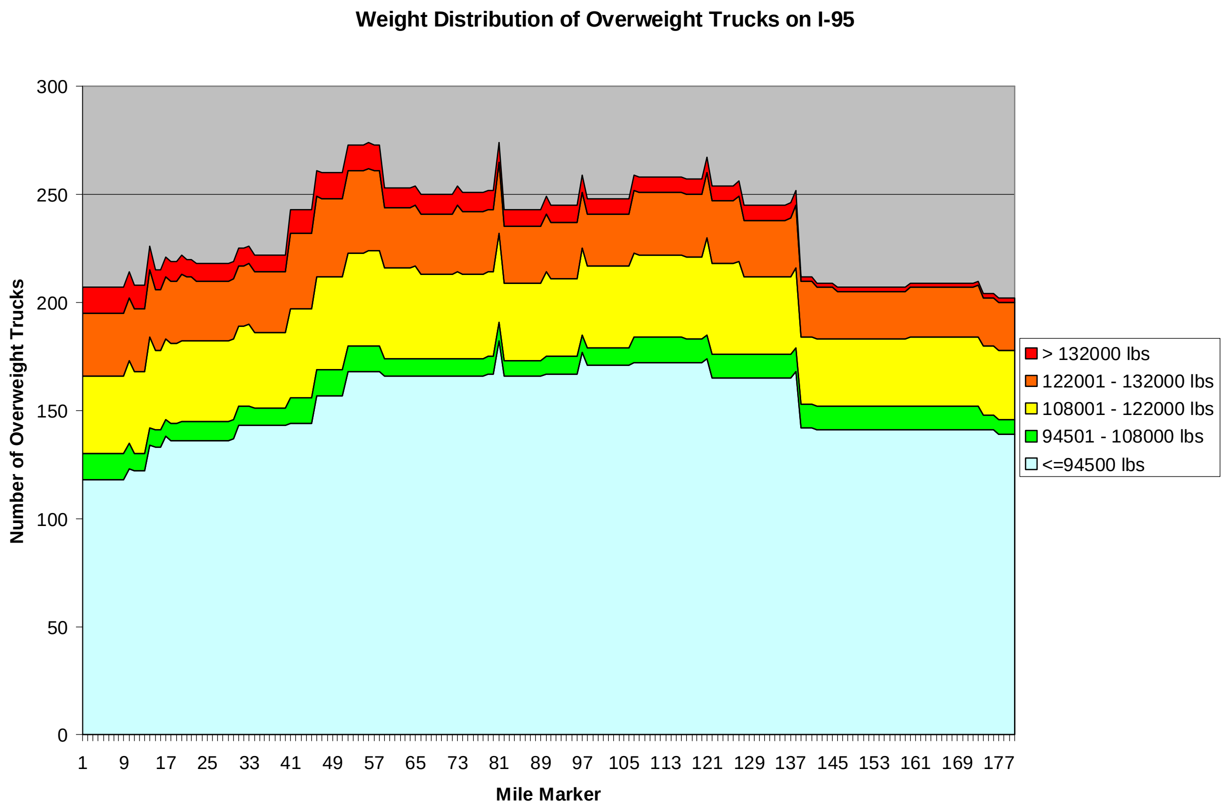


Figure 8-6 I-95 Permitted Overweight Truck Traffic Profile for August 21-25, 2006

Findings for I-95 Permitted Overweight Truck Traffic

This analysis develops a profile for permitted overweight truck traffic along Interstate 95 in North Carolina. The primary benefits of the profile include its usefulness for identifying areas of road stress, identifying places for targeted law enforcement, and its potential for making way for dynamic pricing measures. Future profiles could be improved by incorporating directional traffic flow and by extending data collection to better assess annual trends.

The I-95 graph shows that overweight truck travel along I-95 is relatively continuous without drastic flow changes. Starting from the South Carolina border (mile marker 1), OW truck traffic steadily climbs from a little over 200 passes and plateaus at around 250 passes from mile 60 to mile 138. For the assessed week, overweight truck travel was heaviest along the segment of roadway between mile 52 and mile 58, which correspond to interchanges for highways NC24 and I-295 respectively. Approximately 275 trips were recorded across this stretch of road which is the most used portion of I-95 by OW trucks. There are only two other occasions when the level of roadway use reaches the peak of approximately 275. One occurs at mile marker 81 at the I-40 interchange, and the other occurs at mile marker 121 at the interchange for US64. However, these locations may be considered as severe as the segment between mile 52 and 58 since they are merely point peaks lasting no longer than the length of the interchange. The only sudden significant fall in traffic occurs at mile 138, the interchange for US 64 and NC 33. At this point, traffic which had leveled off at roughly 250 abruptly drops down to just over 200. Despite this, the overweight truck traffic flow for the week was relatively uniform. The results reinforce I-95's reputation as being primarily a through highway in the state.

The overweight truck profile developed for I-95 indicates that the highway is primarily being used for through traffic. The heaviest used portion of highway is the segment between the interchange for NC24 and the interchange for I-295/US13. Other brief spikes of heavy highway use do occur but are too short to be considered significant. The results indicate areas of heavy use that may be candidates for roadway improvement and repair and where illegal overweight trucks may travel, as well as permitted OW vehicles. The results of this study could potentially serve as the foundation for a conceptual framework for a weigh-in-pay-in-motion truck charging scheme.

Extension of the Analytical Method to One Year's Data for 2006

After demonstrating the analytical method for the sample week of August 21-25, 2006, the method was applied to the entire year of 2006. Table 8-4 compares the dataset for one year and one week. Table 8-5 shows the permitted weight categories, totals and percentages for the year 2006. The extension of the spreadsheet methods to the entire year of 2006 also included a closer examination of the highways most frequently used by overweight trucks by weight category (Table 8-6 – Table 8-10). Tables 8-6 to Table 8-10, compared to Table 8-1, also show Interstate routes, for example, by segment type like by-passes such as I-40/I-440. Figures 8-6 to Figure 8-9 graphically display the results of Tables 8-6 to 8-10.

The resulting tables and charts give an excellent summary of the overweight truck profiles on North Carolina highways in 2006.

Table 8-4 Permitted Oversize-Overweigh Truck Records for 2006

	Total	Overweight	Oversize
August 21-25, 2006	4,937	2,234 (45%)	2,703 (55%)
2006	237,511	118,413 (49%)	119,098 (51%)

Table 8-5 Number of Permitted Overweight Trucks by Category (2006)

Weight Category	Number of Trucks	Ratio
Under 94,500 lb	42,471	36%
94,501 ~ 108,000 lb	8,177	7%
108,001 ~ 122,000 lb	34,923	30%
122,001 ~ 132,000 lb	28,750	24%
Over 132,000 lb	4,092	3%
Sum	118,413	100%

Table 8-6 Frequency of Permitted Overweight Trucks Under 94,500 lb

Rank		Interstates		NC Highway		US Highway		SR roads	
		Road	Freq	Road	Freq	Road	Freq	Road	Freq
under 94.5k	1	I40	27944	NC16	3128	US74	10847	SR1101	1139
	2	I85	14426	NC87	3032	US117	7325	SR1140	801
	3	I95	10038	NC132	1953	US421	5192	SR2029	724
	4	I77	8185	NC11	1780	US64	4995	SR1002	718
	5	I26	4315	NC24	1739	US70	4771	SR4450	697
	6	I440	3500	NC49	984	US17	4405	SR2413	640
	7	I485	1631	NC66	974	US1	3762	SR1212	620
	8	I40/85	955	NC211	935	US220	2331	SR1409	494
	9	I277	842	NC41	818	US13	2222	SR1848	456
	10	I240	617	NC42	812	US321	2123	SR1328	445

Table 8-7 Frequency of Permitted Overweight Trucks 94,500 ~ 108,000 lb

Rank		Interstates		NC Highway		US Highway		SR roads	
		Road	Freq	Road	Freq	Road	Freq	Road	Freq
94.5k - 108k	1	I40	4017	NC66	20	US70	1277	SR2029	387
	2	I85	3310	NC87	11	US74	1165	SR4450	378
	3	I95	1841	NC	5	US17	1031	SR1117	360
	4	I77	1591	NC109	5	US64	844	SR1392	348
	5	I26	930	NC24	5	US220	761	SR1007	254
	6	I40/85	544	NC49	5	US421	638	SR1387	196
	7	I485	482	NC150	4	US52	574	SR1002	171
	8	I40/440	246	NC65	4	US301	456	SR1938	129
	9	I440	239	NC16	3	US1	449	SR1009	102
	10	I74	189	NC211	3	US264	395	SR1735	101

Table 8-8 Frequency of Permitted Overweight Trucks 108,001 ~ 122,000 lb

Rank		Interstates		NC Highway		US Highway		SR roads	
		Road	Freq	Road	Freq	Road	Freq	Road	Freq
108k - 122k	1	I40	19517	NC24	3666	US70	6436	SR1117	1019
	2	I85	12503	NC87	1546	US74	5715	SR1919	899
	3	I77	5590	NC16	1357	US17	5571	SR1717	876
	4	I95	4910	NC150	1344	US64	5009	SR1001	805
	5	I440	2779	NC54	1341	US421	4016	SR1007	786
	6	I26	2636	NC11	1332	US1	3777	SR2029	632
	7	I485	2308	NC66	1249	US220	2770	SR4450	618
	8	I40/85	1867	NC55	1214	US52	2657	SR1876	603
	9	I40/440	1114	NC49	1066	US264	2029	SR1100	579
	10	I540	973	NC211	951	US401	1925	SR1002	566

Table 8-9 Frequency of Permitted Overweight Trucks 122,001 ~ 132,000 lb

Rank		Interstates		NC Highway		US Highway		SR roads	
		Road	Freq	Road	Freq	Road	Freq	Road	Freq
122k - 132k	1	I40	15701	NC24	2074	US70	4867	SR1007	713
	2	I85	10827	NC54	2042	US64	3797	SR1002	686
	3	I77	4914	NC55	1857	US1	3509	SR1010	670
	4	I485	3812	NC16	1453	US74	3257	SR1009	581
	5	I95	3195	NC49	1295	US401	2524	SR4450	562
	6	I440	2311	NC150	1076	US52	1976	SR2029	553
	7	I40/85	2068	NC73	1066	US421	1968	SR2000	502
	8	I26	1696	NC66	970	US17	1743	SR1876	443
	9	I540	1668	NC87	757	US21	1709	SR1624	427
	10	I40/440	1571	NC42	729	US29	1400	SR1001	412

Table 8-10 Frequency of Permitted Overweight Trucks Over 132,001 lb

Rank		Interstates		NC Highway		US Highway		SR roads	
		Road	Freq	Road	Freq	Road	Freq	Road	Freq
over 132k	1	I40	2748	NC172	327	US74	779	SR1128	665
	2	I85	1894	NC150	302	US17	445	SR1422	467
	3	I77	1042	NC11	195	US70	412	SR1525	68
	4	I95	1023	NC42	138	US421	372	SR1548	68
	5	I26	710	NC54	115	US64	364	SR1958	67
	6	I485	625	NC55	110	US1	275	SR2120	62
	7	I40/440	488	NC16	109	US13	244	SR1915	61
	8	I40/85	369	NC24	101	US220	237	SR1415	57
	9	I85/40	277	NC87	100	US117	218	SR1848	55
	10	I440	208	NC59	84	US301	210	SR1104	53

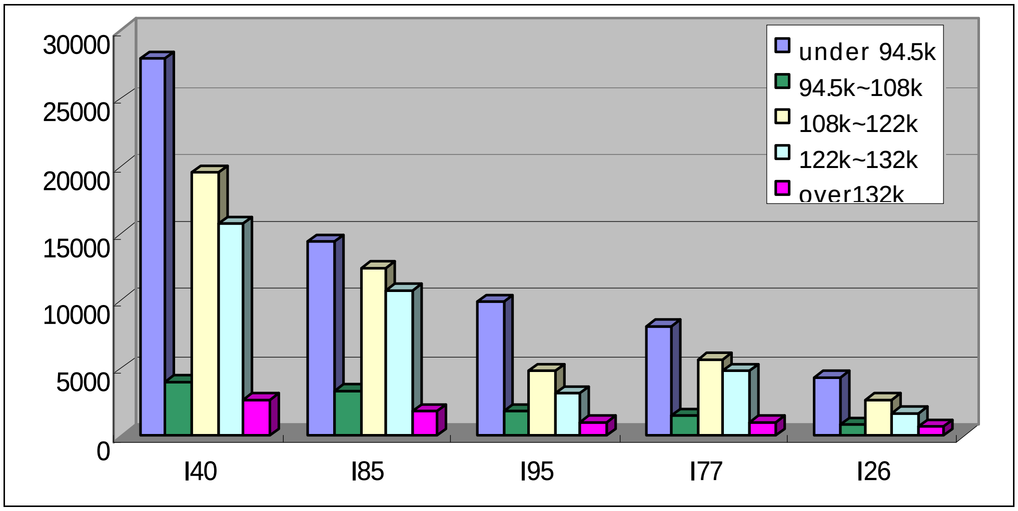


Figure 8-7 Top Five Interstates Carrying Permitted Overweight Trucks (2006)

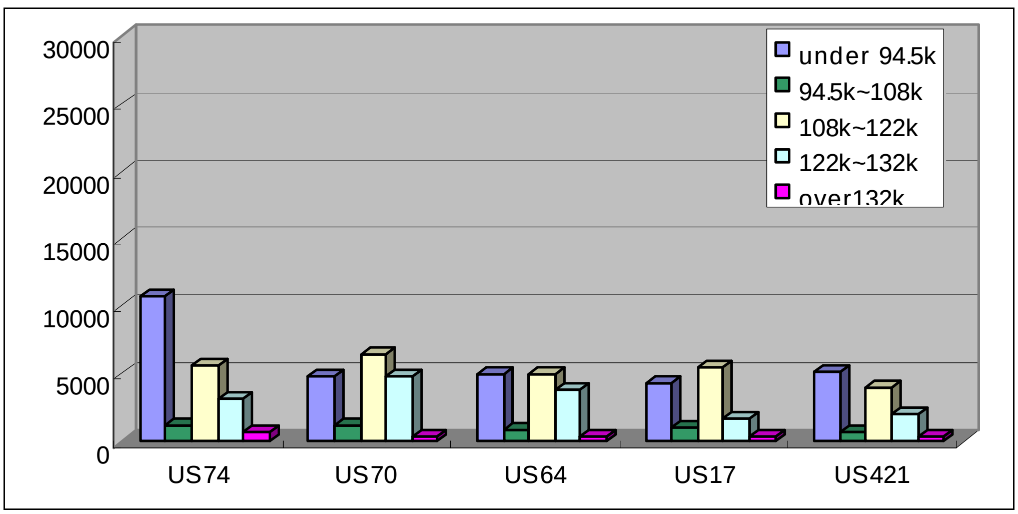


Figure 8-8 Top Five US Highways Carrying Permitted Overweight Trucks (2006)

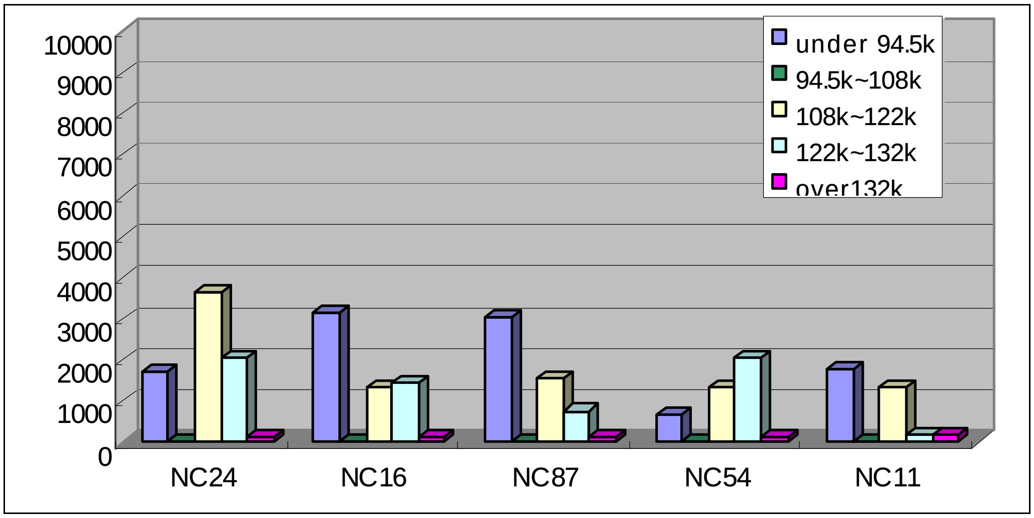


Figure 8-9 Top Five NC Highways Carrying Permitted Overweight Trucks (2006)

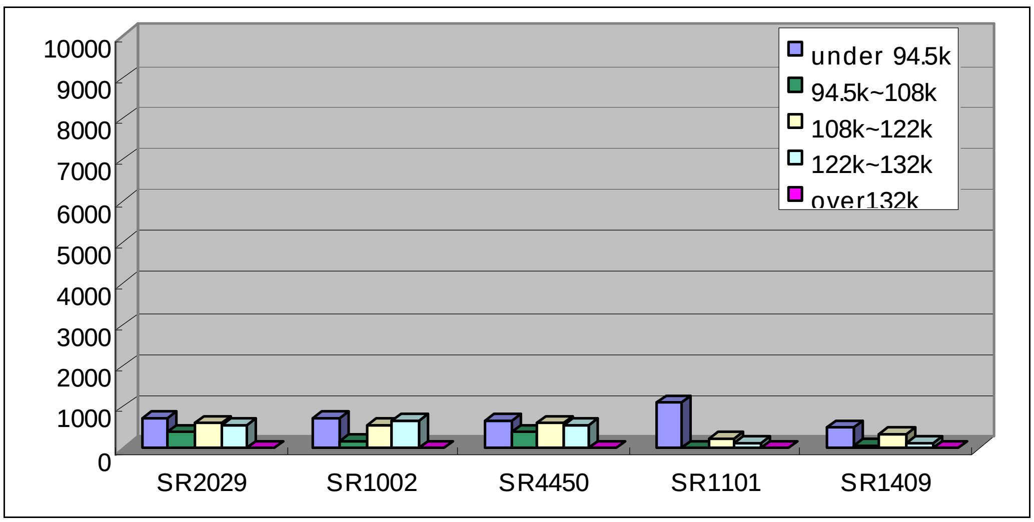


Figure 8-10 Top Five SR Roads Carrying Permitted Overweight Trucks (2006)

Note: The SR results in the table do not distinguish different SRs by County. The results represent statewide frequencies for the same SR #.

Correlation Analysis between One Year's Data and One Week's Data

Given the amount of data and analysis required to assess permitted overweight truck traffic profiles for one year, it is important to determine if a single week's data as used by the prototype model is adequate for overall analysis. If so, sampling a typical week could simplify future applications of the prototype methods. If the correlation is high, there are consistent results, likely constant flow rates, and one week's data may be used to represent an entire year. Thus, Table 8-11 was developed to compare the sample week and annual frequencies of overweight trucks using the representative roads. The correlation between annual and weekly frequencies is a high 0.993 and it may be concluded that a relatively small sample of one week's data can be used for analyzing annual permitted overweight truck traffic.

Table 8-11 Comparison of Annual and Weekly Frequencies (0.993 Correlation)

Road	2006	Aug 21-25	Road	2006	Aug 21-25
I40	69,927	1,337	NC49	3,422	97
I85	42,960	908	NC66	3,264	70
US74	21,763	419	NC150	3,390	71
I77	21,322	400	NC24	7,585	150
I95	21,007	410	NC16	6,050	160
I440	9,037	143	NC87	5,446	100
I485	8,858	140	NC54	4,192	53
I40/85	5,803	101	US1	11,772	277
I40/440	3,791	62	US117	9,398	178
I540	3,524	64	US220	7,245	147
US70	17,763	271	US321	5,047	120
US64	15,009	274	SR2029	2,302	40
US17	13,195	304	SR4450	2,262	40
US421	12,186	234	SR1002	2,169	27
I26	10,287	162	SR1101	1,501	100

Note: The SR results in the table do not distinguish different SRs by County. The results represent statewide frequencies for the same SR #.

Conclusions and Recommendations

The spreadsheet approach for creating the overweight truck traffic profiles is good and provides insightful graphical representations of where the traffic is high. Furthermore, the method ranks highways by functional class and the amount of permitted overweight truck traffic they carry. Such information may be used by planners and designers of highway, pavement and bridges to provide important overload weights and frequencies of those loads. The information may also be used by enforcement officials to plan enforcement strategies targeted at unpermitted overweight trucks. Further, the information may be used to demonstrate the degree to which overweight trucks use North Carolina highways and contribute their fair share or not to highway maintenance costs.

Analysis also demonstrated that the overweight truck traffic on North Carolina highways appears to be relatively constant throughout the year and that one week's data may be used instead of an entire year's data.

The approach has one drawback in that the process does not account for travel direction of each truck. Direction is important to include because interstate travel lanes are physically separated from one another, and in essence, are two different roads. So, for any segment the method does not distinguish the directional distribution of overweight truck traffic. This information would be very useful for engineers, planners, and policy makers as they attempt to pinpoint segments of the roadway carrying the most overweight trucks. Furthermore, day and time of day travel are not incorporated into the analysis. Since NCDOT sometimes sets time restrictions for overweight loads on flexible pavements (e.g., at night when the pavement is cooler and less likely to deform), time should be added to the overweight vehicle dataset.

Two recommendations for future research and application are to improve the profiling process to incorporate direction of truck travel into the final graphic output and to extend the method to other highly used Interstate and US highway segments.

Perhaps most importantly future research should examine the driver application, data collection, and routing process for permitted overweight trucks at NCDOT. The goal would be to determine if computer mapping and routing methods such as those available in the NCDOT GIS Unit (ArcGIS, ArcInfo, ArcMap, etc.) and in the Transportation Planning Branch (TransCAD) can provide improved overweight route planning methods and subsequent assessment methods like those prototyped in this research.

9. Truck Flows on State Routes

This chapter presents a study of the truck flows on secondary roads designated as state routes. State routes (SR) play a significant role in the overall highway network, often providing connections to and from major traffic generators. Although state routes were not an initial focus of the project, it became apparent as the project progressed, that the project team needed to learn about the way trucks use these highways. NCDOT asked for a short list of state routes on which classification counts would be useful; The research team specifically selected high truck volume SR segments, many of these counts were conducted; and this chapter presents the findings from the data obtained.

Introduction

State routes look like "county roads." Two illustrations are helpful. One is SR 1101, called Pear Tree Road, located in Elizabeth City, NC, in Pasquotank County. Shown in the picture below, it runs northwest to southeast, just south of a major quarry.

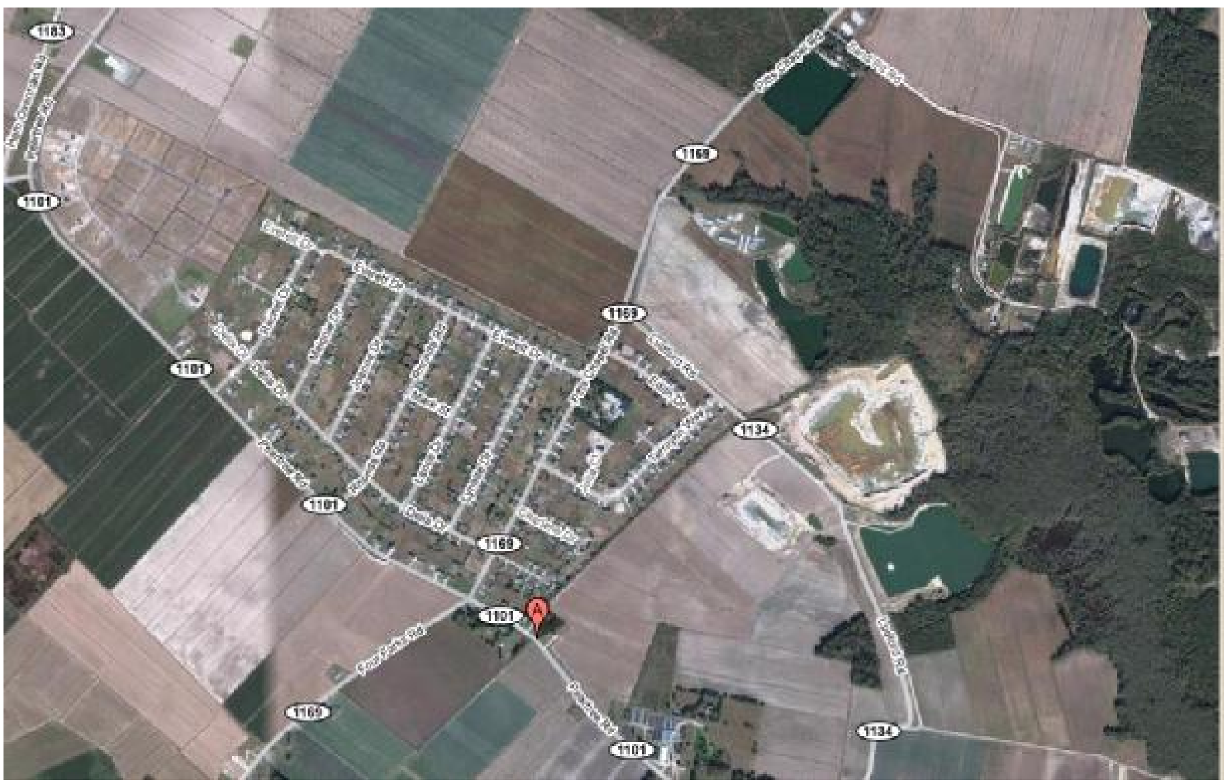


Figure 9-1 State Route 1101, Pasquotank County, Elizabeth City, NC

Another example is SR 1608 in Wilson County. Called Wilco Boulevard (South), in Wilson, NC, it is located just east of US 301 and runs along the southwest side of a major industrial park. It sees significant truck traffic going to and from the tenants of the park.

Figure 9-2 SR 1608, Wilson County, Wilson, NC

State routes represent about 50,000 miles of highway[7], even though they are not necessarily very long. Each county has many SR's using local names, but the SR # is often re-used by other counties (unlike NC or US #s). Local road names distinguish the different SR's with the same #.

Initial Analysis

Because NCDOT could only afford to do classification counts on a limited number of SRs, it was important to select ones where heavy truck use might be present. NCDOT Division Engineers identified 105 state routes where counts might be conducted.

A GIS-based method was then used to select 30 representative SRs from among the 105 candidates.[8] Twenty-nine (29) of these sites and five (5) bypass routes are listed in Tables 9-1 and 9-2 and used for the analysis.[9] The idea was to select SRs that were near areas of high truck traffic, but not near one another. Truck traffic proxy was estimated using employment data for the 250,000 employers in North Carolina. Sixty-five thousand of these employers were studied in detail because the Quick Response Freight Manual suggested, based on the employment data from the North Carolina Employment Securities Commission, that these establishments were likely to be generating more than two truck trips per day.

[7] "NCDOT maintains about 80,000 miles of highway statewide. Texas is the only other state in the country that maintains more mileage." From: http://www.ncdot.gov/download/newsroom/FastFacts.pdf . And, secondary road mileage = 3,950.01 + 2,538.96 + 275.81 + 55,370.55 + 1,684.98 = 63,820.31 miles. From: http://www.ncdot.gov/it/img/DataDistribution/RoadMileageReports/Sld2002a/16.pdf

[8] Five (5) additional bypass routes were added, identified by the NC State Highway Patrol as roads truckers use to avoid weigh stations.

[9] One (1) of the thirty sites was dropped from the data collection plan with NCDOT guidance. Hence, a total of thirty-four (34) sites were used in this analysis (29 + 5 bypass = 34).

Each establishment was located on a map and then the truck trip measure for a given SR was the sum of the truck trips generated within 5-miles of the highway. The state routes selected maximized the total truck trips covered and minimized the extent to which the 65,000 employers were double-counted in the total.

Table 9-1 Average Daily Traffic (ADT) by Vehicle Class for the State Route Locations

LOCATION DESCRIPTION				ADT			ADT by Class															
LOC #	COUNTY	ROUTE	LOCATION	PV (1-3)	SU (4-7)	MU (8-13)	1	2	3	4	5	6	7	8	9	10	11	12	13	Total	PctTrk
1	DARE	SR 1217	W OF US 158	10312	477	84	94	7450	2768	36	393	45	3	71	12	1	0	0	0	10873	5.2%
2	PASQUOTANK	SR 1101	S OF NC 344	5375	203	68	31	4008	1336	29	145	27	2	35	33	0	0	0	0	5646	4.8%
3	WILSON	SR 1608	E OF US 301	2438	208	186	3	1865	570	26	107	70	5	28	134	19	0	0	5	2832	13.9%
4	CARTERET	SR 1147	S OF US 70	2470	151	28	12	1708	750	9	131	10	1	21	6	1	0	0	0	2649	6.8%
5	DUPLIN	SR 1501	E OF NC 403	1724	71	174	4	1394	326	16	40	13	2	12	159	2	0	0	1	1969	12.4%
6	SAMPSON	SR 1134	N OF NC 903	698	48	37	3	516	179	9	31	8	0	6	31	0	0	0	0	783	10.9%
7	ONSLOW	SR 1227	S OF US 258/NC 24	2697	311	159	14	2010	673	31	87	177	16	13	113	27	1	1	4	3167	14.8%
8	ONSLOW	SR 1518	E OF US 17	1945	137	76	12	1408	525	14	109	13	1	29	45	2	0	0	0	2158	9.9%
9	PENDER	SR 1520	N OF NC 210	902	55	27	9	760	133	10	30	13	2	4	20	2	0	0	1	984	8.3%
10	GRANVILLE	SR 1728	S OF US 15	3160	105	46	12	2585	563	18	60	23	4	20	22	4	0	0	0	3311	4.6%
11	ROBESON	SR 1005	N OF SR 1958	2720	150	78	24	2135	561	11	74	57	8	23	53	2	0	0	0	2948	7.7%
12	ALAMANCE	SR 2321	N OF SR 1136	3091	184	311	40	2346	705	14	135	31	4	32	269	9	0	0	1	3586	13.8%
13	ALAMANCE	SR 2326	E OF SR 2321	1641	134	364	18	1202	421	12	101	21	0	22	331	11	0	0	0	2139	23.3%
14	GUILFORD	SR 2133	E OF SR 2016	6340	354	162	39	5090	1211	77	207	47	23	74	71	14	0	0	3	6856	7.5%
15	RANDOLPH	SR 1595	N OF SR 1558	6671	280	196	70	5349	1252	54	194	32	0	69	118	2	6	0	1	7147	6.7%
16	HOKE	SR 1406	W OF SR 1412	2914	121	31	15	2316	583	36	62	22	1	22	7	1	0	0	1	3066	5.0%
17	DAVIDSON	SR 2024	E OF SR 2123	646	235	123	12	522	112	1	27	177	30	6	97	20	0	0	0	1004	35.7%
18	UNION	SR 1501	S OF POPLIN RD	9944	414	144	68	7938	1938	34	284	89	7	56	81	7	0	0	0	10502	5.3%
19	CABARRUS	SR 1002	N OF NC 152	5588	247	74	18	4478	1092	31	193	17	6	29	44	1	0	0	0	5909	5.4%
20	CABARRUS	SR 1394	E OF SR 1305	12019	656	218	44	9710	2265	87	434	113	22	83	125	8	1	0	1	12893	6.8%
21	MECKLENBURG	SR 1625	S OF I-85	6022	606	384	61	4558	1403	108	366	109	23	102	243	19	12	5	3	7012	14.1%
22	MECKLENBURG	SR 1601	N OF DILLING FARM RD	5641	338	338	49	4473	1119	60	188	87	3	83	245	8	0	0	2	6317	10.7%
23	CALDWELL	SR 1310	W OF SR 1392	5011	472	129	74	3968	969	48	213	200	11	34	91	3	0	0	1	5612	10.7%
24	YADKIN	SR 1510	S OF SR 1508	918	40	65	11	705	202	4	32	4	0	12	8	1	43	0	1	1023	10.3%
25	GASTON	SR 1307	N OF I 85	8750	291	141	73	7277	1400	37	223	28	3	55	82	4	0	0	0	9182	4.7%
26	IREDELL	SR 1005	S OF SR 1629	4435	211	105	50	3552	833	21	161	28	1	47	54	4	0	0	0	4751	6.7%
27	IREDELL	SR 1006	E OF SR 1753	2556	125	20	25	2067	464	31	82	12	0	12	6	2	0	0	0	2701	5.4%
28	BUNCOMBE	SR 1718	E OF PATTI LANE	574	348	137	21	381	172	26	54	207	61	12	96	26	0	0	3	1059	45.8%
29	McDOWELL	SR 1246	W OF LYTLE MOUNTAIN RD	683	37	95	17	483	183	5	28	4	0	8	70	12	0	1	4	815	16.2%
30	MITCHELL	SR 1121	S OF HALLTOWN RD	1669	99	23	19	1313	337	7	77	15	0	10	12	1	0	0	0	1791	6.8%
31	RUTHERFORD	SR 2169	S OF US 74 A	9166	422	457	107	7495	1564	56	277	86	3	74	373	6	3	0	1	10045	8.8%
32	CHEROKEE	SR 1537	S OF SR 1544	471	156	13	13	302	156	2	29	124	1	6	4	2	0	0	1	640	26.4%
33	HENDERSON	SR 1006	N OF SR 1513	7917	431	128	98	6336	1483	58	207	136	30	56	53	15	0	0	4	8476	6.6%
34	TRANSYLVANIA	SR 1540	S OF SR 1504	3873	227	48	26	2893	954	12	179	32	4	29	16	2	0	0	1	4148	6.6%
				1	Motorcycles			4	Buses			7	4+ axle SUTs			10	6+ axle STTs				
				2	Passenger Cars			5	2-axle, 6-tire SUTs			8	<=4-axle STTs			11	<=5-axle MTTs				
				3	Other 2-axle, 4-tire SUVs			6	3-axle SUTs			9	5-axle STTs			12	6-axle MTTs				
																13	7+ axle MTTs				

Table 9-2 Percentage ADT by Vehicle Class for the State Route Locations

LOCATION DESCRIPTION				ADT by Class														
LOC #	COUNTY	ROUTE	LOCATION	1	2	3	4	5	6	7	8	9	10	11	12	13	Total	PctTrk
1	DARE	SR 1217	W OF US 158	0.9%	68.5%	25.5%	0.3%	3.6%	0.4%	0.0%	0.7%	0.1%	0.0%	0.0%	0.0%	0.0%	100.0%	5.2%
2	PASQUOTANK	SR 1101	S OF NC 344	0.5%	71.0%	23.7%	0.5%	2.6%	0.5%	0.0%	0.6%	0.6%	0.0%	0.0%	0.0%	0.0%	100.0%	4.8%
3	WILSON	SR 1608	E OF US 301	0.1%	65.9%	20.1%	0.9%	3.8%	2.5%	0.2%	1.0%	4.7%	0.7%	0.0%	0.0%	0.2%	100.0%	13.9%
4	CARTERET	SR 1147	S OF US 70	0.5%	64.5%	28.3%	0.3%	4.9%	0.4%	0.0%	0.8%	0.2%	0.0%	0.0%	0.0%	0.0%	100.0%	6.8%
5	DUPLIN	SR 1501	E OF NC 403	0.2%	70.8%	16.6%	0.8%	2.0%	0.7%	0.1%	0.6%	8.1%	0.1%	0.0%	0.0%	0.1%	100.0%	12.4%
6	SAMPSON	SR 1134	N OF NC 903	0.4%	65.9%	22.9%	1.1%	4.0%	1.0%	0.0%	0.8%	4.0%	0.0%	0.0%	0.0%	0.0%	100.0%	10.9%
7	ONSLOW	SR 1227	S OF US 258/NC 24	0.4%	63.5%	21.3%	1.0%	2.7%	5.6%	0.5%	0.4%	3.6%	0.9%	0.0%	0.0%	0.1%	100.0%	14.8%
8	ONSLOW	SR 1518	E OF US 17	0.6%	65.2%	24.3%	0.6%	5.1%	0.6%	0.0%	1.3%	2.1%	0.1%	0.0%	0.0%	0.0%	100.0%	9.9%
9	PENDER	SR 1520	N OF NC 210	0.9%	77.2%	13.5%	1.0%	3.0%	1.3%	0.2%	0.4%	2.0%	0.2%	0.0%	0.0%	0.1%	100.0%	8.3%
10	GRANVILLE	SR 1728	S OF US 15	0.4%	78.1%	17.0%	0.5%	1.8%	0.7%	0.1%	0.6%	0.7%	0.1%	0.0%	0.0%	0.0%	100.0%	4.6%
11	ROBESON	SR 1005	N OF SR 1958	0.8%	72.4%	19.0%	0.4%	2.5%	1.9%	0.3%	0.8%	1.8%	0.1%	0.0%	0.0%	0.0%	100.0%	7.7%
12	ALAMANCE	SR 2321	N OF SR 1136	1.1%	65.4%	19.7%	0.4%	3.8%	0.9%	0.1%	0.9%	7.5%	0.3%	0.0%	0.0%	0.0%	100.0%	13.8%
13	ALAMANCE	SR 2326	E OF SR 2321	0.8%	56.2%	19.7%	0.6%	4.7%	1.0%	0.0%	1.0%	15.5%	0.5%	0.0%	0.0%	0.0%	100.0%	23.3%
14	GUILFORD	SR 2133	E OF SR 2016	0.6%	74.2%	17.7%	1.1%	3.0%	0.7%	0.3%	1.1%	1.0%	0.2%	0.0%	0.0%	0.0%	100.0%	7.5%
15	RANDOLPH	SR 1595	N OF SR 1558	1.0%	74.8%	17.5%	0.8%	2.7%	0.4%	0.0%	1.0%	1.7%	0.0%	0.1%	0.0%	0.0%	100.0%	6.7%
16	HOKE	SR 1406	W OF SR 1412	0.5%	75.5%	19.0%	1.2%	2.0%	0.7%	0.0%	0.7%	0.2%	0.0%	0.0%	0.0%	0.0%	100.0%	5.0%
17	DAVIDSON	SR 2024	E OF SR 2123	1.2%	52.0%	11.2%	0.1%	2.7%	17.6%	3.0%	0.6%	9.7%	2.0%	0.0%	0.0%	0.0%	100.0%	35.7%
18	UNION	SR 1501	S OF POPLIN RD	0.6%	75.6%	18.5%	0.3%	2.7%	0.8%	0.1%	0.5%	0.8%	0.1%	0.0%	0.0%	0.0%	100.0%	5.3%
19	CABARRUS	SR 1002	N OF NC 152	0.3%	75.8%	18.5%	0.5%	3.3%	0.3%	0.1%	0.5%	0.7%	0.0%	0.0%	0.0%	0.0%	100.0%	5.4%
20	CABARRUS	SR 1394	E OF SR 1305	0.3%	75.3%	17.6%	0.7%	3.4%	0.9%	0.2%	0.6%	1.0%	0.1%	0.0%	0.0%	0.0%	100.0%	6.8%
21	MECKLENBURG	SR 1625	S OF I-85	0.9%	65.0%	20.0%	1.5%	5.2%	1.6%	0.3%	1.5%	3.5%	0.3%	0.2%	0.1%	0.0%	100.0%	14.1%
22	MECKLENBURG	SR 1601	N OF DILLING FARM RD	0.8%	70.8%	17.7%	0.9%	3.0%	1.4%	0.0%	1.3%	3.9%	0.1%	0.0%	0.0%	0.0%	100.0%	10.7%
23	CALDWELL	SR 1310	W OF SR 1392	1.3%	70.7%	17.3%	0.9%	3.8%	3.6%	0.2%	0.6%	1.6%	0.1%	0.0%	0.0%	0.0%	100.0%	10.7%
24	YADKIN	SR 1510	S OF SR 1508	1.1%	68.9%	19.7%	0.4%	3.1%	0.4%	0.0%	1.2%	0.8%	0.1%	4.2%	0.0%	0.1%	100.0%	10.3%
25	GASTON	SR 1307	N OF I 85	0.8%	79.3%	15.2%	0.4%	2.4%	0.3%	0.0%	0.6%	0.9%	0.0%	0.0%	0.0%	0.0%	100.0%	4.7%
26	IREDELL	SR 1005	S OF SR 1629	1.1%	74.8%	17.5%	0.4%	3.4%	0.6%	0.0%	1.0%	1.1%	0.1%	0.0%	0.0%	0.0%	100.0%	6.7%
27	IREDELL	SR 1006	E OF SR 1753	0.9%	76.5%	17.2%	1.1%	3.0%	0.4%	0.0%	0.4%	0.2%	0.1%	0.0%	0.0%	0.0%	100.0%	5.4%
28	BUNCOMBE	SR 1718	E OF PATTI LANE	2.0%	36.0%	16.2%	2.5%	5.1%	19.5%	5.8%	1.1%	9.1%	2.5%	0.0%	0.0%	0.3%	100.0%	45.8%
29	McDOWELL	SR 1246	W OF LYTLE MOUNTAIN RD	2.1%	59.3%	22.5%	0.6%	3.4%	0.5%	0.0%	1.0%	8.6%	1.5%	0.0%	0.1%	0.5%	100.0%	16.2%
30	MITCHELL	SR 1121	S OF HALLTOWN RD	1.1%	73.3%	18.8%	0.4%	4.3%	0.8%	0.0%	0.6%	0.7%	0.1%	0.0%	0.0%	0.0%	100.0%	6.8%
31	RUTHERFORD	SR 2169	S OF US 74 A	1.1%	74.6%	15.6%	0.6%	2.8%	0.9%	0.0%	0.7%	3.7%	0.1%	0.0%	0.0%	0.0%	100.0%	8.8%
32	CHEROKEE	SR 1537	S OF SR 1544	2.0%	47.2%	24.4%	0.3%	4.5%	19.4%	0.2%	0.9%	0.6%	0.3%	0.0%	0.0%	0.2%	100.0%	26.4%
33	HENDERSON	SR 1006	N OF SR 1513	1.2%	74.8%	17.5%	0.7%	2.4%	1.6%	0.4%	0.7%	0.6%	0.2%	0.0%	0.0%	0.0%	100.0%	6.6%
34	TRANSYLVANIA	SR 1540	S OF SR 1504	0.6%	69.7%	23.0%	0.3%	4.3%	0.8%	0.1%	0.7%	0.4%	0.0%	0.0%	0.0%	0.0%	100.0%	6.6%
NC	ADT WEIGHTED AVERAGE			0.8%	71.8%	19.0%	0.7%	3.2%	1.3%	0.2%	0.8%	2.0%	0.2%	0.0%	0.0%	0.0%	100.0%	8.5%
US	RURAL MINOR ARTERIAL (FUNCTIONAL CLASS 6)			0.1%	72.2%	19.1%	0.3%	2.2%	0.7%	0.1%	1.6%	3.5%	0.1%	0.1%	0.0%	0.0%	100.0%	8.6%
US	RURAL COLLECTOR (FUNCTIONAL CLASS 7)			0.0%	74.5%	18.2%	0.4%	3.7%	0.6%	0.0%	0.9%	1.5%	0.0%	0.0%	0.0%	0.0%	100.0%	7.1%

1 Motorcycles	4 Buses	7 4+ axle SUTs	10 6+ axle STTs
2 Passenger Cars	5 2-axle, 6-tire SUTs	8 <=4-axle STTs	11 <=5-axle MTTs
3 Other 2-axle, 4-tire SL	6 3-axle SUTs	9 5-axle STTs	12 6-axle MTTs

To ensure that the locations were distributed geographically, the SR count locations were selected from six regional categories: Rural-Mountain, Urban-Mountain, Rural-Central, Urban-Central, Rural-Coastal, and Urban-Coastal. Five count locations were selected for each. Table 9-2 shows the percentages of truck traffic for each site, the ADT-weighted percentage breakdown for all 34 sites combined, as well as national data for FHWA highway functional classifications 6 (Rural Minor Arterial) and 7 (Rural Collector).[10]

Important observations are that:

- The percent trucks on these state routes (last column) is typical of rural minor arterials nationwide but in excess of rural collectors.
- The percentage of class 5 vehicles (2-axle, 6-tire, single unit trucks) is comparable to that of rural collectors, but higher than rural minor arterials.
- The percentage of class 9 vehicles (5-axle, tractor with single trailer trucks) is less than that for rural minor arterials but higher than rural collectors.
- The ADT's are typical for rural highways, with the maximum being 12,893 vehicles per day (in Cabarrus County).
- The truck percentage for some of these roads is very high. For location 28, it is 45.8%; for location 15, it is 35.7%.
- 40% of the sites have a truck percentage in excess of 10%.
- 10% of the sites have a truck percentage over 25%.
- Most of the large truck volumes are for single unit trucks, and within that cluster, FHWA class 5.[11]
- Six sites (18%) have multiple-unit truck volumes greater than 200 trucks per day (12, 13, 20, 21, 22, and 31); the predominant truck type is FHWA Class 9; and for four of them, there are also large single-unit-truck volumes (20, 21, 22, 31).

A next comparison is the percentage breakdown of FHWA vehicle classes for these facilities compared with WIM sites in similar situations, as in coastal-rural SR's versus coastal-rural WIM sites, etc. The breakdowns of counts by FHWA vehicle class for the corresponding WIM sites were aggregated and averaged and then plotted along with the percentage breakdowns for the individual state route locations.

As Figures 9-3 through 9-8 show, the trends are clear and consistent. In almost every case, the state routes have more vehicles at lower truck classes and less at the higher ones. For example, SR 1406 (Hoke County, Rockfish, NC), shown in Figure 9-3, reaches 80% of its total truck volume at FHWA vehicle class 7, while the corresponding WIM stations have only seen 40% of their truck traffic for vehicle classes 7 or lower. Only SR 1501 (Duplin County, Calypso, NC) sees more vehicles in FHWA class 9 than does the typical WIM site. While this does not tell a story about differences in the axle load distributions, it clearly indicates that there are more trucks of lower vehicle classes on the State Routes than for the comparable WIM sites, with the most significant difference being the percent of vehicles in FHWA class 9.

---

[10] Hallenbec, M., M. Rice, B, Smith, C. Cornell-Martinez, and J. Wilkinson, Vehicle Volume Distributions by Classification, Washington State Transportation Center (TRAC), July 1997.

[11] This is not unexpected, but it is interesting that intuition is consistent with reality.

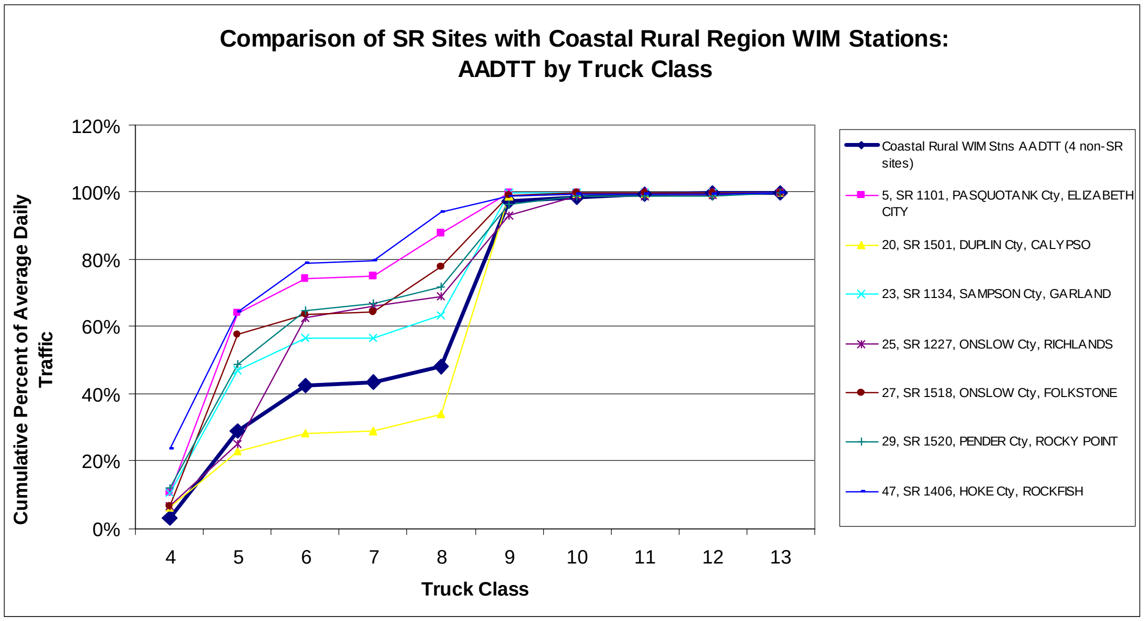


Figure 9-3 Coastal, Rural State Routes

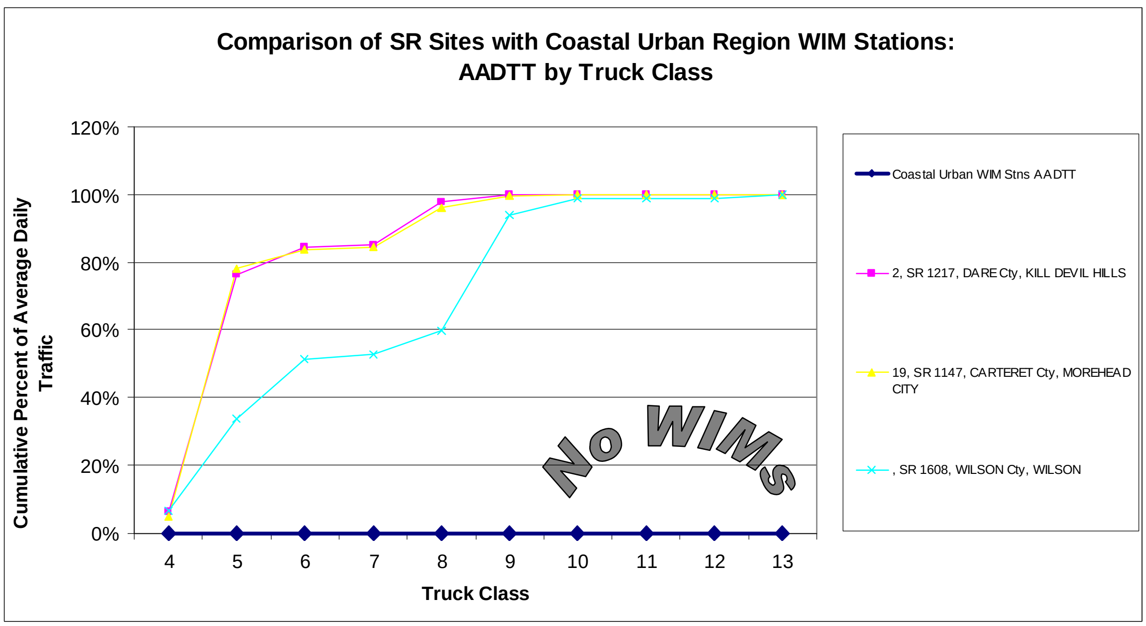


Figure 9-4 Coastal, Urban State Routes

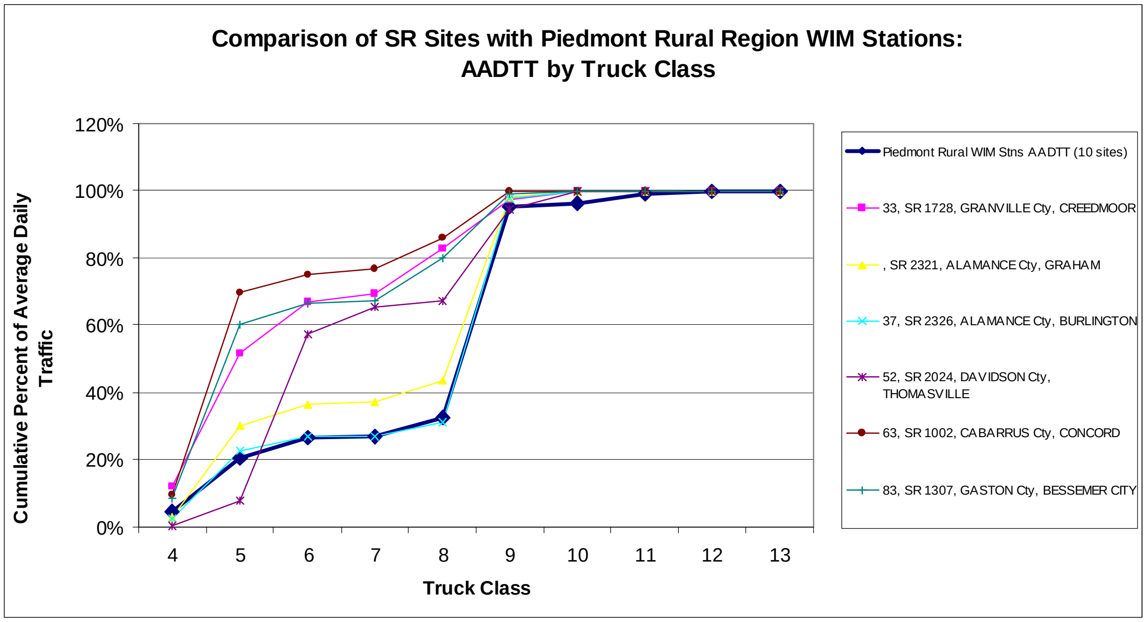


Figure 9-5 Piedmont, Rural State Routes

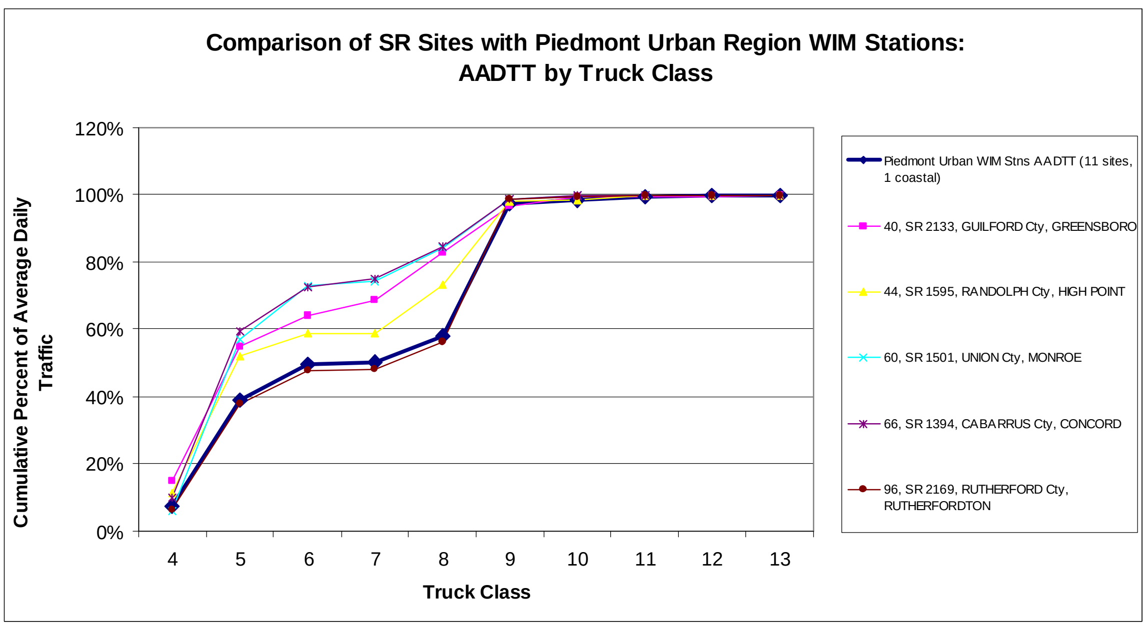


Figure 9-6 Piedmont, Urban State Routes

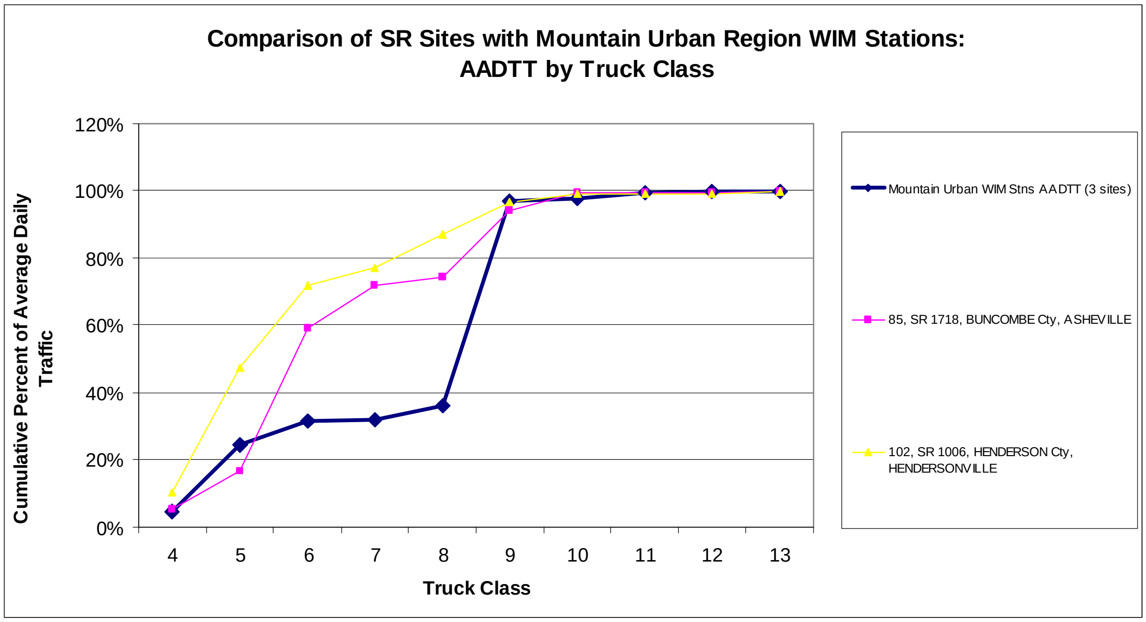


Figure 9-7 Mountain, Urban State Routes

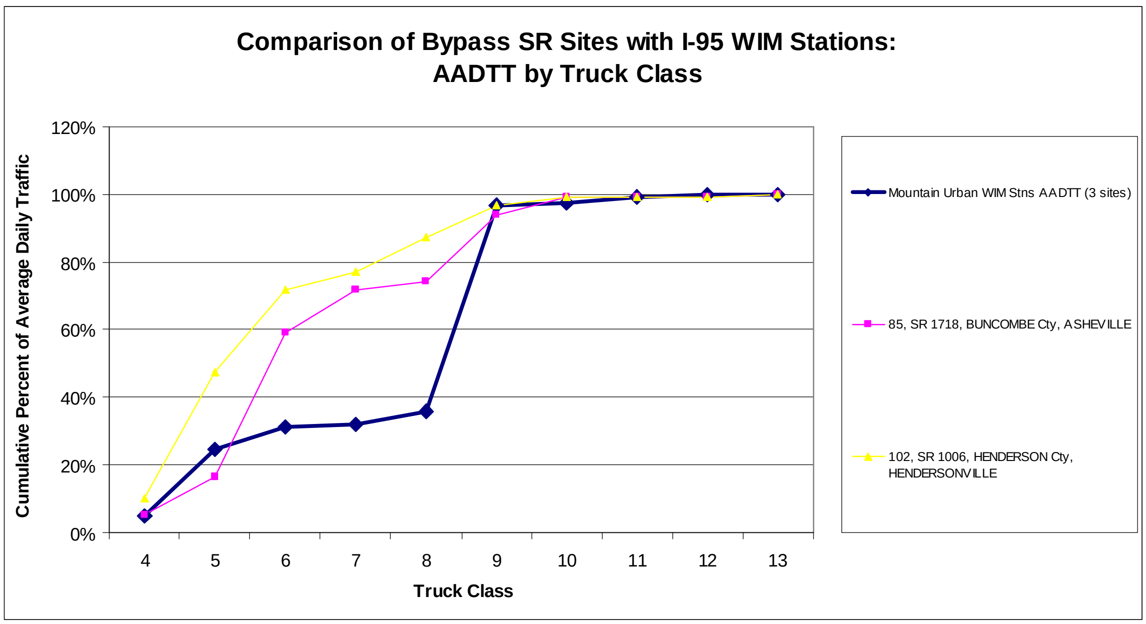


Figure 9-8 I-95 Bypass State Routes

A second analysis of the SR data shows differences in this same information in tabular form. Table 9-3 shows that, percentage-wise, the State Routes have at least twice as many trucks in Classes 4 through 8 as do the WIM stations; but they have less than half as many in Class 9. In some cases, the ratios are strikingly different as in the I-95 Bypass state routes, where the Class 5 percentage on the State Routes is 43.1% while on I-95, the percentage at the WIM station is only 9.5%. Correspondingly, for these locations, the Class 9 percentage is only 20.5% on the State Routes while it is 75% on I-95.

Table 9-3 Percentage Distributions by Truck Class – WIM versus SRs by Region

Truck Class	Coastal-Rural		Piedmont-Rural		Piedmont-Urban		Mountian-Rural		Mountain-Urban		I-95 ByPass		Overall Ratio
	WIM	SRs	WIM	SRs	WIM	SRs	WIM	SRs	WIM	SRs	WIM	SRs	
4	3.3%	11.0%	4.5%	5.9%	7.4%	9.7%	3.5%	4.5%	4.8%	10.6%	3.6%	12.0%	1.99
5	25.8%	36.2%	15.9%	34.4%	31.6%	42.6%	21.0%	38.7%	19.8%	36.7%	9.5%	43.1%	1.88
6	13.4%	14.1%	6.0%	14.5%	10.5%	10.9%	6.5%	22.9%	6.8%	18.0%	3.9%	10.3%	1.93
7	1.1%	1.2%	0.5%	2.4%	0.8%	1.7%	0.6%	0.6%	0.6%	3.5%	0.1%	0.8%	2.72
8	4.6%	8.7%	5.9%	7.9%	7.6%	11.4%	7.9%	7.6%	4.0%	9.7%	5.9%	11.4%	1.58
9	49.3%	26.8%	62.6%	32.5%	39.4%	22.0%	56.5%	15.6%	60.8%	18.5%	75.0%	20.5%	0.40
10	1.0%	1.5%	0.9%	2.3%	1.1%	1.2%	0.7%	2.2%	0.8%	2.3%	0.6%	1.4%	2.13
11	1.1%	0.0%	2.9%	0.0%	1.0%	0.3%	2.6%	6.8%	1.8%	0.2%	0.7%	0.3%	0.76
12	0.4%	0.0%	0.7%	0.0%	0.5%	0.0%	0.7%	0.1%	0.5%	0.1%	0.6%	0.1%	0.11
13	0.1%	0.4%	0.2%	0.0%	0.1%	0.2%	0.1%	0.9%	0.1%	0.3%	0.2%	0.1%	2.91

Axle Weight Distribution Comparisons

An analysis of the axle weight distributions for these sites is a very important thing to do if possible. It can be done if one assumption is made about the characteristics of the trucks using the State Routes. That assumption is: the distribution of axle configurations and axle load distributions for 42 WIM sites in NC is reasonably representative of the axle load distributions for the State Routes. Admittedly, local data specific to the individual State Routes would be much better to use, but those data are not available; and there are too few WIM sites in any one of the individual regional classes (e.g., coastal-urban) to develop meaningful, defensible axle load distributions.

Borrowing from the ongoing MEPDG project, axle configurations and axle weight distributions were developed from 42 WIM sites statewide currently under study. The methodology employed was as follows:

- Determine the distribution of axle weights for single, tandem, tridem, and quad axle configurations[12] observed at 42 WIM sites for vehicles in FHWA Vehicle Classes 4-13. For example, Table 9-4 below shows the distribution for vehicles in FHWA Class 5.

Table 9-4 Statewide Load Spectra (binned by KIPS and Axle Configuration) for Vehicle Class 5

Axle Type	Total	0	12	15	18	21	24	27	30	33	36	39	42
Single	1300530	0	1235452	35501	16239	8376	3216	1202	366	112	47	14	6
Tandem	5	0	3	1	0	0	0	0	0	0	0	0	0
Tridem	0	0	0	0	0	0	0	0	0	0	0	0	0
Quad	0	0	0	0	0	0	0	0	0	0	0	0	0

- Determine the average number of single, tandem, tridem, and quad axles that can be found on vehicles in FHWA Vehicle Classes 4-13. Axle weight distributions were found for each of these axle configurations for every FHWA vehicle class.

[12] This is the terminology being used in the MEPDG project to describe axle clusters with one, two, three, and four axles.

Table 9-5 Average Numbers of Axles by Configuration and FHWA Truck Type

Truck Type	Single	Tandem	Tridem	Quad
4	1.81	0.19	0.00	0.00
5	2.00	0.00	0.00	0.00
6	1.09	0.95	0.00	0.00
7	1.09	0.17	0.81	0.00
8	2.43	0.57	0.00	0.00
9	1.18	1.91	0.00	0.00
10	1.04	1.25	0.50	0.16
11	4.85	0.01	0.00	0.00
12	3.79	0.95	0.00	0.00
13	1.55	1.60	0.36	0.19

- From the above, determine the percentage distributions for axle loads for vehicles in each FHWA Vehicle Class as shown in Table 9-6 below.

Table 9-6 Number of Axles by Axle Weight Class (KIPs) for Each FHWA Truck Class

	Weight Bin																					
VCls	0	12	15	18	21	24	27	30	33	36	39	42	45	48	51	54	57	60	63	66	69	72
4	0	1.48	0.24	0.09	0.05	0.04	0.03	0.03	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0	1.90	0.05	0.02	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0	1.26	0.30	0.15	0.07	0.05	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0	0.48	0.36	0.19	0.09	0.05	0.04	0.04	0.06	0.09	0.12	0.15	0.14	0.10	0.07	0.04	0.02	0.01	0.01	0.00	0.00	0.00
8	0	2.36	0.31	0.17	0.08	0.04	0.02	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0	1.40	0.39	0.25	0.17	0.15	0.16	0.19	0.17	0.13	0.05	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0	1.05	0.33	0.22	0.17	0.15	0.17	0.18	0.13	0.12	0.10	0.10	0.07	0.04	0.03	0.02	0.02	0.01	0.01	0.01	0.00	0.00
11	0	3.17	1.05	0.45	0.15	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0	3.15	0.76	0.39	0.25	0.14	0.03	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0	1.93	0.24	0.12	0.12	0.12	0.12	0.12	0.10	0.10	0.10	0.12	0.13	0.11	0.08	0.06	0.05	0.03	0.02	0.01	0.01	0.01

- Use the data from Table 9-6 in conjunction with the breakdowns of trucks observed by truck class (see Table 9-1) to develop breakdowns of axle loadings for each State Route location and corresponding composite set of WIM stations as shown in Table 9-7 next:

Table 9-7 Axle Weight Distributions for Each State Route in the Piedmont-Urban Region and the Corresponding WIM Stations[13]

Piedmont-Urban Axle Load Breakdowns						
				State Route		
Wght Bin	WIMs	SR 2133	SR 1595	SR 1501	SR 1394	SR 2169
12	64%	72%	72%	75%	75%	64%
15	74%	81%	81%	84%	83%	74%
18	80%	86%	86%	88%	88%	80%
21	84%	89%	89%	91%	90%	83%
24	87%	91%	91%	92%	92%	86%
27	90%	93%	93%	94%	94%	89%
30	93%	94%	95%	96%	95%	93%
33	96%	96%	97%	97%	97%	96%
36	98%	97%	99%	98%	98%	98%
39	99%	98%	99%	99%	99%	99%
42	99%	99%	100%	99%	99%	100%
45	100%	99%	100%	100%	100%	100%

Figures 9-9 through 9-15 display these results in graphical format for each region.

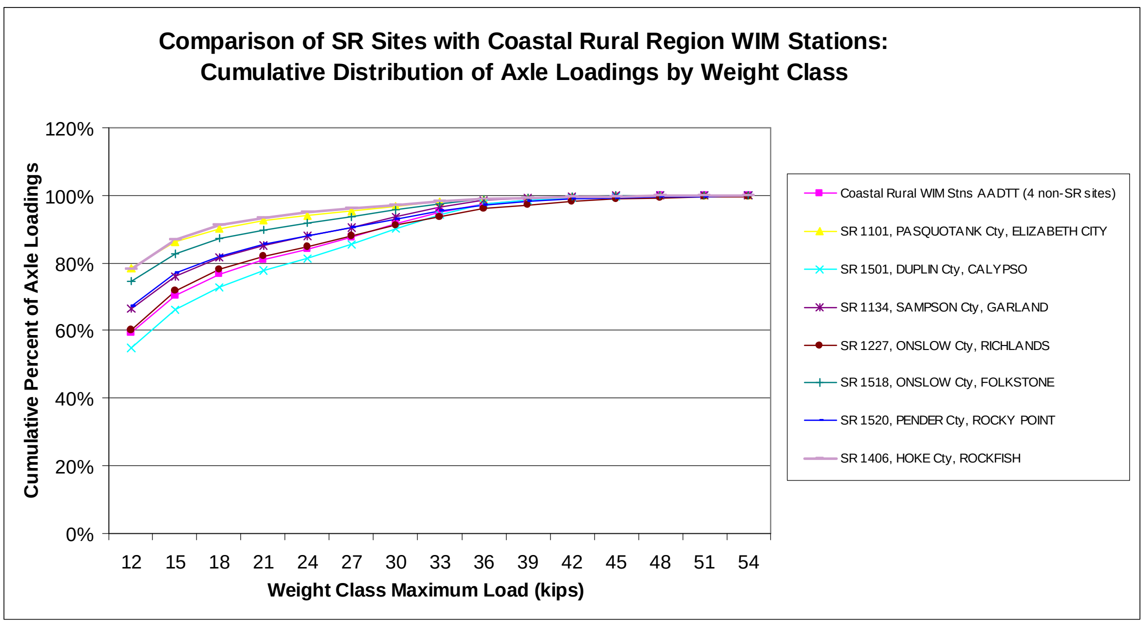


Figure 9-9 Coastal, Rural State Routes

[13] The Excel Workbooks supporting this analysis contain corresponding tables for all of the analysis regions.

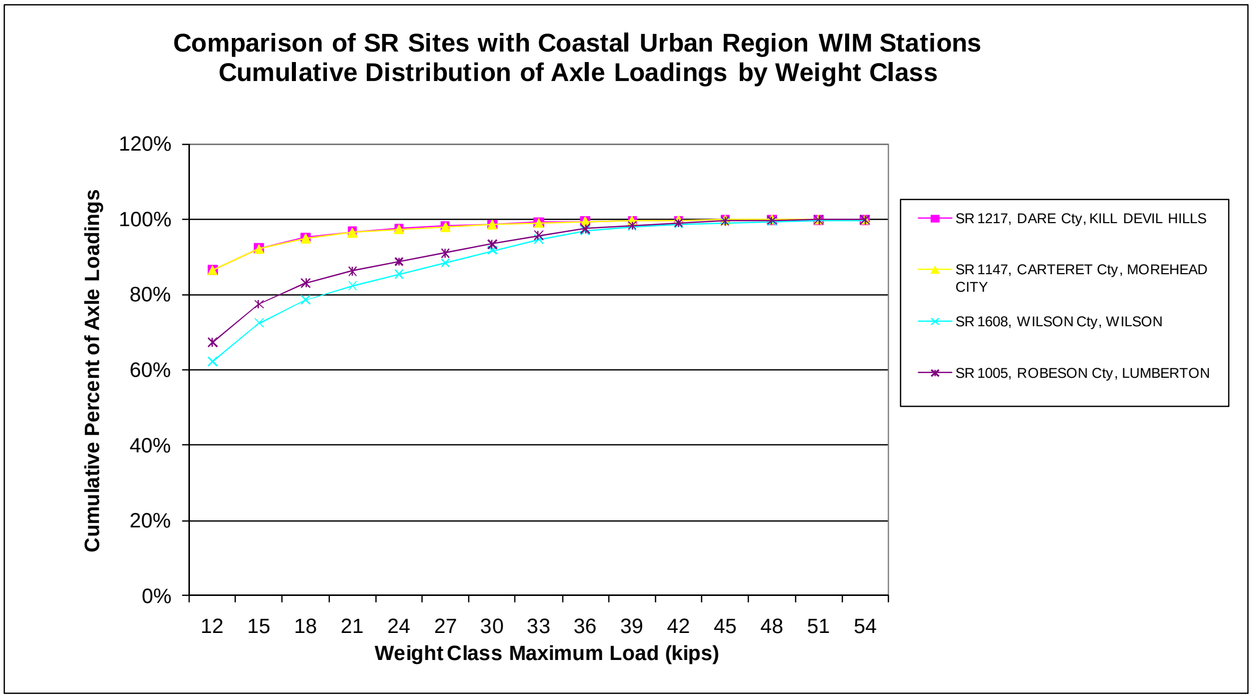


Figure 9-10 Coastal, Urban State Routes

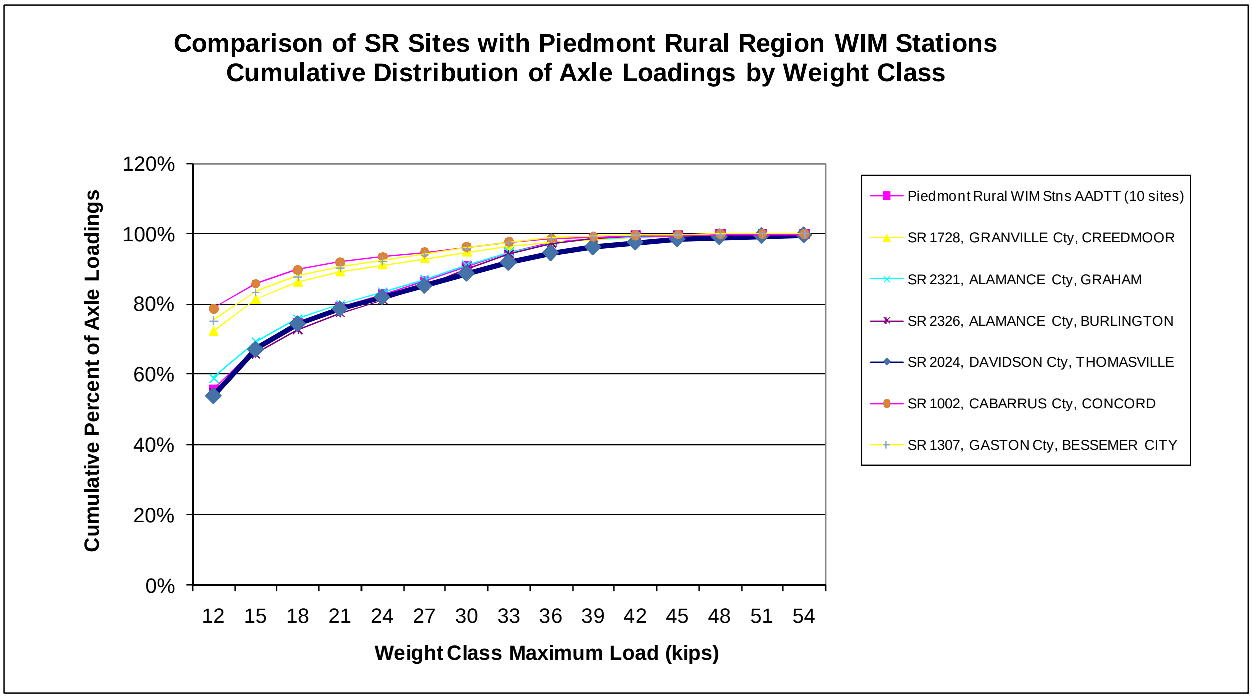


Figure 9-11 Piedmont, Rural State Routes

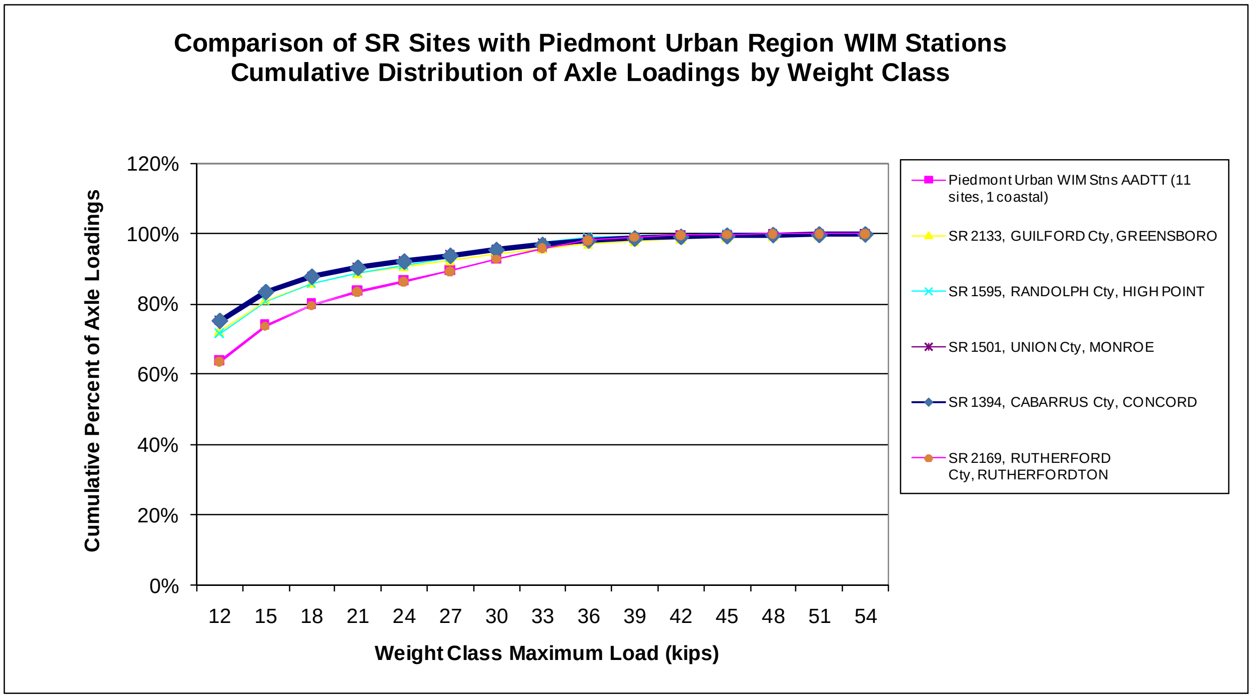


Figure 9-12 Piedmont, Urban State Routes

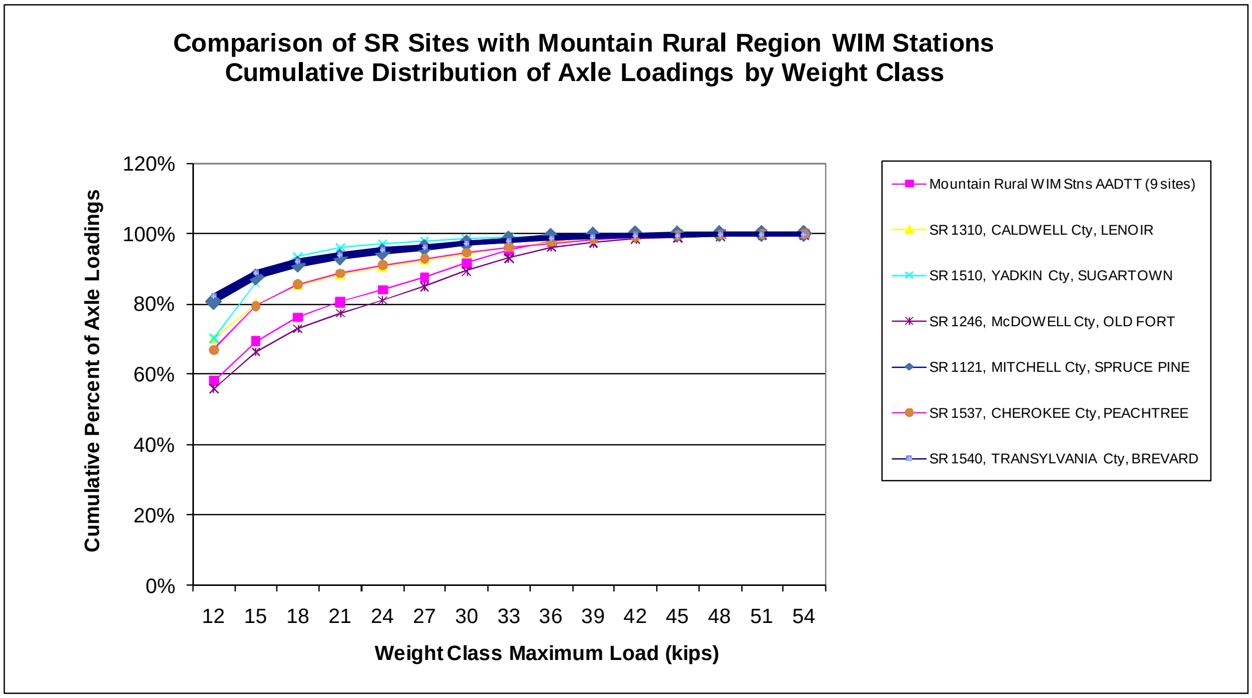


Figure 9-13 Mountain, Rural State Routes

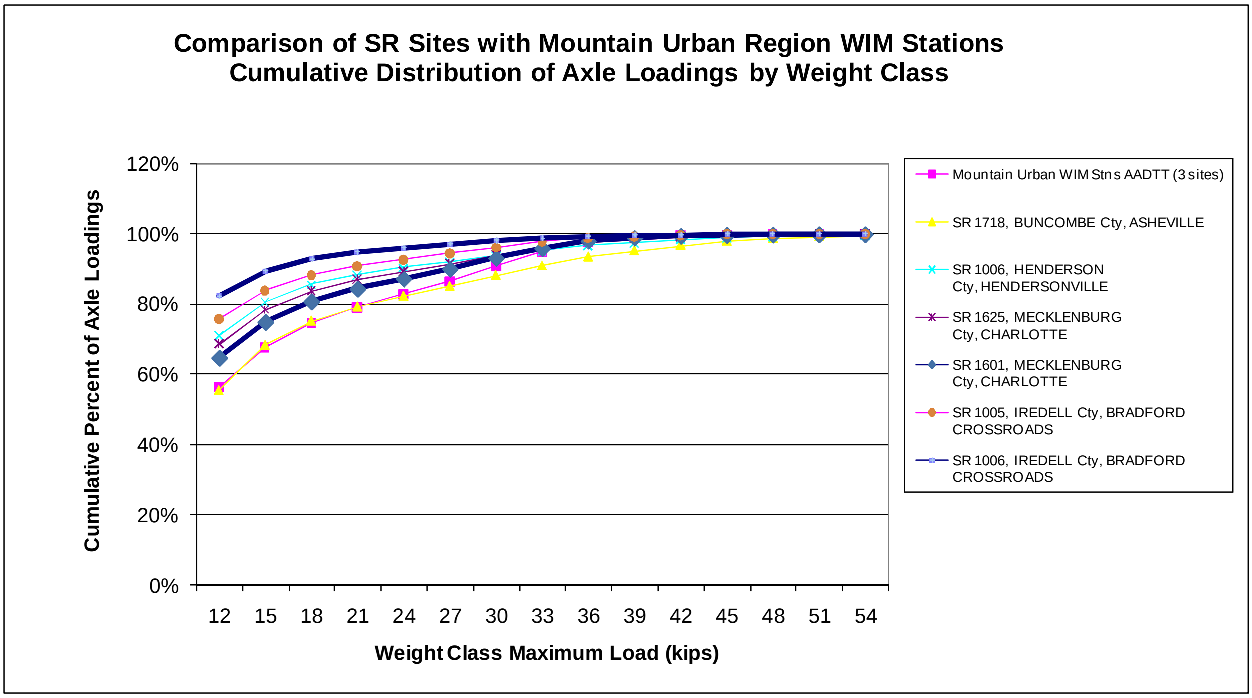


Figure 9-14 Mountain, Urban State Routes

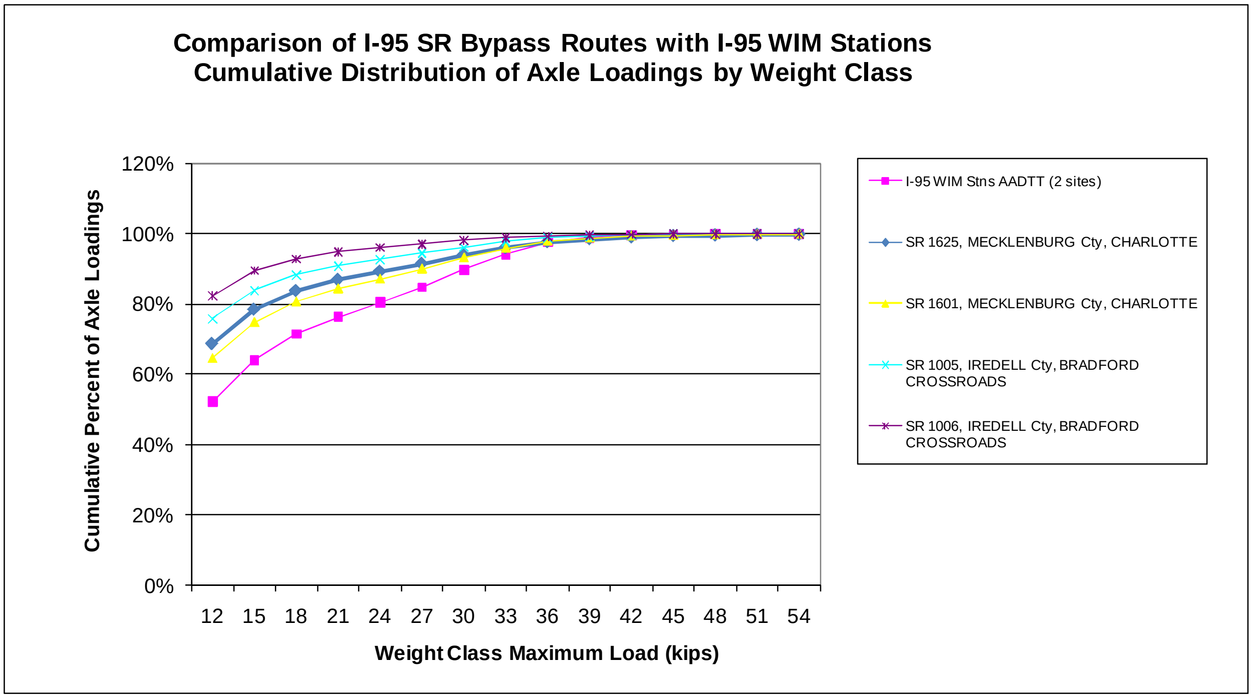


Figure 9-15 I-95, Bypass State Routes

Several important observations from this analysis are as follows:

- The WIM sites almost always have axle load distributions that exceed those of the State Routes. This is true because the distributions for the WIM sites are below and to the right of those for the State Routes.
- However, many of the State Routes have axle weight distributions that come close to matching or exceeding those observed for the WIM stations.
- Two State Routes appear to have axle load distributions which involve more, heavier axle loads than the WIM sites. They are:[14]
    - SR 1501, Duplin County, Calypso, in the Coastal Rural Region, which is near a manufacturing plant; and
    - SR 1246, McDowell County, Old Fort, in the Mountain Rural Region, which is near a commercial area.

Conclusions and Recommendations

The conclusions/recommendations from this analysis are as follows:

- There are state routes where the truck traffic is considerable. These state routes should continue to be monitored in the future.
- The 34 sites studied have truck traffic percentages typical nationwide of rural minor arterials, but higher than rural collectors.
- The state routes sampled see higher percentages of trucks in Classes 4-8 and smaller percentages in Classes 9-13, except Class 10 (6+ axle single trailer trucks). This trend holds true across all the state routes regardless of where they are located.
- The method by which the representative sites were chosen worked very well. With only a couple of exceptions, it identified highways with heavy truck flows. NCDOT should continue to use this procedure in the future to select additional state routes to add to the three-year classification count cycle.
- Many of the State Routes have axle weight distributions that come close to matching those observed for the WIM stations.

[14] NC DOT might want to check the axle load distributions on these two State Routes to see if the distributions really do exceed WIM station observations.

10. Summary Findings & Conclusions

Summary

The purpose of the Truck Traffic Profiles project is to describe the character (profile) of the truck traffic that travels a wide selection of highways in North Carolina. The key questions the team addressed for the Pavement Management Unit at NCDOT were:

- What are the current NCDOT data sets and methods that support estimation of truck traffic profiles? What are the pros and cons of the methods?
- To what extent are permitted overweight vehicles using North Carolina highways? What highways are most heavily used? What procedures are available to identify typical origins, destinations, and routes for overweight vehicles?
- How can current NCDOT methods for estimating truck traffic on North Carolina highways be improved to include vehicle miles traveled (VMT) by truck class, highway functional classification, and region or county?

Such information supports a variety of issues in planning, design, operations, and policy. For example, knowing truck traffic volumes, size, and weight affects highway lane design, pavement design, structure design, and location of traffic sensors and weigh stations. Such information also helps to enforce weight limits on highways and bridges.

The research approach used a variety of data sources (Chapters 3 and 4) including: NCDOT weigh-in-motion (WIM) data from about 44 stations and 48-hour traffic counts at hundreds of urban and rural highways locations. Plus, special counts were taken on carefully selected low-volume State Route (SR) highways to fill in information gaps for those highways.

Besides the usual statewide summaries (Chapter 5) for vehicle class data by county available at NCDOT, the report describes estimates from a statewide truck network model for total truck vehicle miles traveled (Chapter 6) by region (mountain, central, and coastal) and by highway functional classification. Since class 5 and class 9 trucks are the most numerous trucks, their VMT from the statewide model are provided also. The functionality of the truck network model also estimated typical truck traffic trips by origin, destination, and distance traveled by highway functional class and vehicle type. Such information is usually only available from expensive proprietary data.

Using the inventory of NCDOT weight-in-motion sensors, truck traffic profiles for class 5 and class 9 trucks were developed by gross vehicle weight, vehicle class, highway functional classification, and urban and rural locations (Chapter 7). Special profiles for class 5 recreational vehicles in the mountains and class 9 truck traffic on I-95 were also described.

Because of their impact on pavement condition, overweight trucks were a particular focus of this research (Chapter 8). A one-week sample of all overweight truck permits in August 2006 were examined to describe overweight truck traffic profiles by weight and distance traveled on North Carolina Interstates 40, 95, and 77. The top 10 US, NC and SR routes with the highest permitted overweight truck traffic were also identified.

Another special focus for the research was State Routes (Chapter 9). There are no WIM stations on SRs and there is virtually no weight information available for truck traffic on SRs. However, heavy truck traffic can occur near truck generators like industrial sites, quarries, farms and forests. Using truck class counts on more than 30 SRs with likely truck generators, an innovative analysis compares the SR counts to WIM data on US and Interstate highways.

Products of the project include: (1) a discussion of current truck flow estimation processes in North Carolina; (2) tabular information regarding vehicle weights and distances traveled on specific road classes; (3) a database that includes truck traffic profiles for urban and rural areas by NC region, vehicle classifications, weights, trip lengths, and highway types; (4) permitted overweight truck traffic profiles on three major interstates; (5) frequency of use of permitted overweight trucks on the top 10 highways by functional classification; and (6) truck traffic on a wide selection of State Routes near truck generators.

Findings

It was found that NCDOT extensively uses 48-hour class counts to estimate vehicle travel statewide by highway functional class and vehicle type (Chapter 5). Estimates are also made for sub-regions and counties, though the results are not reliable. Data from 46 WIM stations are used to give detailed weight and axle loading information that helps define pavement design parameters and overweight vehicle pavement impacts. Moreover, estimates of commodities moving on North Carolina highways are also made for four basic commodities. The NCDOT commodity method was expanded to a prototype method for more commodities; however, none of the methods reliably provide commodity flows by highway, highway functional class, sub-region or length of typical trip.

Exploration of vehicle miles traveled (VMT) by truck traffic in NC was done via the truck traffic network model created in the HWY 2006-09 project (Chapter 6). The model has a base year 2006 using the National Planning Highway Network (NHPN), the FHWA FAF2 OD dataset, and adjustments for short-haul truck traffic including empties. The model was calibrated and validated at an R^2 of 0.93. Statewide vehicle miles traveled by the trucks on highways in North Carolina were then estimated. The results were categorized in various ways: VMT by region; VMT by county; and VMT by highway functional class, region, and vehicle class. Comparisons to traditional VMT estimates from NCDOT were found to be good.

Truck traffic flow assignments on the network estimated likely truck routing patterns from county traffic analysis zones (TAZ) origins to county TAZ destinations assuming shortest paths are taken by the drivers. There were also some external path itineraries demonstrated to locations outside of NC (Chapter 6).

Based on the truck network model results (Chapter 6), it was discovered that the total VMT for year 2006 was 21,282,059. The Central region had the highest VMT of 13,829,527 which makes sense because the Triangle, the Triad, and Charlotte are located there. Interestingly, the highest VMT in the Central region is 3,677,480 for rural principal arterials (Interstate), possibly suggesting a high level of travel between the cities. VMTs of 4,239,245 and 3,213,288 were found for the Coastal and Mountain regions, respectively. Vehicle class 5 had a VMT of 5,079,819 across the state with class 9 VMT more than double this level. As expected, VMTs on the interstates for class 9 were much higher than those of all other roads studied. When examining the VMTs of the two most common truck classes (5 and 9), it was estimated that the VMTs for each region and highway functional class were as listed in Tables 10-1 and 10-2.

These results should assist the Pavement Management Unit at NCDOT with gauging the volume of traffic crossing various road types in the three major regions of the state.

Table 10-1 NC Truck Network Model Estimated VMT for Base Year 2006

FFC	Functional Classification	Regional Total Truck VMT			Sub Total
		Central	Coastal	Mountain	
1	Rural Principal Arterial - Interstate	3,677,480	1,006,310	1,273,040	5,956,830
2	Rural Principal Arterial - Other	2,077,461	1,399,812	591,434	4,068,707
6	Rural Minor Arterial	1,288,281	669,308	279,991	2,237,580
7	Rural Major Collector	78,887	97,839	38,607	215,333
8	Rural Minor Collector	41,579	25,949	1,712	69,240
9	Rural Local System	73,825	52,097	58,252	184,175
11	Urban Principal Arterial - Interstate	3,114,324	116,599	539,434	3,770,358
12	Urban Principal Arterial - Other Freeways or Expressways	691,733	95,363	32,131	819,227
14	Urban Principal Arterial - Other	1,193,520	391,234	97,605	1,682,359
16	Urban Minor Arterial	42,002	11,692	3,066	56,760
17	Urban Collector	3,756	3,147	322	7,225
19	Urban Local System	1,728	11,216	1,089	14,033
	Centroid Connector	1,544,950	358,678	296,605	2,200,233
	Sub Total	**13,829,527**	**4,239,245**	**3,213,288**	**21,282,059**

FFC	Functional Classification	Regional Truck VMT for Type 5 (2ASU)			Sub Total	%
		Central	Coastal	Mountain		
1	Rural Principal Arterial - Interstate	383,455	104,929	132,741	621,125	10.4%
2	Rural Principal Arterial - Other	511,069	344,363	145,497	1,000,928	24.6%
6	Rural Minor Arterial	411,671	213,878	89,471	715,019	32.0%
7	Rural Major Collector	33,584	41,652	16,436	91,671	42.6%
8	Rural Minor Collector	20,925	13,059	862	34,846	50.3%
9	Rural Local System	38,040	26,844	30,016	94,900	51.5%
11	Urban Principal Arterial - Interstate	485,948	18,194	84,171	588,313	15.6%
12	Urban Principal Arterial - Other Freeways or Expressways	162,278	22,372	7,538	192,188	23.5%
14	Urban Principal Arterial - Other	426,786	139,900	34,902	601,588	35.8%
16	Urban Minor Arterial	21,343	5,941	1,558	28,842	50.8%
17	Urban Collector	2,078	1,741	178	3,998	55.3%
19	Urban Local System	774	5,022	487	6,284	44.8%
	Centroid Connector	772,475	179,339	148,302	1,100,116	50.0%
	Sub Total	**3,270,425**	**1,117,234**	**692,159**	**5,079,819**	**23.9%**

FFC	Functional Classification	Regional Truck VMT for Type 9 (5AST)			Sub Total	%
		Central	Coastal	Mountain		
1	Rural Principal Arterial - Interstate	2,524,497	690,807	873,910	4,089,214	68.6%
2	Rural Principal Arterial - Other	962,701	648,677	274,072	1,885,451	46.3%
6	Rural Minor Arterial	477,263	247,955	103,727	828,945	37.0%
7	Rural Major Collector	18,094	22,441	8,855	49,390	22.9%
8	Rural Minor Collector	6,289	3,925	259	10,472	15.1%
9	Rural Local System	5,157	3,639	4,069	12,865	7.0%
11	Urban Principal Arterial - Interstate	1,939,545	72,616	335,950	2,348,111	62.3%
12	Urban Principal Arterial - Other Freeways or Expressways	340,494	46,941	15,816	403,251	49.2%
14	Urban Principal Arterial - Other	374,542	122,774	30,630	527,946	31.4%
16	Urban Minor Arterial	5,062	1,409	369	6,841	12.1%
17	Urban Collector	197	165	17	379	5.2%
19	Urban Local System	137	890	86	1,114	7.9%
	Centroid Connector	108,146	25,107	20,762	154,016	7.0%
	Sub Total	**6,762,125**	**1,887,346**	**1,668,523**	**10,317,994**	**48.5%**

An analysis similar to the VMT evaluation was conducted for gross vehicle weights (GVW) by region by highway functional type for class 5 and class 9 trucks (Chapter 7). This analysis was performed with the aid of WIM station data. Based on the results, it was discovered that the highest frequency of trucks (by far) was found to be at the urban WIM stations; however, the majority of class 9 trucks were empty or near empty. The reverse trend, of predominantly loaded class 9 trucks being loaded, was observed to occur at the I-95 WIM stations; this same trend, to a lesser degree, is observed on the rural and recreational routes in the Mountain region. Some seasonal differences are observable, but overall trends were quite consistent. Across all of the regions, Class 9 shows two predominant peaks corresponding with empty and almost-full loadings, 35,000 and 75,000 pounds, respectively. For Class 5, there was a single peak for all regions at 10,000 pounds, again, the empty weight of the vehicle. The results of the GVW analysis are summarized in the following table; note that the scale for all the plots is given in the first plot.

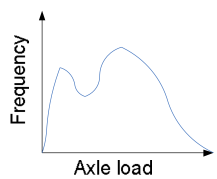
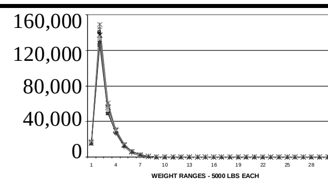
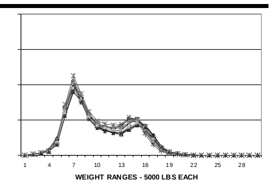
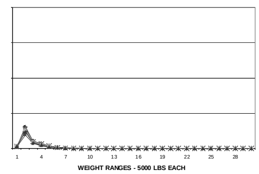
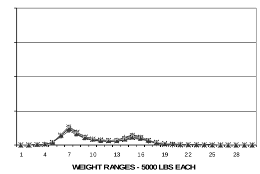
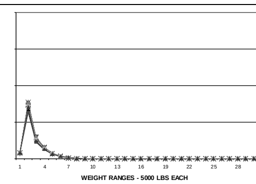
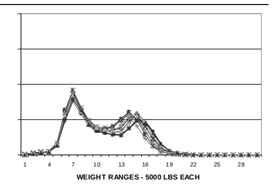
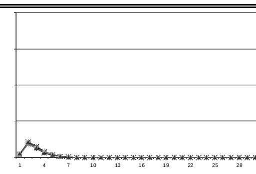
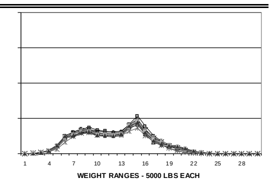
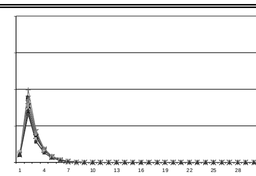
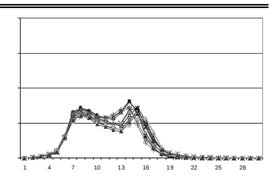
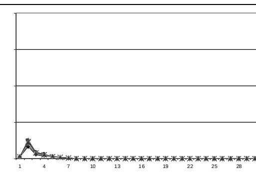
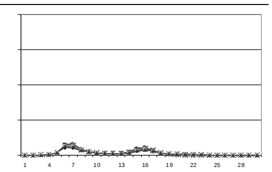
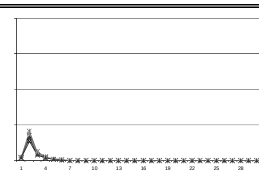
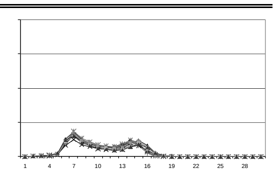
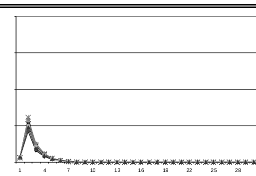
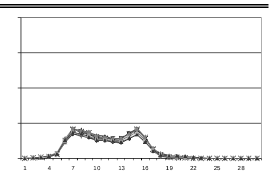
For the permitted overweight truck analysis (Chapter 8), it was discovered that the spreadsheet approach for creating overweight truck traffic profiles was good and provided insightful graphical representations of where the traffic is high. Furthermore, the method ranked highways by functional class and the amount of permitted overweight truck traffic carried. Such information may be used by planners and designers of highway, pavement and bridges to provide important overload weights and frequencies of those loads. The information may also be used by enforcement officials to plan enforcement strategies targeted at unpermitted overweight trucks. Further, the information may be used to demonstrate the degree to which overweight trucks use North Carolina highways and contribute their fair share or not to highway maintenance costs. The analysis also demonstrated that the overweight truck traffic on North Carolina highways appears to be relatively constant throughout the year and that one week’s data may be used instead of an entire year’s data.

Since State Routes are not generally covered by WIM stations, a separate analysis of traffic loadings on SRs in each region was conducted (Chapter 9). The conclusions/recommendations from the SR analysis are as follows:

- There are state routes where the truck traffic is considerable. These state routes should continue to be monitored in the future.
- The 30 sites studied have truck traffic percentages typical nationwide of rural minor arterials, but higher than rural collectors.
- The state routes sampled experience higher percentages of trucks in classes 4-8 and smaller percentages in classes 9-13, except class 10 (6+ axle single trailer trucks). This trend holds true across all the state routes regardless of where the SRs are located.

The method by which the 30 representative sites were chosen worked very well. With only a couple of exceptions, it identified highways with heavy truck flows. NCDOT should continue to use this procedure in the future to select additional state routes to add to the three-year classification count cycle.

Table 10-2 Weight Distribution of Truck Types and North Carolina Highway Type

FHWA Truck Class			Class 5	Class 9
Weight Distribution/ Volume Level by Truck Type by NC Region and Urban or Rural Classification 	**Urban**			
	Rural	Coastal		
		Central		
	I-95			
	Rural & Recreational	Mountains		
		Coastal		
	Urban & Some Recreational			
	Asheville Urban & Recreational			

Note: All vertical scales are the same as shown in the top left graph. Low = 0, High = 160,000.

Future Recommendations

Estimating VMT. The truck traffic network model represents another step toward complete vehicle-path information using sampled data and model estimates of the interactions of vehicles, the network, and the attributes of the network. Additional improvements in the prototype model are required to overcome such limitations as those which are listed below.

- Only ADTT (average daily truck traffic) is estimated for the network model, not total vehicle traffic including automobiles. Since the model does not include automobile trips and truck-only traffic is usually far below roadway capacity, the current network model is not built with a capacity-constrained traffic assignment feature.

- The network is sensitive to input speed, not to traffic volumes on the highway. Consequently any network changes for scenario testing have to be expressed in terms of speed changes to the network links affected. Thus, network improvements from adding lanes (capacity) will not make the model estimate different traffic volumes on the highway.

- Long haul truck traffic estimates depend on national estimates produced by the FHWA FAF2 data. Short haul truck traffic in North Carolina is estimated based on employment (0.1 truck trips/employee/day). This total average rate does not recognize individual NAICS categories of employment. The rate is close to the lower end of the rates reported for some U.S. cities. Because the rate is a state average, it does not explicitly reflect intense truck activity such as that experienced at trucking hubs. This limitation is due to the aggregation of truck activity locations into counties and metropolitan areas, since they serve as traffic analysis zones (TAZs) in this model.

Calculating GVW. Although the WIM data was good in general, it may be helpful to collect more than one year of data to compare trends or to substitute missing or incomplete data. It is also recommended to apply all of the quality control (QC) procedures in the NCSU WIM QC database in the specified order before plotting the GVW plots.

In addition to applying quality control checks, it is also advisable to think ahead and look for alternate database solutions like Oracle or Microsoft SQL Server to store, analyze, and process WIM data. Regular equipment calibration and maintenance will also go a long way in providing good quality data for analysis. In that regard, fine tuning of equipment to fix misclassifications, especially for recreational WIMs is highly desirable.

Assessing Overweight Permits. The approach has one drawback in that the process does not account for travel direction of each truck. Direction is important to include because interstate travel lanes are physically separated from one another, and in essence, are two different roads. So, for any segment the method does not distinguish the directional distribution of overweight truck traffic. This information would be very useful for engineers, planners, and policy makers as they attempt to pinpoint segments of the roadway carrying the most overweight trucks. Furthermore, day and time of day travel are not incorporated into the analysis. Indeed, time is not available in the dataset because the permit administration recognizes the need to allow time flexibility in trip planning.

Two recommendations for future research and application are to improve the profiling process to incorporate direction of truck travel into the final graphic output and to extend the method to other highly used Interstate and US highway segments.

Perhaps most importantly future research should examine the driver application, data collection, and routing process for permitted overweight trucks at NCDOT. The goal would be to determine if computer mapping and routing methods such as those available in the NCDOT GIS Unit (ArcGIS, ArcInfo, ArcMap, etc.) and in the Transportation Planning Branch (TransCAD) can provide improved overweight route planning methods and subsequent assessment methods like those prototyped in this research.

[This page has been intentionally left blank.]

11. References

1992 Census of Transportation, Communications, and Utilities Truck Inventory and Use Survey - North Carolina. Motor Carrier Administration (August 1994). Report No. TC92-T-34.

2002 Design Guide: Design of New and Rehabilitated Pavement Structures." Draft Final Report. NCHRP Study 1-37A. National Cooperative Highway Research Program. 2004. Washington D.C. July.

2004 Fatality Analysis Reporting System (FARS), Special Data Run, National Center for Statistics and Analysis, October 2005 (http://www.trucksafety.org/docs/HOS-chart2%20%283%29.pdf)

Alam, Mohammed, *National Freight Modeling for Highway Capacity Analysis*, USDOT FHWA, (Battelle Memorial Institute, Columbus, OH) 2002.

Corley-Lay, Judith (2005). *White Paper: Impacts of Overweight Trucks and Axle Weight Exemptions.*

Corley-Lay, Judith, NCDOT, Raleigh News and Observer, 2005.

Crainic T.G., Dufour G., Florian M., Larin D. and Leve Z. *Demand Matrix Adjustment for Multimodal Freight Networks,* Transportation Research Record 1771, 140-147. 2001

Federal Highway Administration, *Traffic Monitoring Guide*, Version 2001, Report No. FHWA-PL-01-021, Washington D.C., October 1992.

Freight Analysis Framework. US Department of Transportation (USDOT), Federal Highway Administration (FHWA). 2002.

Freight Analysis Framework: Issues and Plans. FHWA Office of Operations, April 2, 2004. http://www.ops. fhwa.dot.gov/docs/fafplandraft/fafplandraft.htm

History of NC General Statute 20-118 (Exempted Overweight Vehicles) Since 1983, provided by the NCDOT Oversize Overweight Permits Units, 2006.

Lambert, B. *The FAF as a Policy and Systems Analysis Tool,* www.dot.state.ny.us/nasto/programs /lambert .pdf

List, G. F., L. A. Konieczny, et al. *Best-practice truck-flow estimation model for the New York City Region*. Transportation Research Record 1790, pp. 97-103. 2002.

Long-Term Pavement Performance Program. 2004. Federal Highway Administration, Information Management System: Pavement Performance Database. User Reference Guide. McLean, VA. July 2004.

LTPP Standard Data Release 20.0 VR 2005.07, October 2005.

Lu, Q. et al. *Truck Traffic Analysis using Weigh-In-Motion (WIM) Data in California*. University of California, Berkeley, 2003.

Maring, G. and B. Lambert, *The Freight Analysis Framework (FAF) – Status and Future Directions*, USDOT FHWA.

Muthadi, N. Estimation of NC Piedmont Regional Truck Input Data for the Mechanistic-Empirical Pavement Design Guidelines, unpublished term paper for NCSU Course CE501, Fall 2006.

NC Freight Flow Map, http://www.ops.fhwa.dot.gov/freight/state_maps/north_carolina.htm

Nozick, L.K., M.A. Turnquist, and G.F. List. *Electronic Permitting Issuance System for Oversize/ Overweight Vehicles*. Transportation Research Record 1643, pp. 143-151, 1998.

Nozick, L.K., M.A. Turnquist, and G.F. List .*Trade Pattern Estimation between the United States and Mexico*. Transportation Research Circular 459, pp. 74-86, 1996.

Paladugu, B. NCDOT Commodity-Based Approach for Truck Traffic, unpublished term paper for NCSU Course CE501, Fall 2005.

Qu, T., C.E. Lee, and L. Huang, *Traffic-Load Forecasting Using WIM Data*, Center for Transportation Research, University of Texas-Austin, Research Report 987-6, 1997.

Schmoyer, R. and P.S. Hu, *Analysis of Vehicle Classification and Truck Weight Data of the New England States*, Center for Transportation Analysis, Oak Ridge National Laboratory, 1998.

Sherali, H. D., Sivanandan, R. and Hobeika, A. G. *A Linear Programming Approach for Synthesizing Origin-Destination Trip Tables from Link Traffic Volumes*, Transportation Research Part B, Vol. 28B, No. 3, pp. 213-233, 1994.

Southern California Association of Governments Goods Movement Truck Count Study, SCAG, 2002.

Stone, J.R., *Development of Traffic Data Input Rescources for the Mechanistic Empirical Pavement Design Process (MEPDG)*, North Carolina Department of Transportation Project HWY 2010-08 (in progress), 2009.

Stone, J.R., *NC Truck Network Models*, North Carolina Department of Transportation Project HWY 2006-09 (in preparation), 2007.

Stone, J.R., *NC Truck Traffic Forecasting*, Prepared by NCSU Department of Civil, Construction & Environmental Engineering for the North Carolina Department of Transportation, 2004.

Tang, T., FHWA USDOT, *Freight Analysis Framework, Commodity Origin-Destination Database 2002*, http://www.ops.fhwa.dot.gov/freight/freight_analysis/faf/index.htm, 2006.

Taylor, Kent. NCDOT HPMS Data, 2005.

TMIP Peer Review – NCDOT, February 10-11, 2004.
//tmip.fhwa.dot.gov/services/peer_review_program/documents/ncdot/
Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design, NCHRP Report 538, Transportation Research Board, 2005.

TRB Committee on the Future of Freight Transportation, Letter Report to Bruce Lambert, February 9, 2004. http://trb.org/publications/reports/fafltrfeb2004.pdf

Walters, B.L. and R.K. Whitford, Strategy *for Handling the Statistics of Truck Weight Data in Alaska*, Presented at the North American Travel Monitoring Conference and Exhibition, Charlotte, NC, 1998.

Zhou, X., Qin, X. and Mahmassani, H. S. *Dynamic Origin-Destination Demand Estimation Using Multi-Day Link Traffic Counts for Planning Applications.* Journal of Transportation Research Board, 1831, pp. 30-38, 2003.

[This page has been intentionally left blank.]

Appendix – State Route Selection Methodologies for Chapter 9

Prepared by

Christoph Knellwolf
Summer Research Intern

George F. List, PhD

John R. Stone, PhD

Department of Civil, Construction and Environmental Engineering
North Carolina State University
Raleigh, NC 27695

July 2007

Introduction

<u>Purpose</u>
The NCDOT Truck Network project (HWY 2006-09) has very few count stations on rural and urban secondary roads (SR's). For a better understanding of the truck flow on SR's for the NCDOT Truck Profiles project (HWY 2007-05) and to validate the network model, it is necessary to have more SR count stations. The objective of this report is to describe a methodology to select SR count stations from a list of problematic SR routes supplied by NCDOT Division Engineers.

<u>Problem Statement</u>
The highway functional class "secondary road" is the last class to be considered statewide for the two research projects. There are many of these local roads comprising about 50,000 miles, but they are not very long individually. Each county has many SR's using local names, but the SR # is often shared by other counties even though the roads are different and not contiguous. Local road names distinguish the different SR's with the same #. Because NCDOT can count traffic on relatively few of the SR's because of time and cost constraints, it is important to make a good SR selection where damage might occur. That means picking SR's that might have high volume truck traffic. Such a statistically biased sample of about 30 SR's will assess the magnitude of truck traffic on especially heavily traveled SR's from a list of about 105 candidates identified by NCDOT Division Engineers (Attachment 1). In addition it is noted that the implicit assumption underlying the statewide sample of 30 is that the counts can be pooled in order to determine an average for the group, and that the average can be applied to the entire candidate group of 105 SR's identified by the Division Engineers, and perhaps other similar SR's. It is important to note that the results should not be extrapolated to the many other SR's in urban and rural locations that do not have heavy truck traffic.

<u>Background</u>
To get a first idea of problematic SR roads the Division Engineers provided NCSU a list of their critical SR roads. In total there are 105 roads. To make a selection of 30 locations statewide, employment data are used to determine SR routes with potentially heavy truck traffic.

Methodology

Two ideas are explored. The first is a GIS-based method. The other is an operations research (OR) based method. Both are described briefly below, Attachment 2 describes the GIS-based method in more detail and Attachment 3 describes the OR-based method.

Statistical considerations discussed in the Task 3 Report (HWY 2007-05) suggest that a sample of 30 count stations be selected from the 105 candidate count locations defined as problematic by Division Engineers (Attachment 1). To the sample are added five bypass routes identified by the NC State Highway Patrol as roads truckers use to avoid weight stations. The candidate count locations are divided into six categories defined in Task Report 2: Rural Mountain, Rural Central and Rural Coastal; and Urban Mountain, Urban Central and Urban Coastal. Assuming that the 30 samples may be pooled to give good statistics, then five count locations for each of the six categories should be selected.

To begin the SR selection process, NC Employment Securities Commission data for the number of employees by industry location in each NC county were assembled and identified according to four aggregate NAICS codes. The Quick Response Freight Manual provides daily truck trip generation rates per employee for each NAICS code so that the daily truck traffic can be estimated for each industry location. The potential daily truck trips on a particular SR route are defined as the sum of truck trips generated by the industries within a GIS buffer zone with a radius of five miles around a candidate SR.

The GIS Approach

The GIS method generates buffer zones (Figure 1) around the SR's to help guarantee a certain geographical separation among the selected SR locations; to ensure that the same employers do not generate truck trips for different SR's. If there are overlapping buffer zones, the zones with the least potential for truck trips are deleted. If there are no overlapping buffer zones, the ones with the highest total generated trips are chosen. The result is a group of the five SR's in each urban/rural - mountain/central/coastal category with no overlapping buffer zones with the highest total truck trips.

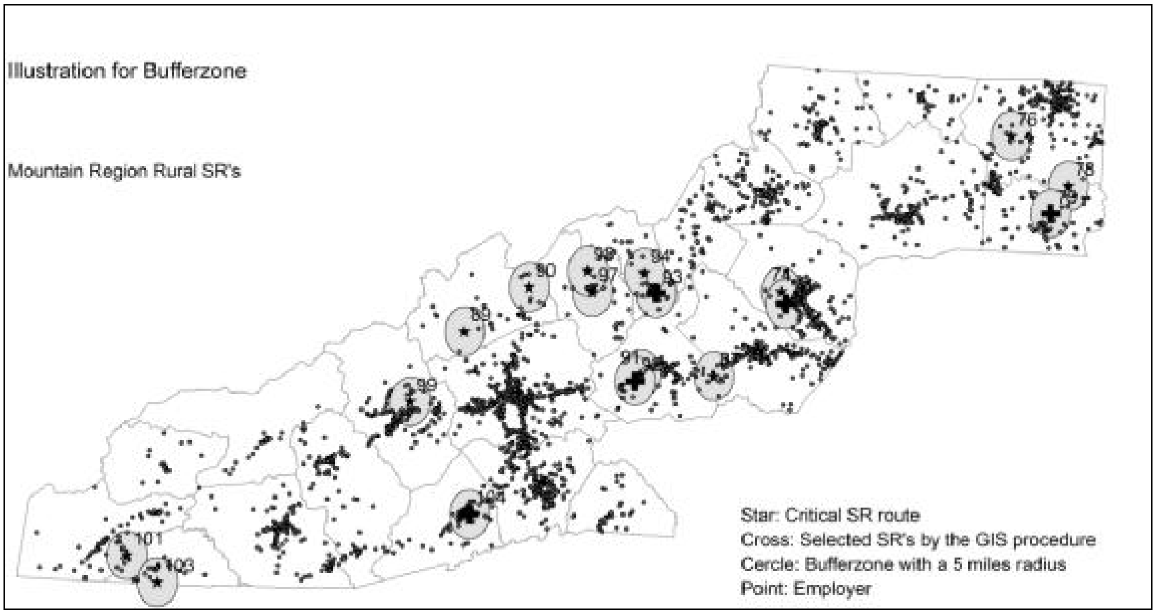


Figure 1 SR Buffer Areas around SR Candidates in the Mountain Region

The Operations Research Approach

The OR approach (Attachment 3) is a more sophisticated technique for selecting the SR sites. It seeks a set of sites that achieve an optimal tradeoff between generated truck trip coverage and spatial separation. One of the challenges with the GIS approach is ensuring that the sites selected are focused on non-overlapping watersheds of generated truck trips. Its sequential procedure helps ensure that this objective is met, but there is no way to prove that this objective has been achieved. This is not a criticism of the procedure; it is only a statement that such an assurance cannot be obtained. The OR approach yields site combinations whose tradeoff characteristics can be document.

The GIS and OR methods are compared in Table 1. Basically the GIS approach employs a heuristic that finds a solution the same as or nearly identical to the one found with the OR approach.

Results

The results of applying the GIS method to the 105 candidate locations provided by the Division Engineer are displayed in Figure 2 and listed in Table 2.

Table 1 Comparing the GIS and OR Approaches

	GIS Approach	Operations Research Approach
Source	Employment data Critical SR routes from Div Engineers	Employment data Critical SR routes from Div Engineers
Logic	GIS	GIS Visual Basic Program
Results	A selection of 5 SR’s with the highest truck trip generation in a fixed minimal distance buffer zone	A selection of groups of 5 SR’s with maximum Truck Trip Generation for a minimal distance
Pros	1 logical, shorter application time	Gives a selection of groups
Cons	The user has no influence on the importance of the geographical dispersion in relation to the truck trip generation.	To generate truck trips for an SR route the GIS work has to be done, as well the OR procedure. Thus, an OR problem has to be solved and the results imported to GIS to locate them.

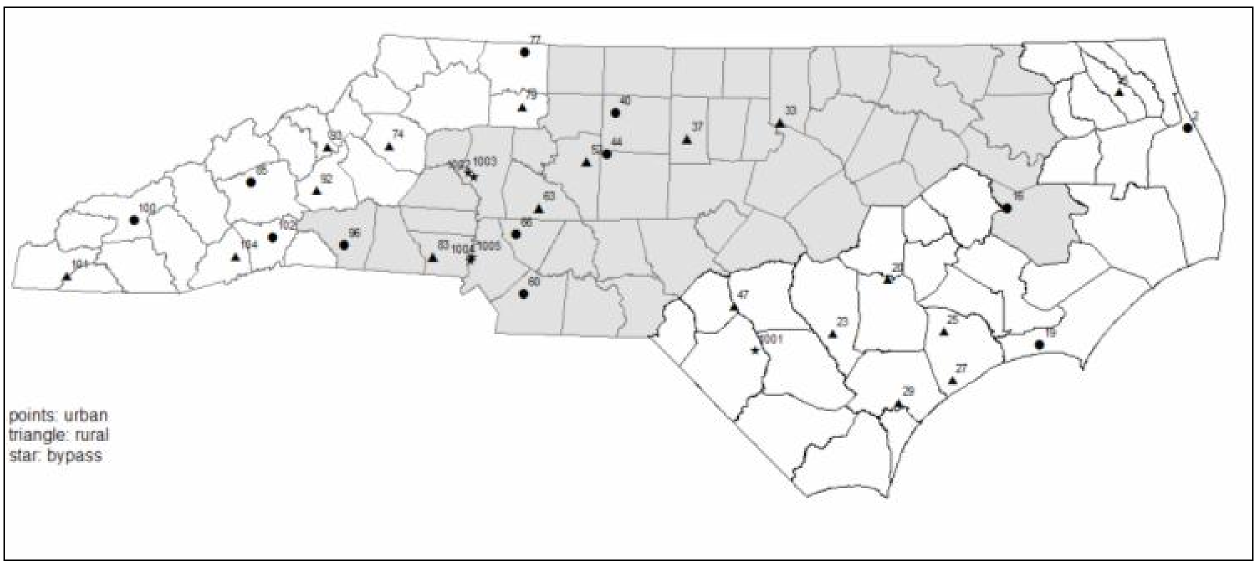


Figure 2 Proposed SR Count Station Locations.

Table 2 Proposed SR Locations for Traffic Counts

Mountain Rural

ID	DIVISION	COUNTY	SR #	ROAD_NAME	Sum_TT
74	11	Caldwell	1310	Abington	2366
93	13	Mitchell	1121	Altapass	1215
104	14	Transylvania	1540	Wilson Rd	1035
79	11	Yadkin	1510	Sugartown	870
92	13	McDowell	1246	Greenlee	783
101	14	Cherokee	1537	Mission	302

Mountain Urban

ID	DIVISION	COUNTY	SR #	ROAD_NAME	Sum_TT
77	11	Surry	1670	Independence	5262

102	14	Henderson	1006	Howard Ga	3941
85	13	Buncombe	1718	Goldview	1704
100	14	Jackson	1337	Battle Rd	362

Central Rural

ID	DIVISION	COUNTY	SR #	ROAD_NAME	Sum_TT
83	12	Gaston	1307	Edgewood	3981
52	9	Davidson	2024	Upper Lake	2027
63	10	Cabarrus	1002	Old Concord	1970
37	7	Alamance	2326	Mt. Herman	1428
33	5	Granville	1728	Cash Road	1256

Central Urban

ID	DIVISION	COUNTY	SR #	ROAD_NAME	Sum_TT
44	8	Randolph	1595	Surrett Dr	12539
40	7	Guilford	2133	Pleasant	8820
66	10	Cabarrus	1394	Popular Tent	8061
60	10	Union	1501	Seacrest	4277
96	13	Rutherford	2169	Oakland R	3906

Coastal Rural

ID	DIVISION	COUNTY	SR #	ROAD_NAME	Sum_TT
5	1	Pasquotank	1101	Pear Tree	2267
20	2	Duplin	1501	Garner Church	1658
29	3	Pender	1520	Martin Marietta	851
25	3	Onslow	1227	Union Chop	358
47	8	Hoke	1406	Rockfish	326
23	2	Sampson	1311	Lisbon Bridge	137
27	3	Onslow	1518	Old Folks	87

Coastal Urban

ID	DIVISION	COUNTY	SR #	ROAD_NAME	Sum_TT
16	1	Washington	1127	Paul Rd	2074
19	2	Carteret	1147	McCabe Rd	1300
2	1	Dare	1217	Collington	1152

Bypass

ID	DIVISION	COUNTY	SR_#	NAME_OR_DE	REGION	Rural/Urban
1001	6	Robeson	1005	Barker Ten Mile	Coastal	Rural
1002	12	Iredell	1005	Old Mountain Rd	Central	Rural
1003	12	Iredell	1006	Island Ford Rd	Central	Rural
1004	10	Mecklenburg	1625	Sam Wilson Rd	Central	Urban/Rural
1005	10	Mecklenburg	1601	Moore’s Chapel Rd	Central	Rural

Comments and Adjustments

In the Mountain region for the urban and rural categories, both the GIS and the OR approaches lead to the same choice. In the Central region the GIS results are close together in spite of the buffer zones. For a wider spread in the Central region, the solution provided by the OR approach has been chosen. In the Coastal region for urban facilities, only three roads are critical, so to get a total number of ten for the urban and rural categories, seven roads are selected using the GIS approach.

A visual inspection of the SR routes with Google Maps gives an idea of the length of the roads, and the associated Google satellite photographs give an overall view of the area including development, industry, forest, etc. that potentially generate truck traffic. The consequence of this inspection sometimes shows that certain roads should be replaced because the roads are too short or have no nearby special industries or truck generators. Such is the case with the roads with IDs 28, 75, 88, and 100. The Roads with ID 28 (Pender Co. SR 1630) and ID 75 (Caldwell Co. SR 1404) overlap with roads with ID 74 (Caldwell Co. SR 1310) and ID 29 (Pender Co. SR 1520), respectively, and are replaced by them as proposed count locations. The road with ID 88 (Burke Co. SR 1825) is a mountain urban road for which category there is no other road to use as a replacement. So a road from the category Mountain Rural is chosen in its place. Thus, ID 88 (Burke Co. SR 1825) is replaced by ID 101 (Cherokee Co. SR 1537).

The entire group of five SR bypass routes (Table 2) is added to reflect bypass truck traffic. Since the SR bypass group is small, there is no analytical selection, and the entire group of five is added to the proposed SR count locations of Table 2. (All the weigh station bypass routes including Interstates, US and NC routes are given in Task Report 3.).

The SR routes chosen by the GIS and OR approaches are based on employment data, and they are the starting point or ending point ("trip ends") of a truck trip. That is another reason for spreading out the locations so that the same employer is not counted for different SR routes. The SR on a bypass route is in the middle of a trip, so it is not important if a bypass route is in proximity to an SR chosen by the GIS or OR method.

It is noted again that the procedures assume that the original 105 candidate SR's are normally distributed and that the resulting 30 samples across three state regions including urban and rural locations represent a data pool the average of which can be applied to the entire 105 SR's. This assumption has to be tested after the truck traffic counts for validity. Alternatively, if NCDOT has the resources, additional SR counts can be taken, for example from the count stations defined by the OR method.

Recommendations for Future Count Station Selection

To avoid selecting roads that have no nearby truck generators, a criterion for rejecting an overlapped buffer should be a visual inspection of an aerial photo as well as considering the potential for truck trips. A visual inspection of the area surrounding the SR is very helpful to confirm the results. Once the field counts are completed, the prototype GIS and SR methods developed in this report can be compared to the predicted truck traffic to validate the approaches based on employment data.

Sources

Converting SR names to SR numbers and counties
https://apps.dot.state.nc.us/srlookup/SecondaryRoads.aspx

Universe File for highway characteristics: data available from the NCDOT GIS Unit.

Employment data: data available from the NC Employment Securities Commission.

Cambridge Systematics, Inc., et al (1996), *Quick Response Freight Manual* Transportation Research Board, Washington D.C.

http://tmip.fhwa.dot.gov/clearinghouse/docs/quick/Quick.pdf

Google Earth and Google Maps for aerial photography and mapping.

Attachment A. Candidate SR Routes for Truck Traffic Study (not including bypass SR's)

Table A-1 Recommendations from NCDOT Division Engineers (June 12, 2007)

SR's recommended for count stations

Division	County	SR #	Name or Description
1	Currituck	1227	South Mills Road
1	**Dare**	**1217**	**Collington Rd**
1	Gates	1212	Reynoldson Rd (high priority)
1	Gates	1215	Tyler Rd
1	**Pasquotank**	**1101**	**Pear Tree Rd**
1	Pasquotank	1144	Simpson Ditch Rd (high priority)
1	Perquimans	1200/1202	Perry's Bridge Rd.
1	Bertie	1001	Wakelon Rd from NC 45 to US 17
1	Bertie	1221	Republican Rd from NC 305 to SR 1225 (high priority)
1	Hertford	1101	Williford Rd from SR 1105 to Bertie County
1	Hertford	1301	Vaughan Creek from SR 1301 to Northampton County (high priority)
1	Northampton	1008	Bryantown Rd from US 158 to SR 1109
1	Northampton	1351	Vaughan Creek Rd from NC 35 to Hertford Co line (high priority)
1	Chowan	1002	
1	Martin	1516	High priority
1	**Washington**	**1127**	**High priority**
1	Hyde	1305	High priority
2	Craven	1005	
2	**Carteret**	**1147**	
2	**Duplin**	**1501**	**From NC 11/903 to NC 403**
2	Duplin	1827	From NC 41 to NC 50 (Pinhook)
2	Sampson	1004	From NC 24(Turkey) to SR 1157 (Ingold)
2	**Sampson**	**1311**	**From US 421 (Clinton) to SR 1006**
3	Onslow	1434	Belgrade-Swansboro Rd
3	**Onslow**	**1227, 1223**	**Union Chappel Church Rd and Duffy Field Rd**
3	Onslow	1222	Bannerman Mill Rd
3	**Onslow**	**1518**	**Old Folkstone Rd**
3	**Pender**	**1630, 1636**	**Rev. Andre Carr Rd and Martin Marietta Access Rd.**
3	Pender	1520	Shaw Highway
3	Pender	1114	Blueberry Rd
5	Wake	1901	Old Weaver Trail between Cash Rd and NC 50
5	Wake	1119	Buckhorn Duncan Rd near Harnett County line
5	**Granville**	**1728**	**Cash Road (tees into Old Weaver Trail in Wake County)**
5	Durham	1632	Red Mill Rd, exit 182 from I-85
5	Person	1322	Shiloh Church Rd, west of 501 north of Roxboro.

6	n.a.		
7	Alamance	1005	Greensboro-Chapel Hill Rd
7	**Alamance**	**2326**	**Mt. Herman Rock Creek Rd**
7	Orange	1357,1372	Efland Cedar Grove Rd
7	Orange	1004	Carr Store Rd
7	**Guilford**	**2133**	**Pleasant Ridge Rd**
7	Guilford	3505	Pleasant Garden Rd
7	Rockingham	1714	Summit Rd
7	Caswell	1133	Cherry Grove Rd
8	**Randolph**	**1595**	**Surrett Dr.**
8	Chatham	1008	Beaver Creek/Farrington Pt. Rd/Farrington Rd/Mt Carmel Rd
8	Lee	1144	Swann Station/Greenlevel Rd
8	**Hoke**	**1406**	**Rockfish Rd**
8	Moore	1004	Hoffman Rd
8	Montgomery	1005	
8	Richmond	1003	
8	Scotland	1001	
9	**Davidson**	**2024**	**Upper Lake Rd.**
9	Davidson	1186	Koontz Rd
9	Davie	1410	Farmington Rd
9	Forsyth	1958	Craig Rd
9	Rowan	1221	Old Beatty Ford Rd
9	Stokes	1695	Dodgetown Road
10	Union	1007,1514	Rocky River Rd
10	Union	1004	Lawyers Rd
10	**Union**	**1501**	**Secrest Short Cut Rd**
10	Union	1315	New Town Rd
10	Cabarrus	1139	Rocky River Rd
10	**Cabarrus**	**1002**	**Old Concord Salisbury Rd**
10	Cabarrus	1006	Mt. Pleasant Rd
10	Cabarrus	2180	Lane St
10	**Cabarrus**	**1394**	**Popular Tent Rd**
10	Cabarrus	1442	Odell School Rd
10	Cabarrus	1445	Derita Rd
10	Stanly	2001	Old Aquadale Rd
10	Mecklenburg	2128,2074	Beatties Ford Rd
10	Mecklenburg	2802	Rocky River Rd
10	Mecklenburg	2424	Popular Tent Rd
10	Mecklenburg	2459	Eastfield Rd
11	**Caldwell**	**1310**	**Abington Rd from SR 1301 to SR 1404**
11	Caldwell	1404	West Caldwell Dr. from NC 18/US 64 to SR 1310
11	Surry	1001	Zephyr Rd from US 21 Bypass to US 601 Bus.
11	**Surry**	**1670**	**Independence Blvd from US 52 Bus. To NC 104 (only 0.26 mile)**
11	Yadkin	1001	Siloam Rd from Surry County to NC 67
11	**Yadkin**	**1510**	**Sugartown Rd from NC 67 to US 601**
12	Lincoln	1279	Finger Mill Rd

12	Catawba	2003	South Main St (Catawba end of Finger Mill Rd)
12	Cleveland	1313	Washburn Switch Rd
12	**Gaston**	**1307**	**Edgewood Rd**
12	Iredell	1843	Tomlin Mill Rd east of I-77
13	**Buncombe**	**1718**	**Goldview Rd**
13	Buncombe	1723	Alexander Rd
13	Burke	1129	Dysartsville Rd from I-40 to SR 1123
13	Burke	1525	Elon Rd from US 70 to SR 1501
13	Madison	1135	Little Pine
13	Madison	1503	Laurel Valley/Windy Gap
13	McDowell	1228	
13	**McDowell**	**1246**	
13	**Mitchell**	**1121**	
13	Mitchell	1197	
13	Rutherford	1510	Hudlow Rd
13	**Rutherford**	**2169**	**Oakland Rd**
13	Yancey	1109	Bolens Creek
13	Yancey	1136	Jacks Creek
14	Haywood	1513	From NC 215 to SR 1550
14	**Jackson**	**1337**	**From US 23/441 to SR 1378**
14	**Cherokee and Clay**	**1537, 1300**	
14	**Henderson**	**1006**	
14	Clay	1115	From NC 69 to end of system
14	**Transylvania**	**1540**	

Bypass SR's Recommended for Count Stations

Bypass

ID	DIVISION	COUNTY	SR_#	NAME_OR_DE	REGION	Ural/Urban
1001	6	Robeson	1005	Barker Ten Mile	Coastal	rural
1002	12	Iredell	1005	Old Mountain Rd	Central	rural
1003	12	Iredell	1006	Island Ford Rd	Central	rural
1004	10	Mecklenburg	1625	Sam Wilson Rd	Central	urban/rural
1005	10	Mecklenburg	1601	Moore's Chapel Rd	Central	rural

Table A-2 Summary of Proposed SR Count Locations

Proposed SR's classified for Traffic Counts

(Subject to NCDOT approval)

ID	DIVISION	COUNTY	SR__	ROAD_NAME
2	1	Dare	1217	Collington Rd
5	1	Pasquotank	1101	Pear Tree Rd
16	1	Washington	1127	Paul Rd
19	2	Carteret	1147	McCabe Rd

20	2	Duplin	1501	Garner Ch
23	2	Sampson	1311	Lisbon Bridge
25	3	Onslow	1227	Union Chp
27	3	Onslow	1518	Old Folks
29	3	Pender	1520	Martin Marietta
33	5	Granville	1728	Cash Road
1001*	6	Robeson	1005	Barker ten mile road
37	7	Alamance	2326	Mt. Herman
40	7	Guilford	2133	Pleasant
44	8	Randolph	1595	Surrett D
47	8	Hoke	1406	Rockfish Rd
52	9	Davidson	2024	Upper Lake Rd
60	10	Union	1501	Seacrest Short Cut Rd
63	10	Cabarrus	1002	Old Concord Salisbury Rd
66	10	Cabarrus	1394	Popular Tent Rd
1004*	10	Mecklenburg	1625	Sam Wilson Rd
1005*	10	Mecklenburg	1601	Moores Chapel Rd
74	11	Caldwell	1310	Abington
77	11	Surry	1670	Independence
79	11	Yadkin	1510	Sugartown
83	12	Gaston	1307	Edgewood
1002*	12	Iredell	1005	Old Mountain Rd
1003*	12	Iredell	1006	Island Ford Rd
85	13	Buncombe	1718	Goldview
92	13	McDowell	1246	Greenlee
93	13	Mitchell	1121	Altapass
96	13	Rutherford	2169	Oakland Rd
100	14	Jackson	1337	Battle Rd
101	14	Cherokee	1537	Mission Rd
102	14	Henderson	1006	Howard Ga
104	14	Transylvania	1540	Wilson Rd

* Bypass SR's recommended by the NC SHP

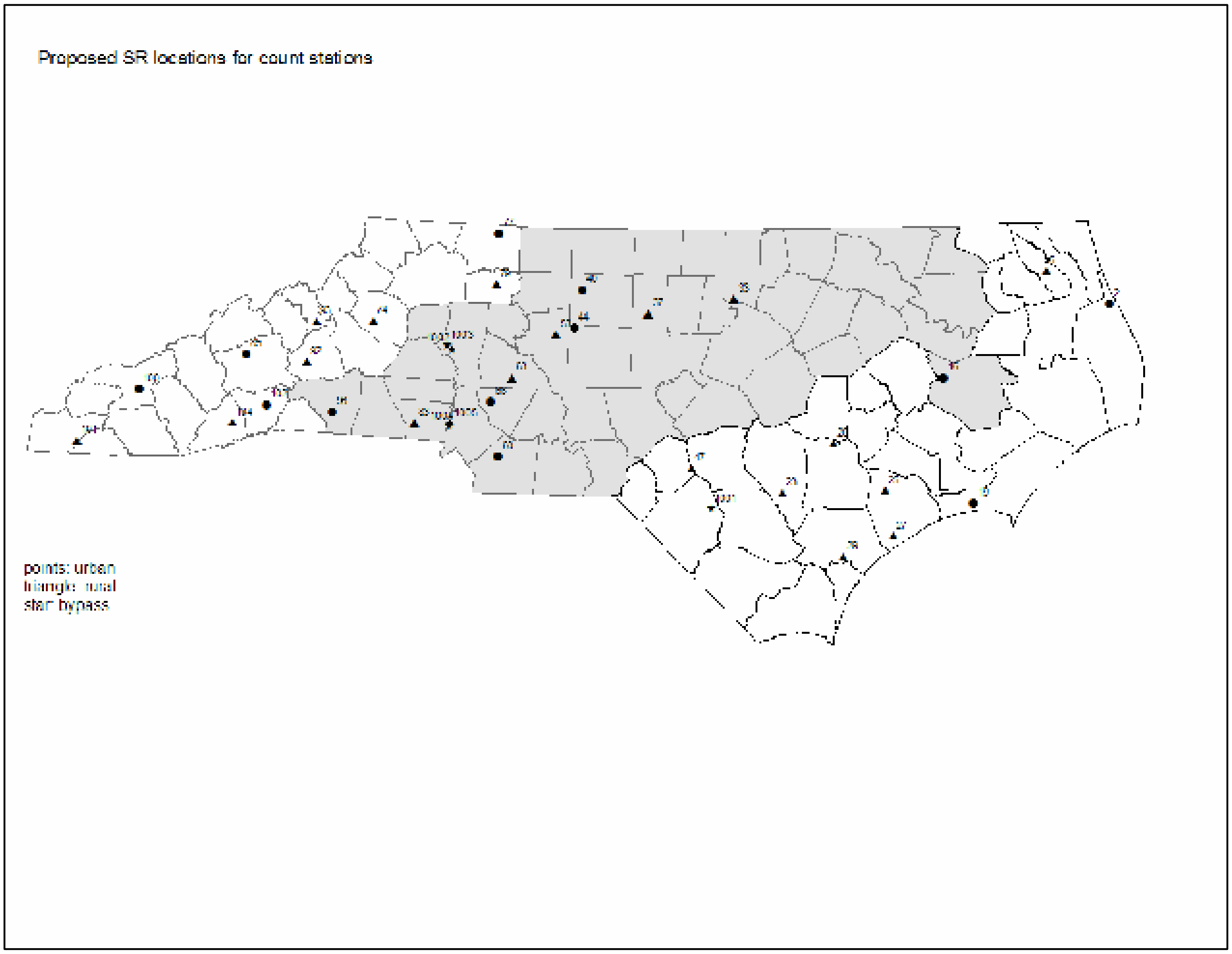


Figure A-1 Summary of Proposed SR Locations for Count Stations

Attachment B. GIS Procedures for Identifying Critical SR Truck Routes

Procedure

The additional SR count locations are placed on routes proposed by the NCDOT Division Engineers. The locations indicate a high truck traffic or other critical issue. The proposed SR routes are categorized by urban / rural locations and three NC regions giving six categories (strata); 2 * 3 = 6 categories. That means five locations have to be selected for each category to reach the desired sample size of 30 assuming that the SR locations can be pooled. This assumption needs to be validated, especially if urban and rural SR data are pooled. If there are more than five proposed SR's in one category, the five with the highest employment activities around them are chosen.

The highest activity implies the highest truck generation in a buffer zone of extent five miles around a SR route. Subsequent figures in this appendix illustrate the 5-mile buffers for candidate SR count locations in the three NC regions.

Truck trip generation is determined by:

truck trips = Σ_i (buffer employment $_i$ * trip rate $_i$) for NAICS employment code i

If there are two overlapping buffer zones, the one with the higher truck volume is retained. If five non-overlapping buffers are not available, then SR routes with overlapping buffers can be chosen manually.

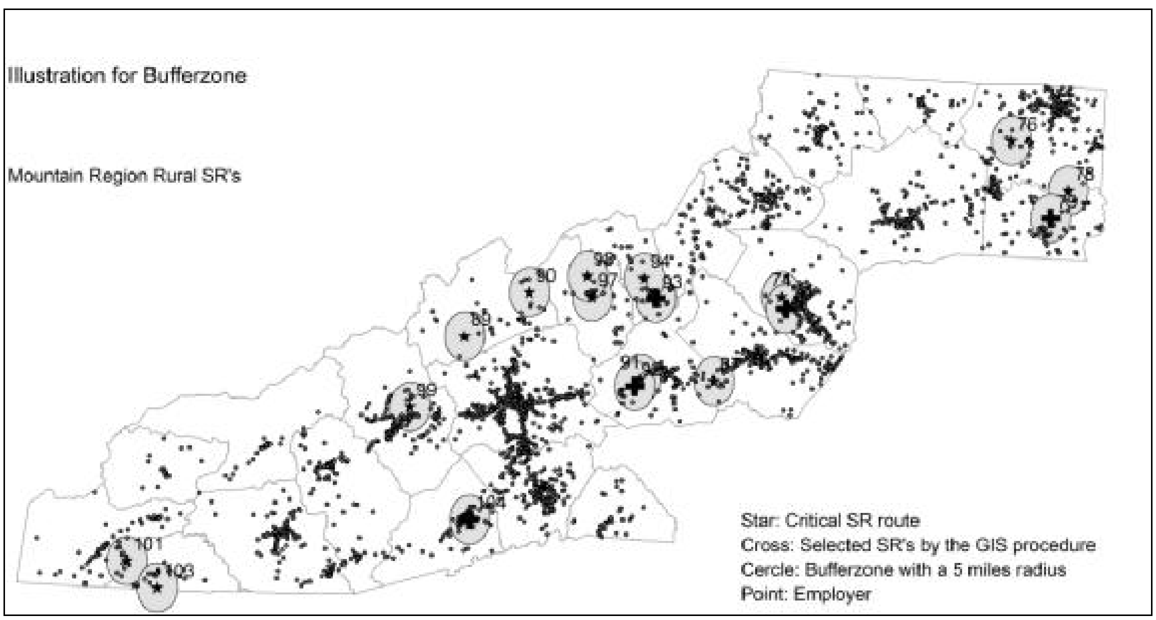


Figure B-1 SR Candidates and Choices in the Mountainous Region

Table B-1 Mountainous Region Rural Count Locations

ID	DIVISION	COUNTY	SR__	ROAD_NAME	X	Y	SUM_TT
75	11	Caldwell	1404	West Caldwell	-81.5892	35.8855	2837
93	13	Mitchell	1121	Altapass	-82.0612	35.9061	1215
104	14	Transylva	1540	Wilson Rd	-82.7060	35.2340	1035
79	11	Yadkin	1510	Sugartown	-80.6351	36.1693	870
92	13	McDowell	1246	Greenlee	-82.1274	35.6443	783

Limitations in the GIS Procedure

Information about Employers

There are about 250,000 employers in North Carolina. To manage these data in GIS and Excel, the 250,000 are reduced to 65,000 by considering only employers that are expected to generate more than two truck trips per day based on the QRS trip generation rates.

Another difficulty is the "headquarters problem". Since paychecks are the basis of the employment data, and paychecks usually come from a central location, the local branch stores of large companies are not represented in the NC ESC database. Hence, truck traffic appears to sometimes be focused on the headquarters rather than distributed among the local sites.

Information about Roads

The information supplied by the Division Engineers is interpreted to mean that an SR is problematic because of heavy truck traffic because that was the basis of the NCSU request for candidate SR's. However, Division Engineers may have other reasons to identify problem SR's such as pavement distress, bridge deficiencies, weather related problems, etc.

Methodology

There is no control regarding the length of the different SR's. Some of them are long and others short. However, the buffer zones do not consider the length difference. They just pool all the potential truck trips on the SR under consideration.

To locate the roads in GIS, the latitude and longitude coordinates of one point on the road are used. These coordinates are generated by Google Earth while looking for a road. That means the point is chosen arbitrarily by Google and long SR's may not be entirely included in the five-mile radius buffer zone. The number of potential truck trips may change if another point on the same SR is chosen. A visual inspection using Google maps and aerial photography may resolve differences and eliminate some short roads in favor of other roads.

Attachment C. Operations Research Method

As indicated in the main report, the OR methodology seeks a set of locations that achieve an optimal tradeoff between generated truck trip coverage and spatial separation. A six-step algorithm is employed:

1) Compute the straight-line separation d_{ij} between each "*ij*" pair of possible locations
2) Query the input data to determine how many locations n should be selected.
3) Find the *ij* pair with the minimum d_{ij} separation
4) Examine all the combinations of n locations that include i and j and find the one that maximizes ΣT the total number of trips covered.[15, 16]
5) Find the next smallest d_{ij} and repeat step 4 including only locations for which $d_{rs} \geq d_{ij}$ for all combinations of rs including those involving i and j.
6) Stop when the next *ij* pair does not have enough locations left to generate combinations of n locations such that $d_{rs} \geq d_{ij}$ for all r and s in the combination.

Figure C-1 helps to illustrate how the method works. A combination of five locations (n = 5) is pictured. The minimum separation is d_{ij}. All the other values of d_{rs} are larger. Each location has an associated number of generated trips. The total of these, ΣT, is computed and recorded. All combinations of n locations such that $d_{rs} \geq d_{ij}$ are evaluated and the one with the largest ΣT is retained for this d_{ij}.

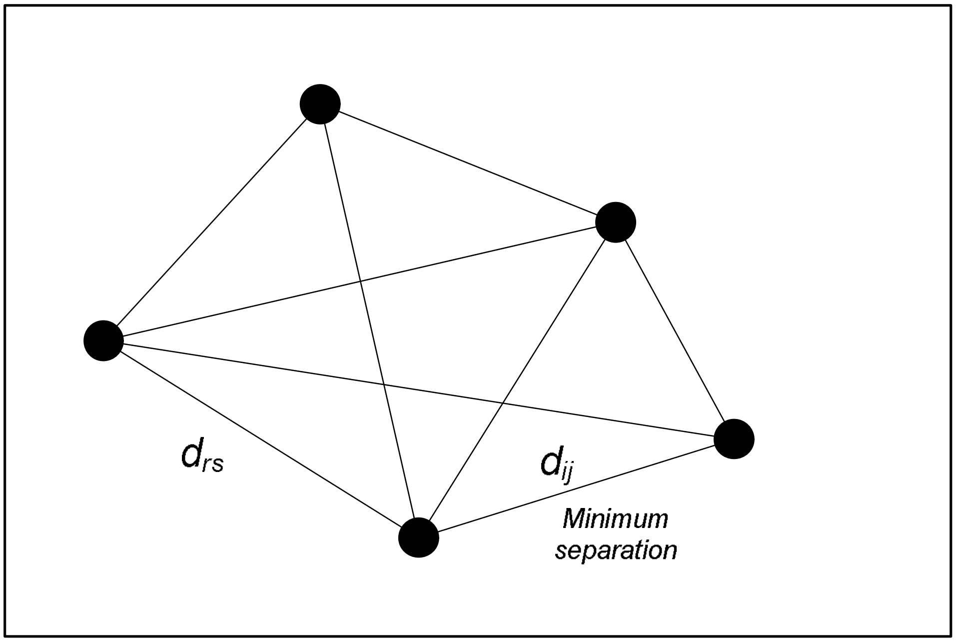


Figure C-1 A Combination of 5 Locations

[15] All the separations between the other locations in the set of n have to be larger because d_{ij} is the shortest.
[16] ΣT allows double-counting of generated trips among locations that spatially overlap. As the value of d_{ij} increases, the double-counting decreases.

Figure C-2 expands on this discussion by showing for the central-rural region all the pair-wise combinations (used in a different sense) of d_{ij} and ΣT that exist for n = 5. Obviously for a given d_{ij} (along the horizontal axis) many values of ΣT exist (along the vertical axis) depending on the locations included in the 5-site set. One of these maximizes ΣT and dominates all the rest. Units of *SumSum* are the sum of the total daily truck trips in one selection of five buffer zones, a 5-site combination. The units of *MinD* are miles calculated from the latitude and longitude of the minimum distance points (Figure C-1).

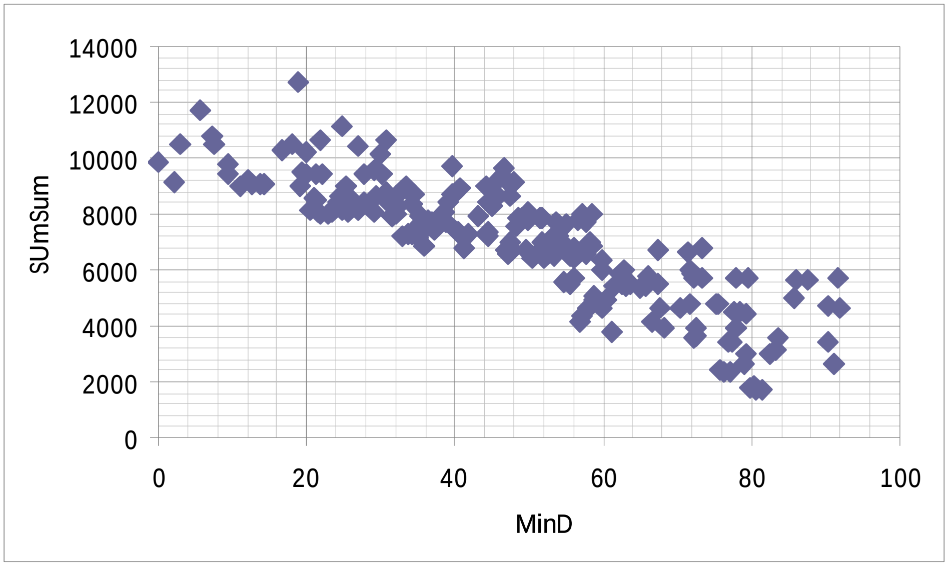


Figure C-2 Separations and Generated Trip Totals Identified

The non-dominated pair-wise combinations of d_{ij} and ΣT can then be identified for 5-site combinations. The result is shown in Figure C-3.

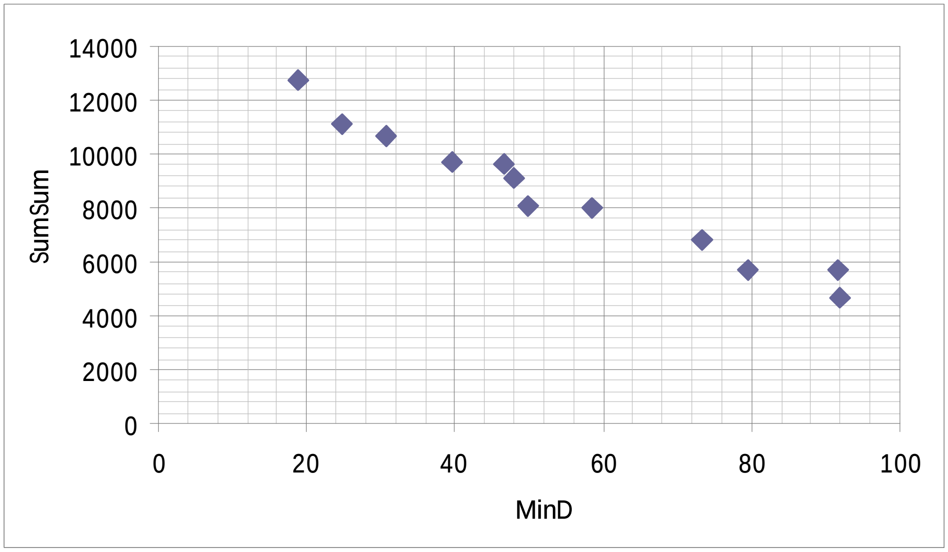


Figure C-3 Non-Dominated Combinations of Minimum Separation and Total Generated Trips given by Quintuples of Locations

The next step is to pick the 5-site combination that has the optimal tradeoff between spatial separation and total generated trips. For example, the combination that has a separation of about 60 miles and a total trips generation of 7800 might be the best.

Visualizing the spread of the groups using GIS can also be helpful. The locations of the SR sites for the Mountain Rural setting are shown in Figure C-4.

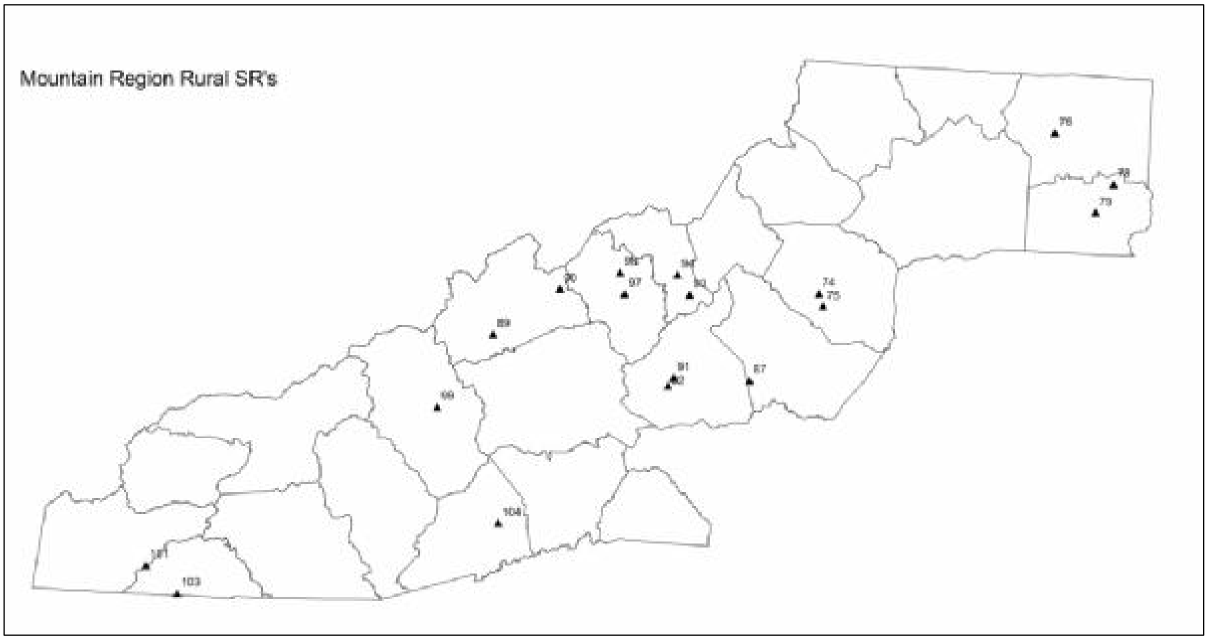


Figure C-4 Proposed Rural SR's in the Mountain Region

The tradeoff surface for the non-dominated 5-site combinations is shown in Figure C-5.

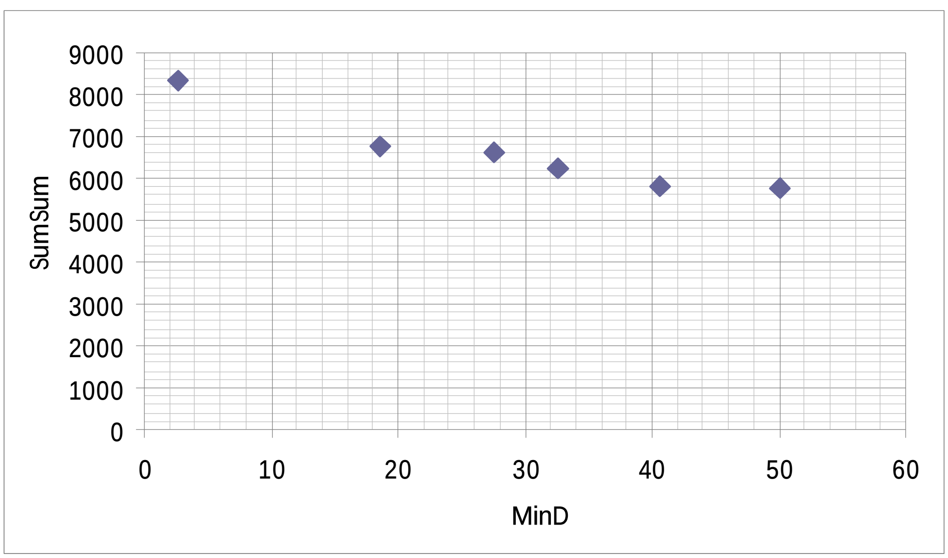


Figure C-5: Non-Dominated Quintuple Solutions for the Mountain Region

Table C-1 presents the results for the non-dominated 5-site combinations shown in Figure C-5. Set GR1 is sties 75, 74, 93, 104, and 79. The minimum separation is 3 miles and the total generated trips is 8323. In contrast, GR6 involves sites 75, 104, 79, 98, and 101; the minimum separation is 50 miles; and the total generated trips are 5752.

Table C-1 Proposed Groups Using the OR Method

Mountain Rural				**Choice**	**GIS**		**x**				
					ChK		**x**				
ID	DIV	COUNTY	SR #	ROAD_NAME	Sum_TT	GR 1	GR 2	GR 3	GR 4	GR 5	GR 6
75	11	Caldwell	1404	West Cald	2837						
74	11	Caldwell	1310	Abington	2366						
93	13	Mitchell	1121	Altapass	1215						
104	14	Transylva	1540	Wilson Rd	1035						
79	11	Yadkin	1510	Sugartown	870						
92	13	McDowell	1246	Greenlee	783						
98	13	Yancey	1136	Jacks Cre	708						
97	13	Yancey	1109	Bolens Cr	699						
99	14	Haywood	1513	Hyder Mtn	677						
94	13	Mitchell	1197	Bear Cree	524						
101	14	Cherokee	1537	Mission D	302						
76	11	Surry	1001	Zephyr Rd	285						
103	14	Clay	1115	Mcclure R	241						
91	13	McDowell	1228	Columbia	214						
87	13	Burke	1129	Dysartsvi	160						
90	13	Madison	1503	Laurel Va	101						
78	11	Yadkin	1001	Siloam Rd	58						
89	13	Madison	1135	Little Pi	33						
					Sum Sum	8323	6740	6634	6259	5827	5752
					Min-D	3	19	28	33	41	50