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RESEARCH ARTICLE

What Level of Tourism Traffic Should be planned for in North Carolina's Major Tourism Areas

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Abstract:

Aims:

The purpose of this research is to provide the North Carolina Department of Transportation (NCDOT) with an execution strategy for using traffic counts in high tourism areas to aid in the development of Comprehensive Transportation Plans (CTPs). Due to the high variability of traffic counts in these localities, it is arbitrary to apply the typical weekday traffic count as the reference metric for developing the CTPs for these areas.

Methods:

A literature review and assessment of best practices, forecasting models, and implementation strategies are provided. The first and primary recommendation with respect to Average Annual Daily Traffic (AADT) calculations and planning is to incorporate peak-usage and directionality; whether it be hourly or monthly. Urban areas will have AADT values similar to the design value. However, seasonal areas, such as tourist locations, will have significant differences between the design value and the AADT.

Results:

While other states (notably Nevada and Florida) have incorporated peak-hour usage ratios into their planning forecasts, the recommendation in this report suggests using an average of the two busiest months (as shown in the case studies) when peak-hour usage rates are unknown.

Conclusion:

The primary recommendations should be addressed tactically (*i.e.*, 3-5 years), and phased-in as resources are available. Other recommendations should be addressed strategically (*i.e.*, 5-10 years), and phased-in as resources are available. Future work, including simulation modeling could be completed to test different levels of funding and to compare different approaches.

Keywords: Traffic, Tourism, AADT, CTP, Transportation planning, Transportation metrics.

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1. INTRODUCTION

The focus of this research is to provide the North Carolina Department of Transportation (NCDOT) with an execution strategy for using traffic counts in high tourism areas to aid in the development of Comprehensive Transportation Plans (CTPs). Due to the high variability of traffic counts in these areas, applying the typical weekday traffic count as the baseline metric for developing the CTPs for these areas is inappropriate. Formerly, the NCDOT utilized local employment data, local population data, and typical weekday traffic data as the baseline for developing CTPs with the aid of local communities within North Carolina. Yet, there is a concern that high tourism areas, such as: Topsail, Atlantic Beach, Lake Lure, Blowing Rock, Boone, *etc*., experience a high variability in traffic due to seasonal tourism. This concern is prevalent in other parts of the United States, and identifying best practices and methods used to provide a strategy to the citizens of these communities is needed [1, 2].

This project incorporates multiple disciplines, including transportation planning, tourism planning, local and urban planning, environmental sustainability, economics, geography, and engineering. The project included data, methods, and resources from all of these fields, including forecasting,

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seasonal variation modeling, regression, Geographic Information Systems (GIS), employment, economic, hotel occupancy, motor vehicle transportation, and tourism behavior. The literature review identifies practices and research literature related to tourism traffic including choice of destinations and travel within destinations. Detailed attention was given to forecasting approaches. Topics included geography, hospitality, urban planning, transportation planning, engineering, business, and tourism databases.

There are a number of factors to consider when forecasting tourism-related traffic. The data collection power of technology (*e.g.*, GPS and GIS location on cellular phones, vehicles) and the analytical capabilities of software and hardware solutions will soon allow for almost instantaneous knowledge with respect to the capacity and utilization of a transportation system. However, there is currently a lag between technological advancement versus the planning and strategic-level thinking of transportation management plans with respect to seasonal variance in traffic across the United States. Due to the importance of the tourism industry on the economy of North Carolina and tourisms' need for efficient transportation systems; it is imperative that equitable plans be made to accommodate this seasonal variation.

There are a number of urban form issues and accommodations to tourism traffic in North Carolina. These areas include topography, aesthetics and character, small town and downtown activity centers, access management, land use regulation, bypasses, scenic byways, turnouts along heavily traveled corridors, highway messaging, highway signs, wayfinding signs, and parking. There are also a number of non-additional infrastructure methods; including the issues related to human behavior, and enhancing bicycle and pedestrian options.

The first and primary recommendation with respect to Average Annual Daily Traffic (AADT) calculations and planning is to incorporate peak-usage and directionality; whether it be hourly or monthly. Urban areas will have AADT values similar to the design value. However, seasonal areas, such as tourist locations, will have significant differences between the design value and the AADT. While other states (notably Nevada and Florida) have incorporated peak-hour usage ratios into their planning forecasts, using monthly rates (as shown in the case studies) can be useful.

An initial recommendation with respect to the calculation of AADT includes updating the seasonality factors with up-to-date data that is collected year-round. Furthermore, it is recommended that AADT is discontinued for areas with seasonal variation in favor of the service level (which includes variation) concept that is used in supply chain management, logistics management, and queuing system design.

The primary case study findings and conclusions were:

- Case Study 1: Watauga/Avery (NC 105)
  - Of the three traffic counter locations' data evaluated, two did not exhibit seasonality and one exhibited only moderate seasonality (peaking in August). The reason for this is due to the constant (year-round) traffic generated by the college students and residents.
- Case Study 2: Outer Banks (US 158)
  - Of the two traffic counter locations' data evaluated, both exhibited high seasonality; peaking in the summer.
- Case Study 3: Wrightsville Beach Area (Wilmington)
  - Urban area with steady traffic from the residents in the Wilmington area.
  - One of the traffic counter location's data exhibited a high seasonality (peaking in the summer); and one exhibited no seasonality. The one that exhibited seasonality included beach traffic.
- Case Study 4: Bryson City
  - The single traffic counter location's data exhibited a high seasonality (peaking in the summer).
- Case Study 5: Asheville
  - Urban area with steady traffic from the residents in the Asheville area.
  - One of the traffic counter location's data exhibited a moderate seasonality (peaking in June and July); whereas the other location did not exhibit seasonality.

This paper is organized as follows. The next section presents a literature review, followed by a section outlining the Model, then the Case Studies and Results are presented for each locality, and then the overarching findings, conclusions, and recommendations are outlined.

2. LITERATURE REVIEW

This project incorporates multiple disciplines, including tourism planning, local and urban planning, environmental sustainability, economics, transportation planning, engineering, and geography. The research included data, methods, and resources from various fields, including geographic information systems (GIS), employment, economic, hotel occupancy, bicycle transportation, pedestrian transportation, forecasting, seasonal variation modeling, regression, motor vehicle transportation, and tourism behavior. Several general references were identified including the Traffic Engineering Handbook [3], Travel Economic Impact Model [4], and the North Carolina Department of Commerce economic impact website related to tourism [5].

2.1. General Tourism Planning

There are a number of publications in Tourism Planning. Clare Gunn's book explores the fundamentals of tourism planning (*i.e.*, sustainability, policy, growth, and ecotourism) on various scales from around the world [6]. Edward Inskeep's book provides an overview of sustainable tourism planning (*i.e.*, institutional, environmental, implementation, socioeconomic, strategic, and development). Seasonality is discussed in terms of capacity for attractions and methods to reduce seasonality (*e.g.*, four-season resorts, promotions in off-seasons) [7]. Takayuki Hara's book describes how quantitative analysis is applied to the tourism industry, including regression, forecasting, and social accounting [8]. Each of these references are practitioner based and general; however, they do not provide details for tourism traffic planning with seasonality [6 - 8].

2.2. General Transportation Planning

The economic impacts of transportation planning are covered by the Victoria Transport Policy Institute [9]. This resource provides a comprehensive overview of transportation planning, including evaluation of transportation benefits, the economic value of walkability (for a locality), evaluation of non-motorized transportation benefits and costs, land use, and transportation diversity.

2.3. Environmental Impacts

Environmentally, tourism gateway communities always have to depend on local residents as well as the economic and cultural factors [10]. Transportation impacts the environment and congestion via the carrying capacity of the roadways. These issues could negatively impact the recreational quality and tourism of an area. For example, emergency response services could be inhibited by transportation congestion during peak times or contribute to environmental impacts by increased emissions and fossil fuel consumption [11, 12]. Sustainable tourism may also depend on these environmental costs and the enhanced mobility [13]; however, emissions and fossil fuel consumption could be reduced if motorized traffic is replaced with an emphasis on public transport, walking, and cycling. Greenhouse gas emissions are dominated by transportation within the tourism industry; thus, infrastructure should integrate the types of transport, alternative designs, and environmental impacts with future importance on decreasing travel distances, increasing passenger load, and promoting technological efficiencies.

2.4. GIS and Visualization

GIS and visualization are influential tools for predicting the aesthetic and environmental impacts of tourism development and alternative transportation plans. GIS can assist quantify land use changes on watersheds, support site selection and corridor suitability analysis, visually depict aesthetic impacts in line-of-sight and viewshed analyses, and environmental impact assessment [14]. The participatory GIS provides an approach for integrating community residential and planner participation and circumventing hurdles in communications [15] or alleviating environmental justice issues [16].

2.5. Public Perception

Citizen and public perception is important for planning projects. Obviously, residents should be questioned regarding their perceptions, experiences, and expectations. Then, one can evaluate how the residents assess tourism and they will interact with the tourists or businesses serving the tourists [17, 18].

2.6. Short Term and Long Term Traffic Prediction

Traffic prediction research spans many different timelines, from several hours to minutes. The research focuses on predicting traffic volume and predicting traffic behavior (e.g., an unexpected event such as a lane closure). Fries *et al*. evaluated software that was used to predict traffic conditions after a traffic incident. They found that large amounts of computational capacity were needed to make accurate predictions [19]. Stathopoulos *et al*. studied multivariate models to predict traffic volume in congested urban areas, which were more accurate than univariate time series models [20]. From a time span perspective, there is a need for different model specifications throughout the day. These methods can also be used for waterways, Lowry *et al*. determined recreational river traffic patterns by applying highway traffic simulation software and methods [21].

Han, Stone, and Huntsinger assigned traffic volumes to small networks using census data, maps, and traffic data in a spreadsheet-model to localities where more complex software had previously been used [22]. Zhong and Hanson used travel demand models to estimate traffic volume in rural areas. In these areas no traffic data was available. The travel demand models consistently overestimated traffic volume originally. However, the models increased in accuracy when reducing the size of traffic analysis zones, and including additional information (*e.g*., number of driveways per kilometer) [23]. Stutz and Runkler predicted long and short term traffic patterns using fuzzy neural networks [24].

3. MODEL

The issue of forecasting traffic for high-tourism and/or recreational areas have been studied in the past [25 - 27]. It has been shown that these areas have an exceedingly high usage rate at peak times when compared to the AADT. The recommendation is to incorporate two additional parameters when applying AADT and seasonality. These two parameters include a K-factor and a D-factor. Conceptually these two parameters will be used to calculate a Design Hour Volume (DHV) and a Directional Design Hour Volume (DDHV).

The ratio of the hourly, two-way traffic to the two-way AADT, unconstrained by capacity is known as the K-factor. The D-factor is the percentage of the total two-way, peak hour traffic traveling in the peak direction. The K-factor and D-factor are ratios and are based on a given hour. For example, K_1 would depict the busiest hour of the year (study period); whereas, K_{100} would depict the 100^{th} busiest hour [25 - 27].

The design hour volume, DHV, is the K-factor multiplied by the AADT. For the peak direction, the directional design hour volume, DDHV, is the AADT multiplied by the K-factor multiplied by the D-factor. For the non-peak direction, the DDHV is the AADT multiplied by the K-factor multiplied by one minus the D-factor [25 - 27].

3.1. Formulas

K-factor = the proportion of AADT occurring during a given hour (*e.g*., the Design Hour Factor)

D-factor = the proportion of the total, two-way design hour traffic, traveling in the peak direction (*e.g*., the Directional Distribution)

DHV = AADT × K-factor

DDHV (Peak Direction) = AADT × K-factor × D-factor

DDHV (Non-peak Direction) = AADT × K-factor × (1 – D-factor)

Further discussion of the K-factor can be found in references [25 - 27].

For example, K_{30} depicts the 30[th] busiest hour (of the year, or study period) for various road types assuming two-way traffic and unconstrained by capacity. The 30[th] hour is chosen because it has been shown to be effective for designing and planning; including, but not limited to, Florida and Nevada.

The K_{30} values act as you would expect, notably:

- The K_{30} factor will decrease as the AADT on a roadway increases.
- The K_{30} factor will decrease as development density increases.
- The highest K_{30} factor (*i.e.*, hourly traffic as a percentage of AADT) occurs on recreational roadways which exhibit high seasonality.

The D_{30} values are used to correct for traffic that is traveling primarily in one direction during the peak hour. Thus, more traffic lanes will be needed for that direction. The D-factor values should average to be 0.5 when averaging over both directions.

The values for K_{30} and D_{30} can be obtained using traffic counts, either continuous counts or short-term counts. They can be estimated based on known values for the recreational, rural, suburban, and urban areas. For example, the values for K_{30} will be approximately 0.14 for recreational, 0.114 for rural, 0.103 for suburban, and 0.097 for urban. The values for D_{30} would average 0.5 (*i.e.*, equal traffic in both directions at peak hour) and adjust accordingly. Both of these parameter values would have to be adjusted for long-term planning, especially as new roadways are being constructed as road choices may change over the project's horizon.

It should be noted that while Nevada in 2012 [26] used the K_{30} and D_{30} values depending on the roadway being studied, Florida has developed a new model that uses different K values (*i.e.*, K_{100}), D values, and percent of vehicles that are trucks based on different locations within the state while tying-in budget considerations [27]. In other words, Florida is planning for the 100[th] busiest hour rather than the 30[th] busiest hour due to budget constraints and other restrictions.

The following standard K factors have been used by the Florida Department of Transportation since at least 2002 [25] and continued to be used as of 2014 [27]. Note that D factors would be determined using traffic counters measuring directionality of the traffic at the corresponding standard K factor representative time period. Thus, once DHV and DDHV are calculated, then a Level Of Service (LOS) analysis can be completed and plans can be made accordingly.

The primary recommendation with respect to the model would be to use the *hourly* traffic counts (either continuous or short-term) to develop K_{30} and D_{30} values for locations and then use DHVs and DDHVs rather than AADTs for planning purposes.

4. CASE STUDIES

Five locations were selected as Case Study locations within the state of North Carolina. These five locations were selected due to their seasonal tourism. The locations include beach locations and mountain locations; thus, some areas will experience high traffic volume in the warmer months and others in the cooler months. These locations were of special interest to the NCDOT and selected with their approval.

4.1. Intermediate Approach used in North Carolina Case Studies

An intermediate approach was needed since hourly traffic counts were not readily available or reliable for all locations. Thus, an adaptation of the monthly traffic counts was used to approximate the K_{30} values. The recommendation is to average the top two monthly counts. This was approximated using data available from Nevada and Florida where the K_{30} ratio was 14% for high-tourism areas, 11.4% for rural areas, and so forth; and relating it to the Case Study locations. Due to the location of the Case Studies it was assumed the DHV and DDHV were equivalent (*i.e.*, the directions of traffic did not matter). Since the average of the top two months will be used, then that will be defined as Design Volume (DV). The following recommendations for each Case Study location are based on the knowledge that transportation funding is limited. Thus, the overarching goal was to provide an expectation of what the two month average for DV would provide. AADT was eliminated as consideration for DV for various administrative, financial, and resource reasons.

4.2. Example of Seasonality and Explanation of Terms Used in Case Studies

Below are the figures for the Outer Banks area for the A2702 traffic counter, which will be included in Case Study 2. Fig. (**1**) is a repetition of Fig. (**9**) and Fig. (**2**) is a repetition of Fig. (**10**). As discussed further in Section 4 this area is considered high with respect to seasonal variation (month-to-month). This example provides details on how to interpret these figures.

	Minimum %AADT:	Maximum %AADT:	Median %AADT:	Standard Deviation:	Multiplier:	Total ADT:	AADT:	DV:
Dare County								
U.S. 158								
A2702	5.11	12.38	8.25	2.34	2.42	21,690	1,807	2,590
A2703	5.70	12.29	7.85	2.37	2.15	117,194	9,766	14,160

Fig. (1). An example of seasonality.

Outer Banks Area
Dare (A2702)

% of Yearly Traffic By Month	
Month	**AVG %**
JAN	5.11
FEB	5.52
MAR	6.65
APR	8.11
MAY	9.91
JUN	11.50
JUL	12.38
AUG	10.22
SEP	8.87
OCT	8.38
NOV	7.33
DEC	6.00

Sorted by % of Yearly Traffic		
Month	**AVG**	**Multiplier**
JAN	5.11	2.42
FEB	5.52	2.24
DEC	6.00	2.06
MAR	6.65	1.86
NOV	7.33	1.69
APR	8.11	1.53
OCT	8.38	1.48
SEP	8.87	1.40
MAY	9.91	1.25
AUG	10.22	1.21
JUN	11.50	1.08
JUL	12.38	1.00

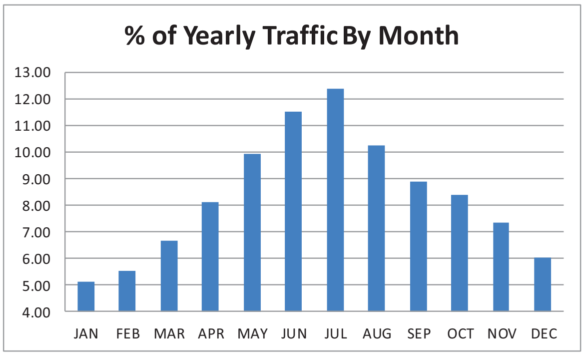

Fig. (2). an example of seasonality.

	Locations:	Route:	Data:	Seasonality Depicted:
Avery County				
North of Spruce Pine				
A0501	0.10 MILES SOUTH OF SR 1103 (BENT RD)	US 19E	2005-2013	No
Watauga County				
Boone				
A9401	0.10 MILES SOUTH OF SR 1672	SR 1508 (Elm Creek Rd)	1995-2006	No
A9403	0.50 MILES NORTH OF US 321 BUS	US 321	1998-2006	Moderate

Fig. (3). Data Summary for Case Study 1.

	Minimum %AADT:	Maximum %AADT:	Median %AADT:	Standard Deviation:	Multiplier:	Total ADT:	AADT:	DV:
Avery County								
North of Spruce Pine								
A0501	7.01	9.26	8.64	0.77	1.32	31,489	2,624	2,878
Watauga County								
Boone								
A9401	7.29	9.13	8.50	0.70	1.25	8,794	733	801
A9403	6.86	10.33	8.18	1.18	1.51	63,006	5,251	6,367

Fig. (4). AADT and DV Summary for Case Study 1.

The minimum, median, maximum, and standard deviation are based across the 12 months throughout the year; as percentages of AADT observed at the site for the entire year. Thus, for Dare County site A2702, the minimum of 5.11 (Fig. **1**) was observed in January (Fig. **1**); meaning 5.11% of the traffic passing A2702 for the entire year occurred in January. Likewise, the maximum was 12.38% occurring in July. The multiplier 2.42 Fig. (**1**) is determined by dividing the maximum (July at 12.38%) by the minimum (January at 5.11%) (*i.e.*, 12.38% ÷ 5.11% = 2.42). The AADT was the actual observed value, and the DV is the average of the top two observed months; for A2702, July and June. Note, medians are reported rather than averages for the 12 months since averages would be 100% ÷ 12 = 8.33% for each location.

The seasonal variation is exhibited in the histogram in Fig. (**2**). In fact, June-August all exhibit twice as much traffic as January (the month with the least amount of traffic) and about 25% more than April and October, which are average months.

The seasonal variation is exhibited in the values within Figures 2.3 and 2.4. The Multiplier is the Maximum divided by the Minimum. A Multiplier of ≥ 2 (or nearly 2) is considered high variation, a 2 > Multiplier ≥ 1.4 is considered moderate, and below 1.4 is considered steady.

Formulas for Case Study:

$DV = (ADT_1 + ADT_2) \div 2$

Where ADT_1 is the highest average daily traffic for a single month in a calendar year, and ADT_2 is the second-highest average daily traffic for a single month in a calendar year.

5. CASE STUDY 1: WATAUGA/AVERY (NC 105)

5.1. Modeling and Data Analysis

The following locations were studied for Case Study 1. Information regarding the county, location of the traffic counter, route, and dates of data collection is provided in Fig. (**3**). Also provided is the research team's evaluation of the seasonality depicted based on the data analyzed (in reference to the other Case Study traffic counter locations) in Fig. (**4**). Finally, the analysis for each counter location is provided in Figs. (**5-7**).

5.2. Values Explained

The minimum, median, maximum, and standard deviation are based across the 12 months throughout the year; as percentages of AADT observed at the site for the entire year. Thus, for Avery County site A0501, the minimum of 7.01 (Fig. **4**) was observed in January (Fig. **5**); meaning 7.01% of the traffic passing A0501 for the entire year occurred in January. Likewise, the maximum was 9.26% occurring in August. The multiplier 1.32 (Fig. **4**) is determined by dividing the maximum (August at 9.26%) by the minimum (January at 7.01%) (*i.e.*, 9.26% ÷ 7.01% = 1.32). The AADT was the actual observed value, and the DV is the average of the top two observed months; in the case of A0501, August and October.

Note, medians are reported rather than averages for the 12 months since averages would be 100% ÷ 12 = 8.33% for each location.

5.3. Case Study 1 Final Recommendations and Conclusions

The Case Study 1 location provides a number of interesting issues with respect to transportation planning, urban planning, and urban form issues. The data shows that there is moderate seasonality in one of the three locations studied for the data collected, compared to other areas studied (*i.e.*, it does not depict as an extreme seasonality component as compared to other Case Study locations). This is likely due to the fact that the university and surrounding community provide a good deal of routine traffic in the area. The typical peaks are in July and October (with August being third highest). The design volume (DV) for the various locations are relatively close to AADT (*i.e.*, when compared to other case study locations) due to the minimal and/or moderate seasonality exhibited by these locations.

6. CASE STUDY 2: OUTER BANKS (US 158)

6.1. Modeling and Data Analysis

The following locations were studied for Case Study 2. Information regarding the county, location of the traffic counter, route, and dates of data collection are provided in Fig. (**8**). Also provided is the research team's evaluation of the seasonality depicted based on the data analyzed (in reference to the other Case Study traffic counter locations) in Fig. (**9**). Finally, the analysis for each counter location is provided in Figs. (**10-11**).

6.2. Values Explained:

The minimum, median, maximum, and standard deviation are based across the 12 months throughout the year; as percentages of AADT observed at the site for the entire year. Thus, for Dare County site A2702, the minimum of 5.11 (Fig. **9**) was observed in January (Fig. **10**); meaning 5.11% of the traffic passing A2702 for the entire year occurred in January. Likewise, the maximum was 12.38% occurring in July. The multiplier 2.42 Fig. (**9**) is determined by dividing the maximum (July at 12.38%) by the minimum (January at 5.11%) (*i.e.*, 12.38% ÷ 5.11% = 2.42). The AADT was the actual observed value, and the DV is the average of the top two observed months; for A2702, July and June.

Spruce Pine Area
Avery (A0501)

% of Yearly Traffic By Month	
Month	**AVG %**
JAN	7.01
FEB	7.51
MAR	7.83
APR	8.63
MAY	8.65
JUN	8.84
JUL	8.98
AUG	9.26
SEP	8.88
OCT	9.03
NOV	8.17
DEC	7.20

Sorted by % of Yearly Traffic		
Month	**AVG**	**Multiplier**
JAN	7.01	1.32
DEC	7.20	1.28
FEB	7.51	1.23
MAR	7.83	1.18
NOV	8.17	1.13
APR	8.63	1.07
MAY	8.65	1.07
JUN	8.84	1.05
SEP	8.88	1.04
JUL	8.98	1.03
OCT	9.03	1.03
AUG	9.26	1.00

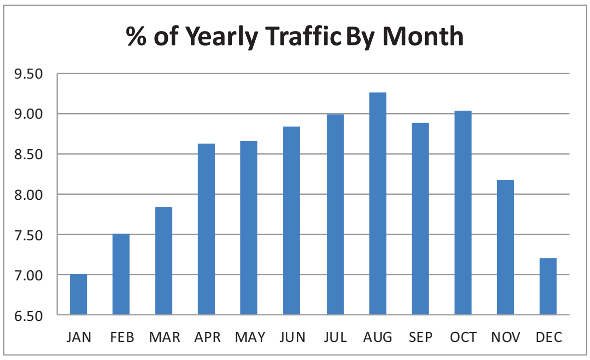

Fig. (5). AADT Summary for Avery (Location A0501).

Boone Area
Watauga (A9401)

% of Yearly Traffic By Month	
Month	**AVG %**
JAN	7.30
FEB	7.29
MAR	7.85
APR	8.74
MAY	8.94
JUN	8.58
JUL	9.13
AUG	9.00
SEP	8.42
OCT	9.08
NOV	8.23
DEC	7.45

Sorted by % of Yearly Traffic		
Month	**AVG**	**Multiplier**
FEB	7.29	1.25
JAN	7.30	1.25
DEC	7.45	1.22
MAR	7.85	1.16
NOV	8.23	1.11
SEP	8.42	1.08
JUN	8.58	1.06
APR	8.74	1.04
MAY	8.94	1.02
AUG	9.00	1.01
OCT	9.08	1.01
JUL	9.13	1.00

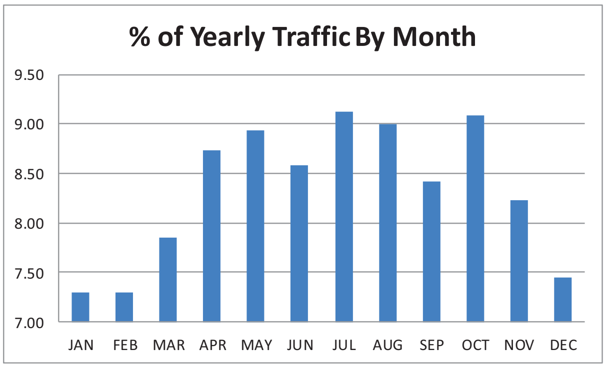

Fig. (6). AADT Summary for Avery (Location A9401).

Boone Area
Watauga (A9403)

% of Yearly Traffic By Month	
Month	**AVG %**
JAN	6.86
FEB	7.12
MAR	6.99
APR	7.54
MAY	8.35
JUN	9.20
JUL	10.33
AUG	9.54
SEP	8.73
OCT	9.77
NOV	8.01
DEC	7.56

Sorted by % of Yearly Traffic		
Month	**AVG**	**Multiplier**
JAN	6.86	1.51
MAR	6.99	1.48
FEB	7.12	1.45
APR	7.54	1.37
DEC	7.56	1.37
NOV	8.01	1.29
MAY	8.35	1.24
SEP	8.73	1.18
JUN	9.20	1.12
AUG	9.54	1.08
OCT	9.77	1.06
JUL	10.33	1.00

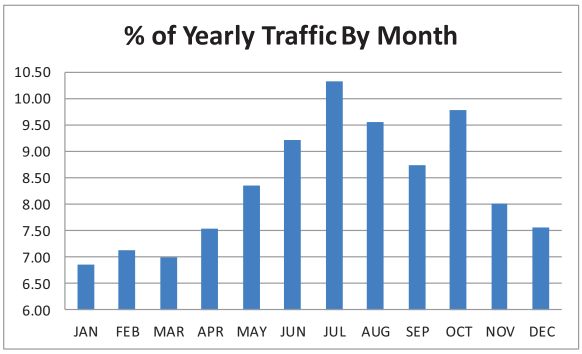

Fig. (7). AADT Summary for Avery (Location A9403).

	Locations:	Route:	Data:	Seasonality Depicted:
Dare County				
U.S. 158				
A2702	0.60 MILES WEST OF SR 1153 (OLD FERRY LANDING RD)	US 64	2005-2013	High
A2703	0.20 MILES WEST OF BARLOW LANE	US 158	1995-2013	High

Fig. (8). Data Summary for Case Study 2.

	Minimum %AADT:	Maximum %AADT:	Median %AADT:	Standard Deviation:	Multiplier:	Total ADT:	AADT:	DV:
Dare County								
U.S. 158								
A2702	5.11	12.38	8.25	2.34	2.42	21,690	1,807	2,590
A2703	5.70	12.29	7.85	2.37	2.15	117,194	9,766	14,160

Fig. (9). AADT and DV Summary for Case Study 2.

Outer Banks Area
Dare (A2702)

% of Yearly Traffic By Month	
Month	**AVG %**
JAN	5.11
FEB	5.52
MAR	6.65
APR	8.11
MAY	9.91
JUN	11.50
JUL	12.38
AUG	10.22
SEP	8.87
OCT	8.38
NOV	7.33
DEC	6.00

Sorted by % of Yearly Traffic		
Month	**AVG**	**Multiplier**
JAN	5.11	2.42
FEB	5.52	2.24
DEC	6.00	2.06
MAR	6.65	1.86
NOV	7.33	1.69
APR	8.11	1.53
OCT	8.38	1.48
SEP	8.87	1.40
MAY	9.91	1.25
AUG	10.22	1.21
JUN	11.50	1.08
JUL	12.38	1.00

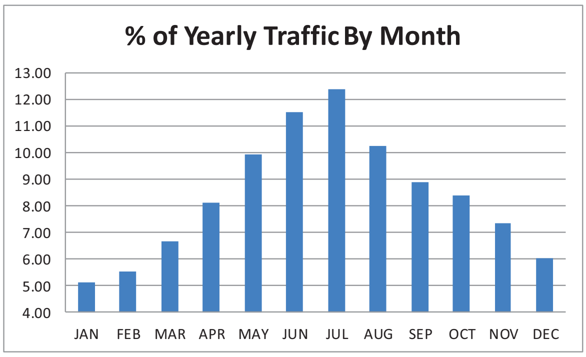

Fig. (10). AADT Summary for Dare (Location A2702).

Outer Banks Area
Dare (A2703)

% of Yearly Traffic By Month	
Month	**AVG %**
JAN	5.85
FEB	5.89
MAR	6.73
APR	8.12
MAY	9.15
JUN	10.84
JUL	12.29
AUG	12.02
SEP	9.20
OCT	7.57
NOV	6.65
DEC	5.70

Sorted by % of Yearly Traffic		
Month	**AVG**	**Multiplier**
DEC	5.70	2.15
JAN	5.85	2.10
FEB	5.89	2.09
NOV	6.65	1.85
MAR	6.73	1.83
OCT	7.57	1.62
APR	8.12	1.51
MAY	9.15	1.34
SEP	9.20	1.33
JUN	10.84	1.13
AUG	12.02	1.02
JUL	12.29	1.00

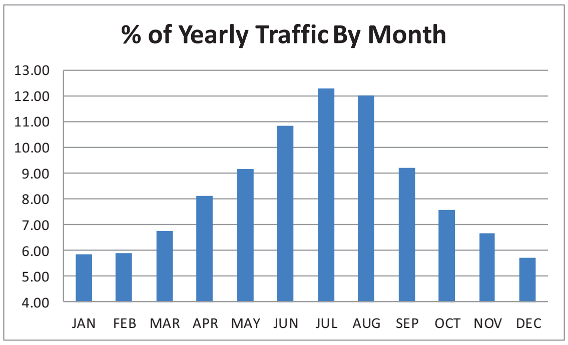

Fig. (11). AADT Summary for Dare (Location A2703).

6.3. Case Study 2 Final Recommendations and Conclusions

The Case Study 2 location provides a number of interesting issues with respect to transportation planning, urban planning, and urban form issues with respect to seasonality in traffic. The local residents exhibited extreme behavior with respect to traffic avoidance and other plans. The opportunity for alternative transportation (*i.e*., walking, bicycles) could be further explored, but would require additional infrastructure and/or infrastructure improvements. The abundance of parking in some areas actually encourages more tourism traffic. The data shows that there is high seasonality in both of the two locations studied for the data collected, compared to other areas studied (*i.e*., it does depict an extreme seasonality component as compared to other Case Study locations). This is likely due to the fact that the permanent population is relatively small when compared to the tourism population. The obvious peaks are in the summer (June-August), and the lows in the winter (December-February). The extreme seasonality represents a significant issue with respect to traffic count variation, essentially making the AADT meaningless for this region. Due to the economy of Dare County (and the Outer Banks, in general) relying heavily on tourism, it makes the transportation network essential to the prosperity of this area and its residents [28, 29].

The design volume for the various locations is significantly larger than AADT (*i.e*., when compared to other case study locations) due to the high seasonality and peak demand exhibited by these locations.

7. CASE STUDY 3: WRIGHTSVILLE BEACH AREA (WILMINGTON)

7.1. Modeling and Data Analysis

The following locations were studied for Case Study 3. Information regarding the county, location of the traffic counters, routes, and dates of data collection is provided in Fig. (**12**). Also provided is the research team's evaluation of the seasonality depicted based on the data analyzed (in reference to the other Case Study traffic counter locations) in Fig. (**13**). Finally, the analysis for each counter location is provided in Figs. (**14-15**).

Locations:		Route:	Data:	Seasonality Depicted:
New Hanover County				
Wilmington/Wrightsville Beach				
A6403	0.02 MILES EAST OF SUMMER REST RD	US 74-76	2007-2013	High
A6405	0.10 MILES EAST OF US 421 NORTHBOUND RAMP	US 76/17 Business	2005-2013	No

Fig. (12). Data Summary for Case Study 3

	Minimum %AADT:	Maximum %AADT:	Median %AADT:	Standard Deviation:	Multiplier:	Total ADT:	AADT:	DV:
New Hanover County								
Wilmington/Wrightsville Beach								
A6403	5.78	11.44	8.19	1.99	1.98	161,987	13,499	18,003
A6405	7.70	8.76	8.30	0.32	1.14	265,808	22,151	23,169

Fig. (13). AADT and DV Summary for Case Study 3.

Wilmington Area
New Hanover (A6403)

% of Yearly Traffic By Month	
Month	AVG %
JAN	5.97
FEB	6.34
MAR	7.50
APR	8.93
MAY	9.99
JUN	10.79
JUL	11.44
AUG	10.29
SEP	8.86
OCT	7.51
NOV	6.60
DEC	5.78

Sorted by % of Yearly Traffic		
Month	AVG	Multiplier
DEC	5.78	1.98
JAN	5.97	1.92
FEB	6.34	1.80
NOV	6.60	1.73
MAR	7.50	1.53
OCT	7.51	1.52
SEP	8.86	1.29
APR	8.93	1.28
MAY	9.99	1.15
AUG	10.29	1.11
JUN	10.79	1.06
JUL	11.44	1.00

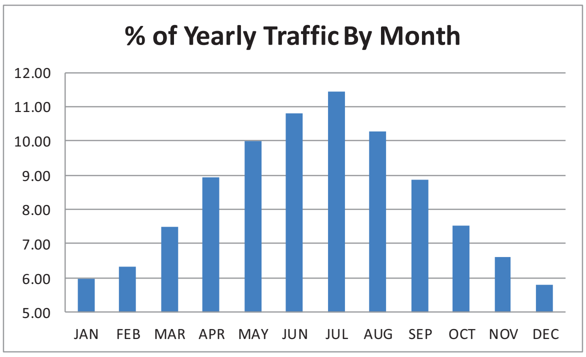

Fig. (14). AADT Summary for Wilmington (Location A6403).

Wilmington Area
Brunswick (A6405)

% of Yearly Traffic By Month	
Month	AVG %
JAN	7.70
FEB	8.27
MAR	8.55
APR	8.62
MAY	8.27
JUN	8.68
JUL	8.76
AUG	8.58
SEP	8.26
OCT	8.32
NOV	8.06
DEC	7.94

Sorted by % of Yearly Traffic		
Month	AVG	Multiplier
JAN	7.70	1.14
DEC	7.94	1.10
NOV	8.06	1.09
SEP	8.26	1.06
FEB	8.27	1.06
MAY	8.27	1.06
OCT	8.32	1.05
MAR	8.55	1.02
AUG	8.58	1.02
APR	8.62	1.02
JUN	8.68	1.01
JUL	8.76	1.00

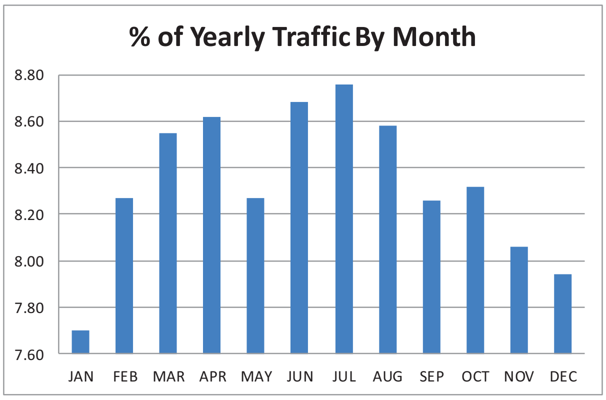

Fig. (15). AADT Summary for Wilmington (Location A6405).

7.2. Values Explained

The minimum, median, maximum, and standard deviation are based across the 12 months throughout the year; as percentages of AADT observed at the site for the entire year.

Thus, for New Hanover County site A6403, the minimum of 5.78 Fig. (**13**) was observed in December Fig. (**14**); meaning 5.78% of the traffic passing A6403 for the entire year occurred in December. Likewise, the maximum was 11.44% occurring in July. The multiplier 1.98 Fig. (**13**) is determined by dividing the maximum (July at 11.44%) by the minimum (December at 5.78%) (*i.e*., 11.44% ÷ 5.78% = 1.98). The AADT was the actual observed value, and the DV is the average of the top two observed months; in the case of A6403, July and June.

7.3. Case Study 3 Final Recommendations and Conclusions

The Case Study 3 location provides a number of interesting issues due to its population size and diversity. The figures and data indicate that the Wilmington area (within the city) and the connecting highways exhibit a relatively steady traffic flow. There are obvious bottlenecks and pinch points. One of the counter locations exhibited extreme seasonality, particularly during the summer months since this was a route that captures the summer tourism traffic; thus, the design volume for this location was significantly higher than AADT. The other counter was relatively steady, not exhibiting seasonality; thus, the design volume and AADT were practically equivalent.

8. CASE STUDY 4: BRYSON CITY

8.1. Modeling and Data Analysis

The following locations were studied for Case Study 4. Information regarding the county, location of the traffic counter, route, and dates of data collection is provided in Fig. (**16**). Also provided is the research team's evaluation of the seasonality depicted based on the data analyzed (in reference to the other Case Study traffic counter locations) in Fig. (**17**). Finally, the analysis for each counter location is provided in Fig. (**18**).

8.2. Values Explained

The minimum, median, maximum, and standard deviation are based across the 12 months throughout the year; as percentages of AADT observed at the site for the entire year. Thus, for Swain County site A8602, the minimum of 5.19 Fig. (**17**) was observed in January Fig. (**18**); meaning 5.19% of the traffic passing A8602 for the entire year occurred in January. Likewise, the maximum was 12.52% occurring in July. The multiplier 2.41 Fig. (**17**) is determined by dividing the maximum (July at 12.52%) by the minimum (January at 5.19%) (*i.e*., 12.52% ÷ 5.19% = 2.41). The AADT was the actual observed value, and the DV is the average of the top two observed months; in the case of A8602, July and August.

8.3. Case Study 4 Final Recommendations and Conclusions

The Case Study 4 location provides a number of interesting issues due to its proximity to the Great Smoky Mountains National Park and its seasonality in the summer months. The figures and data indicate that the Bryson City area exhibits extreme seasonality, nearly equivalent to the levels exhibited in the Dare County (Outer Banks) study (Case Study 2). Interestingly enough, the peak traffic occurs during the summer (same as Dare County), even though Bryson City is in the mountains. This is due to visitors to the Great Smoky Mountains National Park and surrounding areas. The design volume for the counter location is significantly larger than AADT (*i.e*., when compared to other case study locations) due to the high seasonality and peak demand exhibited by this location.

9. CASE STUDY 5: ASHEVILLE

9.1. Modeling and Data Analysis

The following locations were studied for Case Study 5. Information regarding the county, location of the traffic counters, routes, and dates of data collection is provided in Fig. (**19**). Also provided is the research team's evaluation of the seasonality depicted based on the data analyzed (in reference to the other Case Study traffic counter locations) in Fig. (**20**). Finally, the analysis for each counter location is provided in Figs. (**21**-**22**).

	Locations:	Route:	Data:	Seasonality Depicted:
Swain County				
Bryson City				
A8602	0.30 MILES WEST OF NC 28	NC 28	2005-2013	High

Fig. (16). Data Summary for Case Study 4.

	Minimum %AADT:	Maximum %AADT:	Median %AADT:	Standard Deviation:	Multiplier:	Total ADT:	AADT:	DV:
Swain County								
Bryson City								
A8602	5.19	12.52	8.60	2.40	2.41	26,134	2,178	3,079

Fig. (17). AADT and DV Summary for Case Study 4.

Bryson City Area
Swain (A8602)

% of Yearly Traffic By Month	
Month	AVG %
JAN	5.19
FEB	5.58
MAR	6.47
APR	8.05
MAY	9.16
JUN	10.80
JUL	12.52
AUG	11.04
SEP	9.35
OCT	9.20
NOV	6.91
DEC	5.73

Sorted by % of Yearly Traffic		
Month	AVG	Multiplier
JAN	5.19	2.41
FEB	5.58	2.24
DEC	5.73	2.19
MAR	6.47	1.93
NOV	6.91	1.81
APR	8.05	1.56
MAY	9.16	1.37
OCT	9.20	1.36
SEP	9.35	1.34
JUN	10.80	1.16
AUG	11.04	1.13
JUL	12.52	1.00

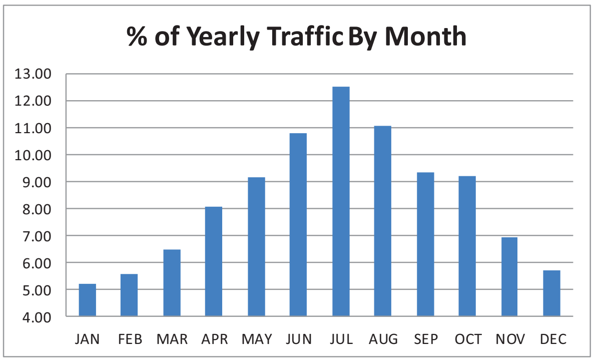

Fig. (18). AADT Summary for Bryson City (Location A8602).

	Locations:	Route:	Data:	Seasonality Depicted:
Buncombe County				
Asheville				
A1001	0.70 MILES WEST OF NC 191 (BREVARD RD)	I-26	2005-2013	No
A1003	1.45 MILES EAST OF SR 1200 (WIGGINS RD))	I-40	2006-2013	Moderate

Fig. (19). Data Summary for Case Study 5.

	Minimum %AADT:	Maximum %AADT:	Median %AADT:	Standard Deviation:	Multiplier:	Total ADT:	AADT:	DV:
Buncombe County								
Asheville								
A1001	7.48	8.71	8.39	0.32	1.17	320,267	26,689	27,777
A1003	6.18	9.86	8.58	1.12	1.59	283,975	23,665	27,531

Fig. (20). AADT and DV Summary for Case Study 5.

Asheville Area
Buncombe (A1001)

% of Yearly Traffic By Month	
Month	AVG %
JAN	7.48
FEB	8.08
MAR	8.37
APR	8.42
MAY	8.52
JUN	8.63
JUL	8.30
AUG	8.42
SEP	8.47
OCT	8.71
NOV	8.36
DEC	8.24

Sorted by % of Yearly Traffic		
Month	AVG	Multiplier
JAN	7.48	1.17
FEB	8.08	1.08
DEC	8.24	1.06
JUL	8.30	1.05
NOV	8.36	1.04
MAR	8.37	1.04
AUG	8.42	1.04
APR	8.42	1.03
SEP	8.47	1.03
MAY	8.52	1.02
JUN	8.63	1.01
OCT	8.71	1.00

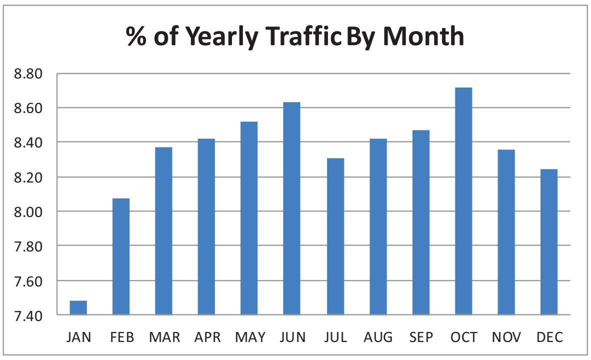

Fig. (21). AADT Summary for Asheville (Location A1001).

Asheville Area
Buncombe (A1003)

% of Yearly Traffic By Month	
Month	AVG %
JAN	6.18
FEB	6.76
MAR	7.49
APR	7.90
MAY	8.67
JUN	9.53
JUL	9.86
AUG	9.24
SEP	8.70
OCT	9.21
NOV	8.49
DEC	7.98

Sorted by % of Yearly Traffic		
Month	AVG	Multiplier
JAN	6.18	1.59
FEB	6.76	1.46
MAR	7.49	1.32
APR	7.90	1.25
DEC	7.98	1.23
NOV	8.49	1.16
MAY	8.67	1.14
SEP	8.70	1.13
OCT	9.21	1.07
AUG	9.24	1.07
JUN	9.53	1.03
JUL	9.86	1.00

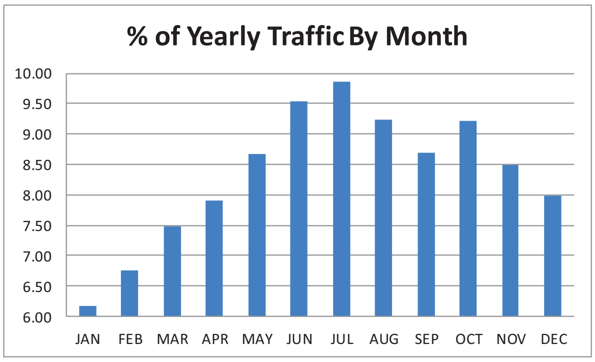

Fig. (22). AADT Summary for Asheville (Location A1003).

9.2. Values Explained

The minimum, median, maximum, and standard deviation are based across the 12 months throughout the year; as percentages of AADT observed at the site for the entire year. Thus, for Buncombe County site A1001, the minimum of 7.48 Fig. (**20**) was observed in January Fig. (**21**); meaning 7.48% of the traffic passing A1001 for the entire year occurred in January. Likewise, the maximum was 8.71% occurring in October. The multiplier 1.17 Fig. (**20**) is determined by dividing the maximum (October at 8.71%) by the minimum (January at 7.48%) *[i.e., 8.71% ÷ 7.48% = 1.17]*. The AADT was the actual observed value, and the DV is the average of the top two observed months; in the case of A1001, June and October.

9.3. Case Study 5 Final Recommendations and Conclusions

The Case Study 5 location provides a number of interesting issues due to its population size and diversity. The figures and data indicate that the Asheville area (within and nearby the city) and the connecting highways exhibit a relatively steady traffic flow with a moderate seasonality for one of the two counters studied. Essentially, the road is not used as much in January, perhaps due to extreme weather events and holidays. The road is used much more often during the summer months (when compared to January). There are obvious bottlenecks and pinch points.

The design volume for one location was approximately equivalent to the AADT and for the other location moderately higher, which is due to the lack of seasonality exhibited by these locations.

CONCLUSION

The primary case study findings and conclusions were:

- Case Study 1: Watauga/Avery (NC 105)
  - Of the three traffic counter locations' data evaluated, two did not exhibit seasonality and one exhibited only moderate seasonality (peaking in August). The reason for this is due to the constant (year-round) traffic generated by the college students and residents.
- Case Study 2: Outer Banks (US 158)
  - Of the two traffic counter locations' data evaluated, both exhibited high seasonality; peaking in the summer.
- Case Study 3: Wrightsville Beach Area (Wilmington)
  - Urban area with steady traffic from the residents in the Wilmington area.
  - One of the traffic counter location's data exhibited a high seasonality (peaking in the summer); and one exhibited no seasonality. The one that exhibited seasonality included beach traffic.
- Case Study 4: Bryson City
  - The single traffic counter location's data exhibited a high seasonality (peaking in the summer).
- Case Study 5: Asheville
  - Urban area with steady traffic from the residents in the Asheville area.
  - One of the traffic counter location's data exhibited a moderate seasonality (peaking in June and July); whereas the other location did not exhibit seasonality.

The first and primary recommendation with respect to AADT calculations and planning is to incorporate peak-usage and directionality; whether it be hourly or monthly. Urban areas will have AADT values similar to the design value. However, seasonal areas, such as tourist locations, will have significant differences between the design value and the AADT. While other states (notably Nevada and Florida) have incorporated peak-hour usage ratios into their planning forecasts, using monthly rates (as shown in the case studies) can be useful.

Specific implementation strategies and recommendations for the five case study locations were provided in those specific sections and outlined in the prior section. This section will focus on two primary areas of consideration with respect to planning for seasonal variation.

Secondly, the baseline models and methods of data collection for areas with anticipated seasonal variability are not current. Simply put, calculating an accurate AADT would require collecting data at both peak and non-peak times. Thus, for this research study, the research team relied heavily on traffic counters that were operational year-round (or close to year-round), with a preference for counters with current data (*i.e*., through 2013). It is our recommendation that the NCDOT modify its procedures to allow for continuous traffic counting in some locations that experience high seasonality (note, the NCDOT is already doing this in many areas), and the NCDOT weight those counters with greater emphasis since the data is more complete than the sampling counters. In some locations, it will be difficult to find a point to collect continuous data. However, in some locations (*i.e*., Outer Banks) there are specific entry and exit points to the area (*i.e*., bridges) that would allow for a fairly accurate count and estimation.

Thirdly, areas that exhibit large seasonal fluctuations are at an inherent disadvantage when compared against areas that do not have variation. This is true with respect to transportation planning as well as other systems. Using the metric AADT is the primary cause for this inherent disadvantage, because by its very nature (*i.e*., average) it does not account for variability (*i.e*., seasonality). Thus, as a forward-thinking (long-term) plan, perhaps the concept of a service level should be enacted. Simply put, a service level approach would suggest designing the transportation system to meet XX% of the demand for any given time period. For a system with low variability, the AADT would be equivalent to a 50% service level. However, for a system with extreme variability, the 50% service level may be above the AADT. Conceptually, the idea of service level is used in supply chain management, logistics management, and queueing systems; which are similar in network structure and in nature to transportation systems. The implementation of this recommendation could be further intensified by the use of GPS, GIS, cellular, and analytics technology. This second recommendation does warrant further discussion and investigation, perhaps with partnering organizations in other states, the Federal Highway Administration, and the Transportation Research Board.

The recommendations within each of the case studies can be addressed directly by the NCDOT, regional personnel, and local governing bodies. The recommendations discussed in the previous section should be addressed by the NCDOT on two levels. The first and second recommendations should be addressed tactically (*i.e*., 3-5 years), and phased-in as resources are available. The third recommendation should be addressed strategically (*i.e*., 5-10 years), and phased-in as resources are available. Future work, including simulation modeling could be completed to test different levels of funding and to compare different approaches.

CONSENT FOR PUBLICATION

Not applicable.

AVAILABILITY OF DATA AND MATERIALS

Not applicable.

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CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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Declared none.

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