

CRONBACH'S COEFFICIENT AS A PERFORMANCE
MEASURE TO ASSESS LINK-LEVEL RELIABILITY

by

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ABSTRACT

RAVI KIRAN PUVVALA. Cronbach's coefficient as a performance measure to assess link-level reliability (Under the direction of DR. SRINIVAS S. PULUGURTHA).

Travel time reliability is commonly used in reference to the level of consistency in transportation service for a trip, corridor, mode or route in terms of its travel time. Typically, reliability is viewed by motorists in relation to their past experience and helps them assess their expected future trip travel time. With increasing congestion levels in most of the urban areas, there is a need to at least be aware of when and where the congestion occurs, thereby, enabling a motorist to estimate the probable travel time as closely as possible.

This research proposes and demonstrates the use of Cronbach coefficient, ' α ' (a two-dimensional measure) as a performance measure complementing the traditional indicators to assess link-level reliability. INRIX travel time data of Charlotte, Mecklenburg County, North Carolina, for the years 2009 and 2010, were used in the current research. Most reliable travel time values for each link is determined, while also classifying the link-level performance into different levels of reliabilities using the scores that are evaluated in this research. Results from this research indicate that categorizing trips using their weekday/weekend information helps in identifying the trends of the travel times corresponding to the trips. Week-of-the-year is found to be one of the main factors influencing travel time. Also, most of the links were found to be highly reliable i.e., the trends of the travel times are identified.

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DISCLAIMER

The views, opinions, findings, and conclusions reflected in this Thesis are the responsibility of the researchers of the subject research project only and do not represent the official policy or position of the USDOT/OST-R, NCDOT, UMD, INRIX, or any other State, or the University of North Carolina at Charlotte or other entity. The researchers are responsible for the facts and the accuracy of the data presented herein. This Thesis does not constitute a standard, specification, or regulation.

INTRODUCTION

Travel time is the duration of the trip on a link (road) and is a measure of service quality of the link. When the traffic flows on a link change, their associated travel times also change. Since the traffic flows are not constant over all days in the year, for that matter even within a single day, the trend of the variation is of utmost importance to estimate the probable travel times for any future trip; hence, bringing the concept of consistency and reliability of travel times into context.

The consistency of a given trip's travel time is defined as the travel time reliability (FHWA, 2006). In other words, it can be defined as "the dependability or consistency in travel times, as measured from day-to-day or/and across different times-of-the-day" (FHWA, 2006). One way to look at travel time reliability is through the historical sense, in which the distribution of travel times from trip history are used to compute statistical parameters such as mean, median, mode, standard deviation, TTI, BTI, PTI, etc. These parameters are indicators of degree of travel time variability of single category trips on a link. In this approach, travel time variation is understood as the degree of travel time variability based on trip history data. Likewise, in a real-time sense, reliability can be considered as motorist experiencing the same trip length (duration-wise) over and over again, i.e., a trip being taken now is compared to some sort of pre-set standard travel time (by the motorist). If a large number of repeated trips on a link fall within the previously observed trip lengths (expected based on any of the characteristics of the trip such as time-of-the-day, day-of-the-week, week-of-the-year, weather condition etc.), it is said to be a reliable link. So, if there is no trend seen or no reliable group

observed in any way, it becomes difficult to have an estimate of the probable travel time of the future trip. It is, therefore, clear that reliability is an important measure that could help assess health and efficiency of transportation system in a region.

Any trip on a link has its corresponding time-of-the-day, day-of-the-week, and week-of-the-year. Each trip has an associated travel time (t) which is a function of these variables. Here, time-of-the-day, day-of-the-week, and week-of-the-year can be treated as the independent variables and (t) as the dependent variable. Variability of travel times can be studied by keeping either one or two of these independent variables unchanged to reduce the number of dimensions. For example, BTI is a reliability index that is often evaluated keeping time-of-the-day and day-of-the-week as constants, making it a one dimensional measure i.e., only one variable (in this case week-of-the-year) changes and the index for the associated travel times is evaluated. In this case, BTI can only be used to address the reliability of travel times on a link for a given time-of-the-day and day-of-the-week. However, if one has to compare the reliabilities of two different days of the week, or reliabilities of Mondays over weekdays, it is not possible using the traditional BTI measure. This limitation is further explained in the next Chapter of this Thesis. This inability to compare the reliabilities of different groups limits these indices from determining the most reliable groups and the most reliable travel times. Hence, a two-dimensional measure is preferred so that different groups can be compared and reliable groups can be determined. This Thesis proposes and demonstrates the working of one such multi-dimensional reliability measure (Cronbach's α). The research objectives are:

- 1) To identify the factor that most contributes to the variability in travel times on a link, and,

2) To enable the motorist with the most reliable travel times of each trip.

A two-dimensional reliability measure (Cronbach's α) is introduced to compare the level of influence of a factor in the variance of travel times on a link. Using Cronbach's α , with absolute reliability scores of the road links, relative comparisons of the links can be made and delays associated with incorrect travel time expectations can be addressed. This enables planners and decision makers prioritize their future investments.

Organization of the Thesis:

The remainder of this thesis comprises chapters. A review of existing literature on travel time value and travel time reliability is discussed in Chapter 1. A discussion on traditional travel time reliability measures is presented in Chapter 2. Cronbach's coefficient is introduced in Chapter 3. A description on study area, data, the research methodology, and illustration of working of the proposed measure is discussed in Chapter 4. Analysis and results obtained are presented in Chapter 5. Conclusions from this research are presented in Chapter 6.

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CHAPTER 1: LITERATURE REVIEW

Historically, traffic congestion was measured in terms of simple averages of travel times. However, most motorists experience and remember more than a simple average throughout a year of commutes. Their travel times vary greatly from day-to-day, and they remember those few bad days they suffered through unexpected delays.

Travel time reliability measures the extent of this unexpected delay. One definition for travel time reliability is the consistency or dependability in travel times, as measured from day-to-day and/or across different times-of-the-day (FHWA, 2006). It is significant to many transportation system users, whether they are vehicle drivers, transit riders, freight shippers, or even air motorists. Personal and business motorists value reliability because it allows them to make better use of their own time. Shippers and freight carriers require predictable travel times to remain competitive.

As reliability is so important for transportation system users, transportation planners and decision-makers should consider travel time reliability as a key performance measure. Several researchers have focused on the concept of travel time reliability in recent years.

A review of literature on value of travel time and travel time reliability as a performance measure is presented next.

Travel Time Reliability from Economy Point of View:

Litman (1999) researched on total North American roadway transportation costs,

including non-market environmental and social costs and found that automobile use is significantly under-priced, resulting in overconsumption and inefficient use of resources. The author also discussed the implications on sustainability criteria such as economic efficiency, equity, environmental impacts, and land use patterns. The author recommended the planners to incorporate total costs analysis in transport planning and policy analysis for better decision making. Existing estimates for a list of twenty costs defined for eleven modes were summarized under three travel conditions to provide average estimated costs per unit of passenger travel in North America.

It is observed that the method used for the study varied from one researcher to another researcher. In that context, Haight (1994) identified the problems in estimating the comparative costs of safety and mobility based on human capital and willingness to pay approaches to see different results.

Studies on monetizing the travel delay include work by Moses and Williamson (1963) on motorists' value of time. The authors gave the value of \$1.55 per hour (\$7.00 adjusted for inflation), which is a little over the minimum wage. Lisco (1968) stated that the traditional value is \$0.86 per hour (\$3.35 adjusted for inflation), but recommended it to be increased to \$2.82 per hour (\$10.98 adjusted for inflation). Keller (1975) tabulated the methods and results for nineteen studies before 1974. Beesley (1974) introduced the concept of traders (those willing to sacrifice cash for time or vice versa) with values of 30-43% of income given for traders. The author also concluded that there are as yet insufficient grounds to reject earlier notions about value of time.

Gronau (1974) analyzed the previous studies and then developed a new method to estimate the value of motorists' time. The authors pointed that the earlier approaches,

which estimated the price of time using conventional methods of analysis (e.g., discriminant analysis, probit, logit), may be appropriate for the analysis of modal split but are completely inadequate for the estimation of the value of time. The author distinguished between the value of time and the amount of money a motorist would forgo for one time unit, price of time.

Reichman (1973, 1974) estimated the motorists' implied value of time by asking; those already on a journey by various modes, how long they estimated the same trip would have taken by alternate modes. Each passenger was requested to separately report time differences by mode and time savings. It was observed that 21 percent of air passengers stated that their time savings amounted to quantities nearly twice as much as the mean of the difference in reported travel times. When asked how much time they would have saved traveling by air, 16 percent of all bus passengers indicated the same discrepancy between differences in time spent and time saved.

Guttman (1975) examined the measurement errors in the previous estimates of value of time and presented a new set of estimates avoiding those errors. Guttman found that failure to take motorists' uncertainty in making choice between alternate routes would bias the estimate by 50% or more. Also, the author found that the inability to account for cross-time substitutions by motorists in peak-hour conditions would result in errors. Peak-hour work trip time was estimated to have a value of \$5.17 per hour (\$16.37 adjusted for inflation). While off-peak work trips were estimated to have a value of \$1.91(\$6.05 adjusted for inflation), off-peak social and recreational trips were estimated to have a value of \$2.08(\$6.59 adjusted for inflation).

Hauer and Greenough (1982) employed a method to estimate the implied value of

time. The experiment was conducted in the Toronto subway system where they offered bribes to the people waiting for trains to miss their train and travel by a later train. Considering the delay demanded and by varying the amount offered, they calibrated the implied value of time. The variables they used were travel time (morning peak, mid-day, and afternoon peak), gender, and income level. The implied median value of an hour was \$55 (\$141.63 adjusted for inflation) during the morning peak for those who were just on time or late for their trip and \$59 (\$151.93 adjusted for inflation) during the evening peak. For those who were early and those who had no fixed arrival time, the values were \$30 and \$17 (\$77.25 and \$43.78 adjusted for inflation), respectively.

Wilman (1980) examined the role of time costs - both on-site and travel - in models describing recreational behavior, and found that both recreation and travel time are costly. The author found that the latter can be valued in terms of its scarcity value, but the former may be most appropriately valued in terms of the "value of travel time saved." Suggestions as to how to measure the on-site and travel time costs were made by the author.

Cesario (1976) found that benefit estimates obtained by explicitly considering travel time sustainability exceed estimates made when travel time is ignored. Cesario's estimates are substantially lower than the ones of Cesario and Knetsch (1970) suggesting that the latter estimates are too high. The reason for the discrepancy is because of the trade-off functions in money and time implicitly considered. Cesario concluded that incorporating travel time valuations in recreation benefit analysis seems vastly superior to excluding them on both theoretical and practical grounds.

Cherlow (1981) discussed several aspects of obtaining accurate valuations of

travel time savings, particularly on commuting trips, emphasizing both the advantages and disadvantages of the various approaches used. Also, the factors that influence the valuation of travel time savings were identified and discussed in their research.

Travel Time Reliability as a Measure of Service:

Several researchers have focused on the concept of travel time reliability in recent years. Iida and Wakabayashi (1989) defined the probability of network nodes being connected or disconnected (a binary approach) as connectivity reliability. Recker et al. (2005) explained the limitation of this binary approach.

Various other indicators were also developed by researchers in the past. Examples include travel time reliability by Asakura and Kashiwadani (1991), socio-economic impact of unreliability and travel demand reduction by Nicholson and Du (1997), capacity reliability by Chen et al. (2002), and travel demand satisfaction reliability by Heydecker (2000). Among all these reliability indicators, travel time reliability is considered as the most superior measure for both network users and planners.

Since the inception of the concept of travel time reliability, there has been increased research to explore methods for travel time reliability measurement. There are essentially two types of approaches involved in the measurement of travel time reliability - heuristic measurements and statistical measurements. Asakura and Kashiwadani (1991) first proposed the use of travel time reliability, and defined it as the probability of successfully completing a trip for a given origin-destination pair within a given interval of time at a specified level of service.

On the same concept, various mathematical models were developed to measure travel time reliability of a transportation system. Small et al. (1982) found that both

passenger trips and freight trips were not predicted to a desired level of accuracy by the agencies and, hence, the passengers and the freight carriers opposed in having their trips scheduled. Chen et al. (2003) and Abdel-Aty et al. (1999) studied the effect of including travel time variability and risk-taking behavior into the route choice models, under demand and supply variation, to estimate travel time reliability. Haitham and Emam (2006) developed a methodology for degraded link capacity and varying travel demand to estimate travel time reliability and capacity reliability. They estimated the expected travel time on a degraded link to be lesser than the free flow travel time for the link with a specific tolerance level. This tolerance pertains to the desired level of service for the link even after its capacity has degraded. Heydecker et al. (2007) proposed a travel demand satisfaction ratio which can be used to evaluate the performance of a road network. For some conditions, the demand satisfaction ratio can be equivalent to the travel time reliabilities. Based on the traditional user equilibrium principle, Chen et al. (2010) proposed a multi-objective reliable network design problem model that took into account the travel time reliability and capacity reliability in order to determine the optimum enhancement of the link capacity. In the statistical approach of measurements, Florida Department of Transportation (Douglas, 2000) used the median of travel time plus a pre-established percentage of median travel time (residual or error term) in estimating the travel time during any period of interest.

The Federal Highway Administration (FHWA) defines travel time reliability to be the consistency in travel time on a daily/timely basis (FHWA, 2006). The performance indicators introduced are 95th percentile travel time, Buffer Time Index (BTI), Travel Time Index (TTI) and Planning Time Index (PTI). These measures are currently the most

widely used measures for reliability and are discussed in the Chapter 3. These statistical measures are mainly derived from the travel time distribution.

Clark and Watling (2005) proposed a technique for estimating the probability distribution of total network travel time, which considers the daily variations in the travel demand matrix over a road traffic network. Differences and similarities in characteristics (average travel time, 95th percentile travel time, standard deviation, coefficient of variation, buffer time, and BTI) were investigated on a radial route by Higatani et al. (2009). Bates et al. (2001) reviewed motorists' valuation of travel time reliability and empirical issues in data collection. The punctuality of the public transit was observed to be highly valued by the motorists.

Literature indicates that most of the researchers in the past have used BTI and PTI as a measure of reliability and TTI as a measure of congestion index (FHWA, 2006). Each index is computed for a dataset (single array), which has all the recorded travel times of the trips that fall in one category. For example, an array can have travel times of all Mondays on a link and for a particular time interval.

BTIs for two datasets are shown in the Table 1. The part (a) of the Table 1 shows travel times based on weekday (260 weekdays in year) and part (b) of the Table 1 shows travel times by day-of-the-week (52 Monday's in a year) for a given year. Examining the Table 1, one can notice that for each time interval/time-of-the-day (first column) there is an associated BTI (last column). The computed BTI values from the two datasets are used to infer which category is more reliable. BTI for each time interval is compared for the two categories and the category with lower BTI is highlighted, showing it is more reliable for that time interval. But, based on this comparison, it is difficult to judge which

category (weekday or Monday) is appropriate or suitable when looking at all the time intervals together (i.e., over a day). This is due to multiple BTI values associated with a link in a category.

In other words, it can be said that these indices possess only a one-dimensional ability to measure the reliabilities of links. Also, week-of-the-year was hardly considered in the past studies while addressing reliability. The week-of-the-year which gives information about month of the trip might well influence the travel time (for example, weeks with long weekends). This research introduces and proposes the use of a new performance measure (Cronbach's α) to evaluate a single index associated for each category (considering week-of-the-year) of travel time data. The proposed performance measure also helps compare which category or group is reliable.

TABLE 1: Illustration of BTI computations for a weekday and day-of-the-week

Time Interval	Weekday #				BTI	Monday				BTI
	1	2	...	260		1	2	-	52	
12:00am-1:00am	1.2	.	.	.	.	2.9
1:00am-2:00am	9.3	.	.	.	.	3.1
..
11:30pm-12:00am	8.7	.	.	.	.	3.7

CHAPTER 2: TRADITIONAL TRAVEL TIME RELIABILITY MEASURES

As mentioned in the previous chapter, many indices have been used to measure reliability at link-level. They include TTI, PTI, and BTI. These measures are described next.

Travel Time Index (TTI):

The TTI is defined as the ratio of the average travel time (TT_{avg}) to the free flow travel time ($TT_{freeflow}$) for any given section on the freeway. For a specific lane and time period, this is calculated as follows:

$$TTI = \frac{TT_{avg}}{TT_{freeflow}}$$

To calculate TTI for a station, weighted average of travel time index of all the n lanes on the basis of Volume at each lane is taken:

$$TTI_{stationavg} = \frac{\sum(TTI_1 * V_1) + (TTI_2 * V_2) + (TTI_n * V_n) \dots}{\sum V_n}$$

Where TTI_n refers to the TTI of the lane with vehicular volume V_n

The TTI for a freeway section is further calculated using a weighted average of all the n station TTI's (TT_{stnn}) on the basis of vehicle miles travelled (VMT), where VMT is the product of traffic volume of a station and the length of link it represents (KDOT & MDOT, 2011).

$$TTI_{sectionavg} = \frac{\sum(TT_{stn1} * VMT_1) + (TT_{stn2} * VMT_2) + (TT_{stnn} * VMT_n) \dots}{\sum VMT_n}$$

Often the formula given below is used for simplicity:

$$TTI = \frac{TT_{95thpercentile}}{TT_{avg}} = TTI_{95thpercentile}$$

TTI is equal to 1 when average travel time and free flow travel time are equal i.e., when there is no delay. If TTI is greater than 1, say 1.5, it implies that the actual travel time is 150% of the free flow time. If the TTI value is lesser than 1, it indicates that the average speed is greater than the prescribed speed limit on the freeway.

Planning Time Index (PTI):

The PTI indicates the variation observed in average travel time. The percentage of time congestion would occur on a link depends on how varying the travel time is on that link. The PTI accounts for this inconsistency. As the name suggests, it pertains to the additional time that the motorists need to incorporate into their trip plan in order to reach the destination on time at least 95% of times (KDOT & MDOT, 2011). The PTI could fluctuate if there are crashes, roadwork or simply congested conditions.

It is the ratio of the 95th percentile travel time over free flow travel time of that segment of the freeway and is represented as:

$$PTI = TTI_{95thpercentile}$$

A higher value of PTI for a segment implies that more time is needed to complete a trip when planning to reach the destination.

Buffer Time Index (BTI):

The BTI is the extra time that a motorist adds to the average travel time of the trip (per unit average travel time on a link) in order to reach on time (KDOT & MDOT, 2011). This is more akin to the time cushion that one would add while estimating travel time of a trip.

$$BTI = \frac{TT_{95th\ percentile} - TT_{avg}}{TT_{avg}}$$

So a lower value of the BTI is desirable, i.e. if 95% of the travel time values in a time interval fall close to the average travel time then the link are considered to be reliable.

CHAPTER 3: INTRODUCTION OF CRONBACH'S α

This chapter introduces the concept, computation, and interpretation of Cronbach's α and how to evaluate the coefficient.

In statistics, Cronbach's α is used as a measure of internal consistency or an estimate of reliability of a test. Yu (2001) stated it is a measure of squared correlation between observed scores and true scores. In other words, Cronbach's α is measured in terms of the ratio of true score variance to observed score variance. The observed score is equal to the true score plus the measurement error. For example, if a student knows 70% of the questions in the test and scores 75%, the additional 5% is because of guessing. In this case, the observed score is 75 while the true score is 70. The additional five points are due to the measurement error, which shows the unreliability of the test. It is assumed that a reliable test should minimize the measurement error so that the error is not highly correlated with the true score. On the other hand, the relationship between true score and observed score should be strong for a test to be a reliable one.

Assumptions in Estimating Cronbach's α :

Several assumptions are made in estimating Cronbach's α . They are discussed next.

- i) It is assumed that the mean of the measurement error should be zero. Failure of meeting this assumption may lead to an over-estimation of Cronbach's α , though in practice this assumption cannot be fully met (Yu, 2001).

- ii) It is also assumed that items must be essentially tau equivalent, in which the true scores for any two items must be within a constant of each other. If this assumption for Cronbach's α is violated, Cronbach's α may under-estimate reliability. For this reason, it is generally agreed that Cronbach's α is a lower bound estimate of reliability because perfect essentially tau-equivalence is seldom achieved (Cortina, 1993).

Using simulations, Zimmerman and Zumbo (1993) found that the violations of these assumptions lead to substantive over-estimation and under-estimation of Cronbach's α .

In the current thesis, travel times are analogous to the scores. It is to be noted that the true scores (expected travel times of the trips) are not fixed; because they change with many factors (time-of-the-day, week-of-the-year, etc.). Hence, the mean of the travel times can be taken as the true score while evaluating Cronbach's α for a certain combination of primary and secondary factors (explained in later sections). Thus, the assumptions can be relaxed for the problem in this thesis.

The following example illustrates a detailed description of Cronbach's α . Consider a case where one needs to determine the reliability of three questions in measuring an entity, say, analytical ability of five persons with various educational levels. The test is intended to rate the persons based on their ability to analyse a given dataset. Note that the assumption in this case is that the ability depends on one's education and are testing the reliability of the questions in the test. The results of the test are recorded as shown in Table 2, where scores for questions are recorded as binary variables.

TABLE 2: Summary of results from test scores

Students	Questions			Total
	Q1	Q2	Q3	
S.1	0	1	1	2
S.2	0	0	1	1
S.3	0	1	0	1
S.4	0	0	1	1
S.5	1	1	1	3
Item Variances	0.2	0.3	0.2	
Variance of Totals				0.8

From TABLE 2,

Sum of individual variances (V1) = 0.2 + 0.3 + 0.2 = 0.7

Variance of the total scores (V2) = 0.8

Number of questions (items) = 3

For the aforementioned problem, Cronbach's α is computed using the following expression (Cronbach, 1951).

$$\alpha = \frac{K}{K-1} \left(1 - \frac{\sum_{i=1}^K \sigma_{Y_i}^2}{\sigma_X^2} \right) \text{ or } \frac{K}{K-1} \left(1 - \frac{V1}{V2} \right)$$

$$V1 = \sum_{i=1}^K \sigma_{Y_i}^2; V2 = \sigma_X^2$$

where, K is the number of questions,

σ_X^2 is the variance of the observed total test scores of a person,

$\sigma_{Y_i}^2$ is the variance of the sums of scores of a question for all the five persons.

Based on K and computed $V1$ and $V2$ from Table 2,

$$\alpha = \frac{3}{3-1} \left(1 - \frac{0.7}{0.8} \right)$$

$$\Rightarrow \alpha = 0.1875$$

A 'zero' value of Cronbach's α indicates that the questions doesn't measure the same entity, in this case their analytical ability. On the other hand, if Cronbach's α is 'one', it indicates that all the questions designed did a perfect job. This happens when the scores of a student remain same for all questions making him score either 3 or 0 in total. The computed Cronbach's α in the above example is 0.1875, indicating that the questions are very less reliable in measuring the analytical ability of the person.

In the above example, the persons are the primary source of variance while questions are the secondary source of variance. In our research, time-of-the-day and week-of-the-year are considered as sources of variance, both primary and secondary. Taking one combination at a time i.e., Cronbach's α is evaluated once with time-of-the-day as primary factor and next with week-of-the-year as primary factor. In general, the primary factor causes the changes in the observations and correlation is evaluated over the secondary factor (test items).

In summary, Cronbach's α measures the correlation between the results coming from various items i.e., the correlation between the columns in the above table or simply, it is the correlation of test with itself.

CHAPTER 4: APPLICATION OF CRONBACH'S α TO ASSESS TRAVEL TIME RELIABILITY

A discussion on study area, data and results obtained are presented in this Chapter.

Study Area Description:

Urban areas such as Charlotte, North Carolina have extensive transportation systems that provide their residents, visitors and businesses with a high level of mobility. This system plays a major role in supporting the region's economy. Like any urban area, Charlotte's ability to compete for job growth and economic development is highly dependent on its transportation system. As the region strives to achieve economic growth in the current competitive scenario, it is essential that its roads, highways and bridges provide efficient and reliable mobility and accessibility to its motorists. These changes would increase job opportunities and enhance the economy.

In a nation-wide assessment of urban interstate congestion study titled "Traffic Congestion in North Carolina: Status, Prospects, and Solutions" (Hartgen, 2007), North Carolina was ranked 48th among the 50 states (Hartgen, 2006). In addition to this, the congestion levels in North Carolina are expected to double in the next 25 years (Hartgen, 2007). The report graded all the 17 metropolitan regions of the state of North Carolina. Charlotte performed poorly with a grade of D, while the regions of Asheville, Jacksonville, and Goldsboro were given grades of A- (Hartgen, 2007). This clearly indicates the necessity of efforts in terms of combating congestion and, hence, the

emphasizing the need for allocation of funds in easing congestion. Saving of travel times is one such approach that is being looked at as a prospective means of minimizing congestion. State's such as North Carolina need to spend \$12.4 billion to get rid of the existing congestion on urban roads and to tackle the growing congestion trends as predicted for the next 25 years (Hartgen, 2007). Congestion could be lowered and system performance improved through better utilization of available funds (Hartgen, 2007). By doing so it is estimated that the state would save \$ 855 million in terms of the value of travel time saved (Hartgen, 2007).

Hence, the current research focuses on evaluating the performance of the transportation system in North Carolina, specific to Charlotte city. The performance measure used in this research will enable the motorist to know the degree of reliability in terms of travel time expectation on any link and, thus, address the issue of delays associated with incorrect travel time expectations used in planning trips.

Data and Computation:

The city of Charlotte, in Mecklenburg County, North Carolina is considered as the study area. INRIX travel time data for 296 and 311 road links in Charlotte area for the years 2009 and 2010 respectively were gathered. The data obtained have travel time data aggregated for every one minute interval with other trip characteristics such as date of the trip, time of trip, and identified TMC code. The raw data obtained from INRIX is shown in the Figure 1. The 1st column corresponds to the TMC of the link, 2nd column (measurement stamp) gives the date and time (1-minute interval) corresponding to the observed readings. The 3rd and 4th column data are thus extracted from the 2nd column. The 8th column gives the average travel time of all the vehicles recorded in the specific 1-

minute interval. Day-of-the-week (DOW) and name-of-the-week (NOW) are extracted from the date column and time-interval-of-the-day (TOD) is extracted from the time column. It is to be noted that DOW is another way of representing the NOW where each day is denoted by a number. Sunday is denoted by 1, Monday by 2, and so on.

	tmc_code	measurement_tstamp	Time	Date	Speed	Avg_Speed	Ref_Speed	Travel_Time_Min	confidence_score	cvalue	DOW	TOD	NOW
1	125P04630	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	50	63	65	0.788	30		2	3PM-4PM	Monday
2	125P04631	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	66	63	65	0.832	30		2	3PM-4PM	Monday
3	125P04632	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	62	61	63	0.527	30		2	3PM-4PM	Monday
4	125P04633	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	62	63	65	0.469	30		2	3PM-4PM	Monday
5	125P04635	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	64	62	64	0.81	30		2	3PM-4PM	Monday
6	125P04636	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	62	63	65	0.402	30		2	3PM-4PM	Monday
7	125P04637	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	64	62	65	0.548	30		2	3PM-4PM	Monday
8	125P04638	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	64	61	63	0.263	30		2	3PM-4PM	Monday
9	125P04639	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	64	62	65	0.449	30		2	3PM-4PM	Monday
10	125P04640	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	63	60	63	0.697	30		2	3PM-4PM	Monday
11	125P04851	2009-03-09 15:01:08.0	15:01:08.0000000	2009-03-09	48	50	58	0.638	30		2	3PM-4PM	Monday
12	125-04629	2009-03-09 15:02:06.0	15:02:06.0000000	2009-03-09	65	63	65	1.846	30		2	3PM-4PM	Monday
13	125-04630	2009-03-09 15:02:06.0	15:02:06.0000000	2009-03-09	62	63	64	0.755	30		2	3PM-4PM	Monday
14	125-04631	2009-03-09 15:02:06.0	15:02:06.0000000	2009-03-09	53	59	65	2.221	30		2	3PM-4PM	Monday
15	125-04632	2009-03-09 15:02:06.0	15:02:06.0000000	2009-03-09	61	63	64	1.627	30		2	3PM-4PM	Monday

FIGURE 1: Travel time data for every 1-minute obtained from INRIX

Once the raw data for the entire year is obtained, it is then aggregated for every 30-minute interval to evaluate travel time reliabilities for the study links for every half-hour interval (48 intervals) in a day. The 30-minute interval level aggregated data is as shown in the Figure 2.

	Tmc_Code	YearNum	WeekNum	Timeofday	Date	MinTravel_Time	MaxTravel_Time	AvgTravel_Time	TT_Percentile_85
1	125+04629	2009	5	11:00PM-11:30PM	2009-07-09	1.854	2.012	1.954066666666667	2.012
2	125+04629	2009	5	11:00PM-11:30PM	2009-08-20	1.771	1.914	1.848733333333333	1.914
3	125+04629	2009	5	11:00PM-11:30PM	2009-09-10	1.695	1.914	1.829966666666667	1.884
4	125+04629	2009	5	11:00PM-11:30PM	2009-09-17	1.826	1.914	1.8708	1.914
5	125+04629	2009	5	11:00PM-11:30PM	2009-11-05	1.672	1.978	1.851533333333333	1.946
6	125+04629	2009	5	11:00PM-11:30PM	2009-12-03	1.582	1.978	1.7964	1.914
7	125+04629	2009	5	11:30AM-12:00PM	2009-06-04	1.798	2.082	1.923066666666667	1.978
8	125+04629	2009	5	11:30AM-12:00PM	2009-08-20	1.745	2.046	1.836433333333333	1.978
9	125+04629	2009	5	11:30AM-12:00PM	2009-10-08	1.72	1.978	1.854733333333333	1.946
10	125+04629	2009	5	11:30AM-12:00PM	2009-10-15	1.826	2.046	1.9748	2.046
11	125+04629	2009	5	11:30AM-12:00PM	2009-10-29	1.72	1.978	1.843566666666667	1.946
12	125+04629	2009	5	11:30AM-12:00PM	2009-12-10	1.798	1.884	1.8436	1.884
13	125+04629	2009	5	11:30AM-12:00PM	2009-12-17	1.826	1.914	1.8576	1.884
14	125+04629	2009	5	11:30AM-12:00PM	2009-12-24	1.604	1.946	1.803533333333333	1.854
15	125+04629	2009	5	11:30PM-12:00AM	2009-10-15	1.771	1.854	1.817933333333333	1.854

FIGURE 2: Travel time data aggregated for every 30-minute interval

It can be observed that all the readings are aggregated into 30-minute intervals (column 4). Note that Column 3 i.e., WeekNum is same as the DOW. The average travel time and 85th percentile travel time are computed using the travel time data and are shown in the columns 8 and 9. Once the data is aggregated, it is then used to evaluate Cronbach's α using the equation discussed in the previous chapter.

Travel time reliability is measured on the basis of various categories of travel times (day-of-the-week, weekend/weekday, time-of-the-day, etc.). A sample data for the year 2009 and for 'Monday' category travel times (85th percentile) are shown in Table 3. In the table, the first row 'week-of-the-year' corresponds to the secondary factor and the first column 'time-of-the-day' corresponds to the primary factor i.e., the travel time is expected to vary with time-of-the-day and is checked for the consistency/reliability over

the 52 weeks of a given year. A higher value of α is obtained when the travel times over the day are well correlated between the 52 weeks of the year. The maximum of '1' is obtained when all the 52 weeks have identical travel times for any time interval of the day (maintaining certain variance within the various time intervals of the day). Reliability scores are compared by changing the primary and secondary factors (like transposing rows and columns in Table 3), and the most reliable groups that gives best expected travel times are identified.

TABLE 3: Sample travel time data of a link and 'day-of-the-week' used for computing ' α '

TOD(Primary factor)	Week-of-the-year (secondary factor)							Sum of travel times
	Week 1	Week 2	Week 3	.	.	.	Week 52	
12:00 AM-12:30 AM	1.826	1.914	1.914	.	.	.	.	96.72
12:30 AM-1:00 AM	1.914	1.946	2.046	.	.	.	.	99.23
1:00 AM-1:30 AM	1.884	2.239	1.884	.	.	.	.	100.28
1:30 AM-2:00 AM	1.978	1.826	1.914	.	.	.	.	92.56
2:00 AM-2:30 AM	1.854	1.826	1.946	.	.	.	.	96.83
.
.
.
11:30 PM-12:00 AM	1.726	1.926	2.027	.	.	.	.	101.23
Item Variance	0.001	0.012	0.021	.	.	.	.

Case Study:

A 2-mile section of freeway on I-85 Northbound direction in the city of Charlotte, NC with TMC code '125+04629' is considered as the case study to illustrate the working of the methodology. Travel time data for the year 2009 was considered to evaluate reliability based on two categories - day-of the-week and weekday/weekend. Two different travel time measures, 85th percentile travel times and average travel times, were also considered to see which of the two travel time measures are more reliable in making an expectation of travel time. This will yield eight categories of Cronbach's α values as summarized in Table 4.

TABLE 4: Characteristics of each category of Cronbach's ' α '

	Category	Primary factor	Secondary factor	Travel Time Measure Used
$\alpha 1$	Day-of-the-week	Time-of-the-day	Week-of-the-year	85th Percentile
$\alpha 2$	Weekday/Weekend	Time-of-the-day	Week-of-the-year	85th Percentile
$\alpha 3$	Day-of-the-week	Week-of-the-year	Time-of-the-day	85th Percentile
$\alpha 4$	Weekday/Weekend	Week-of-the-year	Time-of-the-day	85th Percentile
$\alpha 5$	Day-of-the-week	Time-of-the-day	Week-of-the-year	Average
$\alpha 6$	Weekday/Weekend	Time-of-the-day	Week-of-the-year	Average
$\alpha 7$	Day-of-the-week	Week-of-the-year	Time-of-the-day	Average
$\alpha 8$	Weekday/Weekend	Week-of-the-year	Time-of-the-day	Average

The step-by-step procedure for evaluating Cronbach's α for a TMC code is discussed next.

Step 1: Evaluating Variance 1 (V1):

As mentioned in the example problem used in explaining Cronbach's alpha (Chapter 4), Variance 1 is defined as the sum of all the item variances. In the current example, the variance of all the travel times corresponding to any given week-of-the-year is the item variance of that week-of-the-year. All the item variances are shown in the bottom-most row in the Table 3. Hence, the sum of all the cells in the bottom-most row gives the Variance 1 for the considered problem.

Step 2: Evaluating Variance 2 (V2):

Variance 2, as mentioned in the previous section, is the variance of all the sum of the scores (in this case, sum of the travel times). The sum of the travel times are shown in the right-most column in Table 3. The computed variance of all the cells in this column results in Variance 2.

Step 3: Evaluating Cronbach's α

Cronbach's α is then computed using Variance 1 and Variance 2 from steps 1 and 2. Note that the value of N is 52 in this example. The obtained Cronbach's α is the reliability score for the TMC code '125+04629' for Monday trips, with primary factor as time-of-the-day and using 85th percentile travel times. The same method is applied for all the links using SQL and the variance values are obtained for every TMC and every week-of-the-year as shown in Figure 3. The (a) and (b) parts of the Figure 3 show the variance values for trips by week-of-the-year, whereas (c) and (d) show the variance values for weekday/weekend category trips. It can be noticed that each TMC has 7 values for

variance, one for each day (Sunday to Saturday) in the case of (a) and (b) whereas (c) and (d) has only two values (one for a weekday where wd=1 and the other for weekend where wd=0).

	Tmc_Code	WeekNum	Variance1		Tmc_Code	WeekNum	Variance2
1	125+04629	1	0.787663118489601	1	125+04629	1	1.31080608966295
2	125+04629	2	325.959773625665	2	125+04629	2	490.544851305426
3	125+04629	3	90.3749080684376	3	125+04629	3	138.440957262028
4	125+04629	4	55.3980268744632	4	125+04629	4	108.437931085073
5	125+04629	5	50.4352679299929	5	125+04629	5	88.628840524759
6	125+04629	6	15.1608850017314	6	125+04629	6	37.3944818372911
7	125+04629	7	220.575815691639	7	125+04629	7	284.714168559857
8	125+04630	1	0.251765258680552	8	125+04630	1	0.610629230394807
9	125+04630	2	6.0735552328803	9	125+04630	2	8.50057329365366
10	125+04630	3	0.352447705504659	10	125+04630	3	1.05607943999136

(a) (b)

	Tmc_Code	wd	Variance1		Tmc_Code	wd	Variance2
1	125+04629	0	55.4070769156901	1	125+04629	0	66.7398854108057
2	125+04629	1	21.1369998669426	2	125+04629	1	32.7491097093177
3	125+04630	0	0.533202743164064	3	125+04630	0	1.11133204792319
4	125+04630	1	2.08605544948315	4	125+04630	1	2.67980573514221
5	125+04631	0	5.94362076671007	5	125+04631	0	9.02441576400209
6	125+04631	1	15.3638660871179	6	125+04631	1	27.1267256182327
7	125+04632	0	7.20454829372831	7	125+04632	0	18.6164786240091
8	125+04632	1	6.86098834711359	8	125+04632	1	17.8828797115566
9	125+04633	0	1.26594267567274	9	125+04633	0	3.56438079992813
10	125+04633	1	2.14493755253605	10	125+04633	1	4.87137485873579

(c) (d)

FIGURE 3: Variance calculated for day-of-the-week and weekday/weekend category trips

Similarly, the primary and secondary factors can be interchanged to obtain new values for V1 and V2, and hence, Cronbach's α (referred to as α_2). If the average travel times are used in the place of 85th percentiles, α_5 and α_6 can be obtained.

Cronbach's α computed for each of combinations and their interpretations are

discussed next.

Cronbach's α Computed for the 'Day-of-the-week' category with 'Week-of-the-year' as Primary Factor (α_3, α_7):

'Week-of-the-year' is considered as the primary factor and Cronbach's α is computed for every 'day-of-the-week' (category). In this case, the assumption is that the primary source of variation in travel times on the link is the 'week-of-the-year' associated with the trip. For each day-of-the-week, the corresponding values of Cronbach's α (α_3 and α_7) are mentioned in Table 5.

It can be observed from Table 5 that Mondays are least reliable with this combination while Thursdays are the most reliable. Table 6 summarizes the thresholds to determine the level of reliability. They are same as those used in other studies related to Cronbach's α (George, 2003 and Kline, 2000).

TABLE 5: Cronbach's ' α 's associated for varying categories, primary and secondary factors for a TMC

TMC Code	DOW	WD	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8	Max(α)
125+04629	1	0	0.41	0.17	0.53	0.68	0.58	0.18	0.62	0.63	0.68
125+04629	2	1	0.34	0.36	0.12	0.62	0.37	0.38	0.15	0.67	0.67
125+04629	3	1	0.35	0.36	0.52	0.62	0.38	0.38	0.57	0.67	0.67
125+04629	4	1	0.50	0.36	0.75	0.62	0.31	0.38	0.69	0.67	0.75
125+04629	5	1	0.44	0.36	0.60	0.62	0.38	0.38	0.58	0.67	0.67
125+04629	6	1	0.61	0.36	0.49	0.62	0.61	0.38	0.57	0.67	0.67
125+04629	7	0	0.23	0.17	0.67	0.68	0.25	0.18	0.62	0.63	0.68

*DOW stands for day-of-the-week with Sunday coded as 1, Monday as 2, and so on

*WD represents weekday, coded with 1 for weekday and 0 for weekend

TABLE 6: Reliability thresholds to determine the level of reliability

Cronbach's α	Level of Reliability
≥ 0.9	A (Excellent)
0.7 – 0.9	B (Highly Reliable)
0.5 – 0.7	C (Reliable)
0.4 – 0.5	D (Poorly Reliable)
<0.4	E (Unreliable)

Cronbach's α Computed for the 'Day-of-the-week' category with 'Time-of-the-day' as Primary Factor:

'Time-of-the-day' is considered as the primary factor to evaluate the reliability score (Cronbach's α). Hence, the assumption in this case is that the primary variance in the travel times is due to the time-of-the-day associated with each trip. One can refer to Table 5 for the Cronbach's α values (α_1 and α_5) for each week-of-the-day based on varying time-of-the-day. It can be observed that none of the values is greater than 0.7, which indicates that this combination does not work for any of the seven days-of-the-week.

Cronbach's α Computed for the 'Weekday/Weekend' category with Varying Primary Factors:

The results found after aggregation of data for weekday and weekend are shown as α_2 , α_4 , α_6 , α_8 in Table 5. The primary and secondary factors as well as the travel time statistic associated with each Cronbach's α are shown in Table 4.

Obtaining Most Reliable Travel Time of a Trip:

The evaluated Cronbach's α values are used in estimating the most reliable travel time of any trip on a link. As an example, a motorist wants to make a travel plan on 14th of February 2015 between 10:00 AM to 10:30 AM on the above mentioned TMC and wants to know his/her travel time. The tool developed from this study uses the following steps to make an expectation.

- 1) Identify the day-of-the-week, which is Saturday, a weekend.
- 2) Identify the week-of-the-year, which is 7th week-of-the-year 2015.
- 3) Select the maximum Cronbach's α and note the combination associated with the Cronbach's α .

In this case α_4 is the highest, which implies that the category is weekend and the travel time is week-of-the-year dependent (refer Table 3). Hence, one has to take the average of the 85th percentile travel times observed for the weekend category trips for the 7th week-of-the-year. The result gives the expected travel time of the trip. Figure 4 shows the expected travel times for weekend category based on the 2009 data with primary factor as 'week-of-the-year'. One can observe that the expected travel time depends on the week-of-the-year with each point representing for each week-of-the-year in Figure 4 (total 52 points). Since the data is not available for the first 9 weeks of the year, one does not see any points corresponding to them. This shows the limitation of this approach which is further explained in the later sections. However, the basic idea is to compute the Cronbach's α for all the combinations and take the maximum of these 8 values for any day and then compute the most reliable travel time for any trip.

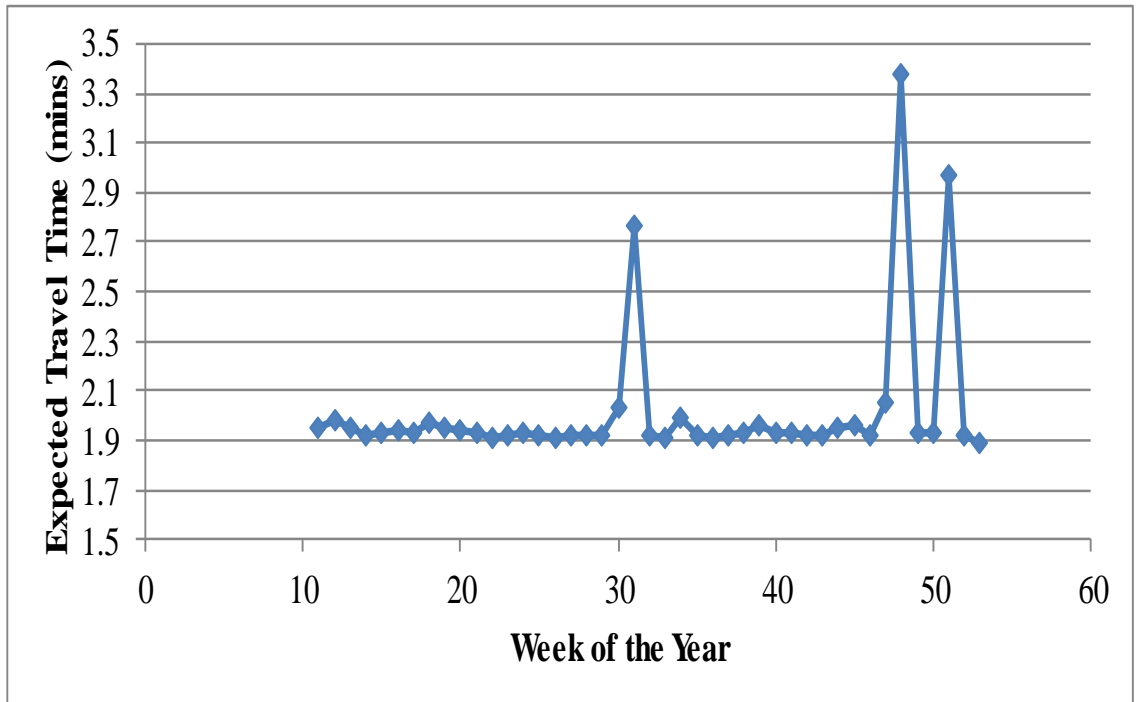


FIGURE 4: Expected travel times for varying week-of-the-year

CHAPTER 5: ANALYSIS OF ALL THE LINKS IN THE STUDY AREA AND THEIR RESULTS

The above analysis to evaluate link-level reliability is applied to all the links considered in the study (296 links for the year 2009 and 311 links for the year 2010). The results obtained are summarized in Table 7. Ranking the links with these reliability scores (the maximum of the 8 scores is taken for a link) help the motorist choose his/her route from various alternatives. Also, the planning agencies can identify the most unreliable links and make necessary recommendations to improve transportation system performance.

Table 9 shows the percentage of cases (2072 cases for 2009 and 2177 cases for 2010) that are reliable for a particular combination associated within Cronbach's α . Table 7 and Table 8 show the percentage of links that are reliable for every combination within Cronbach's α evaluated for each day-of-the-week. It can be observed that a majority of the trips have a higher value of Cronbach's α when the average travel time values are taken instead of the 85th percentile values. This can be attributed to the fact that the data used in the study involves no incidents but only the recurring congestion (if present) and hence not resulting in over-estimation of travel time and reliability. Also, it can be observed that weekday/weekend category grouping is beneficial for a majority of the weekend trips. This implies that one need not worry about the day-of-the-week but just see if it is a weekday or a weekend to plan a reliable trip. This might be because the travel time on a weekend is not much affected by the time-of-the-day as traffic levels are almost

equally spread over the day, whereas during weekdays, time-of-the-day is quite defining the travel time. The same trend can also be observed when the analysis is applied to all cases as shown in Table 9. However, there is no need to generalize here as every link has its own reliable combination to evaluate its reliable travel times.

TABLE 7: Percentage of links with maximum corresponding ' α ' values for the year 2009

	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8
Sunday	3.72	4.05	2.36	5.07	10.14	16.22	14.19	44.26
Monday	0.34	13.18	0.34	1.35	3.04	38.51	5.41	37.84
Tuesday	2.36	11.49	4.73	1.01	3.72	35.14	6.42	35.14
Wednesday	0.00	11.15	2.70	1.69	4.05	35.14	6.76	38.51
Thursday	0.00	11.82	1.01	1.69	6.08	35.47	5.74	38.18
Friday	4.39	11.49	0.34	1.35	7.09	33.45	11.15	30.74
Saturday	4.73	3.72	2.70	4.39	10.47	15.54	28.04	30.41

TABLE 8: Percentage of links with maximum corresponding ' α ' values for the year 2010

	α_1	α_2	α_3	α_4	α_5	α_6	α_7	α_8
Sunday	0.64	3.86	2.25	24.44	7.07	27.33	6.43	27.97
Monday	0.32	9.00	0.32	4.50	5.47	66.24	2.57	11.58
Tuesday	0.64	9.32	0.32	4.18	9.00	62.06	4.82	9.65
Wednesday	0.00	9.32	0.32	4.50	12.86	60.13	2.25	10.61
Thursday	0.00	9.65	0.00	5.14	11.25	61.74	2.57	9.65
Friday	0.32	9.32	0.64	3.22	12.22	60.45	3.22	10.61
Saturday	0.64	2.57	4.82	1.93	6.11	20.26	47.91	15.76

TABLE 9: Percentage of cases with maximum corresponding ' α ' values

Cronbach's Coefficient	% of Cases reliable (2009)	% of Cases reliable (2010)
α_1	2.22	0.37
α_2	9.56	7.58
α_3	2.03	1.24
α_4	2.36	6.84
α_5	6.37	9.14
α_6	29.92	51.17
α_7	11.10	9.97
α_8	36.44	13.69

Level of Reliability based on Cronbach's α

Cronbach's α was used as a performance measure to classify the links/corridors into various level of service categories. Since it is a correlation coefficient, the same threshold values that are used to determine the level of dependence (linear) for various level of reliability classification were used. Table 6 shows the level of reliability classification of any link based on Cronbach's α . If any of the Cronbach's α is greater than 0.9, the link is said to be very highly reliable for the associated combination and one expect the value to be at least greater than 0.7 to comment on its reliability.

A complete analysis was performed in this study, covering 296 and 311 links in the city of Charlotte for the year 2009 and 2010 respectively, consisting around 2,072 and 2177 different combinations based on day-of-the-week ($296*7 = 2,072$ & $311*7 = 2177$). The percent of these cases evaluated for each combination of Cronbach's α falling in various level of reliability category are shown in Table 10. Overall results shows that about 85% of them are highly reliable (level of reliability B and A) and just 1.2% are unreliable. This means that travel times follow certain trends and are predictable in 85% of the cases. The trip durations (travel time of the trip) may be time-of-the-day dependent, week-of-the-year dependent or category of trip (weekday/weekend or day-of-the-week) dependent. Some trips are reliable by using 85th percentile travel time while others are reliable from average travel time point of review. The ability of this new approach in identifying the reliable category from among 8 combinations and also identifying the factor causing the variability helps in finding these trends. Since multiple factors are considered unlike in traditional measures, where only time-of-the-day is considered, a reliable group is identified for each type of trip.

TABLE 10: Percentages of cases falling in each level of reliability

Cronbach Combination	Year	Percentage of cases with reliability level				
		A	B	C	D	E
α_1	2010	18.65	12.59	13.37	20.53	34.86
	2009	10.81	12.84	13.71	28.52	34.12
α_2	2010	27.97	12.22	11.41	19.29	29.10
	2009	17.57	10.81	13.85	31.08	26.69
α_3	2010	4.78	7.58	15.43	39.00	33.21
	2009	6.66	8.16	12.74	33.06	39.38
α_4	2010	4.34	14.47	28.94	34.73	17.52
	2009	12.84	12.84	16.22	34.63	23.48
α_5	2010	26.96	19.66	13.92	17.36	22.09
	2009	13.75	13.71	15.30	26.98	30.26
α_6	2010	36.01	17.68	15.27	13.50	17.52
	2009	20.44	13.34	18.58	23.48	24.16
α_7	2010	7.44	10.24	17.87	40.61	23.84
	2009	14.09	13.90	14.43	29.87	27.70
α_8	2010	7.88	20.74	28.30	31.83	11.25
	2009	27.87	15.71	15.71	25.51	15.20

Cronbach's α Complementing Traditional Reliability Measures:

With Cronbach's α measuring the reliability of the link at macro-level and identifying the most reliable base group (category) that closely predicts the travel time,

one can use these base groups to compute the traditional reliability measures i.e., BTI and PTI at micro-level. For example, if it is found that weekend travel times are more consistent when the primary factor is the week-of-the-year, then BTIs can be evaluated for each week-of-the-year. It can be observed that these BTIs will be much lower than the BTIs that are computed with time-of-the-day as the base group (category). Lower BTIs imply that those set of travel time values are more consistent within themselves. This way Cronbach's α can be used to compute lower BTIs by changing their base groups or combinations. This also serves as the justification of this study.

Figure 5 shows the comparison of the BTIs evaluated for different values of Cronbach's α for the same example discussed earlier. While calculating BTI, only 4 cases arise instead of 8 (since BTI needs only these categories). Figure 5(a) and Figure 5(c) represent the BTIs for the trips for every 30-minute interval of the day (time-of-the-day category). While Figure 5(a) represents Saturday, Figure 5(c) represents weekend. Similarly, Figure 5(b) and Figure 5(d) are for week-of-the-year category. Where, Figure 5(b) represents Saturday and Figure 5(d) represents weekend. From Table 4, since α_4 and α_8 values are 0.68 and 0.63, respectively which are with the combination of 'weekend' category and 'week-of-the-year' as primary factor, the associated BTIs are seen close to zero in Figure 5(d) than the others. One can compare these with the BTIs associated with minimum Cronbach's α values (α_2 and α_4) i.e., Figure 5(b). The number of BTIs greater than 10 is more in this case than any of the other three cases. This reinforces the concept of Cronbach's α complementing the traditional measures.

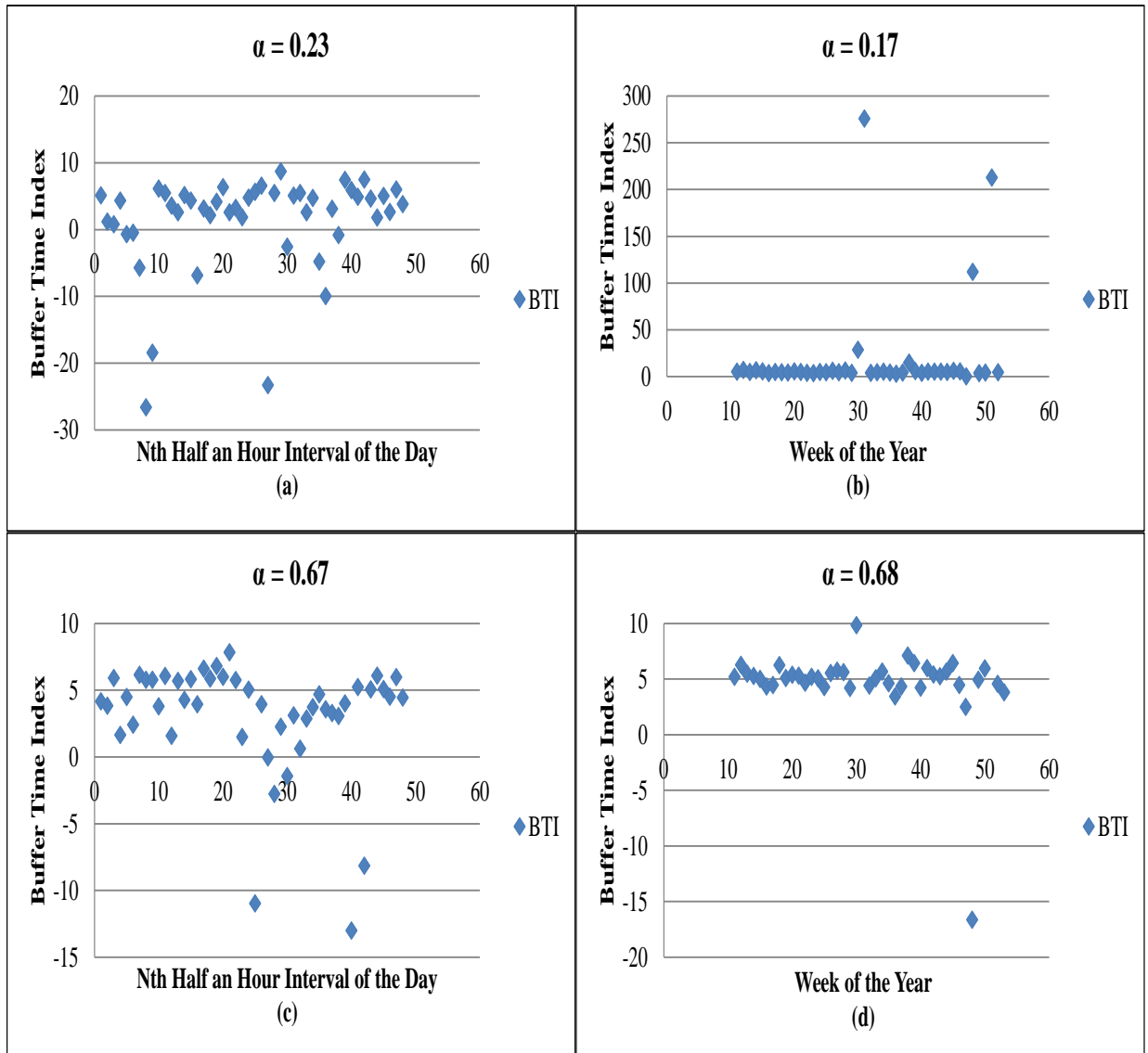


FIGURE 5: Comparison of BTIs evaluated by category of trips

Limitations of the Proposed Measure and Approach

Data availability is one of the major requirements for accurate estimates of reliability scores. The formula used to evaluate Cronbach's α uses variance 1 (V1) which is the sum of item variances and variance 2 (V2) which is the variance of total scores. The lower the ratio of V1 to V2, the higher is Cronbach's α . It is to be noted that lower value of V1 should automatically reflect lower value of V2 because when individual values are closer to each other, the sums of those scores should also be closer unless and

until some values are missing. In case of missing fields, an over-estimation or under-estimation of Cronbach's α values is observed. If the variance 2 (V_2) can be adjusted when missed data is observed, the results can be more credible. To combat this, a method where the total scores are proportionately increased when some values are missed was used in this research. The proposed method has fixed the issue to a high extent though there might be little over-estimation or under-estimation in case of missing fields.

CHAPTER 6: CONCLUSIONS

Delays in a transportation network are almost inevitable with the growing congestion in urban areas. Motorists are more interested in knowing their actual travel time along a link when planning a trip so as to reach their destination within the desired time, rather than completing a trip in the time that one would ideally take to travel on the network (Cesario and Knetsch, 1970). Hence, reliability of a link is crucial to both the motorists and practitioners of transportation systems.

A new reliability measure, Cronbach's α , is proposed to assess reliability of links in the transportation network. This performance measure acts as a macro-level measure of reliability that evaluates the level of consistency of travel times. The proposed reliability measure was found to be a better estimator of expected travel times as compared to the traditional travel time performance measures such as BTI and PTI, which are often evaluated for a fixed criteria (time-of-the-day). This is because the proposed macroscopic measure evaluated reliability not only for a time-of-the-day over the year but also for a week-of-the-year over the time-of-the-day and using both 85th percentile travel times as well as average travel times from the historical data. The reliabilities are evaluated at link-level which also helps identify the most unreliable links in the network.

Overall, results obtained indicate that the mean travel time estimates of the trips aggregated for any time interval from the data yields are more reliable than compared to

85th percentile travel times. Also, weekend trips are not time dependent but are week-of-the-year dependent whereas weekday trips are time dependent in most of the cases. Results also indicate that missing field in the data might result in over-/under-estimation of results. Along with identifying the reliable travel times and reporting absolute reliable scores of the links, a new level of service criteria based on reliability scores is proposed. However, a link with level of service 'A' from this study does not mean a perfect case, as the travel times associated might still be very high just that they are reliable and recurring.

REFERENCES

- Abdel-Aty, M., A., R. Kitamura, and P. P. Jovanis. Investigating Effect of Travel Time Variability on Route Choice using Repeated-Measurement Stated Preference Data. *Transportation Research Record*, No. 1493, 1999, pp. 39-45.
- Asakura, Y., and M. Kashiwadani. Road Network Reliability Caused by Daily Fluctuation of Traffic Flow. PTRC Summer Annual Meeting, University of Sussex, United Kingdom, 1991.
- Beesley, M. E. "Conditions for Successful Measurement in Time Valuation Studies." *Transportation Research Board Special Report No. 149*, 1974.
- Cesario, F. J. Value of Time in Recreation Benefit Studies. *Land Economics*, Vol. 52(.1), 1976, pp 32-41.
- Cesario, F. J., and J. L. Knetsch. Time Bias in Recreation Benefit Estimates. *Water Resources Research*, Vol. 6(3), 1970, pp. 700-704.
- Chen, A., H. Yang, H. K. Lo, and W. H. Tang. Capacity Reliability of a Road Network: An Assessment Methodology and Numerical Results. *Transportation Research Part B: Methodological*, Vol. 36(3), 2002, pp. 225-252.
- Chen, A., J. Kim, S. Lee, and Y. Kim. Stochastic Multi-objective Models for Network Design Problem. *Expert Systems with Applications*, Vol. 37(2), 2010, pp. 1608-1619.
- Chen, A., Z. Ji, and W. Recker. Effect of Route Choice Models on Estimation of Travel Time Reliability under Demand and Supply Variations. *Network Reliability of Transport, Proceedings of the 1st International Symposium on Transportation Network Reliability (INSTR)*, 2003.
- Cherlow, J. R. Measuring Values of Travel Time Savings. *Journal of Consumer Research*, 1981, pp. 360-371.
- Clark, S., and D. Watling. Modelling Network Travel Time Reliability under Stochastic Demand. *Transportation Research Part B: Methodological*, Vol. 39(2), 2005, pp. 119-140.
- Cortina, J. M. (1993). What is Coefficient Alpha? An Examination of Theory and Applications. *Journal of Applied psychology*, 78, 98-104.
- Cronbach, L. J., Coefficient Alpha and the Internal Structure of Tests. *Psychometrika*, Vol. 16, 1951, pp. 297-333.
- Douglas S. M., and G. Morgan. The Florida Reliability Method in Florida's Mobility

Performance Measures Program. Florida Department of Transportation, 2000. Federal Highway Administration (FHWA). Travel Time Reliability: Making It There On Time, All the Time. ops.fhwa.dot.gov/publications/tt_reliability/TTR_Report.htm. Accessed February 16, 2014.

Haight, F. Problems in Estimating Comparative Costs of Safety and Mobility. *Journal of Transport Economics and Policy*, Vol. 28 (1), 1994, pp. 14-17

George, D., and P. Mallery. *SPSS for Windows Step by Step: A Simple Guide and Reference 11.0 Update*, 4th ed., 2003, Boston: Allyn and Bacon.

Gronau, R. Price and Value of Time. *Transportation Research Board Special Report No. 149*, 1974.

Guttman, Joel. Avoiding Specification Errors in Estimating the Value of Time. *Transportation*, Vol. 4(1), 1975, pp. 19-42.

Haitham M., A. D. and B. Emam. New Methodology for Estimating Reliability in Transportation Networks with Degraded Link Capacities. *Journal of Intelligent Transportation Systems*, Vol. 10(3), 2006, pp. 117-129.

Hartgen, D. T. *Traffic Congestion in North Carolina: Status, Prospects and Solutions*. John Locke Foundation, 2007.

Hartgen, D. T., and R. K. Karanam. *More to Do: Performance of State Highway Systems 1984-2004*. 15th Annual Report, Reason Foundation, Los Angeles CA, October 4, 2006.

Hauer, E. and J. C. Greenough. A Direct Method for Value of Time Estimation. *Transportation Research Part A: General*, Vol. 16(3), 1982, pp. 163-172.

Heydecker, B. G., W. H. K. Lam, and N. Zhang. A New Concept of Travel Demand Satisfaction Reliability for Assessing Road Network Performance. *Workshop on Transport Network Analysis*, Matsuyama, Japan, 2000.

Heydecker, B. G., W. H. K. Lam, and N. Zhang. Use of Travel Demand Satisfaction to Assess Road Network Reliability. *Transportmetrica*, Vol. 3(2), 2007, pp. 139-171.

Higatani, A., T. Kitazawa, J. Tanabe, Y. Suga, R. Sekhar, and Y. Asakura. Empirical Analysis of Travel Time Reliability Measures in Hanshin Expressway Network. *Journal of Intelligent Transportation Systems*, Vol. 13(1), 2009, pp. 28-38.

Iida, Y., and H. Wakabayashi. An Approximation Method of Terminal Reliability of Road Network using Partial Minimal Path and Cut Sets. *Transport Policy, Management & Technology Towards 2001: Selected Proceedings of the Fifth World Conference on Transport Research*, Vol. 4, 1989.

The Kansas and Missouri Departments of Transportation. 2011 Kansas City Scout Congestion Index Report. kcscout.net/downloads/Announcements/CongestionReport.pdf. Accessed 9th August, 2014.

Keller, J. Safety at 55. Harvard Senior Thesis, Economic Department, Harvard University. Cambridge, Massachusetts 1975.

Kline, P. The Handbook of Psychological Testing, 2nd ed., Routedledge, London, 2000, pp. 13.

Lisco, T. E.. Value of Commuters Travel Time - A Study in Urban. Transportation. No. 234, 1968.

Litman, T. Transportation Cost Analysis for Sustainability. Victoria Transport Policy Institute, 1250 Rudlin Street, Victoria, BC, V8V 3R7, CANADA. 1999. vtpi.org/sustain.pdf. Accessed 10th August, 2014.

Moses, L. N., and H. F. Williamson. Value of Time, Choice of Mode, and the Subsidy Issue in Urban Transportation. The Journal of Political Economy, Vol. 71(3), 1963, pp. 247-264.

Nicholson, A., and Z. P. Du. Degradable Transportation Systems: An Integrated Equilibrium Model. Transportation Research Part B: Methodological, Vol. 31(3), 1997, pp. 209-223.

Recker, W., Y. Chung, J. Park, L. Wang, A. Chen, Z. Ji, H. Liu, M. Horrocks, and J. S. Oh. Considering Risk-taking Behavior in Travel Time Reliability. California PATH Research Report, UCB-ITS-PRR-2005-3, United States Department of Transportation, 2005.

Reichman, S. Subjective Time Savings in Interurban Travel: An Empirical Study. Highway Research Record, No. 446, 1973.

Small, K. A. The Scheduling of Consumer Activities: Work Trips. American Economic Review, Vol. 72(3), 1982, pp. 467-479.

Wilman, Elizabeth A. The Value of Time in Recreation Benefit Studies. Journal of Environmental Economics and Management, Vol. 7(3), 1980, pp. 272-286.

Yu, C. H. An Introduction to Computing and Interpreting Cronbach Coefficient Alpha in SAS. Proceedings of 26th SAS User Group International Conference, 2001.

Zimmerman, D. W., Zumbo, B. D. Coefficient alpha as an estimate of test reliability under violation of two assumptions Educational & Psychological Measurement, Vol. 53, 1993, pp. 33-50.