Reliability as a Performance Measure: Link-, Corridor, & Area-level

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ABSTRACT

There is a paradigm shift in focus from intersection-level to link-, corridor-, and area-level to assess highway system performance and impact of developments in recent years. The possibility of capturing dynamic and continuous travel time information from private data sources such as INRIX opens many pragmatic avenues to predict reliability of transportation systems. Travel time reliability (or index or variability) is considered the most viable performance measure for link- and corridor-level analysis though it is not being widely used for transportation planning, project prioritization, and allocation of resources. Definitions and thresholds to define reliability need to be clearly established prior to its large scale application. The definition of reliability as a performance measure and associated thresholds to understand the actual performance could vary for a link, corridor or an area. This research aims to fill this gap, define and assess link-, corridor- and area-level reliability measures. Data for the city of Charlotte, North Carolina are used to compute reliability and examine temporal & spatial variations for transportation planning, prioritization, and allocation of resources.

INTRODUCTION

- Reliability is defined as the probability that a component or system will perform a required function (without failure) for a given period of time when used under stated operating conditions (Ebeling, 1997).
- The reliability of a link, corridor or area, therefore, could be defined as the ability to provide an acceptable level of service (LOS) to the traveler under stated environmental and operational conditions during a given period.
- Travel time reliability (TTR) is the level of variability between the expected travel time (scheduled, average/mean or median travel time) and the actual travel time (Elefteriadou, 2005).
- Travelers prefer routes with higher mean travel times and smaller travel time variation to routes with a lower mean travel time and larger variability (Lyman et al., 2008; van Lint et al., 2007).
- Studies also show that travelers remember not only the average travel time, but also the worst few days they have experienced.

BACKGROUND

- Three major components of the reliability are expected travel time, acceptable additional time, and the actual travel time.
  - The acceptable additional time is the additional time that a traveler would find acceptable for an on-time arrival (Elefteriadou, 2005).
  - Buffer Time (BT) is the amount of extra time that must be allowed for the traveler to reach their destination in a high percentage of the trips (Elefteriadou, 2005).
- Among all measures of TTR, Buffer Time Index (BTI) and Planning Time Index (PTI) are standardized and used to compare two different roadway systems. On the other hand, measures such as BT and Planning Time (PT) are incomparable between different systems. These indices are used to compare the before-after condition of a same roadway system.

TABLE 1 Summary of Reliability Measures

Index	Measure / Equation	Index	Measure / Equation
NCHRP (1998) Definition	Std. Dev. of travel time	λ_{Skew} (van Lint et al., 2004)	$(TT_{90}-TT_{50})/(TT_{50}-TT_{10})$
AASHTO (2008) Definition	On-time performance	λ_{Var} (Bogers et al., 2008)	$(TT_{90}-TT_{10})/TT_{50}$
TranSystems Definition (2005)	Probability of on-time performance	Variability (Wakabayashi, 2010)	TT_{85}-TT_{15}
Buffer Time (BT) (Lomax et al., 2004)	$TT_{95}-TT_{Ave}$	Variability (Wakabayashi, 2010)	TT_{80}-TT_{20}
Buffer Time Index (BTI) (Lomax et al., 2004)	$\frac{TT_{95}-TT_{Avg}}{TT_{Avg}} \times 100$	Variability (Wakabayashi, 2010)	TT_{70}-TT_{30}
First worst travel time over a month (Wakabayashi et al., 2012)	TT_{95}	Acceptable Travel Time Variation Index (Wakabayashi, 2010)	$P(TTavg + ATTV)$
Second worst travel time over a month (Wakabayashi et al., 2012)	TT_{90}	Desired Travel Time Reduction Index (Wakabayashi, 2010)	$P(TTavg - DTTR)$
Planning Time (PT) (Wakabayashi et al., 2012)	TT_{95}	Travel Time Index (TTI) (Lyman et al., 2008)	$\frac{TT_{Ave}}{TT_{free\ flow}}$
Planning Time Index (PTI) (Sisiopiku et al., 2012)	$\frac{TT_{95}}{TT_{free\ flow}}$	Frequency of Congestion (Lyman et al., 2008)	Percent of days/periods that are congested
Travel Time Variability (TTV) (Tu et al., 2007)	$TT_{90}-TT_{10}$		

DATA

- Two corridors, 1) a freeway corridor (I-85, 5.75 miles) and 2) a major thoroughfare (North-Tryon, 5.75 miles), in Charlotte metropolitan area were considered for the case study.
- INRIX data was obtained for these corridors for the year 2011.
- Data obtained consists of average travel times on each link along the corridor, for every minute, for the entire year 2011.
- Each link was designated with a Traffic Message Channel (TMC) code. The selected I-85 and North Tryon corridors were divided into 10 and 9 TMC's (say, links), respectively.
- Data was categorized based on TMC code, day-of-week and time-of-day (each hour in a day) to generate a new database for each link.
- As the lengths of the links are different, TTR measures that are standardized (TTR indices) were used to compare different segments at different times of the day.
- Buffer time indices (BTI_{85} and BTI_{95}), as shown in equations 1 & 2, were also computed.

$$BTI_{85} = (TT_{85}\text{-}TT_{Avg})*100/TT_{Avg} \qquad \textit{Equation (1)}$$

$$BTI_{95} = (TT_{95}\text{-}TT_{Avg})*100/TT_{Avg} \qquad \text{Equation (2)}$$

- Similarly, travel time data for each link were aggregated to compute and evaluate the corridor level measures.

RESULTS

TABLE 2 Link-level Travel Time and Reliability Measures for North Tryon during Weekdays

Link	Off Peak Hours (10:00Pm - 11:00Pm)								Peak Hours (8:00Am - 9:00Am)							
	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)
	Min	Max	Avg	15	85	95			Min	Max	Avg	15	85	95		
1	2.20	2.99	2.58	2.57	2.57	2.70	-0.31	4.66	2.03	11.98	2.95	2.70	3.08	3.48	4.26	17.70
2	0.44	1.40	0.49	0.49	0.49	0.49	-1.03	-1.03	0.43	2.04	0.56	0.49	0.59	0.86	5.21	53.88
3	1.50	2.61	1.56	1.54	1.54	1.63	-1.04	4.28	1.63	4.89	2.53	2.19	2.68	3.62	5.83	42.64
4	1.73	2.52	2.12	2.13	2.13	2.13	0.50	0.50	1.18	5.01	2.10	1.67	2.61	3.17	24.41	50.64
5	1.00	1.27	1.06	1.06	1.06	1.06	-0.13	-0.13	0.34	0.92	0.50	0.44	0.55	0.63	9.89	26.96
6	0.12	0.18	0.13	0.13	0.13	0.13	0.21	0.21	0.04	0.39	0.14	0.09	0.18	0.28	25.96	97.12
7	0.07	0.11	0.07	0.07	0.07	0.07	-0.38	-0.38	0.95	2.17	1.19	1.08	1.21	1.33	1.86	12.30
8	0.01	0.03	0.01	0.01	0.01	0.02	-3.99	10.78	0.12	0.52	0.15	0.13	0.16	0.23	3.72	50.33
9	0.40	0.55	0.41	0.41	0.41	0.41	-0.28	-0.28	0.01	0.11	0.03	0.02	0.02	0.04	-5.32	73.57

TABLE 3 Link-level Travel Time and Reliability Measures for North Tryon during Weekends

Link	Off Peak Hours (10:00Pm - 11:00Pm)								Peak Hours (8:00Am - 9:00Am)							
	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)
	Min	Max	Avg	15	85	95			Min	Max	Avg	15	85	95		
1	0.47	0.70	0.49	0.49	0.49	0.50	-0.62	1.62	2.07	3.99	2.67	2.63	2.76	2.84	3.60	6.34
2	2.34	2.91	2.57	2.57	2.57	2.57	-0.15	-0.15	1.85	3.33	2.32	2.25	2.45	2.68	5.58	15.76
3	0.96	1.41	1.06	1.06	1.06	1.06	0.10	0.10	0.11	0.28	0.14	0.14	0.14	0.15	-1.68	10.53
4	2.08	2.87	2.14	2.13	2.13	2.13	-0.23	-0.23	0.42	0.90	0.50	0.49	0.51	0.58	1.86	14.84
5	1.54	3.01	1.57	1.54	1.54	1.63	-1.87	3.41	1.40	3.01	1.94	1.82	2.15	2.51	10.56	28.94
6	0.01	0.08	0.01	0.01	0.01	0.01	-2.27	-2.27	0.05	0.32	0.09	0.08	0.10	0.13	6.61	41.78
7	0.38	0.53	0.42	0.41	0.41	0.41	-0.59	-0.59	0.90	1.58	1.11	1.11	1.13	1.18	2.08	6.69
8	0.13	0.21	0.13	0.13	0.13	0.13	-0.35	-0.35	0.34	1.01	0.50	0.47	0.51	0.56	1.11	12.30
9	0.05	0.11	0.07	0.07	0.07	0.07	-0.12	-0.12	0.01	0.05	0.02	0.02	0.02	0.03	-8.53	71.50

TABLE 4 Link-level Travel Time and Reliability Measures for I-85 during Weekdays

Link	Off Peak Hours (10:00Pm - 11:00Pm)								Peak Hours (8:00Am - 9:00Am)							
	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)
	Min	Max	Avg	15	85	95			Min	Max	Avg	15	85	95		
1	0.30	0.41	0.35	0.34	0.36	0.37	3.59	6.73	0.29	4.43	0.42	0.34	0.36	0.36	-15.39	-13.97
2	0.59	0.77	0.68	0.65	0.71	0.72	4.86	6.48	0.58	6.13	0.68	0.64	0.70	0.71	3.67	5.45
3	0.70	1.01	0.80	0.77	0.83	0.84	4.18	5.81	0.70	0.91	0.79	0.75	0.82	0.84	3.83	6.37
4	0.79	1.18	0.91	0.88	0.94	0.96	3.66	5.31	0.78	1.21	0.89	0.85	0.92	0.94	3.02	5.71
5	0.24	0.31	0.27	0.27	0.28	0.29	2.90	6.18	0.24	0.57	0.27	0.26	0.28	0.28	3.20	5.06
6	0.32	0.44	0.38	0.36	0.39	0.40	2.87	6.31	0.31	0.50	0.37	0.35	0.38	0.39	3.61	5.23
7	0.15	0.19	0.17	0.16	0.18	0.18	3.69	6.05	0.15	0.39	0.17	0.16	0.17	0.18	3.31	5.71
8	0.54	0.80	0.63	0.60	0.65	0.66	3.35	5.10	0.54	0.75	0.61	0.59	0.64	0.65	4.53	6.00
9	0.47	0.70	0.54	0.52	0.57	0.58	3.84	5.68	0.47	0.67	0.53	0.51	0.56	0.57	4.64	6.34
10	0.51	0.74	0.58	0.56	0.60	0.61	3.92	5.64	0.51	0.77	0.57	0.54	0.58	0.60	3.16	6.34

TABLE 5 Link-level Travel Time and Reliability Measures for I-85 during Weekends

Link	Off Peak Hours (10:00Pm - 11:00Pm)								Peak Hours (8:00Am - 9:00Am)							
	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)	Travel Time (Minutes)			Travel Time Percentile			BTI (85)	BTI (95)
	Min	Max	Avg	15	85	95			Min	Max	Avg	15	85	95		
1	0.30	0.41	0.35	0.34	0.36	0.38	3.53	6.95	0.30	0.53	0.34	0.33	0.36	0.36	3.83	5.58
2	0.57	0.80	0.68	0.65	0.71	0.74	4.11	8.20	0.59	0.79	0.67	0.64	0.70	0.72	4.78	7.02
3	0.70	0.93	0.80	0.77	0.83	0.84	3.68	5.30	0.70	0.90	0.79	0.75	0.82	0.83	3.90	5.55
4	0.78	1.02	0.91	0.88	0.94	0.96	3.34	5.64	0.78	1.01	0.89	0.85	0.93	0.94	3.99	5.67
5	0.24	0.34	0.28	0.27	0.29	0.29	3.87	5.69	0.24	0.31	0.27	0.26	0.28	0.29	4.19	6.04
6	0.32	0.44	0.38	0.36	0.40	0.41	4.67	7.85	0.31	0.42	0.37	0.35	0.38	0.40	3.92	7.17
7	0.15	0.19	0.17	0.16	0.18	0.18	3.86	5.62	0.15	0.20	0.17	0.16	0.17	0.18	3.69	6.09
8	0.55	0.71	0.63	0.60	0.66	0.67	4.68	6.27	0.54	0.69	0.62	0.59	0.65	0.66	4.94	6.72
9	0.47	0.62	0.54	0.52	0.57	0.58	4.08	5.92	0.47	0.60	0.53	0.51	0.56	0.57	4.72	6.41
10	0.51	0.70	0.58	0.56	0.60	0.61	3.91	5.63	0.51	0.64	0.57	0.55	0.59	0.60	4.05	5.63

Figure 1 Reliability During Weekday Peak (Left) & Off-peak (Right) Hours

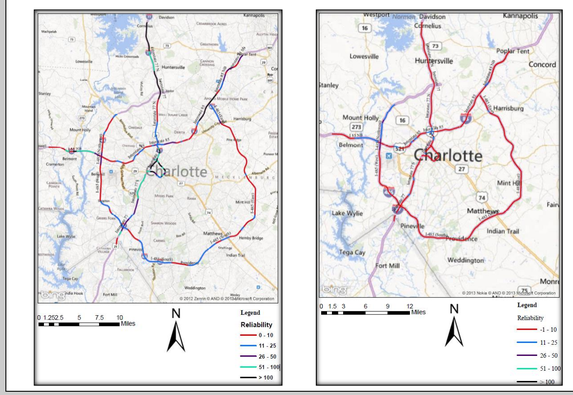

Figure 2 Reliability During Weekend Peak (Left) & Off-peak (Right) Hours

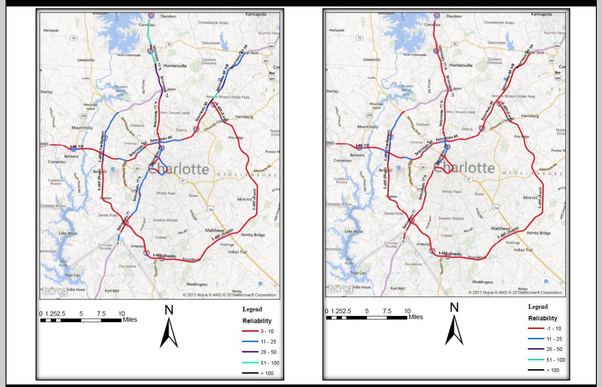

TABLE 6 Summary of Corridor-level Travel Time and Reliability Measures

DOW	TOD	North Tryon Corridor: Travel Time (Minutes) Min	Max	Avg	Travel Time Percentile 15	85	95	BTI (85)	BTI (95)
Weekday	8AM - 9AM	7.25	28.61	10.20	9.32	11.07	12.10	8.54	18.63
	10PM - 11PM	8.06	9.73	8.46	8.44	8.46	8.66	0.04	2.42
Weekend	8AM - 9AM	8.24	21.95	9.36	8.95	9.71	10.17	3.64	8.54
	10PM - 11PM	8.21	9.95	8.48	8.44	8.45	8.72	-0.35	2.83
		I-85 Corridor							
Weekday	8AM - 9AM	4.97	14.96	5.61	5.35	5.71	5.93	1.79	5.61
	10PM - 11PM	5.00	6.29	5.61	5.45	5.74	5.89	2.39	5.06
Weekend	8AM - 9AM	4.93	5.89	5.51	5.34	5.66	5.75	2.87	4.43
	10PM - 11PM	5.02	11.51	5.65	5.46	5.78	5.87	2.30	3.96

CONCLUSIONS & SCOPE FOR FUTURE WORK

- Findings from the analysis of data for links along selected corridors show that only marginal differences exist between minimum, average, 15th, and 85th percentile travel times.
- Links could be ranked based on the computed link-level reliability to examine causes of congestion and allocate resources.
- Identification of specific locations for improvements will be difficult if corridor-level reliability measures are computed and used instead of link-level reliability measures.
- Percent of links or lane miles with poor reliability scores by time-of-day could be used for assessment of transportation network performance (area-level).
- There could be relationship between reliability and volume-to-capacity ratio traditionally used for assessment. This merits an investigation.

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