ELSEVIER

Transportation Research Procedia

Volume 15, 2016, Pages 438–446

ISEHP 2016. International Symposium on Enhancing Highway Performance

Transportation Research Procedia

Development of a Mobility-Based Service Measure for Freeway Facilities

Richard Margiotta[1], Douglas McLeod[2], and Tyrone Scorsone[1]

[1]*Cambridge Systematics, Cambridge, MA, USA.*

[2]*Florida Department of Transportation, Tallahassee, FL, USA*

rmargiotta@camsys.com, Douglas.McLeod@dot.state.fl.us, tscorsone@camsys.com

Abstract

The Highway Capacity Manual (HCM) currently uses a bipolar approach to defining level of service (LOS) for freeway facilities: either (1) weighted density or (2) assigning LOS F if one or more segments experience LOS F. The major shortcoming of this approach is that density is a poor indicator of travelers' experiences under congested conditions; speeds or travel times are more relevant to travelers and are consistent with how agencies measure and report congestion using field data.

This paper deals with this issue by defining a travel time-based service measure for freeway facilities. The main purpose is to bring the HCM in line with empirically-based performance measures used in performance management. Two HCM applications are explored: (1) traditional (static) freeway analysis and (2) the new travel time reliability (TTR) analysis procedure. Several performance measures are explored for the service measures by analyzing field data from seven U.S. urban areas.

A shift away from the current density-based LOS structure is recommended. The new structure uses ranges of the selected travel time measures that indicate different levels of the user experience. This approach is similar to what is done in the HCM for urban streets. Reconciling LOS concepts between freeways and urban streets will make the HCM more usable for the emerging field of performance management. Also, by allowing for multiple levels of flow breakdown (i.e., severity of congestion), the proposed method is sensitive to transportation improvements and demand reduction strategies that are not as expansive as physical capacity additions, especially transportation system management and operations (TSM&O) strategies.

Keywords: Highway capacity, level of service, congestion performance measurement, travel time reliability

1 Introduction

The HCM currently uses density to define LOS for all freeway features. For freeway facilities, the HCM defines LOS thusly:[1]

Selection and peer-review under responsibility of the Scientific Programme Committee of ISEHP 2016

doi:10.1016/j.trpro.2016.06.037

> Because LOS for basic, weaving, merge, and diverge segments on a freeway is defined in terms of density, LOS for a freeway facility is also defined on the basis of density. A facility analysis will result in a density determination and LOS for each component segment. The facility LOS will be based on the weighted average density for all segments within the defined facility.

The definition also allows for oversaturation as defined by a value of 1.0 or higher for the demand volume-to-capacity ratio (v_d/c) on **any** component segment on the facility.

The major shortcoming of this approach is that density is a poor indicator of travelers' experiences under congested conditions; speeds or travel times are more relevant to travelers and are consistent with how agencies measure and report congestion using field data. Further, five of the six LOS ranges exist where speeds are relatively high (above approximately 50 mph) and only one LOS range is used to define the congested regime, which is of the highest interest in large urbanized areas. Especially with regard to operations improvements, many congestion management techniques will improve congestion (e.g., delay) but the facility will still be classified as LOS F under the current definition.

A second shortcoming is the reliance on the LOS for each segment to determine the facility LOS. Having this detail is important for identifying physical bottlenecks and other deficiencies, but the user experience in terms of travel time occurs over the entire facility. Therefore, the authors believe that a LOS scheme based on travel time should be for performance of the **facility as a whole**, not a summation of the LOS of segments that comprise the facility.

Finally, the measurement of congestion with empirical data has improved immensely over the past decade. Agencies and researchers involved in monitoring mobility performance use measures that are based on travel times, not density, at least in urban situations. It is critical that the HCM's view of performance mesh with that of the wider profession in order for it to provide relevant analyses. Even if a travel time-based service measure is not adopted, defining ranges for reporting purposes that cover both monitoring (measurement with empirical data) and forecasting would provide consistency. This consistency would allow direct comparisons across studies and enables a systematic assembly of evaluation studies. This new perspective is especially critical as the profession adopts a performance management philosophy, as advanced by the MAP-21 legislation.[2]

2 Requirements for a Freeway Facility Service Measure

If travel time is to be the basis for LOS on freeway facilities, what aspect of travel time performance should be used? The traditional HCM LOS methodology considers only a single demand and that no disruptions exist, a relatively ideal condition that travelers can expect to experience only a few times per year ("static" approach). The update to the HCM will include a more sophisticated accounting of the sources of congestion, based on the research conducted in Strategic Highway Research Program 2 (SHRP 2) Project L08.[3] This project was designed to incorporate reliability into the HCM. It considers all the potential sources of recurring and nonrecurring congestion, including variations in demand, incident, weather, and work zone conditions ("stochastic" approach). The result is a distribution of travel times which more realistically reflects how a facility will perform over the course of time (for example, a year). Measures that capture the nature of the travel time distribution are referred to as "reliability measures". The SHRP 2 L08 Project recommended several measures for this purpose (Table 1). The SHRP 2 L08 research led directly to the reliability method for freeway facilities that is being included in the next update of the HCM, including the specification of performance measures. It is likely that both freeway facility methods (static and stochastic) will remain in the HCM for the foreseeable future.

A large body of research exists on developing and applying travel time reliability measures, including the work of the U.S. Federal Highway Administration[4]; Lomax *et al.*[5] and Van Lint and van Zuylen.[6] Two SHRP 2 projects used much of this previous research to identify the most relevant performance measures as well as measurement and modeling methods to develop them. SHRP 2 Project L03 tested a large set of measures and identified a core set of reliability measures.[7] SHRP 2 Project L08 extended the list of measures slightly.[3]

Very little work has been done in terms of creating a travel time reliability service measure, a performance measure used to determine levels of service (LOS). Lyman and Bertini recently investigated the use of travel time reliability as a criterion for selecting improvements but didn't establish thresholds.[8] To the authors' knowledge, the only previous work on developing a service measure for travel time reliability – including recommended levels of service – was the work by Chen, Skabardonis, and Varaiya, who made a preliminary investigation into the subject, matching mean and standard deviation of travel times to the current *HCM* levels of service.[9]

Reliability Performance Measure	Definition
Core Measures	
Planning Time Index (PTI)	95th percentile Travel Time Index (TTI) (95th percentile travel time divided by the free-flow travel time)
80th Percentile Travel Time Index	80th percentile Travel Time Index (80th percentile travel time divided by the free-flow travel time)
Semi standard Deviation	The standard deviation of travel time pegged to free-flow travel time rather than the mean travel time (variation is measured relative to free-flow travel time)
Failure Measure (speed-based)	Percent of trips or VMT with space mean speed less than 50 mph, 45 mph, and 30 mph
Reliability Rating	Reliability Rating: Percent of trips or VMT serviced at or below a threshold travel time index (1.33 for freeways, 2.50 for urban streets)
Supplemental Measures	
Standard Deviation	Usual statistical definition
Misery Index (Modified)	The average of the highest five percent of travel times divided by the free-flow travel time

Table 1: Recommended Travel Time Reliability Metrics From SHRP 2 Project L08

Reliability measures are a viable option for a freeway facility service measure, and several of them are already in widespread use as performance measures. A TTR-based approach would base freeway facility LOS on the amount of variability in travel times. At first glance, this may seem incongruous – shouldn't the severity of travel time (or speed) conditions be considered? That is, what about the case where travel times are reasonably low but variability is high – wouldn't using variability alone paint a false picture of congestion problems on the facility? The answer is "no" – as average congestion level increases, so does reliability (i.e., reliability gets worse). Figures 1 and 2 demonstrate this fact. These plots show two common reliability metrics – the 80th and 95th percentile travel time indices – against the mean travel time index (TTI). The TTI is the ratio of the actual travel time to the travel time that would occur under free flow conditions. As the average congestion condition increase, so do the reliability metrics. Congested highways are unreliable highways, as a general rule.

Another option is to use a measure of central tendency from the travel time distribution as the service measure: the mean or 50th percentile. In empirically-based performance reports, average conditions are often used as the primary measure of interest, sometimes used in conjunction with one or more reliability measures. Central tendency measures have been used in the HCM and other modeling practices for a long time, so the profession is more used to interpreting them. The static HCM freeway facility method only produces a value based on fixed conditions, ostensibly a measure of central tendency.

Regardless of what measure is chosen, it is clear that the current freeway facility LOS categories are insufficient to characterize congestion. They are an extension of the LOS concepts for basic freeway segments and they offer no insight into the severity of congestion. That is, five of the six LOS categories occur prior to the breakdown conditions with no regard for how severe the breakdown is. For example, consider two highway segments that are operating very close to breakdown conditions. The addition of a few more vehicles on the first segment will cause traffic flow to breakdown. Alternately, on the second segment, breakdown will occur if multiple lanes are blocked due to an incident. The performance of these two conditions will be radically different (i.e., the incident case will cause a more longer queue), yet these conditions are assigned the same LOS (“F”).

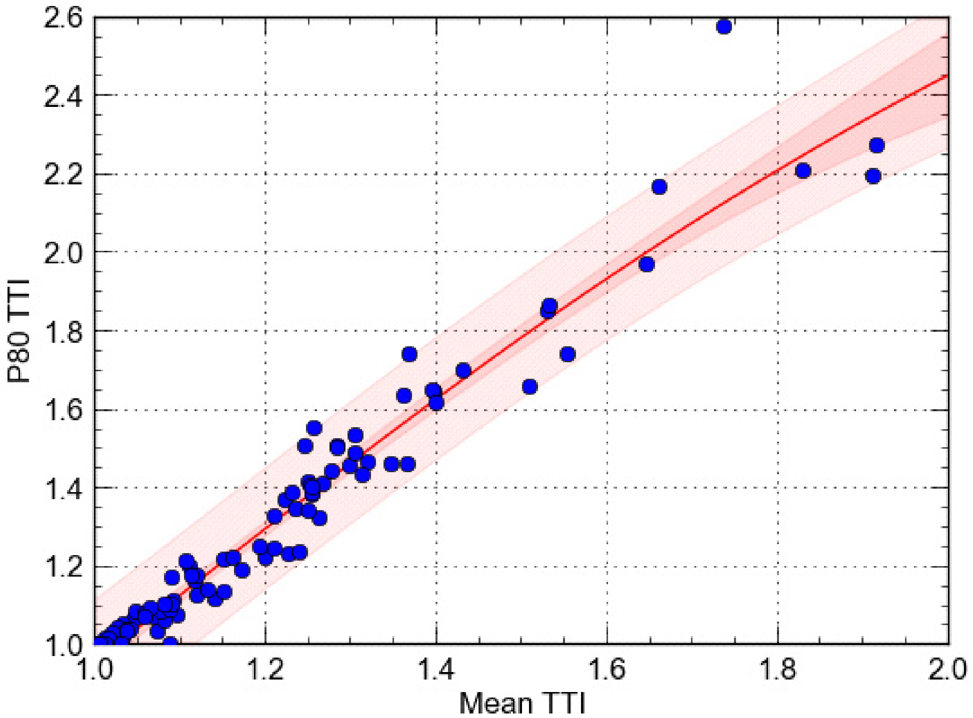

Figure 1: Relationship between 80th percentile TTI and mean TTI, on freeways in five large Florida urbanized areas, peak period, 2012

3 Selecting a Freeway Facilities Service Measure

Despite the appeal of using TTR as the service measure, we are recommending that a mean value be used because means are more commonly understood by the profession. Also, as shown in Figures 1 and 2, reliability measures can be statistically approximated from the mean value with a reasonable consistency. Two choices are apparent for the metric to be used as the service measure: space mean speed (SMS) and mean TTI (MTTI). Of these, the MTTI appears to be in more widespread use by empirically-based performance measurement systems. Although the two metrics are very closely related, MTTI depends on free flow speed, which is used throughout the HCM for performance measures.

Setting LOS ranges is a subjective activity but it can be informed by data. Here we use two data aids to help us set the ranges: (1) the HCM speed-flow relationships for freeway segments and (2) empirical data on MTTI and SMS from several urban facilities.

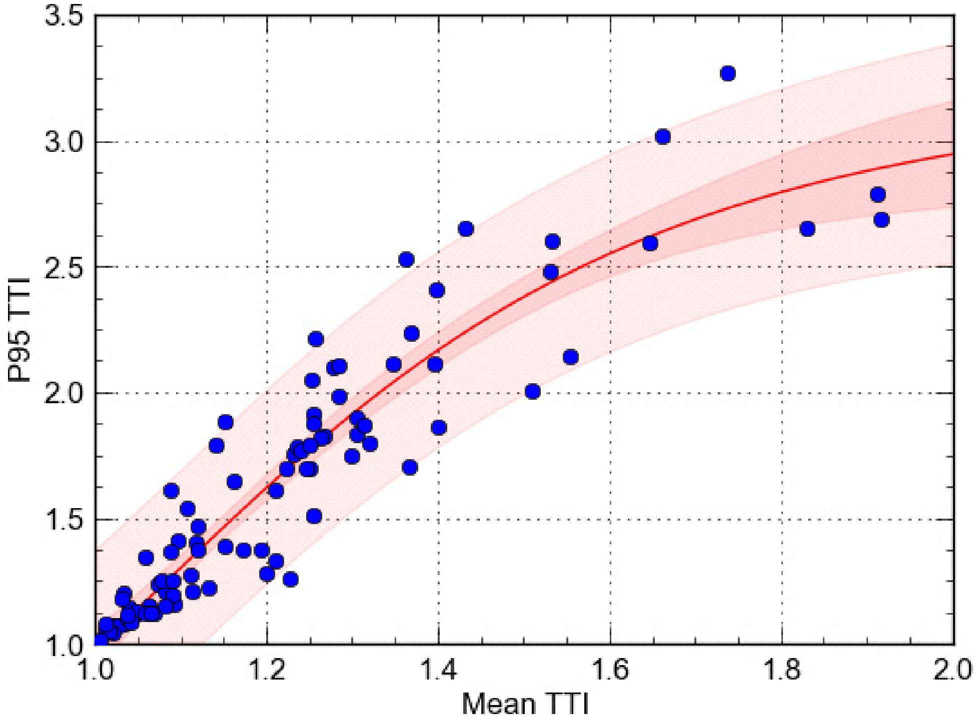

Fig. 2: Relationship between 95th percentile TTI and mean TTI, on freeways in five large Florida urbanized areas, peak period, 2012

The HCM speed-flow curve for freeway segments is shown in Figure 3. It must be considered that these relationships pertain to relatively short highway distances; freeway facilities will be comprised of multiple segments and we are concerned with travel over the entire facility. Two pieces of information from these curves are useful for setting LOS ranges. First, the curves are flat for over an extended range of volumes. This range can be used to define the first range ("unimpeded flow"). Second, if we treat the range between unimpeded flow and breakdown as "transitional flow", and convert the speeds at capacity to MTTI, we obtain the following values:

- FFS_{55} : TTI = 1.10
- FFS_{60} : TTI = 1.17
- FFS_{65}: TTI = 1.24
- FFS_{70} : TTI = 1.31

The above values indicate the sensitivity of the TTI to free flow speed, which makes it unsuitable for a service measure. For example, a TTI of 1.3 on a facility with a free flow speed of 55 mph would indicate significant queuing whereas a facility with a free flow speed of 70 mph would not experience any queuing.

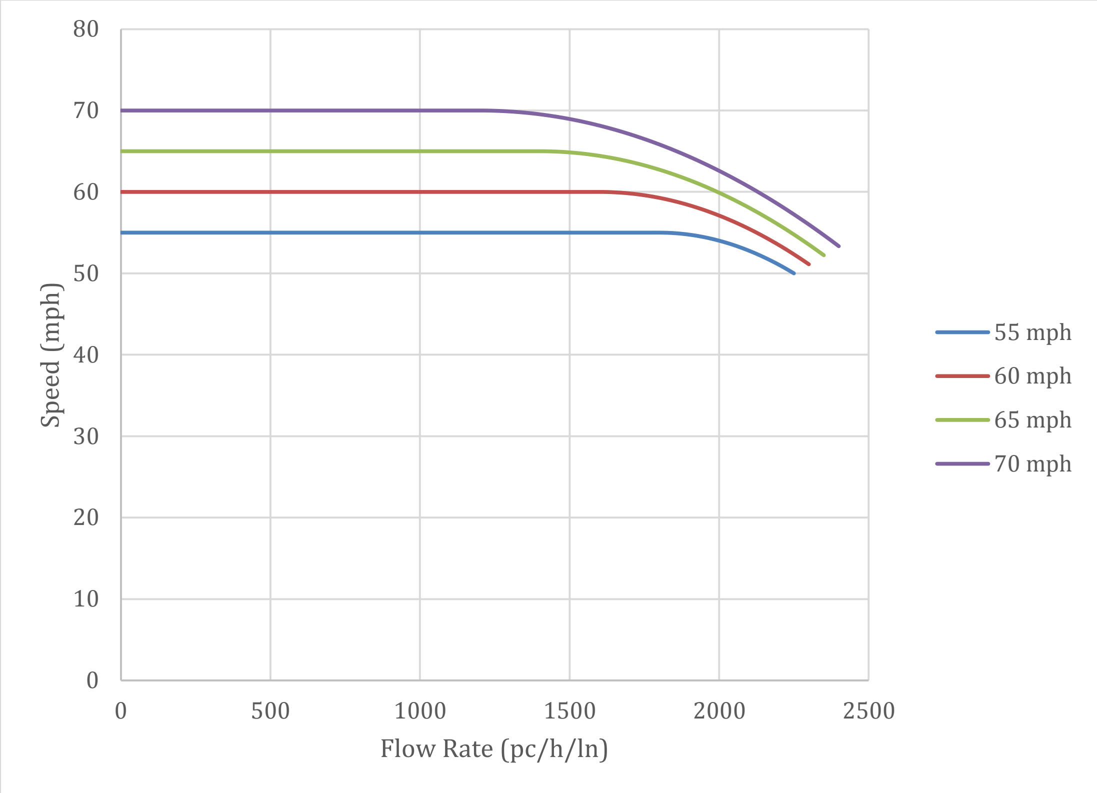

Figure 3: Speed/Flow Curves from the HCM

One way to account for the variation in TTI is to use a constant reference speed for all facilities rather than free flow speed. If we compute speed at capacity we find it varies in a fairly tight range from 50.0 mph to 53.3 mph for free flow speeds between 55 mph and 70 mph. If we select 50 mph as the reference speed, we can define a new measure, $MTTI_{50}$. Selecting the reference speed at the approximate point of capacity neglects any delay that may occur in unsaturated conditions but it is similar to what some U.S. transportation agencies have done in defining performance measures.

A more objective measure than a TTI-based one is SMS over the entire facility. Table 2 displays congestion and reliability measures for selected freeway facilities in the U.S. These data were taken from continuously operating freeway detectors. Speed data from the multiple detectors were converted to travel times over each facility and performance measures were based on the facility travel times. Peak periods were defined as 7:00 – 9:00 AM and 5:00 – 7:00 PM. For these time periods, facility SMSs are rarely below 30 mph.

Based on these data and the previous discussion, we offer service ranges for freeway facility performance based on SMS (Table 3). These values are meant to be applied to freeway facilities that are comprised of multiple (three or more) basic freeway segments with a total length not less than 3 miles. The reporting time interval is not less than one hour. The ranges are meant to be used with the HCM method that includes travel time reliability, as the field data in Table 2 includes the effects from the various sources of congestion (e.g., incidents, demand fluctuation). The service ranges are a significant departure from those used on basic freeway segments in that they are not based on density covering primarily unsaturated conditions. However, because they are based on speed they are similar in concept to the service measures for urban streets. This is due to the requirement of measuring travel over the entire facility as experienced by users.

The corresponding $MTTI_{50}$ values to the SMS ranges are also provided in Table 3. We have chosen a minimum value of 1.00 for $MTTI_{50}$ resulting in only five LOS categories. LOS A could be defined by as any values less than 1.00, but typical performance monitoring conventions don't allow it to drop below 1.00.

Although we have assigned the traditional LOS categories of A through F, we also recognize the discontinuity with traditional freeway LOS categories, where a LOS score of F has usually been interpreted as failure. The problem with the traditional approach is that many degrees of failure exist. In our approach, failure is a relative term. It is possible to have a freeway segment classified as LOS F under the traditional method, yet the facility as a whole can function at a better LOS. For this reason, our proposed method is not a replacement for the traditional approach. Both methods should be used. The proposed method for reporting purposes and for identifying how badly the facility as a whole performs, which is useful for comparing multiple facilities. The traditional method should be used as a way to diagnose specific problems on the facility, especially physical bottlenecks.

It should be noted that the HCM's Freeway Facilities method is capable of producing the recommended service measure (along with many other performance measures) and in doing so accounts for the effects of merge, diverge, and weaving areas. The recommended service measure is applicable to any facility length that can be modeled with the HCM Freeway Facility method.

4 Summary and Next Steps

Performance monitoring practice for mobility is rapidly evolving as new data sources emerge. Among practitioners, it is common to report performance for facilities rather than individual segments. It is therefore critical that the HCM provide performance reporting at the same level. This scale of reporting will become even more relevant when the ability to measure entire trips is attained.

The current version of the HCM does not provide a service measure that captures the performance of the facility from the user's perspective, even though the freeway facility methodology is capable of producing it. The authors have developed a service measure based on space mean speed over the entire facility as a way to define quality of service for freeway facilities. This definition is based on examining field data from a variety of urban facilities in the U.S. The authors have also defined a variant on the travel time index which uses a reference speed of 50 mph as a supplement for the space mean speed based LOS ranges.

The use of space mean speed is a major deviation from current practice. Perhaps the biggest difference is that the concept of failure is no longer binary. Currently, a "failed" facility is one where any segment has a demand-to-volume ratio greater than 1.0. In the field, the presence of queuing leads to a continuum of failure (as defined by breakdown flow), from minor to catastrophic. The proposed approach accounts for the highly variable nature of traffic flow "failure" on users. By allowing for multiple levels of flow breakdown (i.e., severity of congestion), the proposed method is sensitive to transportation improvements and demand reduction strategies that are not as expansive as physical capacity additions, especially transportation system management and operations (TSM&O) strategies. Such strategies are routinely implemented on heavily congested facilities where the scale of the improvement would not reclassify its LOS with the current HCM method.

City	Route	Length	Peak Period	FFS	MTTI	MTTI(50)	SMS	95th %ile TTI	TTI(50)
Atlanta									
	I-75	4.15	AM	73	1.071	1.001	68.6	1.129	1.000
	I-75	4.15	PM	74	1.874	1.354	44.7	3.202	2.190
	I-75	3.52	AM	71	1.471	1.101	49.1	1.954	1.398
	I-75	3.52	PM	70	1.106	1.008	63.9	1.267	1.000
	I-75	2.91	AM	71	1.508	1.100	48.1	1.873	1.315
	I-75	2.91	PM	71	1.508	1.187	51.5	2.754	1.963
	I-75	2.80	AM	70	1.359	1.037	52.5	1.706	1.211
	I-75	2.80	PM	69	2.520	1.813	29.5	3.398	2.425
	I-285	5.46	AM	70	1.084	1.004	64.7	1.169	1.000
	I-285	5.46	PM	70	1.898	1.428	43.1	3.354	2.407
	I-285	5.84	PM	71	2.098	1.534	40.0	3.915	2.778
Minneapolis									
	I-394	4.23	AM	69	1.470	1.132	49.1	2.152	1.568
	I-394	4.23	PM	69	1.602	1.223	46.1	2.536	1.848
	I-494	3.91	AM	72	1.653	1.222	47.7	2.462	1.714
	I-494	3.91	PM	72	1.133	1.015	64.5	1.240	1.000
	I-494	4.48	AM	72	1.395	1.067	53.4	1.912	1.328
	I-494	4.48	PM	72	1.784	1.304	44.6	2.837	1.978
	I-494	4.16	AM	72	2.438	1.819	33.9	4.120	3.057
	I-494	4.16	PM	72	1.997	1.531	43.9	3.941	2.979
Seattle									
	I-405	4.68	AM	60	1.289	1.096	47.6	1.687	1.406
	I-405	4.68	PM	60	2.252	1.887	30.9	3.725	3.104
	I-405	8.82	AM	60	2.791	2.331	23.5	3.857	3.214
	I-405	8.82	PM	60	1.096	1.015	55.3	1.293	1.078
	I-405	3.57	AM	60	1.236	1.070	49.6	1.655	1.379
	I-405	3.57	PM	60	1.176	1.075	53.1	1.722	1.435
	I-405	8.05	AM	60	1.031	1.009	58.6	1.041	1.000
	I-405	8.05	PM	60	1.782	1.514	38.4	3.105	2.587
Tampa									
	I-275	5.90	AM	69	1.074	1.003	64.6	1.198	1.000
	I-275	5.90	PM	69	1.160	1.004	60.2	1.335	1.000
	I-275	4.65	AM	74	1.120	1.011	66.9	1.429	1.000
	I-275	4.65	PM	74	1.378	1.122	59.0	2.497	1.704
	I-275	3.70	AM	71	1.833	1.380	45.0	3.299	2.341

Note: AM peak period is 7:00 – 9:00 AM and PM peak period is 5:00 – 7:00 PM

Table 2: Performance Measures for Selected U.S. Highway Sections

Service Range	SMS Range	Corresponding $MTTI_{50}$	Description
A	>= 55 mph	1.00	Unimpeded/Uncongested
B	50 <= SMS < 55 mph		Transitional
C	42.5 <= SMS < 50	1.18 <= TTI_{50} < 1.00	Mild Congestion
D	35 <= SMS < 42.5	1.43 <= TTI_{50} < 1.18	Moderate Congestion
E	30 <= SMS < 35	1.67 <= TTI_{50} < 1.43	Heavy Congestion
F	< 30 mph	1.67 <= TTI_{50}	Extreme Congestion

Notes: (1) Facilities should be at least 3 miles long and include 3 or more individual segments.
(2) Reporting time interval not less than 1 hour.
(3) Minimum value of TTI_{50} is set at 1.00.

Table 3: Proposed Service Ranges for Freeway Facilities, HCM Reliability Method

In addition to being consistent with current monitoring practice, the new service measure is also in concept similar to that used for urban streets in the HCM. That is, they are both based on travel speed (i.e., space mean speed) over the entire facility.

The next step is to deliberate the proposed service measure and LOS categories with the Highway Capacity and Quality of Service (HCQS) committee. Even if formal service measure does not emerge from these deliberations, the performance ranges defined here should be used to report the performance of freeway facilities (without the LOS letter grade). This step would provide a consistent basis for comparing the performance of freeway facilities across agencies. Beyond HCQS deliberations, consideration should be given to extending the service measure to travel time reliability.

References

[1] Highway Capacity Manual 5th Edition (HCM2010), Transportation Research Board, 2010.
[2] MAP-21 §2002; 23 USC 601-609.
[3] Kittelson Associates et al., Incorporation of Travel Time Reliability into the HCM, SHRP 2 Project L08, Final Report (in publication), April 2013.
[4] Federal Highway Administration, Traffic Congestion and Reliability: Trends and Strategies for Advanced Mitigation, U.S. Department of Transportation, 2005.
[5] Lomax, T., D. Schrank, S, Turner, R, Margiotta, Selecting Travel Reliability Measures, Texas Transportation Institute. tti.tamu.edu/documents/474360-1.pdf. July 14, 2007.
[6] Van Lint, J. W. C. and H. J. van Zuylen, H.J., Monitoring and Predicting Freeway Travel Time Reliability. In Transportation Research Record: Journal of the Transportation Research Board, No. 1917, TRB Washington, D.C., 2005.
[7] Cambridge Systematics et al., Analytic Procedures for Determining the Impacts of Reliability Mitigation Strategies, SHRP 2 Project L03 Final report, 2013.
[8] Lyman, Kate and Bertini, Robert, Using Travel Time Reliability Measures to Improve Regional Transportation Planning and Operations, presented at 87th Annual Meeting of the Transportation Research Board January 13–17, 2008.
[9] Chen, Chao, Skabardonis, Alex, and Varaiya, Pravin, Travel Time Reliability as a Measures of Service, presented at 82nd Annual Meeting of the Transportation Research Board, January 2003.