Traffic Flow Analysis Beyond Traditional Methods

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ABSTRACT

Traditional traffic engineering methodology is usually concentrated on one specific hourly traffic demand, *q*, which is then compared with the capacity, *c*, for the highway facility under consideration to estimate the expected traffic flow performance. To estimate demand, one or two hour-long periods are analyzed to represent the whole variety of potential traffic volumes. Generally conditions for the remaining 8,758 hours of the year are not observed or considered. In addition, the use of this brief period makes it difficult to estimate the overall economic loss resulting from traffic congestion.

This traditional approach is expected to be enhanced in the future in two aspects. This wider view becomes possible due to improved information availability and enhanced data processing capabilities to be expected for the near future.

Instead of considering demand, capacity, and quality of flow as three separate terms, the new term *efficiency* is introduced. The maximization of the *efficiency* usually reveals the optimum utilization of a traffic facility. This new term, *efficiency*, has the potential to provide an objective parameter to distinguish between LOS D and E for freeway facilities instead of using subjective assessment, as is currently done.

Capacity and traffic demand can be treated as random variables. Moreover, demand can be estimated over the sequence of the hours of a whole year. The comparison of demand with capacity over the whole year will reveal the cumulative delay, which can be assessed in terms of economic losses. Thus a more complete picture of the consequences caused by different design decisions is available to the decision maker. Aspects of randomness, systematic capacity variation, incidents, and accidents can be included into the evaluation easily. These principles are illustrated for the application on two tunnel-related studies.

1. INTRODUCTION

With the new U.S. *Highway Capacity Manual* (HCM 2000), the traditional basis for a standardized analysis of road traffic qualities is continued. This concept had its origin in the 1965 HCM, which also forms the basis for similar guidelines in countries around the world. This paper focuses on several aspects of the HCM, as follow:

- Traffic capacity and quality of flow are analyzed for specific peak hours, during which shorter peak intervals (e.g., 15 minutes) are also considered.
- Traffic quality during these one-hour intervals is classified into six “levels of service” (LOS) which are denoted by the letters A (free flow traffic) through F (congested), a standard that has since adapted for other contexts, such as airport service quality assessment. The LOS concept as it is currently used is strictly bound to a short interval evaluation period (e.g., 1 hour).

- LOS classifications are based on one or more “measure of effectiveness” (MOE), such as average travel velocity. The MOEs incorporate the decisive aspects of traffic quality. An MOE should usually be an expression of trip time or trip delay (May 1998). The definition of those MOE values that determine the thresholds between successive LOS is based on agreement among experts. Usually there is no objective way to determine the threshold MOE values used to define a particular LOS. A more rational manner of derivation would be desirable, especially to discriminate between the higher LOS like D (sufficient) to E (capacity) to F (oversaturation).

There may be other aspects of the traditional approach for highway traffic quality assessment methods that should be re-evaluated. This paper focuses on those characteristics mentioned and presents approaches that may be better adapted to the demands faced in assessing future development.

Future development may be characterized by only a few aspects, including:

- In most countries, the ability to enhance the highway and street infrastructures is quite limited by financial and environmental restrictions. Consequently, use of the existing structures needs to be as intensive as possible.
- In most countries of the world an increase in road transportation demand is expected under near-term future conditions.
- These developments are likely to oversaturate the highway infrastructure, which has already occurred to a tremendous extent in the metropolitan areas of most countries, and is expected to spread over more sections of the highway network for longer periods of the day.

This latter aspect makes it necessary to treat LOS F, “oversaturation” with much more differentiation and to assess this undesired, although unavoidable, traffic condition with more detailed analytical methods. Some authors (Baumgaertner 1996; Cameron 1996) have proposed extending LOS categories beyond LOS F up to G, H, I, and J. However, these classifications would still be based on single-hour analysis. The NCHRP research project 3-55(4), under the leadership of Dolf May, and the TRB’s HCM committee (Committee A3A10) have also discussed splitting LOS F into several subregions, e.g., F1, F2, and F3 (May 1998). This approach was proposed to address the duration of congestion; however, no consensus could be achieved regarding the details of each classification. One substantial reason for the lack of consensus may be the feeling that LOS F considerations cannot be restricted to single-hour analysis because severe congestion on one element of the highway network at a time, *t*, produces consequences for subsequent time intervals and adjacent sections of the network. Thus, the degree of congestion is not only a function of the time period under consideration, but also a function of traffic demand during the following periods. For these reasons, the treatment of congestion in traffic performance analysis may need a completely different approach than the one-hour analysis.

2. CAPACITY AND EFFICIENCY

The traditional parameters to describe traffic flow performance on a section of a highway for a short-time interval (e.g., 1 hour or less) are:

- traffic volume, q (in veh/h or pcu/h), as a measure of traffic demand;
- capacity, c (in veh/h or pcu/h), as the maximum possible throughput of the highway facility;
- average travel velocity, V_T (in veh/h), on the section under investigation;
- traffic density, k, (in veh/km or pcu/km), which is obtained from

$$k = \frac{q}{V_T} \tag{1}$$

The classification of traffic flow performance into distinct LOS is then based preferably on V_T. In cases where V_T indicates little difference across the range of traffic conditions, from nearly empty roads up to close below capacity, which is the case on US freeways, k is also used as an MOE surrogate to define the LOS.

As stated previously, the exact values of the MOEs that denote the limits between LOS cannot be determined on an objective basis. Instead, they are based on traditions and agreements among experts. One focus of this paper is to emphasize that the most important definition, the limit between LOS D and E, should be better supported by a more objective framework.

Table 1 summarizes a concept that treats traffic flow analogous to mechanical systems. This could provide the basis for an improved approach.

TABLE 1 Comparison of Parameters from Mechanics and Traffic Flow

Mechanical system			Single vehicle trip			All vehicles on a road section		
Parameter	Symbol	Unit	Parameter	Symbol	Unit	Parameter	Symbol	Unit
force	P	N	vehicle	veh	veh	M 1)	M	veh
distance	S	m	distance	S	m	length 2)	S	km
time	t	s	time	t	s	duration 3)	T	h
velocity	v	m/s	velocity	v	m/s	velocity	V_T	km/h
work	$W = P \cdot S$	$N \cdot m$	work	$W = veh \cdot S$	$veh \cdot m$	traffic work	$W = M \cdot S$	$veh \cdot km$
power	$E = W/t$	$N \cdot m/s$	power	$E = W/t$	$veh \cdot m/s$	power (efficiency)	$E = W/T$	$veh \cdot km/h$

1) set of vehicles passing the section within duration T of the time interval.
2) length of the highway section under consideration.
3) duration of the time interval under consideration.

In applying the context of mechanical system analysis to traffic flow, we replace "force" by "vehicle" (or, in a wider context, transported unit) to see different quantities of traffic performance:

- velocity, v, which should be represented by the average travel velocity, $v = V_T$, on this section
- traffic power, which might be better called efficiency, E. With $M = q \cdot T$ and $S = V_T \cdot T$ we get:

$$E = q \cdot V_T \cdot T \qquad (2)$$

E is the number of (veh · km) which are produced by the highway section per unit of time. To obtain real values for E we must know the real speed-flow-relation ($V_T = F(q)$), which can only be based on empirical observations. The point with the maximum achievable q is still called the capacity c of the highway section.

Figure 1 shows E as a function of q for a freeway section in comparison to the speed-flow curve. The left figure applies for a basic three-lane freeway segment with a free flow speed of 120 km/h, based on Exhibit 23-3 of the HCM (2000). The right figure represents a freeway segment with three lanes in one direction with 20% of heavy vehicles, in accordance with the proposed speed-flow function for Germany (Chapter 3, HBS, 2000). We see that the efficiency reaches its maximum at a flow rate of nearly 0.9 times the capacity.

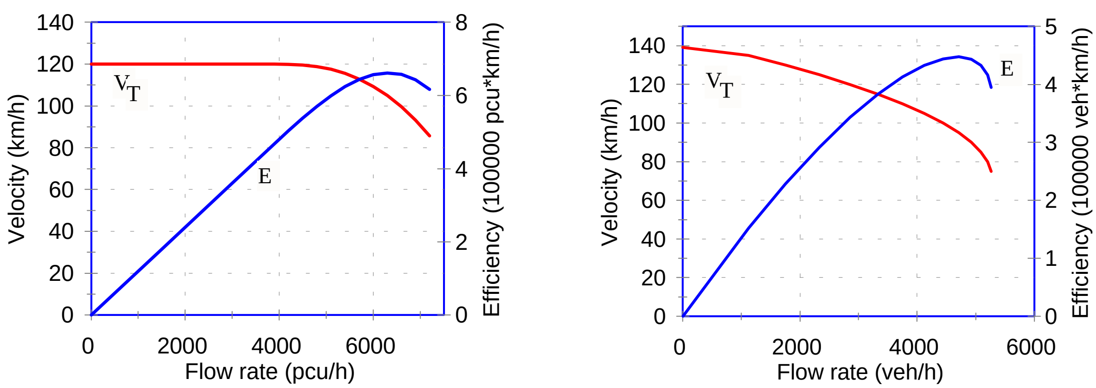

FIGURE 1 Efficiency as a function of flow rate compared to the speed-flow curve for freeways — examples.

It is a useful objective to maximize this term E ; for example, a toll freeway where tolls are collected according to miles traveled should not admit more vehicles than $q_{E\,=\,\max}$. Otherwise the freeway company's income would actually be reduced from the maximum possible. Also public operated freeways should maximize traffic performance in this sense.

These aspects make $q_{E\,=\,\max}$ an exceptional point on the q-axis. This point should not be exceeded by the traffic flowing on the freeway, even if it is possible. Above this point, the highway is not operating at its highest possible level even if the highway is still working. Thus, for purposes of highway planning or control, situations with $q > q_{E\,=\,\max}$ should be avoided. As illustrated, $q_{E\,=\,\max}$ is therefore a useful threshold to define the transition from LOS D to LOS E.
Figure 2 illustrates the same dependency for a two-lane rural highway. The left figure is

based on Equation 20-5 the HCM (2000), which uses a linear relationship for $V_T = F(q)$. For the example, a free flow speed of 90 km/h has been used with no overtaking prohibition. The right side figure applies for the German HBS function $V_T = F(q) = a - b \cdot \sqrt{q}$. With $a = 107$ and $b = 0.98$, this curve should describe flow on a straight and level two-lane highway with 10% of heavy vehicles. Note that in the left figure, the traffic volume is given as *passenger car units per hour* whereas on the right side the volume is indicated in *vehicles per hour*. In both cases the volume includes flow in both directions. Here we see that the efficiency is steadily increasing in such a way that it obtains its maximum at capacity. It can be concluded that a maximum of E with a traffic flow below capacity c is only obtained if the shape of the $V_T = F(q)$-curve is convex, which is usually the case for freeways but not for two-lane roads or single-lane segments.

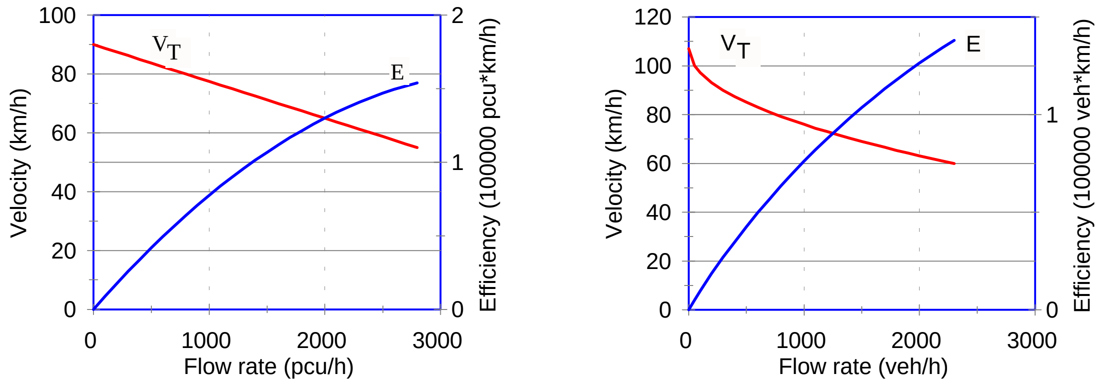

FIGURE 2 Efficiency as a function of flow rate compared to the speed-flow curve for two-lane rural highways — examples.

So far this aspect has only been determined for uninterrupted flow facilities. For intersection traffic performance analysis the term E, in analogy to Equation (2), could be defined as

$$E = q \cdot \frac{3600}{D} \cdot T \tag{3}$$

with

E	=	efficiency of intersection operation	(veh/s)
q	=	traffic demand	(veh/h)
T	=	duration of analysis period (usually $T = 1$ h)	(h)
D	=	total delay per vehicle = $F(q, c)$	(s)
c	=	capacity	(veh/h)

since at an intersection the length, *S*, of the observed section has a value of $S = 0$. Here *E* obtains the unit “veh/h” like a traffic volume, although it is a completely different term.

Figure 3 shows examples of the dependence of the term *E* on the flow rate compared to the relationship of average delay to flow rate for intersections. On the left we see an example for an unsignalized intersection minor movement with capacity of $c = 400$ veh/h, where the delay is calculated from Equation 17-38 of HCM (2000). The right hand figure indicates the same type of relation for a signalized intersection lane group with a capacity of $c = 600$ veh/h. We see that in both cases *E* is maximized at a flow rate of around 60% of the capacity *c*. This seems to be a rather general relation for intersection delay and efficiency.

It is hardly to imagine that for the case of an intersection $q_{E\ =\ \max}$. could become a point to determine the margin between LOS D and E because utilization of the facility does not seem to be sufficient from an economics point of view. Thus, for intersection analysis, this concept of efficiency — if it is to become of more interest — needs some more sophistication or adjustments.

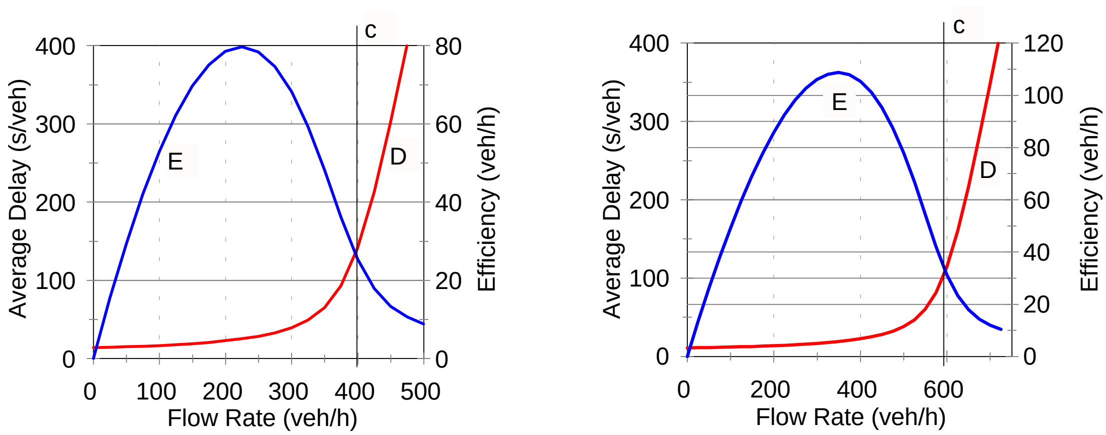

FIGURE 3 Efficiency as a function of flow rate compared to average delay for an intersection — examples.

This approach to efficiency maximization is also of some concern in railway engineering (Schwanhaeuser 2000). There the maximum of *E* is also obtained between 0.6 *c* and 0.9 *c*. The lower value applies for links where long-distance, high-speed trains, which are very sensitive to delays, dominate the system.

3. DETERMINATION OF DEMAND

Demand *q* (in veh/h) is a parameter of highest variability. The HCM (2000) explains this very clearly using a set of examples in Chapter 8. The demand flow shows typical patterns of variation over the weeks of the year, over the days of the week, and over the hours of the day. However, within all these variations it is not clear how to determine the decisive peak hour flow that is used to determine the required size of a highway facility. On the other hand, selecting an adequate demand somewhere between the highest flow that could ever occur and the average flow is a decision of highest importance. This selection is "a compromise between providing an adequate level of service for every (or almost every) hour of the year and economic efficiency" (HCM 2000, p. 8-8). If this is true, the selected peak hour flow for an easy-to-build country road must be different than the peak hour flow for a very expensive construction project, such as a tunnel, even though both have the same average daily traffic (ADT).

In this situation, the HCM proposes to use the *x*-th highest hour of the year as the peak hour traffic demand, that is the basis for all of the subsequent calculations and decisions. For *x*, values of 30 to 100 (i.e., the 30th to the 100th highest loaded hours of the year) are proposed. This leads to *K*-values of 0.091 (urbanized) to 0.1 (rural areas):

$$\text{DHV} = \text{AADT} * K \tag{4}$$

with

DHV = design hour volume (veh/h)
AADT = average annual daily traffic (veh/d)

After this first easy step, the current procedures generally ignore the fluctuation in demand. The user of the calculation-oriented chapters of the HCM usually is not aware of the weaknesses embedded into this *K*-factor. For example, the economic losses resulting from traffic congestion during the 30 (if $x = 30$) overloaded hours of the year (e.g., the cost of travel time) are not considered to be important for the subsequent calculations or decisions. Also another tendency of decision error could occur, if for example an additional lane might be necessary for a metropolitan freeway to comply with the 30th hour demand, but would not be required for the 200th hour, then the financial investment might not be justified. The current practice, however, does not provide easy access to any database on which a real economic assessment could be founded.

To address this concern, it is desirable to evaluate traffic flow performance for more than one design period. If, however, we continue to use the single design hour and, given that the computations will be done by computers in the future, there is no reason to strive for less than performing a whole-year analysis (WYA) that addresses capacity during each hour of the year.

To form the basis for these very comprehensive calculations, it is necessary to develop a realistic demand pattern over the whole year. This can only be based on empirical data. For example, in Germany a system of continuous counting facilities is distributed over the federal and state highway network. This system was started in the 1970s and now includes 1,200 sites that are evaluated year round. The data are stored in a central computer. In addition to this federal counting system, there are innumerable state- and city-owned counting sites. Private telephone companies also have recently installed thousands of sites where private data collection equipment is operating to provide customers with current traffic information (Schnoerr 2000).

Using this vast data base, the German Federal Highway Agency (BASt) has found that patterns over time, i.e., for a whole year, can be very well described by typical and standardized patterns. (Heidemann and Wimber 1982; Laffont et al. 1999). Heidemann and Wimber have defined the following sets of patterns:

- 6 patterns over the year (A through F; Figure 4)
- 6 patterns over one week (A through F)
- 6 patterns over one day (A through F) for each day of the week (Figure 5)

The patterns for the year, the week, and each day of the week could be combined with one another. Based on the continuous counts, the types of pattern that apply for each individual highway are known for the whole federal network and most of the state highway network (also classified by both directions). Moreover, in practice it is easy, based on local experience, to classify a road or a major urban street into the typical patterns. In addition, special types of daily traffic flow patterns for urban streets have been developed by Schmidt (1996).

Using this information, it is easy to generate an artificial, but rather reliable, traffic demand pattern HV(t) for each hour t (with $1 \leq t \leq 8760$) over the whole year. Thus, using common traffic engineering methods, the traffic performance for the highway facility under consideration during each hour of the year could be predicted. From these results, the travel times for all road users can be summed up over the whole year. Then, on a yearly basis this sum can be compared with the costs of construction and operation of highway facilities, which are also generally calculated on a yearly basis for cost-benefit analyses.

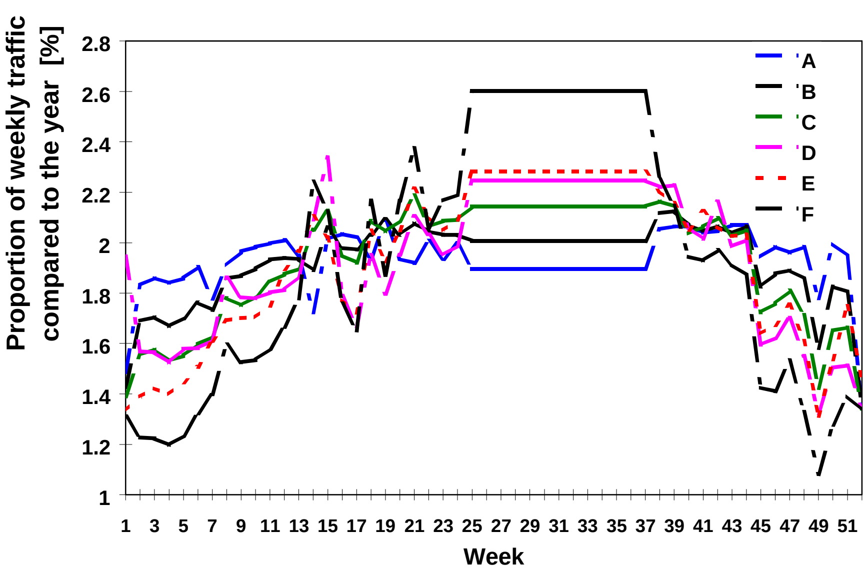

FIGURE 4 Typical patterns over time for one year (Laffont et al., 1999).

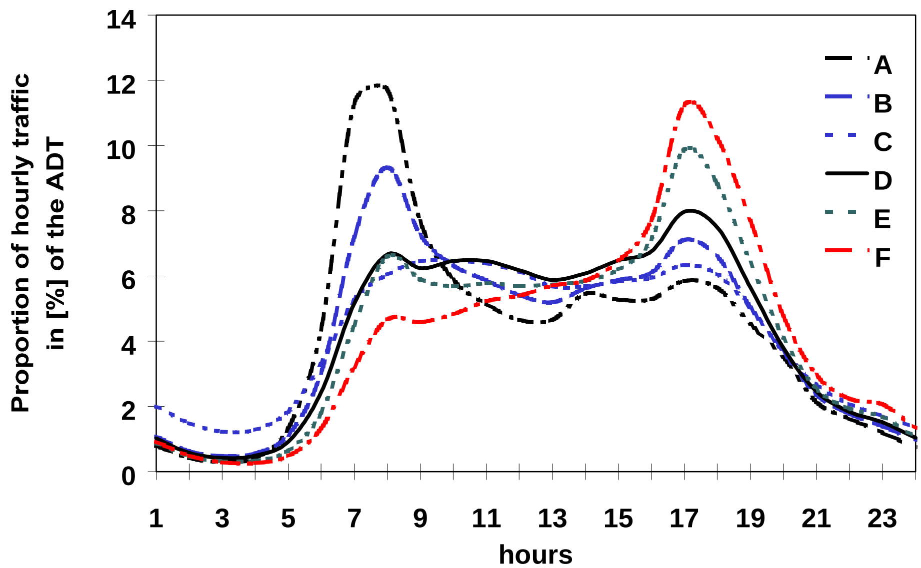

FIGURE 5 Typical patterns over time for a Monday (Laffont et al., 1999).

Another complication that can be added to the problem is that the real traffic demand does not exactly follow this deterministic hourly pattern created from standardized curves. Around this expected deterministic pattern there is an additional fluctuation, which could be described by some random components. Exhibit 8 - 7 in HCM 2000 gives a few examples for this. This random fluctuation is proposed to be described by a random variable ε with expectation μ and standard variation σ, the nature of which still needs some investigation. It could either be treated as additive or multiplicative. Some evidence argues towards an additive use of ε, which implies that during periods of low demand the fluctuation is relatively larger than during peak periods. The average μ of the random term, with an additive use of ε , is assumed to be $\mu = 0$ and $RHV(t) = HV(t) + \varepsilon$ must always be ≥ 0. For practical use it desirable that σ is constant. But also a σ depending on the demand q would not cause too severe problems. With the information currently available, the σ value must still be estimated based on local experience. The implication of this random demand component ε leads us to a Monte-Carlo-type simulation to evaluate the expected traffic performance. This means that fictitious traffic demand patterns over several years (e.g., $n = 10$ or even 100 years) are generated from the patterns shown in Figures 4 and 5 with the addition of the random term ε, which is generated for each hour by a random generator. Using traffic engineering methods, accumulated travel times are calculated for the whole simulated period. Division by n reveals the average accumulated travel time per year, which can be assessed by money equivalents (e.g., in Germany around \$3.50 for one car-hour to around \$60 for one bus-hour).

4. RANDOM AND TIME-DEPENDENT CHARACTER OF CAPACITY

The capacity of a highway facility is not a constant value, a fact which is also emphasized in Chapter 2 of the HCM 2000. Specifically, the capacity of a highway facility can vary under two aspects:

- Sysematically: Determined by objective influences such as daylight/darkness, weather, driver population and motivation, and other time-dependent aspects, which are systematically related to the various hours of the year. Because we know something about these dependencies (Ponzlet 1996), these effects could also be included in the analysis.
- Random fluctuation.

The latter is an aspect of special importance for uninterrupted flow facilities such as a freeways because, according to many of the more recent approaches from traffic flow theory, the point in flow volume where traffic flow could suddenly collapse down to congestion has many aspects of randomness. This random character of capacity is meanwhile emphasized by many researchers (Minderhoud et al. 1996).

If, however, capacity has a random component, also under consistent demand patterns the traffic performance could vary considerably from day to day if demand is close to average capacity. This aspect can frequently be observed in reality on metropolitan freeways.

As a consequence, the variability of capacities can be included into the whole year simulation if the regularities of randomness, like the type of distribution function for capacities as well as their parameters, are better known. More work is needed to characterize this variability; however, reasonable assumptions could be useful for initial studies and applications.

5. USE AND EXTENSION OF THE CONCEPT OF WHOLE YEAR ANALYSIS (WYA)

Planning and design requires selecting among several alternatives. Therefore, the whole year evaluation described above would need to be made for each of the design variants. Then, by comparison with the costs of construction, maintenance, and operation for each specific variant, it can be determined if the construction of a specific variant is justified and which variant provides the best cost/benefit ratio.

Some analysts may argue that this method to assess of traffic performance is too elaborate; however, with modern computer capabilities this way of calculation is not a real problem, and it could be done on a standard PC in very short time. Therefore, it is only a question of providing the right software to bring this capability (to compare the real benefit of a new or improved highway facility with the costs) onto the desk of the project engineer.

In Germany an intermediate procedure for a whole year analysis has been standardized for many years. The second version of this is the EWS (1997). Here, instead of a complete sequence of demands, three typical levels of demand are analyzed. Also this analysis can only be performed by computer. Thus, there is no reason to do the analysis without expanding calculations to each of the 8,760 hours of the year.

Other dimensions that may complicate the analysis include:

- Oversaturation at a bottleneck, such as a bridge or a tunnel or an important intersection within a highway system, could impede traffic flow in the whole network. In this case, the dynamics of route choice and, moreover, of trip generation and attraction in the whole area might be influenced by the capacity of a single point or section. Then the impacts of capacity should be evaluated on a network-wide basis. Of course, this type of analysis frequently is already done based on the traditional transportation planning tools or based on simulations. Currently, however, this is mainly done with typical one-hour traffic demands. Also, in the future, these network-wide performance investigations could be extended into a whole year analysis. Again, the possibilities for more complex traffic performance determinations are mainly a question of standardized software tools.

- Besides the value of time, other impacts of road traffic should be considered in such complex investigations, including environmental impacts such as fuel consumption and emissions. This extension of the analysis would allow the traffic engineer to improve his understanding of the problem and how his or her decisions affect ecology, resource consumption, or environmental quality.

6. EXAMPLES FOR APPLICATION

Two projects testing the extended capacity and performance analysis described above have recently been done in Germany. The first concerns a long tunnel of about 20 km. Recently, a set of studies were performed for a tunnel or a bridge connecting Germany (island of Fehmarn) directly to Denmark (island of Lolland) crossing the Baltic Sea over a length of 20 km. The future traffic demand (measured in ADT) can only be estimated with a high degree of uncertainty. It is also expected that high peaks in demand will only occur on summer holiday weekends. Under this scenario, the basic question was: Must a tunnel have four lanes or is a 2-lane facility with one additional emergency lane (in the center between the two directional lanes) sufficient? A second question was: How sensitive is the answer related to the reliability of the predicted ADT ?

For the analysis (Brilon and Lemke 1997) two hypothetical traffic demand patterns were estimated over the whole year based on experiences with current traffic flow patterns between Germany and Denmark (e.g., on the existing mainland freeway — case 1; and with ferry transportation at the location of the planned tunnel — case 2). Using these demand patterns, combined with experience regarding speed-flow relations for tunnels (Lemke 2000; Brilon and Lemke 2000), the travel times for all hours of the year could be estimated. For the analysis incidents (such as car breakdowns) and accidents were of highest importance. They were simulated based on data regarding how frequently they occur in tunnels. The duration of each breakdown as well as the degree of capacity reductions caused by these events were modeled and compared to documented events. Congestion and traffic spillback caused by accidents and incidents were modeled using the Lighthill-Witham theory. The calculations were repeated for various AADT values.

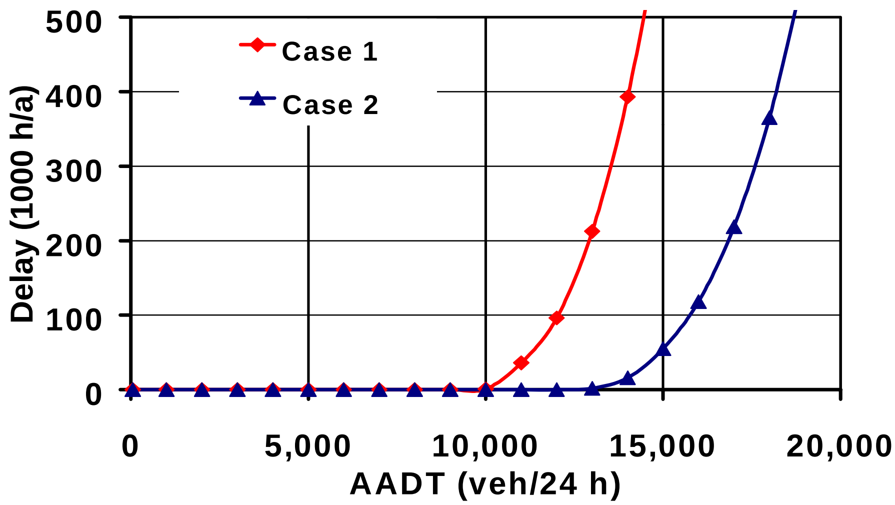

FIGURE 6 Sum of all delays during the year, depending on the AADT, for the 2-lane Fehmarn-Belt Tunnel.

The basic findings from this study are illustrated in Figure 6. It shows that the sum of all delays during the year depends on the AADT. For case 2 with an AADT up to 15,000 veh/d, no significant delays are caused by additional traffic. Therefore, up to this demand level, the decision regarding the number of lanes is not very sensitive to errors in demand predictions. However, above this margin a steep increase in the sum of all delays is caused by even slightly more traffic in the 2-lane tunnel. This steep increase is mainly caused by delays associated with incidents and accidents. This result underlines the importance of considering incidents during highway planning decisions. The difference between the two flow patterns over the year underlines that the kind of flow pattern has a significant impact on design decisions.

The other example of applying for the new analysis concept also involves tunnels. The previous German guideline for determining freeway tunnel cross sections (BMV 1985) had to be replaced using more current information. To accomplish this, a rather comprehensive investigation was initiated by the German Federal DOT (Brilon and Lemke 1999). Again, one combination was selected from the set of standardized demand patterns over time. This demand pattern was regarded as typical for freeways under heavy traffic. The pattern was compared with speed-flow curves obtained from studies in several tunnels. In this case, a Monte-Carlo-type simulation for several years was not performed. Instead, the delay consequences for an accident and for an incident during each hour of the year were evaluated. These delays, multiplied by the probability of incident occurrence, then were added to the usual travel time. These calculations have been made for different tunnel section lengths, gradients, and volumes of heavy vehicles both for 2-lane and 3-lane (per direction) tunnels. One set of calculations covered tunnels with hard shoulders. The other addressed tunnels without any emergency lane. Here it was clear that the occurrence of accidents and incidents caused the most significant difference in travel time consumption between these two alternatives. The differences in travel time costs (including also the costs for vehicle operation, like fuel consumption) for a two-lane (per direction) tunnel can be obtained from Figure 7. All of these costs are mainly caused by delays due to incidents and accidents. Here it becomes obvious that above an AADT of 70,000 veh/d the lack of a hard shoulder causes significant delays and related economic losses if they are accumulated over the whole year. Below an AADT of 50,000 veh/d, the construction of a hard shoulder does not significantly reduce delays.

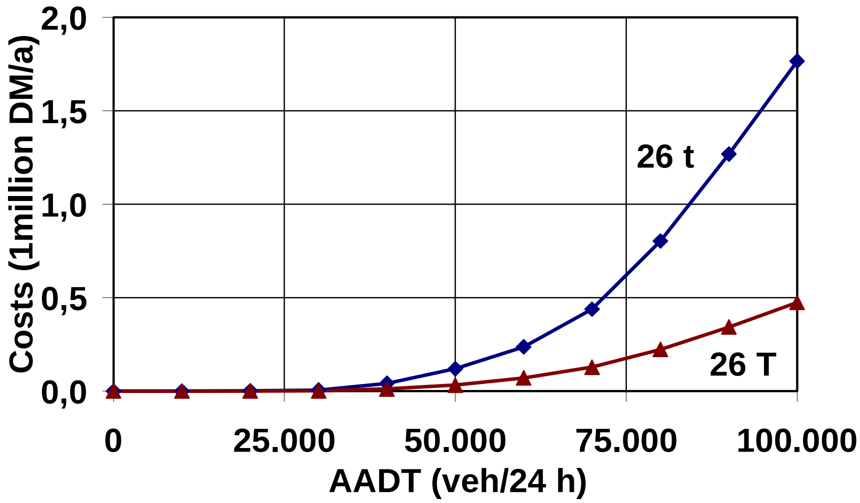

FIGURE 7 Costs of travel time plus costs of vehicle operation (sum per year in German Marks) for delays in a two-lane freeway tunnel without a hard shoulder (26t) and in a two-lane (per direction) tunnel with an emergency lane (26T); (no gradients, length of tunnel: 2000 m).

Accident cost reductions stemming from the presence of a hard shoulder were estimated for the complete project (Brilon and Lemke 1999). In this way, the whole benefit (travel time and safety) could be compared with the additional cost of construction, maintenance, and operation associated with a hard shoulder. For this comparison the costs of tunnel construction, depending on the type of structure constructed and the kind of rock, soil, or water surrounding the tunnel, were estimated based on another comprehensive investigation.

The result of this effort was the formation of an easily applicable procedure by which a useful and appropriate freeway tunnel cross section can be defined at an early stage of tunnel planning (Brilon and Lemke 1999). This procedure has been officially introduced by the German Federal DOT in 2000.

7. RELATIONS TO THE LOS CONCEPT

The results from the whole-year analysis (WYA) do not directly compare with LOS evaluations, which only cover traffic performance during one rather arbitrarily defined peak hour. WYA does not replace peak-hour analysis completely; instead WYA produces a more comprehensive measure of traffic flow performance, which enables a real cost-benefit comparison for highway construction and traffic control investments. It is a more reasonable tool for planning decisions than hourly based evaluations. It might be that, in addition to peak-hour LOS, performance levels based on WYA also will be defined at some later date.

WYA is especially valuable in providing a more rational evaluation of oversaturation conditions. When based on an hourly evaluation, they are usually classified as LOS F without any further differentiation. However, oversaturation is becoming more and more common during peak hours on most metropolitan highway networks. From that experience, we have learned that even under oversaturated conditions, a facility can still provide different degrees of traffic performance, characterized by such elements as lengths of queues, maximum delays, or duration of congestion or more comprehensively characterized by the sum of all lost times. These different levels of traffic performance under congested conditions should also be addressed by engineers during traffic planning and design. To accomplish this, we will first need measures to quantify the different degrees of traffic quality under congestion. The WYA could provide one reasonable approach to this problem.

8. CONCLUSIONS

The traditional methods to evaluate highway traffic performance based on the LOS concept could be improved at several points. One such aspect is the more or less arbitrary determination of thresholds between subsequent LOS. Here the concept of efficiency maximization might provide a new approach, especially for the margin between LOS D and E. At this point, however, the concept needs more refinement and practical tests.

Another aspect is the limited capability of the current concept in its ability to describe differences of traffic quality within the LOS F classification. Moreover, the current concept for the determining peak-hour demands does not allow the assessment of an economic trade-off between traffic quality and costs. Here the whole-year analysis could provide an important foundation on which to base design decisions. Current knowledge about typical traffic demand patterns and increasing computer power should simplify the use of this tool on a regular basis. This basic idea needs a lot more formulation in detail, tests for practicability, and standardization if the concept proves to be a useful instrument. Two tunnel-related studies of the whole-year analysis indicate that delays resulting from incidents and accidents are the reason for much more of delay then the speed-volume relation that commonly forms the basis for traffic engineering considerations.

The considerations described here are rather technically oriented. Beyond traffic engineering, however, there are significant and substantial future demands that should be observed, developed, and incorporated into traffic engineering methodology and into technical guideline procedures. The first and most important aspect is the demand for a sustainable development, which is becoming a central objective of planning policies throughout the world (UNCED 1993). The need for sustainable development concerns all aspects of human activities. Among those, motor vehicle traffic on highways plays a central role. Thus, there is a substantial need to integrate traffic flow performance indicators that address sustainable development objectives into the measures of effectiveness and thus into the assessment of traffic quality. This is also a challenge for the further development of the HCM, which is the most important traffic planning and design document worldwide.

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