International Journal of Research
Available at
https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 17
December 2017

A Review on New Design Load Concept for Highway Infrastructures

Amit Kumar
Assistant Professor Department of Civil Engineering UIET, MDU, Rohtak (HR)

Abstract: *This paper proposes a design load concept that treats capacity and traffic flow as random variables. This contrasts with the n^{th} hourly volume concept which neglects the highest traffic volumes, which produce a disproportionate share of the social or generalized costs of any facility. It will be shown that the traffic flow is normally distributed within time windows, but varies in the standard deviation depending on the volume to capacity ratio. A new definition of capacity is given and estimated for an example. The method estimates the probabilities of traffic flow being larger than the capacity for any given scenario. This reserve capacity is linked to breakdown probabilities, queue lengths and therefore generalized costs of facility use. These results could easily be integrated into a cost benefit analysis, which systematically focuses on the most expensive situations.*

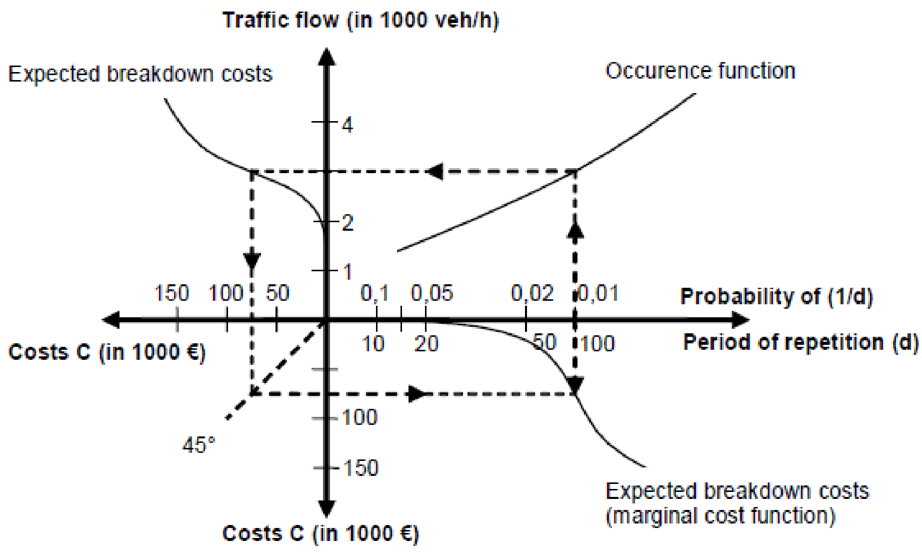
Keywords: Design Concept, Highway Infrastructure, PLM, Reserve Capacity, Generalized Costs.

Introduction:

Highway design is commonly based on the idea, that a particular percentile of annual distribution of hourly volumes, defines the economically relevant load. The question, if a design providing for a fixed percentile of the hourly volumes of a year is economic, has never been answered in detail. This paper provides initial ideas of how one might be able to address this issue and obtain a new, consistent design concept for road infrastructures. While the paper will focus on motorways, it aims to be general and applicable to any type of road facility. Central to any design concept is the conceptual separation of traffic load and facility capacity. Existing approaches often do not explicitly keep these two effects apart. Generally speaking, the capacity has been identified as the maximum expected traffic flow that can be achieved repeatedly. In this context the single capacity gives no information about the frequency or probability that the flow can reach the expected value under a sufficient demand. A modern design concept has to take this into account and be includable into a cost benefit framework to assess the alternatives to improve an infrastructure in a proper way. It is therefore desirable to use a method that links the estimated demand with the resulting generalized costs for a given infrastructure design.

Review of Literature:

It is known that the hours with the highest traffic volumes produce the largest contributions to the total generalized costs of a facility. The scenario concept proposed below is adapted from hydraulic engineering where the costs of a certain breakdown event (e. g. flooding due to high volumes) are estimated and valued. By combining the period of repetition with the expected costs that a breakdown will produce at a certain flow, one can define a marginal cost function which is needed for a cost benefit analysis. In this context a scenario is an event that will result in increased generalized costs, and usually these events are relatively easy to identify from an engineering perspective. An example of a scenario with the duration of one hour is a certain traffic volume during the peak hours of a common weekday that is expected to occur e.g. 200 times a year. It could be assumed that this scenario group has a considerable share in the total generalized costs. Another scenario could be a lower traffic volume that prevails 500 times a year for one hour, resulting in lower generalized costs for the single event but having a higher frequency. A benefit of the scenario concept emerges from the increasing accuracy of a cost-benefit analysis with the preciseness and level of disaggregation of the defined scenarios. For application purposes not all possible scenarios have to be regarded for a cost-benefit analysis. With respect to transport engineering, the scenario concept focuses on hours with high frequencies of repetition and high traffic volumes, for which the costs start to, grow non-linearly and which have substantial spatial spill-over effects. Boundaries are defined in this context to restrict the minimum and maximum traffic flows considered, as traffic flows below the lower limit produce (nearly) no congestion costs and the upper limit excludes extremely rare events. The boundaries have to be properly defined that the excluded scenarios, have a negligible influence on the total costs. Externalities and safety costs are in the first instance assumed to vary directly with the volume, but defined scenarios can also cover these effects.



General design of cost function based on occurrence function and breakdown function

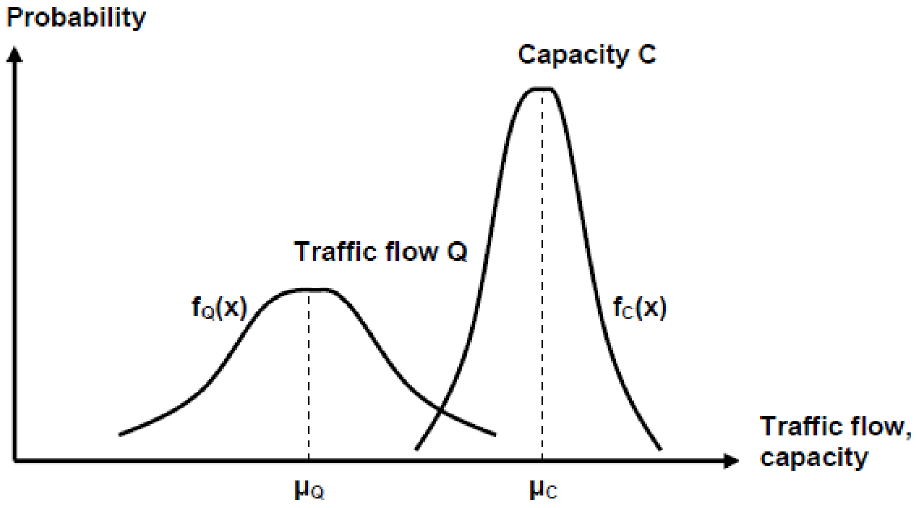
Generally speaking, the total yearly costs of the facility must be known. That means, for each event the resulting costs need to be provided. As the hourly volume distribution is known, the frequency of each demand level is known and can be described by an occurrence function that maps the number of occurrences per year to traffic flows. In Figure the occurrence function is embedded into a monogram of the cost function of an infrastructure element. In this a breakdown describes a major increase in travel time, so the function of the breakdown costs returns the expected generalized marginal costs for a given flow. These costs base on the willingness to pay for a reduction in travel time and for a reduction in the variation of travel time, having a share in the total generalized costs. Combining the occurrence function and the function of breakdown costs leads to the marginal cost function. It serves as the basis for a cost benefit analysis as it maps the probability of occurrence to the resulting costs of the scenarios considered. With the risk of a scenario being the product of the probability of occurrence and the generalized costs of the event the expected yearly marginal costs are computed by integrating over the risk of all regarded scenarios. First new results on breakdown probabilities are presented to support the idea of capacity as a random variable, which is matched to the idea that long intervals of a flow can be thought of a set of shorter intervals with the mean of the long intervals but a predictable standard deviation and distribution. These two concepts are combined through the idea of a reserve capacity, which is then used to estimate the capacity distribution. The reserve capacity is the basis of an initial cost estimate associated with a particular load situation.

Breakdown Probability:

Traditionally one assumes that a breakdown occurs when the flow regime changes from the upper branch (under saturated flow) to the lower one (over saturated flow) of the fundamental diagram. Alternatively, one could define a breakdown as an event, when the flow is deteriorating by a defined speed reduction; say 15 km/h before and after the event. The probabilities of such capacity violations have been shown recently to grow with traffic flow. Capacity defined through capacity violations and mainly perceived through speed reduction has therefore not a fixed value, but is better described as random variable with a certain set of moments (mean, variance, skew etc.) There are different methods to calculate the breakdown probability for a given traffic volume on a highway. A breakdown is usually indicated by a speed drop and the probability of the event is associated with the traffic volume before it occurs. In the literature we can find general approaches analyze the breakdown probability for classes of traffic volumes whereas use the product limit method (PLM) to estimate the survival times of flow regimes. They define that a breakdown has occurred when the mean speed of all lanes drops for five minutes below a critical speed 70 km/h that they employ to separate free flow from congested traffic. The traffic flow during the one minute interval before such a breakdown corresponds to the maximum traffic flow that can be handled at the moment under the given conditions. In contrast to apply the product limit method (PLM) to identify the breakdown probabilities (speed drop below 90 km/h) of motorways. This method is based on the theoretical concept of a hazard data analysis where the lifetimes are substituted by traffic flow. On the one hand, this method provides steadily increasing breakdown functions, but on the other hand, it is not completely clear whether this method can be applied here, since traffic flow is not characterized by a continuous increase during an episode in the free flow traffic flow regime. When estimating the probability distribution of breakdowns due to traffic volume from counting data, it is important that the counting station be located at the bottleneck of an infrastructure element. Doing this, one avoids measuring effects due to upstream or downstream congestion. The breakdown probability of the presented alternative method is calculated by defining capacity to be the 60-minute traffic flow before a breakdown occurs speed drop below 80 km/h in a following 5 minute interval. This method is compared with the methods of using 5 minute intervals and 80 km/h as breakdown speed. The breakdown probability is calculated by dividing the number of intervals marked as "before breakdown" by the total number of intervals in this class.

Reserve capacity of a road section:

In the following, the random variable of the capacity of an infrastructure element will be denoted as C with the probability density function $f_C(x)$ and the traffic flow as random variable Q with probability density function $f_Q(x)$.



Traffic flow and capacity as random variables

An infrastructure element fails to work properly (i. e. a breakdown occurs) if the traffic flow q exceeds the current capacity c (q and c denote realizations of the random variables Q and C). The capacity C and the traffic flow Q are defined such that both variables are statistically independent. In the structural reliability theory this case is called the fundamental case.

Structure of New Design Concept:

The proposed new design concept is based on a comparison of the generalized costs of two or more planning scenarios usually the status quo and a modification of the existing system. It integrates the elements discussed above in the following steps:

- Definition of capacity, as random variable Description of the distribution of demand, again as a random variable.
- Identification of possible critical scenarios.
- Estimation of frequency or probability of occurrence of scenarios employing the idea of a random reserve capacity (e. g. over one or 20 days, months, years).
- Cost calculation (calculation of queuing length) for each scenario.
- Total cost estimate calculated as the sum of the expected costs given by the product of the probability of occurrence and the costs of the event over all events.

In contrast to the concept of the nth hourly volume concept, which neglects the cost of the n highest traffic volumes, this concept takes all traffic volumes into account or, more generally all traffic scenarios. The intervals with the high traffic volumes are evaluated, as these volumes contribute the largest amount to the total generalized cost over each year.

Conclusion:

The design concept presented can be applied with little modification to most infrastructure elements. The general concept of reserve capacity is already shown in the unsignalised intersections. A coherent concept for all kinds of infrastructure elements is both a desirable goal and feasible. An advantage of the method in comparison shown in comparison to many existing concepts is its scalability in accuracy. The more detailed the demand and capacity estimations are, the more reliable are the results. In addition, in this paper the capacity is assumed to be normally distributed within a given time window. It has to be verified whether this assumption is true or if the error in this assumption is small enough, since a normally distributed variable simplifies the calculation. The method introduced here requires no redefinition of capacity in the general sense. In the Highway Capacity Manual and in the Swiss norm the capacity of an infrastructure element is defined as the largest traffic volume that is expected to pass a section within a given time interval under given road, traffic and operation conditions. Therefore, this definition is coherent with the definition needed for the design concept presented. However the capacity must be described not only by the expected value but additionally by its variance or, more generally by its distribution. A remaining task is the integration of the proportion of heavy vehicles into the measurement of capacity. As the percentage of heavy vehicles influences the behavior of the traffic flow and not actually the capacity, it is questionable if a reduction factor should be bound to the capacity or if this factor should rather be connected to the traffic flow. Here it was assumed that the traffic flow and the capacity are independent variables and that an influence of the traffic flow on the capacity is negligible. If this assumption is not true, a possible solution to this problem would be introduction of safety or reduction factors that are easy to implement into this concept and which will be a topic for the on-going research at ETH. To integrate this method into cost-benefit analysis, it is necessary to assess the additional travel times due to high demand/capacity situations and due to breakdowns and especially queuing. Consequently, it has to be evaluated whether a queuing model or some functions such as a modified BPR function could be developed, or if different methods need to be found. A simple solution would be estimate the average speed drops after a breakdown, combined with the average duration of the congested state. But more sophisticated methods may be necessary, as long as they do not complicate the application too much. A further area of work is the extension of this design concept to networks, as the effect of the joint distribution of breakdowns will need to be assessed in this case.

References:

[1] Shapiro, S. S. and M. B. Wilk (1965) An analysis of variance test for normality (complete samples), Biometrika, 52 (3 and 4) 591-611, Oxford University Press, London. Van Toorenburg, J. (1986) Praktijwaarden vorr de capaciteit, Rijkswaterstaat dienst Verkeerskunde, Rotterdam.

[2] Aerde, M. (1995) A single regime speed-flow-density relationship for freeways and arterials, Presented at the 74th TRB Annual Meeting, Paper No. 95080, Washington D.C.

[3] Minderhoud, M. M., H. Botma and P. H. L. Bovy (1996), An assessment of

roadway capacity estimation methods, Delft University of Technology, Delft.

[4] Vereinigung Schweizerischer Strassenfachleute (VSS) (1999) SN 640 018 Leistungsfahigkeit Verkehrsqualitat Belastbarkeit, VSS, Zurich.

[5] Okamura, H., S. Watanabe and T. Watanabe (2000) An empirical study on the capacity of bottlenecks on the basic suburban expressway sections in Japan, Transportation Research Board, Circular E-C018, 120-129, TRB, Washington D. C.

[6] Transportation Research Board (2000) Highway Capacity Manual (2000), National Research Council, Washington D. C.

[7] Bovy, P. H. L. (2001) Traffic flooding the Low Countries: How the Dutch cope with motorway congestion, Transport Reviews, 21 (1) 89-116, Taylor & Francis Group, London.

[8] Matt, R. L. and L. Elefteriadou (2001) Defining freeway capacity as function of breakdown probability, Transportation Research Record, 1776, 43-51, Washington.

[9] Gulvanessian, H., J. A. Calgaro und M. Holicky (2002) Designers guide to, Eurocode: basis of structural design, Thomas Telford Publishing, London.

[10] Bates, J., I. Black, J. Fearon, C. Gilliam and S. Porter (2002) Supply models for use in modelling the variability of journey times on the highway network, EFC, Strasbourg.

[11] Chen, C., A. Skabardonis and P. Varaiya (2003) Travel time reliability as a measure of service, Transportation Research Record, 1855, 74-79, Washington D. C.

[12] Axhausen, K. W., A. Konig, G. Abay, J. J. Bates and M. Bierlaire (2004) Swiss value of travel time savings, paper presented at the 2004 European Transport Conference, Strasbourg.

[13] Brilon, W., M. Regler and J. Geistefeldt (2005) Zufallscharakter der Kapazität von Autobahnen und praktische Konsequenzen Teil 2, Straßenverkehrstechnik, 49 (4) 195-201, Kirschbaum Verlag, Bonn.