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Editorial Open Access

The Stochastic Capacity of a Roadway: Is it the Answer for Better "Real-Time" Management of Freeway Operations?

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Editorial

Engineering design entails fulfilling a need in a cost-effective manner under the given constraints. If it is a structure that is being designed, the description of loads that the structure will have to hold needs to be estimated first. Based on this demand the engineer will then find the matching supply, which is the size of the components of the structure that can meet this demand. In simple terms, it is a demand-supply equilibration for which the engineer aims.

In theory, the design of roadway facilities proceeds in a similar manner. Given an existing or projected demand, measured in terms of number of vehicular trips per hour for example, the engineer needs to determine the required number of lanes of road. This matching of supply of transportation service with the demand for travel is based on the capacity of a lane of road. The capacity of a road segment is defined as the number of vehicles per hour that a lane of road can process. But how is the capacity of a roadway lane determined?

The Highway Capacity Manual (HCM) defines vehicle capacity of a road as, "the maximum number of vehicles that can pass a given point during a specified period under prevailing roadway, traffic, and control conditions" [1]. The HCM states further that prevailing roadway, traffic, and control conditions define capacity and any change in the prevailing conditions changes a facility's capacity.

From this definition it is clear that capacity of a roadway even for a fixed location is not constant. Consider a segment of a freeway as an example. The prevailing roadway conditions are the geometric and pavement conditions. Geometric conditions can be considered to remain unchanged; the pavement can deteriorate over time, but in the short term it can also considered to be unchanging. Control conditions on a freeway also remain constant in most cases. Traffic conditions, on the other hand, are variable, since they depend on the mix of vehicle and driver types. So the capacity of a freeway segment changes continuously. On other road types, the variation in capacity can be even more pronounced because of the uncontrolled access to the road.

So how can an engineer determine the number of lanes given the demand for a planned road or a future demand for an existing road? What should the supply for transportation service be to meet the existing or projected demand? There is no straightforward answer to this question. The HCM does provide "base capacity" figures that are dependent on the chosen free-flow speed. Free-flow speed is related to the design speed, a parameter that the designer chooses before designing a road.

The HCM provides guidelines to adjust the demand to prevailing traffic conditions; guidelines are also provided to adjust the free-flow speed to prevailing roadway conditions. The adjusted demand flow rate and the free-flow speed are used to compute another parameter of traffic flow, the density of vehicles on a unit length of road. The quality of flow is rated based on the computed density. Even though the capacity of the road segment is not computed directly, the methodology just described can be used to ascertain whether the demand for travel can be satisfied with the existing or planned supply of transportation service.

For strategic planning purposes the indirect method of judging the adequacy of a road to satisfy the demand by computing the density obviates the need to estimate the capacity of a road. For tactical and operational analysis however, knowledge of the capacity of a road segment for a given period of time is essential. For example, traffic engineers need to know the number of vehicles to allow onto a freeway from an on-ramp during peak flow conditions. Knowledge about the capacity of the freeway where the on-ramp volumes will enter will be beneficial to traffic engineers. If the volume on the freeway is approaching its capacity, traffic engineers will want to reduce the rate of flow entering from on-ramps through ramp metering. When flows approach capacity minor perturbations in the traffic stream can lead to a breakdown that can persist for hours after the event. With roads in urban areas being increasingly congested traffic engineers should have information about critical parameters such as road capacity to be able to perform their jobs adequately.

A step towards finding a better definition of roadway capacity is based on probabilistic analysis. A probability model that has been recommended by some researches is to assume that the stochastic capacity of a roadway follows a Weibull distribution [2-4]. The Weibull distribution function can be defined by two parameters, the shape and the scale parameters. According to Aghadashi [4], the Weibull parameters are functions of the geometry of the road. Brilon et al. [2], on the other hand, state that the scale parameter is dependent on the geometric, traffic, and control conditions of the road; specific factors affecting the shape parameter are not listed. Both groups of researchers cited above, estimated values of the Weibull parameters from observed traffic flow data for the segments of the roads that they studied.

The ability to define the distribution of stochastic capacity of a roadway is an improvement over the previous practice of assuming a base capacity that was dependent on the free-flow speed. However, the major flaw in the new method is that the estimated capacity does not truly reflect the capacity existing at a given time. The shape and the scale parameters are estimated for given section of the road for traffic conditions prevailing at the time of data collection; they do not reflect the conditions prevailing at or shortly before the time when traffic engineers have to decide about control measures to apply to ensure smooth operations of the freeway under their purview. Traffic

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conditions change continuously; control measures should be able to respond to such changes in near real-time.

One solution to this problem is to predict the traffic state based on assessments of current and past measurements. That can be done by forecasting the state of traffic volume using a Kalman filter that is employed in a dynamic state-space model framework where parameters of the state are permitted to change with time [5]. With the near real-time forecasting of the traffic state possible with this scheme, control measures can be adjusted to ensure optimal operations of the freeway. So to answer the question posed in the title, defining the distribution of the stochastic capacity of a roadway may be beneficial for a theoretical understanding of traffic flow, but it does not lead to better management of real-time traffic operations on a freeway.

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