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SAFETY LEVEL OF SERVICE MEASURES OF EFFECTIVENESS AND THE HIGHWAY CAPACITY MANUAL: A CASE STUDY

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Abstract: *Highway Capacity Manual - HCM, is the primary tool used for analysis and design of highway (rural and urban) facilities. Their recommendations and decisions are made based primarily on operational measures. Studding the HCM methodologies and procedures we concluded there currently exist no tools to help the traffic practitioner determine the likely impact on safety of operational, road and terrain changes. Namely, there is no traffic safety integration into the Manual.*

Our primary purpose is to focus on issues associated with the development of a comprehensive safety-based methodology, making an overview of the background and currently used safety Level Of Service-LOS models and methodologies, and secondly to present a case study approach for M-5 two lane two way highway in the Republic of Macedonia. Here the accident frequency as a proposed "Measure Of Effectiveness-MOE" is emphasized.

KEY WORDS: TRAFFIC SAFETY, LEVEL OF SERVICE METHODOLOGY, TWO-LANE TWO-WAY HIGHWAYS, HIGHWAY CAPACITY MANUAL

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1. INTRODUCTION

The original definition of Level Of Service-LOS, was given in the 1965 Highway Capacity Manual - HCM and is as follows: Level of service is a qualitative measure of the effect of a number of factors, which include speed and travel time, traffic interruptions, freedom to maneuver, safety, driving comfort and convenience, and operating costs. [10]

As present, HCM established the concept of LOS for measuring the quality of the driver's experience on a highway facility. It uses LOS, the commonly accepted measure of effectiveness for highway analyses, to translate the numerical results of traffic operation analyses into letter grades, which are more readily understandable by the general public. The HCM is a collection of facts and procedures that allows the analyst to determine relationships among physical characteristics, operational characteristics and LOS. But, current LOS evaluation criteria do not include safety measures, in other words safety is not included in the manual, contrary on the original definition where safety is explicitly names as one of the qualitative measures of LOS. Lacking convenient evaluation tools, limits designers ability to detect potential safety problems in design, to select safety cost-effective design parameters, compare the safety of design alternatives, or to optimize the safety of particular designs.

2. BACKGROUND AND CURRENTLY USED SAFETY LOS MODELS

There has been a wealth of research into accident prediction modeling and the place of safety in assessing operational performance of highways. Earlier sources include a summary of research findings prepared by Oppenlander and Dawson in 1970, [3]. Cirillo et al., in 1969 describe six multiple regression models to predict accident frequencies and accident severity distributions on ramps. Traffic volumes were found to be a key variable in predicting accidents. Geometric features of ramps considered in ramp length, speed-change, lane length, presence of curvature, maximum curvature on ramp, ramp grade, right and left shoulder widths, minimum stopping sight distance, change lane design speeds, [4]. Several USA and European studies described by Lamm et al., in 1999 have examined the relationships of grade, volume, and sight distance with accidents on a variety of facility types, [5]. Zegeer et al., in 1991 developed accident prediction models for curves on two-lane roads for the Federal Highway Administration using databases of 10.000 non-isolated curves in Washington State and over 3.000 isolated curves from several other states, [6]. More recently, Vogt and Bared (1998) built accident models for segments of two lane rural roads, [7]. A model developed by Turner (1984) from over 2000 bridges in Texas predicts accident rates at bridges on two lane roads based on volumes and geometrics, [8]. In a 1997 study, funded by the Federal Highway Administration, Bauer et al., developed statistical models for defining the relationship between traffic accidents and highway geometric design elements, [9].

2.1. Safety Measures Of Effectiveness

Considering the references, a list of safety performance measure could be conducted. It will enable decision makers to assess the appropriate safety LOS for that case. Some of the safety indicators are listed below.

a) **Time-Headway:** Longer headways allow the driver more time to respond to the situations and to control the vehicle. They are thus associated with safer driving behavior.
b) **Speed:** Higher speed may increase the probability and severity of collisions (accidents).
c) **Acceleration:** Increased accelerations mean increased speed fluctuations which may increase the probability of rear-end accidents.
d) **Response Time:** Longer response times may result in reduced headways and could increase the probability of accidents.
e) **Lane changes**: More lane changes increases the probability of accidents.

2.2. Safety level of service measures of effectiveness and the HCM

The HCM procedures are closed-form, macroscopic, deterministic, and static analytical procedures that estimate capacity and performance measures to determine the level of service (e.g., density, speed, and delay). They are closed-form because they are not iterative. The practitioner inputs the data and the parameters and, after a sequence of analytical steps, the HCM procedures produce a single answer. Moreover, the HCM procedures are macroscopic (input and output deal with average performance during a 15-minute or a 1-hour analytical period), deterministic (any given set of inputs will always yield the same answer), and static (they predict average operating conditions over a fixed time period and do not deal with transitions in operations from one system state to another), [10]. As such, these tools do not provide any microscopic point of view on the vehicle movement. On the contrary, microscopic vehicle generation and movement is a primary key for analyzing the performance of the transportation facilities, and accidents analysis too. That's why the HCM procedures are limited in their ability to detect potential safety problems in design, select safety cost-effective design parameters, compare the safety of design alternatives, or to optimize the safety of particular designs.

Efforts toward integrating safety into the HCM have been made but are few and flawed. The studies described: Including of crash frequency and severity measures in their measures of safety but do not base models on real data; Provide some limited number of variables to be included in a safety measure, but provide no LOS measure; Make no attempt to (nor do they provide guidance for) combine the, sometimes conflicting, safety and operational LOS measures; Use the existing LOS delay boundaries and arbitrarily create new boundaries for the safety LOS measure.

3. SAFETY LOS MEASURE OF EFFECTIVENESS AT THE M-5 HIGHWAY AVERAGE AND SPECIFIC SECTION GRADE

A case study analysis estimates a Safety Measure Of Effectiveness-SMOE along the M5 Highway sections in the Republic of Macedonia. M5 Highway is two-way two-lane rural highway with Annual Average Daily Traffic - AADT = 4000 [veh/day], [2]. Each of the analyzed were 300 [m] long sections with average and specific geometric design elements, respectively (table 1, table 2).

Kind of terrain, geometric design elements and traffic conditions are addressed in the operational analysis of average road section and specific upgrades and downgrades.

Table 1: Geometric design elements for average two-way two-lane section under study

Geometric design element	*Symbol*	*Average conditions (value)*
Section Length	L [m]	300
Longitudinal Grade	UN [%]	1.00
Limited Speed (free flow conditions)	Vsl [km/h]	100.0
Lane Width	w [m]	3.25
Shoulder Width	w_s [m]	0.35
Terrain	-	level

Source: Field data, authors

Table 2: Geometric design elements for specific two-way two-lane section under study

Geometric design element	*Symbol*	*Specific conditions (value)*
Section Length	L [m]	300
Longitudinal Grade	UN [%]	8.00
Limited Speed (free flow conditions)	Vsl [km/h]	80.0
Lane Width	w [m]	3.00
Shoulder Width	w_s [m]	0.30
Terrain	-	rolling

Source: Field data, authors

As stated before, the accident frequency as Safety Measures Of Effectiveness-SMOE has been considered, and here expressed as follows:

$$AF = \frac{NOA}{[km]} \tag{1}$$

Where:
AF - Accident Frequency
NOA - Number Of Accidents
km - Kilometer

Based on the linear empirical model from Rahim F., Benekohal and Asma M.Hashmi [11], which is:

$$N_{2-l} = \frac{\{[A + B(AADT) \cdot C \cdot D] \cdot F_1 \cdot F_2 \cdot F_3 \cdot F_4\}}{1.609} \text{[annual accidents/km]} \tag{2}$$

here:
N_{2-l} - annual accidents per kilometer on two lane two way highway
A=1.362; B=0.000222; C=0.0862; D=0.0492 - model parameter [11]
F_1 - access control adjustment factor, (table 3)
F_2 - grade adjustment factor, (table 4)
F_3 - horizontal curve adjustment factor, (table 5)
F_4 - grade and horizontal curve adjustment factor, (table 6)

We have found the form of linear model based on field collected data, which shows:

- Accident frequency on the section under average geometric and traffic conditions is :

$$AF = \frac{NOA}{[km]} = 0{,}85 \text{ [annual accidents/km]} \tag{3}$$

• Accident frequency on the section under specific geometric and traffic conditions is as follow:

$$AF = \frac{NOA}{[km]} = 5{,}70 \text{ [annual accidents/km]} \quad (4)$$

Table 3: Access control adjustment factor

Highway access control	F_1
With control	1.00
Without control	1.12

Source: [11]

Table 4: Grade adjustment factor

Highway in	F_2
Level terrain	1.00
Rollingl terrain	1.38
Mountainous terrain	0.95

Source: [11]

Table 5: Horizontal curve adjustment factor

Highway with	F_3
Horizontal curve radii (R>400m)	1.00
Horizontal curve radii (R<400m)	1.67

Source: [11]

Table 6: Grade and horizontal curve adjustment factor

Highway with	F_4
Grade (UN<3%) Horizontal curve radii (R>400m)	1.00
Upgrade (UN>4%) Horizontal curve radii (R<400m)	1.69
Downgrade Horizontal curve radii (R<400m)	1.76

Source: [11]

Legend:

(horizontal hatching) The value of the adjustment factors for average geometric and traffic conditions

(vertical hatching) The value of the adjustment factors for specific geometric and traffic conditions

Source: Made by the authors

By comparing accident frequency values as a Safety Measure Of Effectiveness-SMOE for highway sections under study, distinctly difference could be stated. Variable is greater in a specific vs. average conditions, as well as compared with the default values [11]. Namely, at the highway section on level terrain, with access control, with grade UN < 3% and horizontal curve radii R>400m, safety level of service conditions are satisfactory. On the other side at the highway section on rolling terrain, with access control, with grade UN > 4% (UN=8%) and horizontal curve radii R<400m, safety level of service conditions are not satisfactory. By translating the results with the HCM level of service language, Safety Measure Of Effectiveness-SOME could be expressed with two later grades S-SATISFACTORY and NS-NOTSATISFACTORY. This measure is a qualitative LOS measure of the effect from a number of geometric and traffic factors on the two-lane two-way highway in the Republic of Macedonia.

4. CONCLUSION

Based on our purposes to focus on the issues associated with the development of a comprehensive safety-based methodology we had made an overview of the background and currently used safety LOS models and methodologies, as well as the presentation of a case study approach for M-5 two-lane two-way highway in the Republic of Macedonia. A case study approach shown in this work, represent the approximation of a real safety conditions on a rural two-lane M5 highway in average and specific geometric and traffic conditions. The accident frequency as a SMOE for the highway sections under study shows a great difference between the values in a specific vs. average conditions, and a difference in LOS satisfaction compared with the default values for two-lane two-way highways. Used model allows qualitative assessments of safety LOS using quantitative information. Finally, the state of the art analysis shows the majority of past researches. HCM and other existing methodologies and procedures shows efforts for developing but not an exactly developed tool. which could help the traffic practitioner to determine the likely impact on safety of road (terrain) and traffic changes. Namely, there is no traffic safety integration into the Manual. Since, traffic safety is a complex problem, proposed SMOE is just one from a dozen Safety and Level Of Service Measure Of Effectiveness. Consequently, there is a great issue for safety-based iterative, microscopic, stochastic, and dynamic analytical procedure or methodology development. The paper includes a discussion and hopes to evoke a deeper examination of the complexities in using simulation as a comprehensive tool for safety analysis.

REFERENCES

[1] Highway Capacity Manual, Transportation Research Board, Washington, D.C., 2000.

[2] Буневска, Ј., Функционално вреднување на вонградски патишта и градски сообраќајници: оперативна анализа на дволентен вонградски пат во просечни и специфични услови, Технички факултет Битола, Битола, 2005.

[3] Oppenlander, J.,C., Dawson, R., F.: Traffic Control and Roadway Elements-Their Relationship to Highway Safety. Highway Users Federation for Safety and Mobility, 1970.

[4] Cirillo, J.,A., et.al.: Analysis and modeling of relationships between accidents and the geometric and traffic characteristics of the interstate system. FHWA, August 1969.

[5] Lamm, R., Psarianos, B., Mailaender, T.: Highway Design and Traffic Safety Engineering Handbook, McGraw-Hill,1999.

[6] Zegeer. C., et al.: Cost-Effective Geometric Improvements for Safety Upgrading of Horizontal Curves, Federal Highway Administration, 1991.

[7] Vogt, A., Bared, J.: Accident Models for Two-Lane Rural Segments and Intersections. Transportation Research Record 1635, pp.18–29., 1998.

[8] Turner, D.,S.: Prediction of Bridge Accident Rates, Journal of Transportation Engineering, 110(1), ASCE, New York, NY, 1984.

[9] Bauer, K.,M., Harwood, D.,W.: Statistical Models Of Accidents On interchange Ramps and Speed-Change Lanes, Federal Highway Administration, Washington, D.C.,1997.

[10] Transportation Research Board, Transportation research circular E-C081, Highway Capacity and Quality of Service Committee, A Research Program for Improvement of the Highway Capacity Manual, Washington, D.C., December 2005.

[11] Kuzovic, Lj.: Utvrdjivanje potreba i opravdanosti izdvajanja tranzitnog saobracaja sa gradskih arterija izgradnjom obilaznica. Saobracajni fakultet univerziteta u Beogradu, Beograd, 1997.