Determining the Accident Modification Factors Based on Iranian Road Accident Models

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ABSTRACT
Road accident models are the mathematical equations of various attributes in road environment which may not be directly applicable in economic appraisal and optimization procedures in road safety projects. There is a need to use a mediator variable to estimate the amount of decrease in traffic accidents as a function of improvements in geometric features and environmental condition of the road. This mediator variable, known as "Accident Modification Factor (AMF)", converts the initial form of a raw statistical accident model to an indicator applicable in economic appraisal models. Numerous equations have been established before by various researchers to estimate the AMF quantities. In this paper, the AMF factors applicable in road safety economic appraisal and optimization models are developed using the valid statistical accident models in Iran. In accordance to the validity of the models existing and currently used in Iran, AMF factors are suggested for three types of geometric features consisting of: (1) road width and surface condition, (2) horizontal curves, and (3) roadside hazards. The proposed equations of AMF factors have been utilized in the recently established resource allocation algorithm for road safety projects in Iran.

Keywords: Accident Modification Factors, road safety, road width, horizontal curves, roadside hazards.

1. INTRODUCTION

Undoubtedly, the traffic crashes happening in any road situation are the results of a complex trend of causes containing the three traditionally recognized factors: human, vehicle, and road. But as an extent to the previous studies about the AMF factors and generally the road accident models, only the existing physical characteristics of a given road segment (i.e. typically the geometric features of the road) are considered as the main independent variables addressing a statistical crash model. By the other hand, in this paper the author does not aim at establishing the statistical road accident models but using the models which were previously set up by the other researchers, and then delivering them to the prospective road safety practitioners interested in road safety operation analysis, especially the optimization practices.

What is important for assessing the conditions both before and after geometric improvements and safety measures is presenting an index for measuring the efficiency of geometric improvements as compared to the costs of implementation of the projects. To achieve such an approach, a new index known as Accident Modification Factors (AMF) has been used in recent years. The factor shows the difference in the rate of possible accidents for each state of a geometric position according to the basic state of the same position.

2. PREVIOUS STUDIES

In previous studies, a set of statistically analyzed AMF factors are developed as the base literature of the AMFs. Amongst them one can mention the factors addressed to determine the safety effects of geometric improvements for (1 and 2):

- Lane width
- Shoulder width and its surface type
- Horizontal curves
- At-grade intersections
- Roadside layout
- Permanent Raised Pavement Markers

The major application of AMF factors is related to the optimization algorithms developed for improvement of geometric designs in making and rehabilitating the roads in order to achieve a minimum accident rate in line with the implementation budgets. Two of the most important applications of such processes are the IHSDM model (1) (Interactive Highway Safety Design Model) and RSRAP (2) (Resurfacing Safety Resource Allocation Program) in 3R (Resurfacing, Restoration, and Rehabilitation) projects. The IHSDM model assesses the impact of safety behaviors of the parameters of one road segment or an intersection.

RSRAP model which was presented in 2003, also uses sub-models and figures presented for AMFs to calculate the number of reduced accidents due to implementation of 3R projects in the form of benefit gained by correcting geometric features of the roads for each geometric improvement alternative, and by including this benefit among other benefits and costs tends to determine the net benefit gained from 3R improvement alternative, and finally presents the best strategy.

3. CONCEPT AND APPLICATION

In road safety economic appraisal programs, the expected benefits are the function of the value attributed to the accident reduction and defined as the product of the accident reduction and the average cost of each accident (equation 1).

$$B = AR \times AC \tag{1}$$

Where:
B= Benefits of accident reduction
AR= Number of accidents reduced
AC= average cost of each accident

The average cost of each accident is the value which may be estimated as the weighted average of each fatal, injury, and property damage only (PDO) crashes due the accident severity distribution and effects on social costs. The number of accidents predicted in a road segment is a figure based on accident experience and the geometric and environmental configuration of the road. For a specific geometric feature improvement, the number of accident reduction is defined as the difference of number of current road accidents in "*existing*" geometric condition and the number of accidents predicted (i.e. expected) for the "*after*" condition. In another word, the number of accident reduction is in proportion with the magnitude of road safety operations and geometric improvements. This reduction may be estimated using a so called "*mediator variable*" as a factor applying the results of a road accident model in an economic appraisal problem. In recent years the terms *Crash Reduction Factors* (CRFs) and *Accident Modification Factors* (AMFs) are broadly identified as the most useful concepts for the mediator variable. To illustrate the concept discussed here, the following equation may be noted:

$$AR = \left(AN_{before} - AN_{after}\right) = AN\left(1 - AMF\right) \tag{2}$$

Where:
AR= Accident reduction
AN_{before}= Number of accidents experienced before safety geometric improvements
AN_{after}= Number of accidents predicted for after safety geometric improvements
AN= Existing number of accidents which equals AN_{before}
AMF= Accident Modification Factor for the safety improvement

The sign (-) for AMF parameter in equation 2 implies the reverse influence of the factor in reducing the accidents. It means that the less the AMF factor, the higher the amount of accident reduction. The AMFs higher than 1.0 refer to the increase in accidents which seems meaningless in safety improvement programs and provide a use in knowing what types of treatments to avoid in a particular context (but they be helpful in another type of road environment).

To compare the geometric condition attributed to both before and after the implementation, a typical AMF is defined for the improvement job itself, which is determined by dividing the AMF for after improvement by the AMF for before improvement. Each AMF for before and after geometric condition is stated based on the nominal (or base) condition.

The abovementioned discussions are mathematically stated below:

$$AMF_{before} = \frac{AMF_1}{AMF_{base}} \tag{3}$$

$$AMF_{after} = \frac{AMF_2}{AMF_{base}} \tag{4}$$

$$AMF_{GI} = \frac{AMF_{after}}{AMF_{before}} = \frac{AMF_2}{AMF_1} \tag{5}$$

Where:

AMF_{before} and AMF_{after}= The AMF for after geometric improvement and the AMF for before geometric improvement, respectively.

4. AMF FOR ROADSIDE HAZARD AREAS

The expectancy for colliding with a roadside fixed object by a vehicle is presented by *Ayati and Shahidian* (3) as following:

$$E(C) = ADT \cdot P(E) \cdot L \cdot P(A|E_X) \tag{6}$$

Where:
$E(C)$ = the expected collision
ADT= average daily traffic (vpd)
$P(E)$ = the probability of vehicle encroachment to the roadside
L= the roadside hazard length (m)
$P(A|E_X)$ = the probability of the collision to a hazardous object located at X meters away from the edge line, when the vehicle encroaches to the roadside (Figure 1)

The presence of horizontal curves, vertical curves, and narrow lanes increases the frequency of the vehicle encroachments to the roadside. The amount of the probability for this event can be estimated as following:

$$P(E) = E_{BASE} \cdot F_{HC} \cdot F_{VG} \cdot F_{LW} \tag{7}$$

Where:
E_{BASE}= 0.00031
F_{HC}= the adjustment factor related to the horizontal curves (table 1),

F_{VG}= the adjustment factor related to the longitudinal slope (table 2), and
F_{LW}= the adjustment factor related to the lane width (table 3).

TABLE 1 Adjustment Factor Related to the Horizontal Curves (3)

Curve Radius (m)	F_{HC} (inner curve)	F_{HC} (outer curve)
< 95.5	2	4
95.5-191	191/R	(573/R)-2
191 >	1	1

TABLE 2 Adjustment Factor Related to the Longitudinal Slope (3)

G (longitudinal slope)	F_{VG} (upward)	F_{VG} (downward)
0%-2%	1	1
2%-6%	1	0.5+0.25G
>6%	1	2

TABLE 3 Adjustment Factor Related to the Lane Width (3)

ADT	Lane width (m)			
	2.7	3.0	3.3	3.6
<400	1.05	1.02	1.01	1.0
400-2000	1.05+(2.85e-4)(ADT-400)	1.02+(1.75e-4)(ADT-400)	1.01+(2.5e-4)(ADT-400)	1.0
>2000	1.5	1.3	1.05	1.0

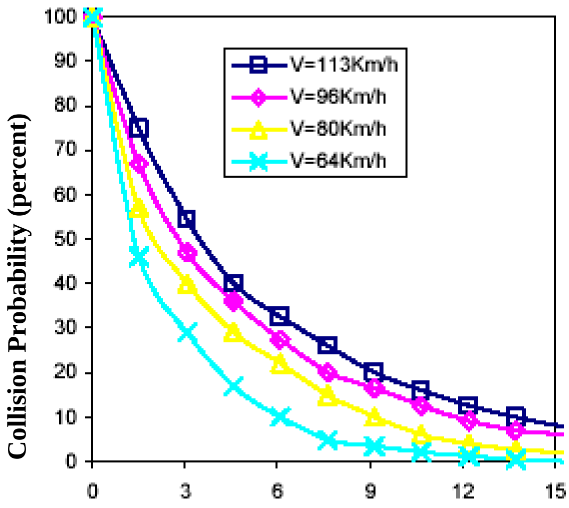

FIGURE 1 Probability of Vehicle Collision with a Fixed Object in Roadside (3)

The values for P (A/E_X) may be found to establish the equation for each curve in figure 1. The base condition for each vehicle speed group in this paper is defined as following:

- The radius of the horizontal curve is greater than 191 meters,
- The longitudinal slope is between 0 and 2 percent,
- The lane width is 3.65 meters,
- The fixed objects are located at least 15 meters away from the road edge lines, and
- The length of the roadside hazard is 1 kilometer.

According to these situations the AMF for base condition equals 1.0. In this condition the factors F_{HC}, F_{VG}, and F_{LW} all equal 1.0 and the probability for vehicle encroachment to the roadside will be the base value 0.00031. In the situation when fixed objects are located at least 15 meters away from the road edge line, the collision probability in case the vehicle encroaches to the roadside will only be a function of the vehicle speeds. Hence, the value of this probability can be found using table 4.

TABLE 4 Vehicle Collision Probability when the Objects are Located 15 Meters Away from the Edge Line

Speed range (km/h)	Average speed (km/h)	$P(A/E_X)$
$V < 72$	64	0
$72 \le V < 88$	80	0.025
$72 \le V < 104$	96	0.075
$104 \le V$	113	0.1

Using the above discussions, the accident frequency for base condition is estimated as following:

$$AN_{RSbase} = ADT \times 0.00031 \times 1.0 \times P(A/E_{15}) \tag{8}$$

Where:
AN_{RSbase}= the roadside accident frequency in base condition.

According to the parameters for base condition as well as the definition for AMF factors as the proportion of accident frequencies in a given condition to the accident frequencies in the base condition, the AMF for any given characteristics of the roadside hazard geometries is estimated as following:

$$AMF_{RS} = \frac{ADT \times P(E) \times L \times P(A/E_X)}{ADT \times 0.00031 \times 1.0 \times P(A/E_{15})} \tag{9}$$

$$AMF_{RS} = F_{HC} \times F_{VG} \times F_{LW} \times L \times \left[\frac{P(A/E_X)}{P(A/E_{15})}\right] \tag{10}$$

Where:
AMF_{RS}= AMF for roadside hazard areas,
F_{HC}, F_{VG}, F_{LW}, L, and $P(A|E_X)$ = as defined in previous equations, and
$P(A|E_{15})$ = the probability of the collision to a hazardous object located 15 meters away from the edge line, when the vehicle encroaches the roadside.

Equation 10 gives the AMF value for any given geometric and safety characteristics of a roadside hazard area.

5. AMF FOR LANE WIDTH AND PAVEMENT CONDITION

The model to estimate the accident rate in Iran as a function of pavement condition, road width, and traffic flow and in term of a 4-month accident frequency per kilometer is given by *Ameri et al* (4) as following:

$$AR = 0.00709 PCI^{-0.00679} . SN^{-0.665} . RW^{-5.379} . ADT^{2.063} \tag{11}$$

Where:
AR= accident rate in a road segment (accident frequency per kilometer in 4 months),
PCI= pavement condition index,
SN= skid number,

RW= road width (meters), and
ADT= average daily traffic (vpd).

In this equation the road width includes the total width of the traveled way. Here, the base condition for the pavement characteristics and road width is defined as the situation when the lane width is 3.65 meters, the pavement condition index is 100, and the skid number is 60. In the base condition, the annual accident frequency per kilometer of a roadway and per 1000 vehicles is 0.0475 accidents. In this condition, the accident frequency for a roadway with length of L and traffic volume of ADT is:

$$AN_{LW-S\,base} = 3.0754 \times 10^{-8} \times L \times ADT^{2.063} \qquad (12)$$

Therefore, considering the concept of the AMF, we come to the factor for a road segment of a given pavement condition and road width as following:

$$AMF_{LW-S} = \frac{AN_{LW-S}}{AN_{LW-Sbase}} = \frac{0.02127(L)(PCI^{-0.00679})(SN^{-0.665})(RW^{-5.379})(ADT^{2.063})}{3.0754 \times 10^{-8}(L)(ADT^{2.063})} \qquad (13)$$

$$AMF_{LW-S} = 6.916 \times 10^{5}(PCI^{-0.00679})(SN^{-0.665})(RW^{-5.379}) \qquad (14)$$

To find the AMF equation for characteristics of road width and pavement condition, the traffic flow for before and after the safety improvement is assumed as constant. Furthermore, using the lane width value instead of the road width of a two-lane two-way road changes the AMF equation as below:

$$RW = 2LW \qquad (15)$$

$$AMF_{LW-S} = 16620 \times (PCI^{-0.00679})(SN^{-0.665})(LW^{-5.379}) \qquad (16)$$

In equation 16, the LW is the lane width in term of meters. This equation may be applied as the main equation to estimate the AMF for lane width and pavement characteristics of a roadway.

6. AMF FOR HORIZONTAL CURVES

An accident model related to the horizontal curves in Iran is presented based on the degree of curvature. The statistical equation illustrating the model is (5):

$$N_{acc} = 3.494D^{2} - 3.122D + 2.001 \qquad (17)$$

Where:
N_{acc}= accidents per year, and
D= degree of curvature.

This parabolic regression model is the best proposed one amongst a few other mathematical regression equations whose correlation factor is 0.86, higher than the factor for the other types of regression. Changing the parameter D to the value of curve radius R, we have:

$$N_{acc} = AN_{HC} = 3.494\left(\frac{572.96}{R}\right)^2 - 3.122\left(\frac{572.96}{R}\right) + 2.001 \quad (18)$$

Equation 17 is a concave parabolic equation whose depth point shows the minimum degree of curvature or the maximum radius of a horizontal curve. It can be considered that at the beginning of the curve, the number of accidents reduces with the increase in degree of curvature (i.e. decrease in curve radius) till reaching the depth point, thereafter accidents increasing with the increase in degree of curvature. It is obvious that the initial trend of decrease in the accidents may not be rational considering the failure in a horizontal curve condition. Hence, in equation 17 only the ascendant part of the curve can be considered in the analysis as the function of accident frequencies versus degree of a curvature. Therefore, the minimum number of accidents occurs when the degree of curvature is laid at the zero derivative of the parabolic function in which the base condition for a horizontal curve may be defined. The minimum degree of curve or the maximum radius for this base condition can be calculated as following:

$$\frac{dN_{acc}}{dD} = 6.988D - 3.122 \quad (19)$$

$$\frac{dN_{acc}}{dD} = 0 \Rightarrow D = 0.447 \,;\, R\text{=1282m} \quad (20)$$

The conclusion made by equation 20 implies that the base condition for a horizontal curve is the situation where the curve radius is equal or greater than 1282 meters. Indeed, the radii beyond this value will result in an AMF equaling 1.0. Note that at this point of the base condition, the minimum number of the accidents is not zero but 1.304 accidents per year. Finally, dividing the accident function illustrated in equation 18 by the accidents achieved for the base condition (1.304), we can come to the AMF equation for horizontal curves as following:

$$AMF_{HC} = 2.68\left(\frac{572.96}{R}\right)^2 - 2.39\left(\frac{572.96}{R}\right) + 1.535 \quad (21)$$

Where:
AMF_{HC}= AMF for a single horizontal curve, and
R= curve radius (in meters).

7. CONCLUSION

In this paper, after defining Accident Modification Factors (AMF), the said factors were studied for road width and surface condition, roadside hazards, and horizontal curves. In road width and surface condition, the AMF factor has been calculated based on lane width, pavement condition index, and skid number. For roadside hazard zones, the distance of a fixed object from edge line and the geometric features in which the roadside hazard is located are considered. For the horizontal curves, the curve radius is taken in the AMF equation. The AMF factors presented for the said three features depend on the physical conditions and dimensions as well as the potential risk in each type of conditions. In the presented equations, some parameters are included in the mathematical expressions based on engineering judgments for determining the rate of potential risks. Also, it should be noted that due to the use of already validated models introduced in previous studies, there is no need to redo the validation procedure for AMF factors obtained from these models.

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