Selection Process for Local Highway Safety Projects

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This report presents a procedure (a) to identify accident problem locations, (b) to develop accident countermeasures, and (c) to rank highway safety projects according to their relative cost-effectiveness. The procedure is designed to be applicable to all highway operating agencies in order to assist them with the resource-allocation decision. The procedure was developed by the Oakland County Road Commission with assistance from staff of the Southeast Michigan Council of Governments and the Oakland County Transportation Systems Management Committeee. The procedure integrates techniques used by the Oakland County Road Commission to identify problem locations and develop project concepts as a means to evaluate those concepts for safety and other impacts. Although highway safety is the primary concern of the Oakland County Road Commission in developing this procedure, other variables (e.g., traffic congestion, air quality, and fuel conservation) can also be included in the process.

The Oakland County Road Commission (OCRC), in the face of growing liability exposure and an ever-increasing frequency of traffic accidents, has recently adopted highway safety as its number one priority. Traffic congestion and flow, although not ignored in the decisionmaking process, are to take a back seat to safety. As a result of this change in orientation, it became necessary to develop a new procedure for the allocation of resources that incorporates safety as the primary goal.

A substantial amount of research has developed means to identify hazardous locations and to evaluate projects in terms of cost-effectiveness, net benefits, and so on (1-5). Many of the approaches suggested are too complex to be implemented by local highway agencies, which have limited resources. Often researchers have described only part of the process that leads to the resource-allocation decision. For example, a number of reports concerning the identification of hazardous locations have been published over the years, but this activity is only one step in the decisionmaking process.

The purpose of this study is to present a comprehensive approach to the development and implementation of a highway safety project on the local level. The process described is designed to be applicable to all local highway agencies in order to assist them with resource-allocation decisionmaking.

The process was developed by OCRC with the assistance of staff from the Southeast Michigan Council of Governments (SEMCOG) and the Oakland County transportation systems management (TSM) committee. Some stages in the process have been used in the past by OCRC to assist in making decisions about safety improvements, but during the TSM planning process the various stages of the process were integrated and other factors were included.

In summary, the four stages of this process are as follows:

1. Identification of problem locations,
2. Development of project alternatives,
3. Evaluation of project alternatives, and
4. Project programming.

Although the process is not unique, the stages in the process present approaches that can be readily implemented by local highway authorities, regardless of size or sophistication. The process places emphasis on highway safety, but includes other factors related to traffic congestion, energy consumption, and economic and environmental concerns.

IDENTIFICATION AND EVALUATION OF SAFETY PROJECTS

Since OCRC established highway safety as its number one priority, numerous techniques have been used to identify problem locations and formulate project concepts. Many of the approaches used were too complex to integrate into daily operations. Others were very time-consuming or expensive in terms of the additional resources needed.

The approach presented in this study reduces the need for extensive data and additional resources. It is simple enough to be used daily as an operational tool.

Identification of Problem Locations

OCRC and most local highway authorities have at their disposal computer or manual files of traffic accidents within their jurisdictions. In Michigan, the Office of Highway Safety Planning maintains the Michigan Accident Locator Index (MALI), which can provide local highway agencies with site-specific accident statistics. Most other states have similar systems.

The statistics available through these systems or maintained manually provide the basis for the identification of problem locations. At OCRC three statistics are used during this stage of the decisionmaking process:

1. Average accident frequency per year at a site,
2. Average accident rate per million vehicle miles of travel (VMT) (for links) or million vehicles (for intersections) at a site, and
3. Percentage of injury and fatal accidents to total accidents at a site.

Three years worth of data are used to compute yearly averages so that the effects of one abnormal year on any of these factors is minimized.

Average accident frequency per year is the primary measure of a site-specific accident problem at locations that have similar traffic volumes. When two locations have similar traffic volumes, the one that has the greater accident frequency usually has a greater accident problem. Most locations that have high accident frequency can normally be associated with high traffic volumes, low average vehicle speeds, and a high percentage of property-damage-only (PDO) accidents. Due to the low severity rate of accidents at these locations, the level of societal costs and liability of the highway agency may not be reflected by high accident frequencies. Other measures should also be considered.

The accident rate per million VMT or million vehicles is used to control for the effects of traffic volumes on accident frequency. When two locations have dissimilar traffic volumes, the one that has the highest accident rate relative to the amount of traffic may have a greater accident problem. In other words, the frequency of accidents at this location could be abnormally high relative to the amount of traffic it carries.

Whereas, the accident frequency measure favors high-volume locations, the accident rate measure favors those that have low traffic volumes. For example, the accident and traffic characteristics of three intersections are given in the following table:

Figure 1. Oakland County traffic accident summary.

ACCIDENT RATE	ACCIDENT FREQUENCY (ACCIDENTS PER YEAR) 0-3	4-7	8-11	12-15	16-19	20-23	24-27	28-31	32-35	36-150
0.00 - 0.59	149	64	6	5	0	0	0	0	0	0
0-60 - 1.19	43	68	59	28	9	5	6	1	1	3
1.20 - 1.79	10	32	36	30	20	15	6	6	5	6
1.80 - 2.39	9	12	22	18	20	16	11	4	7	13
2.40 - 299	1	10	15	8	9	8	11	2	8	20
3.00 - 3.59	0	7	1	6	6	2	7	3	3	17
3.60 - 4.19	1	3	4	6	2	3	0	2	4	10
4.20 - 4.79	0	2	1	1	2	2	0	2	1	5
4.80 - 5.39	0	1	1	2	4	0	1	1	0	1
5.40 - 24.00	5	9	4	3	2	2	1	2	3	7

Priority 2 Priority 1

Intersection	Accidents per Year	AADT	Accident Rate (accidents/ million VMT)
A	100	100 000	2.74
B	80	20 000	10.96
C	2	200	27.40

If accident frequency is used as the only measure of an accident problem, then intersection A would be perceived as having the greatest accident problem. If the accident rate per million vehicles is used in an isolated manner, intersection C would be considered the worst.

To simplify the process of identifying accident problem locations, a 10x10 accident analysis matrix (6) can be devised, based on statistically determined intervals in accident rate and frequency. Separate matrices are used for intersections and road segments. Average yearly accident frequency and accident rate are used to plot road segments and intersections within the appropriate matrix cells. The highest priority locations are those plotted in cell (10,10). A diagonal reading across the matrix gives other priority groups. Figure 1 provides an example of such a matrix used by OCRC. By locating within Figure 1 each of the three hypothetical intersections in the foregoing example, intersection B is given priority over the others.

Once locations are ranked into these priority groups, they are ranked within each priority group by accident severity:

$$\text{Severity factor} = (\text{Fatal accidents} + \text{injury accidents}) \div \text{total accidents} \quad (1)$$

The accident analysis matrix technique is a good indicator of priority locations, but must be followed up by other analyses to determine possible accident countermeasures and the relative cost-effectiveness of implementing those countermeasures at various locations.

Development of Project Alternatives

Once problem locations are identified by using the foregoing technique, OCRC assigns an interdisciplinary team to review each problem location and determine alternative project concepts. The project review teams are composed of staff from traffic engineering, design engineering, and transportation planning. The major objective of this approach is to mitigate all roadway and environmental characteristics that impact negatively on highway safety. The team-review approach uses the interdisciplinary expertise of team members to devise a variety of strategies for accident reduction. If constraints on staffing present a problem, the general approach can be carried out by an individual staff member. The approach is designed to be flexible, although specific guidelines for the location review should be devised by the implementing agency.

In the OCRC approach, a field review of the problem location is carried out and site conditions are noted, diagrammed, and photographed. Some problems in design or geometrics might be obvious; others may be more nebulous. Often a survey of property owners adjacent to the site is necessitated in order to determine the operational characteristics of traffic at the site. If time is not a constraint, a windshield survey can be taken to record drivers' reactions.

Information obtained during this stage of the team-review process includes the following:

1. Existing and expected traffic volumes,
2. Turning movement counts,
3. Existing right-of-way,
4. Signing and other traffic control devices,
5. Roadside obstacles,
6. Vehicle speeds,
7. Pavement or surface condition,
8. Shoulder width and condition,
9. Existence of on-street parking,
10. Sight distance,
11. Roadway design characteristics,
12. Roadway geometrics, and
13. Visual evidence of traffic accidents (e.g., scarred trees and scraped guardrail).

Simultaneous with the field review, an analysis of the accident history of the site is carried out. Each reported accident is investigated individually, and information for all accidents is tabulated. Collision diagrams are drawn and accident patterns are noted. The final step in the team-review process is to relate these accidents to the physical or operational characteristics of the site. By doing so, alternative sets of accident countermeasures can be determined for each particular location.

Cost estimates are assigned to each alternative project concept at a specific location. The project alternatives for a location normally range from low-cost alternatives to major reconstruction. If a project at a location is necessarily deferred, a set of interim accident countermeasures is devised to reduce accidents during the period of deferral. The product of this team-review process is a report that indicates existing conditions at the location and specifies the various improvement alternatives proposed.

Table 1. Safety improvement rating sheet for links.

Impact Criteria	Points Possible	Accident Frequency		
		High[a]	Medium[b]	Low[c]
Frequency reduction (%)				
>30	7.5	50+	20.0-49.9	<20.0
10-29	5.0	50+	20.0-49.9	<20.0
<10	2.5	50+	20.0-49.9	<20.0
Rate reduction (%)				
>30	7.5	26.0+	3.44-25.99	<3.44
10-29	5.0	26.0+	3.44-25.99	<3.44
<10	2.5	26.0+	3.44-25.99	<3.44
Severity accident reduction (%)				
>30	25.0	25+	6.0-24.9	<6.0
10-29	15.0	25+	6.0-24.9	<6.0
<10	5.0	25+	6.0-24.9	<6.0

[a]Multiply by 1.0. [b]Multiply by 0.5. [c]Multiply by 0.25.

Table 2. Safety improvement rating sheet for intersections.

Impact Criteria	Points Possible	Accident Frequency		
		High[a]	Medium[b]	Low[c]
Frequency reduction (%)				
>30	7.5	25+	10.8-24.9	<10.8
10-29	5.0	25+	10.8-24.9	<10.8
<10	2.5	25+	10.8-24.9	<10.8
Rate reduction (%)				
>30	7.5	3.50+	1.66-3.49	<1.66
10-29	5.0	3.50+	1.66-3.49	<1.66
<10	2.5	3.50+	1.66-3.49	<1.66
Severity accident reduction (%)				
>30	25.0	15+	5.0-14.9	<5.0
10-29	15.0	15+	5.0-14.9	<5.0
<10	5.0	15+	5.0-14.9	<5.0

[a]Multiply by 1.0. [b]Multiply by 0.5. [c]Multiply by 0.25.

Evaluation of Safety Project Alternatives

During the team-review process, an attempt is made to relate existing environmental characteristics of a location with the accident history at that location. The project alternatives developed must then be evaluated to determine the effectiveness of the proposed projects. At this point one of the group of alternatives at a specific location is chosen for implementation. Then each of the chosen alternatives is ranked among all projects according to its relative cost-effectiveness.

During the recent development of the Oakland County TSM plan, a procedure for evaluating and ranking project alternatives in terms of cost-effectiveness was devised. Although the process weighs highway safety above all other planning criteria, traffic congestion and delay, air quality, energy conservation, intermodal coordination, and social and economic impacts can be integrated. The process assigns points to alternative safety projects based on the relation between the amount of safety improvements the project provides and the existing level of accident experience at the project location.

Three variables are used to measure a project's impact:

1. Accident frequency,
2. Accident rate, and
3. Severe accident frequency.

Accident frequency is the average annual number of accidents at a particular location. The ranges indicated in Tables 1 and 2 (i.e., high, medium, and low) were determined by using three years of accident data for Oakland County roads and intersections. The high category indicates locations that experience a critical level of accidents. The medium category indicates locations that experience accident frequencies greater than the average for all locations. The low category includes those locations that have less than average accident frequency among all locations.

Accident rate is the number of accidents at a particular location relative to the amount of traffic at the location. Accident rate must be considered when reviewing locations that have dissimilar traffic volumes. For example, a 1-mile long road segment that has 10 accidents/year and 1000 vehicles/day has an accident rate of 27.40 accidents/million VMT, whereas a 1 mile road segment that has 10 accidents/year and 10 000 vehicles/day has an accident rate of 2.74 accidents/million VMT. The segment that has 1000 vehicles/day has a greater accident problem than does its more heavily used counterpart. Again, the high and medium category ranges have been determined from a review of data from all locations in Oakland County.

Severe accident frequency is the average annual number of accidents that result in personal injury or fatality. A reduction in the frequency of severe accidents has a dramatic impact on the reduction of cost to society, therefore, the benefits of a project are increased.

Tables 1 and 2 are used to determine the points of effectiveness associated with each project. For example, a project is proposed for a road link that has more than 50 accidents per year. The proposed project is expected to reduce accidents by 15 percent. Therefore, the project received five points for accident frequency reduction. This procedure is carried out for all three impact criteria to determine the final safety effectiveness score for a project.

The safety-effectiveness score is then divided by the estimated project cost and multiplied by one million to determine the cost-effectiveness of the proposed project:

$$\text{Cost-effectiveness} = a/b \times 10^6 \tag{2}$$

where a is the safety-effectiveness score and b is the estimated project cost. Projects that have the greatest scores are given priority for implementation.

In order to ensure consistency in evaluating alternative projects, a set of uniform accident-reduction factors (7,8) is used to determine a project's impact on accident frequency, rate, and severity. The accident-reduction factors shown in Table 3 are used by OCRC. Percentage reductions in various types of accidents are related to specific types of improvements. In addition, each accident type is associated with a severity factor so that reductions in severe accidents can be determined. The average percentage of severe accidents are as follows:

Accident Type	Average Severe (%)	Accident Type	Average Severe (%)
Right angle	42	Fixed object	36
Left turn	43	Overturn	62
Rear end	26	Pedestrian	97
Head-on	42	Bicycle	86
Side-swipe	15	Car-train	52
Parking maneuver	18		

In order to determine the estimated reduction in accidents the following formula is used:

$$R = \Sigma R_i \quad (3)$$

where R is the total estimated annual accident reduction and R_i is the estimated reduction of type i accidents.

$$R_i = A_i \times P_i \quad (4)$$

where A is the average annual type i accidents and P_i is the estimated fractional reduction of type i accidents.

$$P_i = 1 - (1-P_{i1})(1-P_{i2})(1-P_{i3})\ldots \quad (5)$$

where P_{i1}, P_{i2}, P_{i3} are the estimated fractional reduction of accident type i caused by improvements 1,2,3,....

The percentage reduction in accident frequency is determined by the following equation:

$$\text{Percentage reduction} = R/E \quad (6)$$

where E is the existing frequency of accidents at a location. The percentage reduction in accident rate equals that for accident frequency. Therefore, no additional calculation need be performed to determine a project's impact on accident rate.

To determine the estimated reduction in severe accidents the following calculation is performed:

$$S = \Sigma S_i \quad (7)$$

where S is the total estimated annual reduction in severe accidents and S_i is the estimated reduction in severe accidents of type i.

$$S_i = R_i \times Sr_i \quad (8)$$

where Sr_i is the average percentage of severe type i accidents.

The safety project-evaluation process described above can be implemented easily by local highway agencies regardless of their size or sophistication. Access to a computer will facilitate the process.

Perhaps the biggest advantage to using Tables 1 and 2 is that they provide a rather simplistic approach that, with little explanation, can be used by nontechnical staff of small municipalities. For this reason alone, the tables should be retained. However, note that the selection of the number of columns (low, medium, and high) and the selection of the corresponding multipliers (0.25, 0.5, 1.0) was somewhat arbitrary. Although it was designed to

Table 3. Accident reduction factors.

	Accident Type										
Improvement	Right Angle	Left Turn	Rear End	Head-On	Side-Swipe	Parking Maneuver	Fixed Object	Overturn	Pedestrian	Bicycle	Car-Train
Traffic control devices											
Install new traffic signal	0.5		+0.5[a]						0.2	0.2	0.3
Install pedestrian signal									0.4	0.2	
Add separate left-turn phase											
With new left-turn		0.7	0.2	0.1	0.2						
Without left-turn lane		0.4									
Prohibit left turns		0.9	0.3						0.1	0.1	
Prohibit right turn on red	0.3		0.2		0.2				0.3	0.2	
Upgrade signals	0.1	0.1	0.2	0.1	0.1				0.1	0.1	
Improve timing and interconnect	0.1	0.1	0.2						0.1	0.1	
Install fully actuated signal	0.1	0.8	+0.5[a]		0.2				+0.1[a]	+0.1[a]	
Install 12-in lens			0.1								
Install advance warning flashers	0.3		0.3	0.1					0.1	0.1	0.2
Remove signal	+0.3[a]	+0.1[a]	0.9						+0.1[a]	+0.1[a]	
Upgrade signing	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Install special curve warning signs				0.2	0.2		0.2	0.2			
Minor leg stop control	0.5	0.3	+0.2[a]	0.1					0.2	0.2	0.2
Install all-way stop	0.7	0.5	+0.5[a]	0.3			0.2		0.3	0.3	
Overhead lane signs			0.1		0.2						
Overhead warning signs	0.2	0.2	0.2								
Install yield signs	0.3	0.2	+0.2[a]						0.2	0.2	
Intersection directional and warning signs	0.2	0.1	0.2	0.1			0.1				
Edge markings							0.2	0.1			
Centerline markings				0.2	0.3						
No passing stripes				0.3	0.3						
Raised permanent reflectorized markers				0.2	0.2		0.1	0.1			
Railroad crossing gates											0.6
Channelization											
Add center left-turn approach lane											
With left-turn phase		0.7	0.2	0.1	0.2						
Without left-turn phase		0.5	0.2	0.1	0.2						
Add right-turn lane and deceleration lane			0.2		0.1						
Add passing lane			0.3								
Add continuous left-turn lane		0.3	0.5	0.2	0.3						
Extend lane drop and acceleration lane			0.3	0.1	0.3		0.1				
Add median and median barrier		0.5		0.5	0.3						
Other											
Remove on-street parking	0.1		0.1		0.3	0.9	0.4		0.3	0.3	
Revise driveways	0.1		0.1			0.2					
Remove fixed object							0.8				
Widen lane width		0.1		0.2	0.5	0.3	0.3	0.2		0.3	
Widen shoulders				0.1	0.1	0.3	0.2			0.1	
Install curbing							0.5				
Resurface			0.1	0.1	0.1	0.1	0.1	0.1			0.1
Deslick	0.1		0.4	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Improve horizontal alignment				0.2	0.2		0.2	0.2			0.1
Improve vertical alignment				0.2	0.2		0.1	0.1			0.2
Illuminate	0.1		0.1	0.1	0.1		0.1	0.1	0.1	0.1	0.1
Improve superelevation				0.2	0.2		0.2	0.2			
Install guardrail							0.4				
Increase radii at intersection	0.1		0.2		0.1	0.1	0.1	0.1	0.1	0.1	
Improve sight distance at intersection	0.3	0.1		0.1	0.1	0.1			0.1	0.1	0.3
Widen bridge				0.4	0.4		0.4				
Pave approach	0.1		0.2						0.1	0.1	0.1

[a]Increase rather than reduction.

give more credit to increasingly worse locations, the tables could just as easily have been set up with only two columns (low and high) or a very large number of columns, each with multipliers that increase in value. The same arbitrary situation exists in the point spread for giving credit to the reductions (e.g., for frequency, 2.5, 5.0, and 7.5).

An obvious improvement to Tables 1 and 2 would be to develop a function that increases the multiplier or points proportionate to the increase in the scale under consideration (e.g., increase in frequency or increase in frequency reduction). Equation 9 provides such a function.

$$CE_{ij} = \left\{ [P_F(F_j/F_{max})(FR_{ij}/FR_{max}) + P_R(R_j/R_{max})(RR_{ij}/RR_{max}) + P_S(S_j/S_{max})(SR_{ij}/SR_{max})] \div C_{ij} \right\} \times 10^6 \quad (9)$$

where

- i = alternative improvement under consideration,
- j = location to be improved (i.e., intersection, curve, or link),
- CE_{ij} = cost-effectiveness of improvement i at location j,
- C_{ij} = cost of improvement i at location j,
- P_F = points (max) for reduction in frequency,
- F_j = frequency of accidents at j,
- F_{max} = maximum frequency possible at any location,
- FR_{ij} = estimated frequency reduction for i at j,
- FR_{max} = maximum possible reduction in frequency at any location,
- P_R = points (max) for reduction in accident rate,
- R_j = accident rate at j,
- R_{max} = max possible rate at any location,
- RR_{ij} = estimated rate reduction for i at j,
- RR_{max} = max possible reduction in rate at any location,
- P_S = points (max) for reduction in severity,
- S_j = number of severe accidents at j,
- S_{max} = max possible number of severe accidents at any location,
- SR_{ij} = estimated reduction in severity for i at j, and
- SR_{max} = max possible reduction in severity at any location.

As should be readily apparent, the first set of factors represents the potential credit for accident frequency, the second set for accident rate, and the third set for accident severity. For convenience, $P_f + P_r + P_s = 100$. The multiplier of 10^6 at the end is included simply to provide a meaningful cost-effectiveness number for easy comparison.

The establishment of the maximums (e.g., F_{max}) is not as critical as might appear, provided the same maximums are used for all comparisons. One approach might be to simply use the highest value for the group of alternative projects under consideration. For example, if 100 alternative projects were being considered, the location that has the highest frequency might be used in setting F_{max}. The same process would then be followed for all of the other maximums. Another approach might be to simply select maximums that are known to be unobtainable at any location. Again, the key is to use the same values for evaluating all alternative projects.

Although numerous values must be plugged into this equation, it is still simple enough that it can be programmed on many hand-held calculators for easy computation when a large number of alternatives are under consideration. It also provides a rational application of points or credits among alternatives and perhaps a better spread of resulting cost-effectiveness values.

Integration of Other Factors

During the development of the Oakland County TSM plan (9), the foregoing safety project-evaluation procedure was expanded to integrate other factors relevant to TSM project planning and programming. Although the enhancement of highway safety was retained as the primary criterion in the evaluation process, the following criteria were also considered (10):

1. Operations improvements, including reduction in traffic delay, importance of the project to the transportation network, and improvement in operations and roadway geometrics;
2. Improvement in air quality;
3. Reduction in fuel consumption;
4. Impact on other modes;
5. Impact on social and economic factors; and
6. Improvement in maintenance and service factors.

Points were awarded to projects for improvements in the traffic operations criteria that were weighted by the existing level of service (LOS) at the project location (11,12). The improvements in air quality and fuel conservation that result from a project were based on the reduction in traffic delay effectuated by the project. The other evaluation criteria were scored on a subjective basis. Cost-effectiveness for a project is determined by summing the effectiveness points assigned to the project, dividing by the estimated project cost, and multiplying by one million. Projects are then ranked by their cost-effectiveness and budget constraints are applied. Table 4 provides an example of the final product of this procedure.

Table 4. Highway projects listed by cost-effectiveness.

Project Location	Description	Safety	Traffic Operations	Air Quality	Fuel Conservation	Intermodal Impacts	Socioeconomic Impacts	Maintenance	Total	Cost ($)	Cost-Effectiveness
Elizabeth Lake–State to Telegraph	Interconnect signals	8.8	13.0	2	2	0	0	2	27.8	3 300	8424
Main–University	Remove parking, stripe for left-turn lane	23.8	13.0	5	5	2	2	3	53.8	10 000	5380
M-59–Crescent Lake	Add left-turn phase	18.8	3.0	0	0	0	0	0	21.8	10 000	2180
Farmington–Nine Mile	Widen for left-turn lanes	36.2	21.0	3	4	2	0	3	69.2	75 000	923
John R–Woodward Heights	Widen for left-turn lanes	36.2	3.5	1	1	3	0	2	46.7	130 000	359
John R–Nine Mile	Increase corner radii	5.6	6.0	1	2	3	0	2	19.6	55 000	356
Twelve Mile–Middlebelt	Widen for left-turn lanes	17.5	3.0	1	1	1	0	1	24.5	75 000	327
Ten Mile–Novi	Widen intersection	22.5	4.2	3	4	0	0	3	36.7	150 000	245
Pontiac Trail–Decker	Widen for left-turn lanes	5.0	2.5	2	3	0	2	3	17.5	80 000	219

CONCLUSION

The final product of this entire process is a list of projects ranked according to relative cost-effectiveness. By applying budget constraints to this listing of projects, a yearly or multiyear program is devised. The process explained presents a simple technique for facilitating the resource-allocation decision. It is designed to be applicable to all local highway organizations regardless of their size or sophistication.

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Analysis of Accidents in Traffic Situations By Means of Multiproportional Weighted Poisson Model

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This article describes a model that enables traffic engineers to get insight into the factors that influence the occurrence of accidents. This model has a multiplicative form and describes how the expected number of accidents depends on road and traffic characteristics. Because of the input of observations where no accidents occurred, a logarithmic transformation to linearize the model was impossible without biasing the estimates considerably. By introducing the maximum likelihood estimation theory, a model was developed that also analyses situations where no accidents occur. This method was first applied successfully in 1974 for the analysis of accidents on Dutch polderroads. This article also describes the results obtained by the method from a study that tries to establish a relation between road and traffic characteristics on one hand and the safety of cyclists and moped riders on the other. Influencing factors are (a) motor car, moped, and cycle traffic flows; (b) width of cycle lane and median width; (c) access roads to houses; (d) type of road surface of the cycle lanes; and (e) parking bays and bus stops. A further application is given by the study of interurban car traffic. Daily traffic flows proved to be the most important variable, followed by the presence of obstacles and intersections and crossings of various kinds.

Traffic accidents are caused by errors of judgment on the part of road users or by defects in vehicles. The occurrence of accidents is related to the psychological characteristics of the traffic participants as well as to the physical characteristics under which they take part in traffic. These physical characteristics are, for instance, the weather conditions (e.g., fog or slipperiness), the light or dark period of the day, and the road characteristics. One of the tasks of the traffic engineer is to examine whether the accident rate can be lowered by improving the traffic situation.

The occurrence of accidents can be analyzed by means of mathematical models. Regression analysis is often used; sometimes analysis of variance and factor analysis are also used to ascertain the effect of road and traffic characteristics (1-3). Some have used linear regression. Often, a multiplicative model is made linear (4,5).

The use of multiple linear regression implicitly assumes that the observation results are distributed normally. This assumption is not very realistic since the analysis is specifically concerned with traffic situations in which few accidents occur. The probability that the number of accidents would become negative is not negligible in that case.

The drawback of an erroneous assumption with respect to the sampling distribution is even greater in the use of the multiplicative model linearized by a logarithmic transformation. The logarithm of zero is not defined, and a zero observation can therefore not be included in the investigation. The zero observations are sometimes omitted from the analysis. This seems undesirable because traffic situations where no accidents occur are of a very real importance. Other devices are sometimes used; for instance, a small number (e.g., 0.5) may be added to