Prioritization and selection of risk alleviation measures through traffic impact and risk assessment analysis

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Abstract

The present paper aims at the development of a decision - support framework that enables the identification and a priory evaluation of measures for the improvement of road safety at accident - prone intersections in an area. The framework consists of four main calculation modules. The first module involves statistical analysis methods, which are used for a preliminary selection of the intersections to be improved, depending on their accident indices. The second module is an econometrical module, which calculates the costs of the implementation of the measures, and consequent savings, owing to the expected reduction of the number of accidents. Furthermore, the third module is based on traffic engineering analysis principles, and is used for traffic impact assessment at the intersections, before and after the implementation of the road safety measures. Finally, the fourth module comprises an evaluation method relying on the indices estimated in the previous modules that enables the analyst to prioritize the intersections and the respective improvement.

The framework has been implemented in an urban area. After prioritizing the intersections based on road safety parameters and processing, all the data required for the next modules, the effectiveness and efficiency of road safety measures was assessed through the estimation of savings in accident costs and traffic implications.

Introduction

One of the main concerns of roadway network operators is the identification of the sites and the measures to be implemented, that will result in the most cost-effective scenario for the improvement of road safety in an area.

Taking into account the limited resources available, prioritization of the above is a very helpful tool in the hands of the decision makers. Some tools that have been developed and used mainly rely on statistical methods for the analysis of accident indices and the estimation of the significance of the impact of implemented road safety measures. However, road safety is not the only criterion for estimating the effectiveness of implemented measures. It has been observed that in cases where measures have been introduced for improving road safety, traffic performance may deteriorate, in terms of travel time, accessibility, and convenience.

In order to compensate for the above, various methodologies have been developed, which take into account both the safety, as well as traffic operation aspect of the network [1]. These methodologies analyze the impact of the proposed measures in terms of minimization of accidents, as well as the effect on traffic due to the introduction of the road safety measures. Quantification of the above impacts and effects may be consider the number of accidents, the travel time savings or increase (i.e. travel delays), or may interpret the above in monetary terms, taking into account also the cost of implementing the road safety measures.

In the present paper, the general aspects of the above presented methodology has been elaborated and adjusted in the requirements of an urban area in Greece. More specifically, a set of accident prone intersections has been selected, based on statistical methods, in order to justify the significance of the accidents. A safety and traffic performance analysis has been made for each one of them, based on their current status, in order to quantify the safety and traffic parameters. Furthermore, and depending also on the geometric characteristics of the intersections, improvement measures have been identified and proposed. Assuming implementation of these measures, a safety and traffic analysis was conducted, and the effects of the measures were again quantified. Furthermore, the cost associated to the implementation of each measure was estimated.

Evaluation of the measures was conducted based on the results of the above analysis, following a multilayer prioritization methodology. The outcome of this process was the prioritization of the implementation of the measures to the relevant intersections.

The remaining of the document is formulated as follows:

Paragraph 2 presents the methodology as it has been elaborated and adapted to the available data that may be used for the analysis. In this chapter, first the four modules are presented, and then the method employed for the safety analysis and the estimation of the traffic performance are discussed.

In paragraph 3 the presentation of the evaluation methodology is given. This evaluation concerns the comparison of the before and after the measures implementation for the same intersections, as well the prioritization amongst all the intersections and the proposed measures.

A case study is conducted in paragraph 4, and the data entry and processing, as well as the results are presented. A sensitivity analysis has been included that indicates the variability of the results as the sequence with which the criteria are considered changes.

Finally, conclusions and propositions for further discussion is given in the last paragraph of the paper.

Methodology

General

The methodology used in this paper is composed of four main modules and one preparatory stage. The preparatory stage involves the establishment of a preliminary list composed of sites, which satisfy two criteria. The first criterion is that accidents must have occurred at these sites, or at least near accident situations must have been observed. The second criterion is that the measures that may be implemented in order to improve the site as concerns its safety level are measures that may affect traffic. Both criteria are considered important for the feasibility of implementing the methodology.

The modules that are being implemented, according to the methodology are as follows:

Module 1: Statistical analysis regarding the safety of the sites under study, in order to identify the significance of the existence of accidents or almost accident situations. For the sites that are considered as possible sites for improving safety, a thorough analysis has to be conducted in order to identify the inefficiencies in the geometrical or operational characteristics, and propose remedial measures that may be implemented.

Module 2: Analysis of the safety as concerns the possible anticipated effect that the proposed measures may have on the number of the accident or the near accident situations. This module exploits the experience that is provided by numerous studies, as concerns the percentage changes in the safety indicators for a specific geometric and operational status of the site. Assuming introduction of a specific measure, or combination of specific measures, the percentage reduction of the accidents, or near accident situations is estimated. This percentage, if multiplied by the number of accidents (or near accidents) gives the change in the number of accidents at the site, upon introduction of the measure(s).

Module 3: Traffic performance estimation for the before and after the implementation of the measure(s) cases. The performance is quantified in travel time before and after, as well as delays resulting from the comparison of the two cases (with and without the measures). Traffic engineering techniques are used in this module, which take into account the effect in traffic of changes in the geometry of the site (e.g. increase number of lanes), or the traffic operation schemes (e.g. instalment of a traffic light).

Poster Presentations

Module 4: Evaluation of the proposed measures and prioritization. The evaluation of the proposed measures utilises the results of the previous analysis, as well as the associated cost for the implementation of the measures. It estimates some common indicators for all the sites under study and the proposed measures, which are used for the prioritization of the measures following a multilayer prioritization methodology. The prioritization is done at stages, assuming one criterion at each stage, clustering, and reorganizing the priorities within each cluster.

Accident analysis

Accident analysis is realized through the estimation of the projected annual number of accidents at intersection j (N_j), the accident reduction rate for the improvement measure k (CRF_k), the proportion of the total number of accident where (CRF_k) applies depending to the accident severity s (RF_s), and the accident cost depending on the severity s, also (AC_s). The present value of the benefits of improvement measure k at intersection j is calculated as [2]:

$$B_{jk} = \left[\sum_{s=1}^{2} N_j (CRF_k) RF_s AC_s \right] (P/A,i,n) \qquad (1)$$

where

$(P/A,i,n)$ = present value factor, which is calculated as:

$$(P/A,i,n) = \frac{(1+i)^n - 1}{i(1+i)^n} \qquad (2)$$

where

i = interest rate
n = time horizon of improvements

Traffic performance

This analysis is based on Highway Capacity Manual 2000 (HCM 2000), under which the traffic delays are estimated for the before and after scenario [3].

The steps followed for the analysis of the signalized intersections, according to the Manual are:

- Data entry
- Left turn estimations
- Volume estimation
- Traffic signal estimation
- Volume to capacity (v/c) estimation
- Estimation of average delay per vehicle and level of service

Average delay is estimated as [3]:

$$d = d_1(PF) + d_2 + d_3 \qquad (3)$$

where

d = total delay (sec/veh),
d_1 = homogeneous delay (sec/veh),
PF = traffic signal coordination coefficient,
d_2 = incremental delay (sec/veh),
d_3 = initial delay (sec/veh).

Homogeneous delay is computed assuming homogeneous arrivals, stable flow and no initial queue, as follows [3]:

$$d_1 = \frac{0{,}5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1,X)\frac{g}{C}\right]} \qquad (4)$$

Poster Presentations

where

C = period (sec),

g = utilized green time (sec),

X = v/c ratio.

Incremental delay takes into account the effect of random arrivals and queues, and is estimated as follows:

$$d_2 = 900T\left[(X-1) + \sqrt{(X-1)^2 + \frac{8kIx}{cT}}\right] \qquad (5)$$

where

T= analysis period (hr),

k = incremental delay factor,

I = coefficient for the existence of upstream signalized intersection

c = capacity (veh/hr),

X = saturation rate v/c.

Two types of unsignalized intersections may be analyzed; intersections controlled with STOP on the secondary streets, giving priority to the main street, or two way stop controlled intersections (TWSC[1]), and intersections controlled with STOP at all approaches, or all way stop controlled intersections (AWSC[2]). Each intersection type is analyzed based on different equations.

The average stop delay at TWSC intersections, for any secondary movement is estimated as follows [3]:

$$d = \frac{3600}{C_{m,x}} + 900T\left[\frac{V_x}{C_{m,x}} - 1 + \sqrt{\left(\frac{V_x}{C_{m,x}} - 1\right)^2 + \frac{\left(\frac{3600}{C_{m,x}}\right)\left(\frac{V_x}{C_{m,x}}\right)}{450T}}\right] + 5 \qquad (6)$$

where

V_x = flow rate for movement x (veh/hr),

$C_{m,x}$ = capacity for movement x (veh/hr),

T = analysis period (hr).

The average stop delay for AWSC intersections is estimated as follows [3]:

$$d = t_s + 900T\left[(x-1) + (x-1)^2 + \frac{h_d x}{450T}\right] + 5 \qquad (7)$$

where

x = reliability index ($vh_d/3600$),

t_s = service time (sec),

h_d = time headway at start (sec),

T = analysis period (hr).

The above equation applies to each lane group considered for the intersection under study. In order to estimate the average delay per vehicle for the intersection, the following equation is used:

$$d_A = \frac{\Sigma d_i v_i}{\Sigma v_i} \qquad (8)$$

where

d_A = average delay for approach A (sec/veh),

d_i = average delay for lane group i (of approach A) (sec/veh),

v_i = flow rate of lane group i (veh/hr).

and

[1] Two-way stop-controlled

[2] All-way stop-controlled

Poster Presentations

$$d_I = \frac{\Sigma d_A v_A}{\Sigma v_A} \qquad (9)$$

where

d_I = average delay for the intersection (sec/veh),

d_A = average delay for approach A (sec/veh),

v_A= flow rate of approach A (veh/hr).

The difference of the intersection average delay for the before and after the implementation of the measures cases is then estimated as:

$$\Delta d = d_b - d_a \qquad (10)$$

where

Δd = delay difference (sec/veh),

d_b = average intersection delay before the implementation of the measures (sec/veh),

d_a = average intersection delay after the implementation of the measures (sec/veh).

The before average delay (d_B), and the average delay change (Δd) are the indices resulting from this analysis.

Evaluation

Multilayer prioritization takes into account the benefit to cost ratio, as resulted from the comparison of the monetary values of accident savings and the installation of the improvements measures (B/C), the delay changes (Δd) and the delay under the before scenario (d_b).

Furthermore, two approaches may be followed, depending on the sequence under which the safety and the traffic effectiveness are considered [4]. According to the first approach, the intersections and improvement measures are prioritized based on the B/C ratio, and clusters are being identified. Within each cluster, intersections are then prioritized based on the delay changes, and new clusters are defined. Final prioritization is attempted based on the delay under the before scenario.

Similarly, the second approach is implemented through the prioritization of the intersections based on the delay changes. Intersections within the same clusters are further prioritized based on the B/C ratio, and finally the resulting clusters are once more prioritized based on the delay under the before scenario.

Case study

The above methodology has been implemented in an urban area (central business district -CBD) in Greece. The study emphasized on the intersections of the area, for which accident data were collected.
The following steps were followed:

Step 1: Establishment of a preliminary list composed of the accident intersections, open to improvements. The selection of the intersections to be considered for the application of the methodology presented above, was accomplished based on a statistical analysis of the historical data on accidents.

Step 2: Accident analysis and estimation of the traffic measures of effectiveness under the existing scenario (before the measures). The result of this step is the estimation of the number of accidents per accident category, and their attributes, and the delay per vehicle for each intersection.

Step 3: Similar estimations as in step 2 are being made in this step, under the proposed scenario (after the measures). Combination of the figures of the current and previous steps, result in the estimation of the number of accident and delay changes, owing to the proposed measures

Step 4: Calculation of the costs (C) for the proposed measures. Quantification of the benefits associated to the accident changes in monetary terms (B). Calculation of the B/C ratio.

Step 5: Prioritization of the intersections based on the B/C ratio and the delay changes. Sensitivity analysis of the results depending on the sequence of the criteria under which the intersections are prioritized.

Data entry and processing

Based on the statistical analysis conducted on the accident data of the intersections of the under study area, nine intersections were selected, as significantly the most accident prone sites.

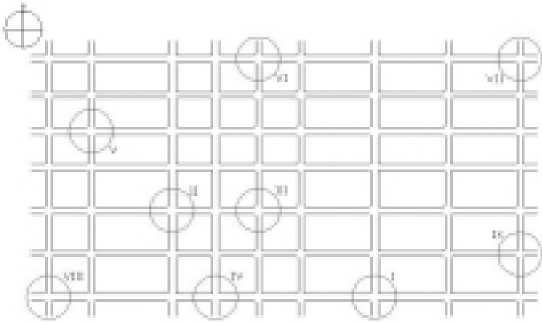

Figure 1: Central business district and accident prone intersections.

Based on the analysis of the frequency of accidents per accident type, each intersection was allocated a specific improvement measure, which is expected to provide a better road safety condition.

Table 1: Accident prone intersections and proposed improvement measures.

Intersection	Road safety improvement measure
I	a) Addition of a designated left turn lane b) Signalization improvement
II	Addition of a designated right turn
III	Traffic light installation
IV	Channelization (flared approach)
V	Construction of raised median
VI	Installation of street lighting
VII	Traffic light installation
VIII	Addition of a designated left turn lane
IX	Traffic light installation

In order for a common procedure to be used for the estimation of the accident rate changes before and after the introduction of the improvement measures, Safety Performance Functions (SPF) were implemented [4], according to which the expected number of accidents at an intersection is estimated as a function of various the daily volume on the main approach, the daily volume on the secondary approach, the number of approaches at a distance of 76 m from the intersection, the proportion of left and right turns, the proportion of heavy vehicle etc.

For the distribution of the estimated number of accidents per accident type, the Federal Highway Administration (FHWA) proposed proportions were adopted [4], thus 39,7% of the accidents was assumed to be with fatalities and/or injuries, whereas the 60,3% with property damage only.

The accident rate change due to the proposed improvement was estimated based on the following equation [2]:

$$CRF_{\text{int}\,i} = 1\text{-}(1\text{-}CRF_{1i}) \times (1\text{-}CRF_{2i}) \times \ldots \times (1 - \times CRF_{ni}) \qquad (10)$$

where:

$CRF_{\text{int}\,i}$ = accident rate change for interchange i

CRF_{ki} = accident rate change for interchange I under the implementation of improvement measure k

The benefit B in the B/C ratio was estimated based on the cost per accident for all accident types considered at the intersection. The cost C in the denominator was estimated based on the relevant cost of the measures proposed. All of the above values were calculated for a time period equal to the life cycle of the improvement measures.

The delay changes and delays before the measures were estimated based on the HCM methodology [3], and expressed in delay changes and delay per vehicle, respectively.

Results

The results of the above implementation are depicted in table 2. These are mainly illustrated as the values of the considered criteria, namely B/C, d_b και Δd.

Table 2: Performance of improvement measures at intersections

Intersection	B/C	d_b (sec/veh)	Δd (sec/veh)
I	15,66	69,6	48,8
II	6,78	48,4	19,3
III	1,53	107,5	77,8
IV	35,41	20,1	15,0
V	6,43	192,4	174,8
VI	5,89	0	0
VII	1,29	4,4	-6,0
VIII	8,88	50,0	23,1
IX	4,02	0	0

Based on the method that considers the B/C ratio as the first criterion to be taken into account, the intersections are prioritized as presented in table 3.

Table 3: Intersection prioritization based on the B/C ratio.

Group	Subgroup	Intersection	B/C	d_b(sec/veh)	Δd(sec/veh)	1st level	2nd level	3rd level
1	1	IV	35.41	20.1	15,0	1	1	1
2	2	I	15,66	69,6	48,8	2	2	2
3	3	VIII	8,88	50,0	23,1	3	3	3
4	4.1	V	6,43	192,4	174,8	5	4	4
	4.2	II	6,78	48,4	19,3	4	5	5
	4.3	VI	5,89	0	0	6	6	6
5	5	IX	4,02	0	0	7	7	7
6	6.1	III	1,53	107,5	77,8	8	8	8
	6.2	VII	1,29	4,4	-6,0	9	9	9

Based on the method that considers the delay changes as the first criterion to be taken into account, the intersections are prioritized as presented in table 4.

Table 4: Intersection prioritization based on the delay changes.

Group	Subgroup	Intersection	Δd(sec/veh)	B/C	d_b(sec/veh)	1st level	2nd level	3rd level
1	1	V	174,8	6,43	192,4	1	1	1
2	2	III	77,8	1,53	107,5	2	2	2
3	3	I	48,8	15,66	69,6	3	3	3
4	4.1	IV	15,0	35,41	20,1	6	4	4
	4.2	VIII	23,1	8,88	50,0	4	5	5
	4.3	II	19,3	6,78	48,4	5	6	6
5	5.1	VI	0	5,89	0	7	7	7
	5.2	IX	0	4,02	0	8	8	8
	5.3	VII	-6,0	1,29	4,4	9	9	9

Conclusions

Prioritization of interchanges in order for road safety improvement measures to be assessed has been implemented in an urban area. The criteria used for this prioritization are related to safety, as well as traffic operation, and relevant indices are estimated. Further, a multilayer prioritization method is adopted in order to combine these indices, and provide valuable information to decision makers as to which intersection and measure may be the most cost-effective to implement. Main advantages of this method are the consideration of both safety and traffic operation related issues; also, the flexibility it provides to decision makers in selecting the most prevailing criterion. Disadvantages of the method is the sensitivity of the results owing to the selection of the importance of the criteria, which mainly relies on the experts opinion and the point of view of the decision makers.

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