Multi-Criteria Analysis to Evaluate Road Safety Measures and Allocate Available Budget

---

Maria Grazia Augeri, Rosario Colombrita, Agata Lo Certo
Department of Civil and Environmental Engineering - University of Catania- Italy

Salvatore Greco, Benedetto Matarazzo
Department of Economics and Quantitative Methods - University of Catania - Italy

Synopsis

A suitable road safety improvement program involves firstly the identification and investigation of sites with a high accident rate. Successively, specific countermeasures must be developed in order to reduce the number or severity of accidents of the dominant type at the location.

The aim of this research is to provide the decision maker with a decision support system for highway safety resources allocation among different hazardous sites. In fact, budget constraints impose to prioritize and select crash countermeasures taking into account different objectives and maximizing the efficiency of investment.

The principal objectives included in the analysis are the lowering the expected number of accidents of different types and severity and the minimization of the cost.

We consider also the possibility that some countermeasures can be implemented alternatively at same site, selecting then the best solution that optimize the objectives.

The considered objectives are non commensurable because accidents of different type and severity are heterogeneous among them and with respect to the related cost. Since we want to avoid to convert everything in monetary terms using some cost-benefit analysis methodology, we propose a multiobjective optimization methodology that permits to express the different objectives in their respective units.

As each considered countermeasure can be realized or not, without any possibility of realizing it partially only, our multiobjective optimization methodology considers discrete 0-1 variables (0 for “non implementation of the countermeasure”, 1 for “implementation of the countermeasure”).

The joint consideration of a multiple objective optimization and of discrete 0-1 variables is the major distinctive feature of the proposed approach in comparison with other competitive methodologies presented in literature.

A simple example is presented to illustrate the salient features of the proposed methodology.

Multi-Criteria Analysis to Evaluate Road Safety Measures and Allocate Available Budget

Recently road agencies have been shown an increasing interest in road safety improving programs whether for the severity of the problem or for public awareness and legislative innovations.

In Italy, the “National Road Safety Program” (PNSS) supports an integrated program of road safety improvements, that finances the initiatives of local administrations and agencies managers of road networks.

Unfortunately, the available resources are always inadequate to upgrade and maintain all their highway infrastructures that are in the need of safety improvements. Therefore, safety engineers need tools that allow them to use available budget optimally to achieve the greatest overall safety benefit.

The preliminary identification of hazardous sites can help in the allocation of the limited funds in order to obtain maximum benefit.

Detailed studies of accident type, frequency, pattern, at these locations can lead to the identification of system fault and of the related countermeasures (Ogden, 1996). However, an efficient methodology for road safety management can not only provide “problem and countermeasure” identification but it must help the decision maker in selecting and prioritizing crash countermeasures at different sites under conflicting objectives and constrains.

Cost-benefit analysis has been, traditionally, applied to set priorities in road safety projects, but the difficulties in estimating both costs and benefits have involved towards different approaches. The weakness of cost-benefit analysis, in fact, is that the estimation of benefits in term of savings in crash costs is difficult and controversial.

In literature, there are various studies that use cost-benefit analysis to evaluate the effectiveness of highway safety improvement projects (SEMOG, 1997).

Recently, numerous researchers have developed multi-objective decision support systems, that fits better this type of decision process (Lambert ed al, 2003, Frohwein et al., 1999). An interesting series of this approach applications, to different transportation fields, is presented in a study funded by the Midwest Regional University Transportation Center and the Federal Highway Administration (Chowdhury et al., 2002).

The aim of our research is to provide the decision maker with a decision support system for highway safety resources allocation among different hazardous sites, considering simultaneously improvement projects of different kinds.

We propose a multiobjective optimization methodology to deal with the problem of efficient allocation of available funds. The principal objectives included in the analysis are the lowering the number of accidents of different types and severity and the minimization of the cost.

We consider also the possibility that some countermeasures can be implemented alternatively at same site or in combination, selecting then the best solution that optimize the objectives.

Since each considered countermeasure can be implemented or not, without any possibility of realizing it partially only, our multiobjective optimization methodology considers discrete 0-1 variables (0 for “non implementation of the countermeasure”, 1 for “implementation of the countermeasure”).

The joint consideration of multiple objective optimization and of discrete 0-1 (so called multiple objective combinatorial optimization, see Ehrgott and Gandibleux, 2005) variables is the major distinctive feature of the proposed approach in comparison with other competitive optimization methodologies presented in literature being multiobjective but not discrete (Chowdhury et al. 1998) or discrete but not multiobjective (Pal and Sinha 1998).

ROAD SAFETY EVALUATION

The analysis of road accident data is the starting point for every highway safety improvement program. Generally, this analysis aims to identify hazardous road sites and to recognize the factors which caused an anomalous repetition and concentration of accidents on these sites. After getting detailed information about site conditions, the next step is selecting the most suitable countermeasure or set of countermeasures, based on their potential effectiveness in terms of accidents reduction expected at a location.

Finally a formal economic appraisal procedure has to be performed to rank candidate projects and to develop a work program.

Hence, an efficient road safety improvement program can be resumed in the following next steps:

1. accident data collection and database organization;
2. identification of high accident rate road sites applying statistical methods;
3. investigation of hazardous sites and diagnosis of accident patterns, determining which sites are treatable;

4. countermeasures selection;
5. economic evaluation and prioritization of road safety improvement projects taking into account objectives and constraints.

The focus of this paper is to develop a decision support system which assists the decision maker in the final choice among candidate road safety improvement projects according to his/her preferences (objectives) and taking into account constraints (step 5).

Therefore, the preliminary steps 1 to 4 of the road safety evaluation process are briefly described. In particular, the selection of road safety improvement projects is performed using a two-stage method which consists firstly in a road network analysis to identify high accident rate sites that are most in the need of further consideration. After that a site investigation is carried out in order to obtain more complete information required for the selection of the most suitable crash countermeasures. At the end of these preliminary stages a list of road safety improvement projects is given.

Then the method developed for the economic evaluation and prioritization of these candidate projects is described more in details. In conclusion, an application of this method on a rural road of Sicily road network is presented.

Road network analysis

Detailed information on road network accident history are necessary to recognize roadway safety deficiencies, although by themselves are not sufficient to identify properly safety improvement solutions.

In Italy, accident data are supplied by ISTAT (Italian National Statistical Institute). ISTAT database contains rough information, not sufficient for detailed analysis that must be completed and corrected though direct examination of police crash report (Augeri, 2003).

The minimum information required for the analysis are:

- accident localization;
- date and time;
- weather and road surface conditions,
- accident type;
- number of fatalities and/or non-fatal injuries;
- number and types of involved vehicles.

Other information about geometric, functional and operational infrastructure characteristics such as road alignment, intersections layouts, cross section composition, side slopes and obstacles, traffic volume and composition, are also important and could contribute to improve the quality of results.

The first step of the process is a preliminary road network screening which permits to identify high accident rate sites though accident data analysis.

In this study, the adopted approach for the identification of high-crash locations is the Quality Control Method based on Italian draft guidelines “Criteri per la classificazione della rete delle strade esistenti ai sensi dell’art. 13, comma 4 e 5 del Nuovo Codice della Strada”, derived from Swiss norm SN 641310a.

This method allows to find those sites (road sections or intersections) showing an accident rate (AR) greater than the expected one in normal conditions. AR is defined for each road site as the ratio of the observed number of accidents and the risk exposure (given by the product of all traffic flow in the observed period for road section or intersection).

The procedure to identify blackspots is based on statistical control of quality. The control is carried out on the hypothesis of the Poisson statistical distribution of accidents that better describes the phenomenon, on the basis of which the control limits for a level of confidence (δ) can be individuated.

Therefore, sites showing an accident rate (AR_i) higher than the upper limit of confidence interval, are defined as blackspots.

In literature, there are other more accurate studies that take into account, for example, the “regression to the mean phenomenon” (Cafiso and Augeri, 2003, Higle, 1998) but for the scope of this study the reliability of results that can be achieved using Quality Control Method is acceptable.

Site investigation and countermeasures selection

After blackspots identification, a detailed study of each accident occurred at those sites is carried out in order to verify the repetition of one or more accident type, defined as dominant accident/s.

For each type of dominant accident there are different possible causes and consequently different countermeasures can be implemented individually or in combination.

After identifying dominant accident types, direct inspections of hazardous sites help to recognize safety deficiencies and to select the suitable countermeasure or set of countermeasures.

In order to compare the relative economic attractiveness of each countermeasure the following parameters must be determined:

- benefits in terms of the expected reduction of accidents number as a result of implementing a safety countermeasure, defined as Accident Reduction Factor (ARF);

- cost-related parameters, including implementation cost, operating and maintenance (O&M) cost, service life.

Regard to benefit estimation numerous studies enclose crash reduction factors that indicate the effectiveness of different crash countermeasures, based on past and current evaluations of safety improvement efforts (Lin et al., 2003). In this study, the ARFs, used for countermeasures evaluation were drawn from technical literature data (Ogden, 1996, SEMCOG, 1997, Shen et Al., 2004).

When a combination of countermeasures is applied the multiple ARFs involved can't simply be added together. Different formulas are presented in literature to determine the total ARF that reflected the aggregate effect of the countermeasures (Shen et Al., 2004).

Regard to cost estimation, implementation cost includes only the designing and building costs. In some cases, another possible measure of the effectiveness of a countermeasures is the difference between the annual average O&M costs for the location before project implementation and after implementation, as a project can reduce overall annual O&M costs.

The service life defines, instead, the time period over which a countermeasure is expected to reduce crash rates and/or crash severity, not the physic life expectancy of the countermeasure itself (e.g., FHW A, 1981a).

Obviously, the level of detail that can be reached by this methodology application is strictly related to the available information (type of data, historical data, etc).

OPTIMAL BUDGET ALLOCATION

Previous paragraphs have discussed the identification and the investigation phases that carry out a listing of safety improvement projects to be adopted at hazardous sites.

The remaining question is the choice of which projects should be implemented and in what priority order, taking into account objectives to be maximize or minimize and constraints.

In this study, the main objectives can be defined as follow:

- maximize the estimated number of reduced accidents after the implementation of specific countermeasures;
- minimize the severity of accidents after the implementation of specific countermeasure (that means maximize the estimated number of reduced accidents with highest severity level).

With the aim to estimate more accurately the benefit of a countermeasure it is necessary to take into account beyond the number also accident severity, since serious accidents involve higher costs. Hence, accidents are distinguished by type and severity level, taking into account the gravity of its possible consequences. As shown in table 1, "head on" crashes have the highest severity level due to the fact that they involve more serious damages to persons and properties while "rear end" crashes, usually, have lighter effects.

Table 1: Accident types by severity level

Accident type	Severity level
t_1 Head on	s_I
t_2 Hit pedestrian or cyclist	s_{II}
t_3 Front-lateral	s_{III}
t_4 Off road or out of control	
t_5 Hit obstacle	s_{IV}
t_6 Lateral	s_V
t_7 Rear end	

Costs, instead, are considered as constraints but they can be an objective to minimize.

Like in most transportation projects, main other objectives should be taken into account, such as speed and level of service, which would be impacted by implementing countermeasures, but at this stage they have been omitted without invalidating analysis results.

The mathematical formulation of problem is given in next paragraph.

Multiobjective combinatorial optimization model

The multiobjective optimization methodology (for a general survey on multiple objective optimization methodology see Ehrgott and Wiecek, 2005) we are proposing considers the following variables:

- x^i_t = decision variable, which is implementation of crash countermeasures associated to the accident of t^{th} type, $t=1,\dots,m$, on road site i, $i=1,\dots,n$; $x^i_t = 1$ if the countermeasures is implemented, $x^i_t = 0$ if it does not implemented;
- n^i_t= number of crashes associated to the accident of t^{th} type on road site i;
- k^i_t=crash reduction factor of accidents of t^{th} type on road site i;

- c^i_t= cost of implementation of crash countermeasures associated to the accident of t^{th} type on road site i;
- C=budget, i.e. total cost available for the implementation of all countermeasures.

Mathematically, the problem is defined as

Maximize

$\sum_{i=1}^{n} n^i_1 x^i_1 k^i_1$ (total reduction of accident of 1^{st} type)

$\sum_{i=1}^{n} n^i_2 x^i_2 k^i_2$ (total reduction of accident of 2^{nd} type)

…

$\sum_{i=1}^{n} n^i_m x^i_m k^i_m$ (total reduction of accident of m^{th} type)

Minimize

$\sum_{t=1}^{m}\sum_{i=1}^{n} c^i_t x^i_t$ (total cost)

Subject to the constraint that

$\sum_{t=1}^{m}\sum_{i=1}^{n} c^i_t x^i_t \leq C$ (budget)

Some other constraints related for example conjoint implementation of some countermeasure can be considered. Thus, if implementation of crash countermeasure x associated to the accident of t^{th} type on road site i is incompatible with implementation of crash countermeasure x' associated to the accident of t^{th} type on road site i we adjoin the following constraint

$x^i_t \, x'^i_t=0$

in such a way that at least one between x^i_t and x'^i_t must be equal to 0.

Analogously, if at least one between implementation of crash countermeasures x and x' associated to the accident of t^{th} type on road segment i must be implemented we adjoin the following constraint

$x^i_t+x'^i_t\geq 1$

in such a way that at least one between x^i_t and x'^i_t must be equal to 1.

In multiobjective optimization problem there is generally no solution which is better than all others for all the considered objectives. Thus in above multiobjective optimization problem, in general, it is not possible to find a combination of implementation of crash countermeasures (mathematically a solution vector **x**=(x^i_t,t=1,…,m, i=1,…,n) of decision variables) maximizing the total reductions of accidents of all different types and minimizing the total cost while satisfying the constraints.

In this context, two important concepts are the dominance relation and the efficient solution. A solution vector **x** dominates another solution vector **x'** if for all objectives **x** gives a not worse value than **x'** and there is at least one objective such that **x** gives a better value than **x'**.

Of course, if a solution vector **x'** is dominated by some other solution vector **x**, **x'** must not be selected. A solution vector is efficient if it is not dominated by any other solution vector. Thus we look for efficient solution vectors of the problem.

However, they in general are very numerous and therefore, in general to present the whole lists of efficient solution vectors to the decision maker is not very useful for him. The decision maker is instead interested in some information permitting him to understand the general characteristics of the Pareto efficient frontier, i.e. the set of all the solution vectors, and to advance toward a final decision.

We propose a procedure to permit to the decision maker to explore the efficient frontier in order to select a solution vector that in his view gives the most satisfactory compromise between different objectives. This procedure is based on the concepts of ideal point and nadir.

The ideal point of a multiobjective optimization problem is a vector giving the maximum value that we can obtain on each objective when we optimize it only. The ideal point in general does not correspond to a possible solution of the problem because if one maximizes an objective in general cannot optimize other objectives. The nadir of a multiobjective optimization problem is a vector giving the worst value we obtain on each objective when we optimize some other objective.

The information given by ideal point and nadir together is the following: for each considered objective they gives an interval of possible values for the multiobjective optimization problem such that the ideal point gives the optimal value one can obtain and the nadir the worst one.

The procedure we propose have the following development. Firstly we calculate the ideal point and the nadir of the considered initial problem and we propose them to the decision maker.

On the basis of the ideal point and the nadir the decision maker can adjoin other constraints on the required minimal value of considered objectives. For example he can say that he want a total reduction of accident of t^{th} type not smaller than a certain threshold r^{th} and a total reduction of accident of t'^{th} type not smaller than a certain threshold r'th.

On the basis of these new constraints which are adjoined to those ones of the original problem, a new ideal point and a new nadir are calculated and proposed to the decision maker.

If he is satisfied by the interval of objective values proposed by the ideal point and the nadir the procedure proposes him the solution vector that, satisfying all the present constraints, corresponds to the optimization of the objective considered the most important (for example the total reduction of accident of t^{th} type).

If the decision maker is not satisfied, he can introduce new constraints and the procedure restarts until the ideal point and the nadir are considered satisfactory for him. Let us remark that the constraints adjoined in each step by the decision maker are not irreversible.

If he realizes that a too higher requirement on some objective impedes to obtain satisfying values on another objective, he can reduce the requirement on the first objective. Let us also observe that the proposed methodology is strongly based on a dialogue with the decision maker and therefore it is an interactive multiobjective optimization methodology (for a general survey on interactive multiple objective optimization see Korhonen, 2005).

APPLICATION

A sample of nine sites were extracted from a Sicilian rural road (SS 417) to demonstrate the formulation of the method. The sample locations were identified using the road safety evaluation approach explained previously. For each site under consideration, table 2 shows the accidents number of those types identified as treatable. They are observed in a period of five years (1998-2001).

Table 2: Accidents data of each hazardous site

Site	Number of accidents to be treated (by type and severity)						
	t_1	t_2	t_3	t_4	t_5	t_6	t_7
	s_I	s_{II}	s_{III}		s_{IV}	s_V	
1	0	0	2	0	0	0	0
2	2	0	0	4	0	0	0
3	0	0	2	0	0	1	3
4	3	0	0	8	0	0	1
5	0	0	2	0	0	0	1
6	0	0	0	3	0	0	0
7	0	0	3	1	0	0	0
8	0	0	6	0	0	0	4
9	0	0	4	0	0	0	2

For these accident types the suitable countermeasures that potentially could reduced their frequency have been identified. In particular, five different types of countermeasures were chosen to be applied. Table 3 shows, for each countermeasures, the parameters adopted to evaluate all alternative solutions that is the accident reduction factor, the implementation cost and the service life.

Considering the finality of this application, the implementation costs are approximate and the service life is evaluative only qualitatively (Long, Medium and Short term).

Table 3: Countermeasures decision parameters

Countermeasures	Accident Reduction Factor [%]							Implementation cost [€]	Service life
	t_1	t_2	t_3	t_4	t_5	t_6	t_7		
Access control	0	20	55	0	0	20	55	1.000.000	LI
Channelization	0	0	30	0	0	30	30	150.000	L
Roundabout	70	-10	70	0	0	70	-10	400.000	L
Provide correct curve superelevation	50	0	0	50	0	50	0	15.000	M
Painted median with turn protection	0	30	25	0	0	25	25	5.000	S

The candidate projects, for each site under consideration, are shown in table 4. For every project the decision parameters are the expected number of reduced accidents after its implementation (distinguished by type and severity level) obtained by the product between the observed accidents and the ARF, implementation cost and service. At site 8, two alternative projects are proposed.

Table 4: Decision parameters for each candidate projects

Candidate projects	Expected number of reduced accidents after countermeasures implementation (by type and severity)							Implementation cost [€]	Service life
	t_1	t_2	t_3	t_4	t_5	t_6	t_7		
	s_I	s_{II}	s_{III}		s_{IV}	s_V			
Access control at site 1	0,00	0,00	1,10	0,00	0,00	0,00	0,00	1.000.000	L
Provide correct curve superelevation at site 2	1,00	0,00	0,00	2,00	0,00	0,00	0,00	15.000	M
Roundabout at site 3	0,00	0,00	1,40	0,00	0,00	0,70	-0,30	400.000	L
Provide correct curve superelevation at site 4	1,50	0,00	0,00	4,00	0,00	0,00	0,00	15.000	M
Roundabout at site 5	0,00	0,00	1,40	0,00	0,00	0,00	-0,10	400.000	L
Provide correct curve superelevation at site 6	0,00	0,00	0,00	1,50	0,00	0,00	0,00	15.000	M
Painted median with turn protection at site 7	0,00	0,00	0,75	0,00	0,00	0,00	0,00	5.000	S
Roundabout at site 8	0,00	0,00	4,20	0,00	0,00	0,00	-0,40	400.000	L
Channelization at site 8	0,00	0,00	1,80	0,00	0,00	0,00	1,20	150.000	L
Access control at site 9	0,00	0,00	2,20	0,00	0,00	0,00	1,10	1.000.000	L

The multiobjective combinatorial optimization model, previously described, is applied for allocate a fixed amount of budget (2.000.000 €) between the competing sites.
Considering only budget constraint, 432 possible projects combinations were generated by solving the model. For this initial problem, the model gives the ideal point and the nadir that give an interval of possible values for the multiobjective optimization problem such that the ideal point gives the optimal value one can obtain and the nadir the worst one. These values are shown in table 5.

Table 5: Ideal point and nadir of the exemplary application considering only budget constraint

Constraints		Ideal point	Nadir
Implementation cost [€]	2.000.000	5	1850
Number of reduced accidents of severity s_I	-	2.5	0
Number of reduced accidents of severity s_{II}	-	0	0
Number of reduced accidents of severity s_{III}	-	16.05	0.75
Number of reduced accidents of severity s_{IV}	-	0	0
Number of reduced accidents of severity s_V	-	2.7	0
Long term service life	-	1	0
Medium term service life	-	3	0
Short term service life	-	3	0

On the basis of the ideal point and the nadir the decision maker can adjoin other constraints on the required minimal value of considered objectives. For example, he establishes that the expected number of reduced accidents of type 1 and type 3 are, respectively, equal to 2 and to 15. In this case 5 possible combinations were generated, as shown in table 6.

Table 6: Possible projects combinations obtained adjoining two other constraints

Candidate projects	Possible projects combinations				
	A	B	C	D	E
Access control at site 1					
Provide correct curve superelevation at site 2	X	X	X	X	X
Roundabout at site 3	X		X		X
Provide correct curve superelevation at site 4	X	X	X	X	X
Roundabout at site 5		X		X	X
Provide correct curve superelevation at site 6	X	X	X	X	X
Painted median at site 7			X	X	X
Roundabout at site 8	X	X	X	X	
Channelization at site 8					X
Access control at site 9	X	X	X	X	X

On the basis of these new constraints which are adjoined to those ones of the original problem, a new ideal point and a new nadir are calculated and proposed to the decision maker (table 7).

Table 7: Ideal point and nadir of the exemplary application obtained adjoining two other constraints

Constraints		Ideal point	Nadir
Implementation cost [€]	2.000.000	1.845.000	2.000.000
Number of reduced accidents of severity $s_{I.}$	2	2.5	2.5
Number of reduced accidents of severity $s_{II.}$	-	0	0
Number of reduced accidents of severity $s_{III.}$	15	16.05	15.05
Number of reduced accidents of severity $s_{IV.}$	-	0	0
Number of reduced accidents of severity $s_{V.}$	-	2.6	1.1
Long term service life	-	1	0
Medium term service life	-	3	3
Short term service life	-	4	3

If the decision maker is satisfied by the interval of objective values proposed by the ideal point and the nadir, he can chose the projects combination that he prefers evaluating in details the values assumed by each objective. The objectives overall values of each project combination are shown in table 8.

Table 8: Objectives values corresponding to each projects combination

Objectives	Possible projects combinations				
	A	B	C	D	E
Implementation cost [€]	1.845.000	1.845.000	1.850.000	1.850.000	2.000.000
Number of reduced accidents of severity $s_{I.}$	2,5	2,5	2,5	2,5	2,5
Number of reduced accidents of severity $s_{II.}$	0	0	0	0	0
Number of reduced accidents of severity $s_{III.}$	15,3	15,3	16,05	16,05	15,05
Number of reduced accidents of severity $s_{IV.}$	0	0	0	0	0
Number of reduced accidents of severity $s_{V.}$	1,1	0,6	1,1	0,6	2,6

If the decision maker is not satisfied, he can introduce new constraints putting, for example, the expected number of reduced accidents of type 5 equal to 2.6 that represents the ideal point for this objective. Adjoining this constraint the model generates only one possible projects combination, corresponding to E combination described in tables 6 and 8.

The procedure can restart until the decision maker considers satisfactory the ideal point and the nadir. In fact, if he realizes that a too higher requirement on some objective impedes to obtain satisfying values on another objective, he can reduce the requirement on the first objective.

CONCLUSION

In this paper, a decision support system for resources allocation in road safety improvement programs has been presented. This tool helps the decision maker in selecting and prioritizing different candidate countermeasures at hazardous sites.

The methodology developed is a multiobjective combinatorial optimization model that considers as primary objectives the lowering the expected number of accidents of different types and severity and the minimization of the cost, considering budget constraint.
The joint consideration of a multiple objective optimization and of discrete 0-1 variables is the major distinctive feature of the proposed approach in comparison with other competitive methodologies presented in literature.
In order to demonstrate the effectiveness of the proposed model an application has been presented. In particular, analyzing obtained results some interesting features are highlighted.
The decision parameters, included in the analysis, are easily obtainable and comprehensible to the decision maker.
The decision process is reversible, that is if the decision maker realizes that a too higher requirement on some objective impedes to obtain satisfying values on another objective, he can reduce the requirement on the first objective.
In conclusion, this methodology does not provide decisions but is strongly based on a dialogue with the decision maker and therefore it is an interactive multiobjective optimization methodology.

REFERENCES

Augeri M.G., Cafiso S., La Cava G. (2003), *"Road safety evaluation using GIS for accident analysis"*, *First International Conference on Sustainable Planning & Development,* 1-3 October 2003 Skiatos Island, Greece

Cafiso S., Augeri M.G, (1997) *"Statistical analysis of accidents on italian highways"* , XIIIth IRF World Meeting, Toronto (Canada), giugno 1997

Chowdhury M.A., Garber N.J., Li D. (2000), *"Multiobjective methodology for highway safety resource allocation",* Journal of Infrastructure Systems, 6(4), ASCE

Chowdhury M.A., Tan P., William S.L. (2002), *"An interactive multiobjective decision support framework for transportation investment"* Midwest Regional University Transportation Center - College of Engineering Department of Civil and Environmental Engineering, University of Wisconsin, Madison - United States Department of Transportation

"Criteri per la classificazione della rete delle strade esistenti ai sensi dell'art. 13, comma 4 e 5 del Nuovo Codice della Strada" – Rapporto finale del CNR – marzo 1998.

Ehrgott M., Wiecek M.M. (2005), *"Multiobjective programming"*, in: J. Figueira, S. Greco, M. Ehrgott (eds), Multiple Criteria Decision Analysis, State of the Art Surveys, Springer, pp. 667-722

Ehrgott M., Gandibleux X. (2002), *"Multiobjective combinatorial optimization"*, in: M. Ehrgott, X. Gandibleux, (eds), Multiple Criteria Optimization – State of the Art Annotated Bibliographic Surveys, Kluwer Academic Publishers, Boston, MA, pp. 369-444

FHWA (1981), *"Highway Safety Improvement Program (HSIP) User's Manual*", FHW A-TS-81-218. National Highway Institute, Federal Highway Administration

Frohwein H.I., Lambert J.H., Haimes Y.Y., Schiff L.A. (1999), *"Multicriteria framework to aid comparison of roadway improvement project"*, Journal of Transportation Engineering, 125(3), ASCE

Higle J., Witkowski J. (1998), *"Bayesian Identification of Hazardous Location",* Transportation Research Record n. 1185

Iowa Department of Transportation (1997), *"SEMCOG Traffic Safety Manual"*, Southeast Michigan Council of Governments

Korhonen P. (2005), *"Interactive Methods"*, in: J. Figueira, S. Greco, M. Ehrgott (eds), Multiple Criteria Decision Analysis, State of the Art Surveys, Springer, pp. 643-665

Lambert J.H., Baker J.A:, Peterson K.D. (2003), *"Decision aid for allocation of transportation funds to guardrails"*, Accident Analysis and Prevention 35, Elsevier

Lin F., Sayed T., Deleur P. (2003), *"Estimating safety benefits of road improvements: case based approach"*, Journal of Transportation Engineering, 129(4), ASCE

Ogden K.W. (1996), *“Safer roads: A guide to road safety engineering”*, University Press, Cambridge

Pal R., Sinha K. (1998), *“Optimization approach to highway safety improvement programming”*, Transportation Research Record 1640, TRB, National Research Council, Washington, D.C.

Shen J., Rodriguez A., Gan A., Brady P. (2004), “Development and application of crash reduction factors: a state-of-the-practice survey of State Departments of Transportation”, TRB Annual Meeting.

VSS SN 641310a *“Analyse des accidentes de la circulation”*, April 1983.