AN OPTIMIZING APPROACH FOR HIGHWAY SAFETY IMPROVEMENT PROGRAMS

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ABSTRACT

AN OPTIMIZING APPROACH FOR HIGHWAY SAFETY IMPROVEMENT PROGRAMS

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Improvements to highway safety have become a high priority for highway authorities due to increasing public awareness and concern of the high social and economic costs of accidents. However, satisfying this priority in an environment of limited budgets is difficult. It is therefore important to ensure that the funding available for highway safety improvements is efficiently utilized. In attempt to maximize the overall highway safety benefits, highway professionals usually invoke an optimization process.

The objective of this thesis study is to develop a model for the selection of appropriate improvements on a set of black spots which will provide the maximum reduction in the expected number of accidents (total return), subject to the constraint that the amount of money needed for the implementation of these improvements does not exceed the available budget. For this purpose, a computer program, BSAP (Black Spot Analysis Program) is developed. BSAP is comprised of two separate, but integrated programs: the User Interface Program (UIP) and the Main Analysis Program (MAP). The MAP is coded in MATLAB and contains the optimization procedure itself and performs all the necessary calculations by using a Binary Integer Optimization model. The UIP, coded in VISUAL BASIC, was used for monitoring the menu for efficient data preparation and providing a user-friendly environment.

Keywords; traffic safety, accident black spot, branch-and-bound, binary integer programming, highway safety improvements, optimal fund allocation.

ÖZ

KARAYOLU GÜVENLİĞİ İYİLEŞTİRME PROGRAMLARI İÇİN BİR OPTİMİZASYON YAKLAŞIMI

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Kazaların artan sosyal ve ekonomik maliyelerine kamuoyunun ilgisinin artmasıyla birlikte, karayolu güvenliği için yapılan iyileştirmeler, karayolu uzmanları için öncelikli hale gelmiştir. Ama, sınırlı bir bütçe ile bu önceliği sağlamak güçtür. Bundan dolayı, karayolu güvenliği iyileştirmeleri için var olan fonlardan etkin bir şekilde yararlanılmasını sağlamak gerekir. Karayolu uzmanları, karayolu güvenliğinin faydalarını maksimize etmek için genellikle optimizasyon yöntemlerine başvururlar.

Bu tez çalışmasının amacı, bir grup kara noktadaki iyileştirme alternatiflerinin optimum seçimini, beklenen kaza sayılarındaki azalmayı maksimize edecek şekilde ve seçilen bu iyileştirmelerin uygulanması için gerekli olan projelerin maliyetleri toplamının mevcut bütçeyi aşmaması koşulunu sağlayabilecek bir bilgisayar programı geliştirmektir. Bu çalışmanın sonucu olarak “Kara Nokta Analiz

Programı (BSAP)" adı verilen bir bilgisayar programı oluşturulmuştur. BSAP iki ayrı fakat birbirini tamamlayan programdan oluşur. Bunlar, Kullanıcı Ara Yüzü ve Asıl Analiz Programlarıdır. Asıl Analiz Programı optimizasyon sürecini içinde barındırır ve gerekli hesaplamaları MATLAB dilinde yazılmış olan, İkili Tamsayı Programlama (Binary Integer Programming) yöntemini kullanarak yapar. Kullanıcı Ara Yüzü Programı veri girişini düzenlemek ve kullanım kolaylığı sağlamak amacıyla VISUAL BASIC dilinde yazılmıştır.

Anahtar kelimeler; trafik güvenliği, kaza kara noktası, böl-ve-sınırla, ikili tamsayı programlama, karayolu güvenlik iyileştirmeleri, optimum fon dağılımı.

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CHAPTER I

INTRODUCTION

Traffic accidents cause fatalities, physical injuries, property damages, as well as highway congestion. Although the records of General Directorate of Highways (KGM) gives smaller number of fatalities, in Turkey it is estimated that more than nine thousand persons are killed in road accidents every year [1]. In other words, around 25 people were killed every day on Turkish roads. In addition to fatalities and injuries, accidents cause huge economic losses to our country. It has been estimated that the socio-economic costs of road accidents amount to 2,000,000 billion TL per year (1999 price level) [1].

Recognizing the traffic safety problem and the importance of reducing the frequency and severity of road accidents, detailed analysis should be carried out to determine which section of a road is a hazardous location. A hazardous location can be defined as any section or spot that exhibits an abnormally high accident potential. The higher potential for accidents is usually expressed in terms of any accident measure such as accident frequency, rate, severity or a combination. Road safety can be improved by identifying and evaluating features that make sites hazardous and implementing countermeasures to eliminate them. There are four basic strategies for accident reduction through the use of countermeasures [6]:

Single site (black spot programs) - the treatment of specific types of accident at a single location;

Mass action plans - the application of a known remedy to locations with a common accident problem;

Route action plans - tile application of known remedies along a route with a high accident rate;

Area with schemes - the applications of various treatments over a wide area of town/city, i.e. including traffic management and traffic claming (speed reducing devices).

Every country develops its own highway safety improvement program to reduce the losses due to traffic accidents. When the improvement alternatives to be applied to every candidate black spot of the country are considered, the large number of possible combinations requires a methodology for prioritizing them, so that the return from the utilization of a limited budget is maximized. There are several approaches to setting priorities for selecting highway improvement and maintenance projects. Optimal allocation of funds to highway improvements is a complicated but extremely important task. A procedure based on Benefit-Cost Ratio (BCR) rankings of projects has been in use for many decades for highway safety budget allocations. However, this procedure is not capable of dealing explicitly with the problem of the optimal allocation of resources to maximize safety effectiveness since the solution is only approximate and typically fails to use the entire budget.

Given a set of black spots and a set of recommended improvements for each of them, the problem addressed in this thesis is to allocate an available budget among these black spots, in order to maximize the expected benefits achieved through the implementation of these projects. In other words, a computer program seeking for the answer to the question: “What improvement projects should be undertaken in what locations so that the safety effectiveness is maximized?” is to be developed. For an efficient utilization of the resources, it is necessary to evaluate alternative projects for all black spots simultaneously. For this purpose, a Binary Integer optimization model is formulated and solved by Branch-and-Bound Algorithm. As a result of this study a computer program; BSAP (Black Spot Analysis Program) is developed. BSAP is comprised of two separate but integrated programs: the User Interface Program and the Main Analysis Program. The Main Analysis Program contains the optimization procedure itself and performs all the necessary calculations. The Main Analysis Program is coded in the MATLAB language due to its efficiency in performing scientific calculations. However, the MATLAB language is very poor in terms of user interface. Thus, the user interface is handled through the User Interface Program so that the Main Analysis Program is transparent to the users, i.e., the users do not work directly with the Main Analysis Program. The User Interface Program is coded in VISUAL BASIC language, which is more capable at providing a user-friendly environment through the use of windows, screens, and menus.

Benefit and cost estimates of improvement projects must be known in order to find the optimal budget allocation. The determination of costs of projects is a rather simple process and can be estimated quite accurately. Cost estimates consist of the total value of the construction cost and any additional operating and maintenance cost and rely on the results of similar projects recently completed or the expertise of those who have been involved in similar projects. On the other hand, benefit estimation is a very difficult and complicated process. To estimate the benefits Accident Reduction Factors (ARFs), material and immaterial damage costs and corrections on police records due to fatalities that do not occur at the incident place have to be taken into account. These values are obtained from the statistical analysis of past accidents and the results of previously implemented projects. For the case of Turkey, since there were no studies carried out for the development of these values, the use of average values based on research of other nations and corrected to account for the conditions in Turkey were inevitable. In the concept of Traffic Safety Project, Sweroad (Swedish National Road Consulting AB) prepared a Road Improvement and Traffic Safety Program for Turkey with substantial reports. Most of the default values (accident costs, accident correction factors, etc.) used in BSAP, which can be revised with the new ones whenever appropriate data is available, are based on the results of these reports.

CHAPTER II

IMPROVEMENT PROCESS FOR ACCIDENT BLACK SPOTS

Accident Hazardous Location is a certain site at which there is a tendency for road accidents to cluster together, commonly termed as ‘Accident Black Spot’ [6]. A highway safety project is the process of applying one or more countermeasures to reduce identified or potential safety deficiencies at a site (spot or section) on the highway or its environs. The improvement process for accident black spots is composed of several activities as shown in Figure 2-1.

Identification of Black Spots is the procedure of using accident records to identify roadway locations showing high accident hazard. Any method that identifies locations with an abnormally high number of accidents can successfully be used to find potential project locations.

Diagnosis is the process of analyzing accidents in high-hazard locations by conducting engineering studies. At this step accident history and site conditions are reviewed for identification of items that may be contributing or causing accidents.

Countermeasures Selection is a methodical analysis which uses accident patterns and other information gathered in "Identification" and "Diagnosis" steps to identify possible accident countermeasures for the candidate black spots. Countermeasures are highway safety treatments or corrective activities designed to alleviate a safety problem or a potentially hazardous situation [7]. Safety improvements may range from the installation of a single advance warning sign; to the implementation of several safety improvements at a single site.

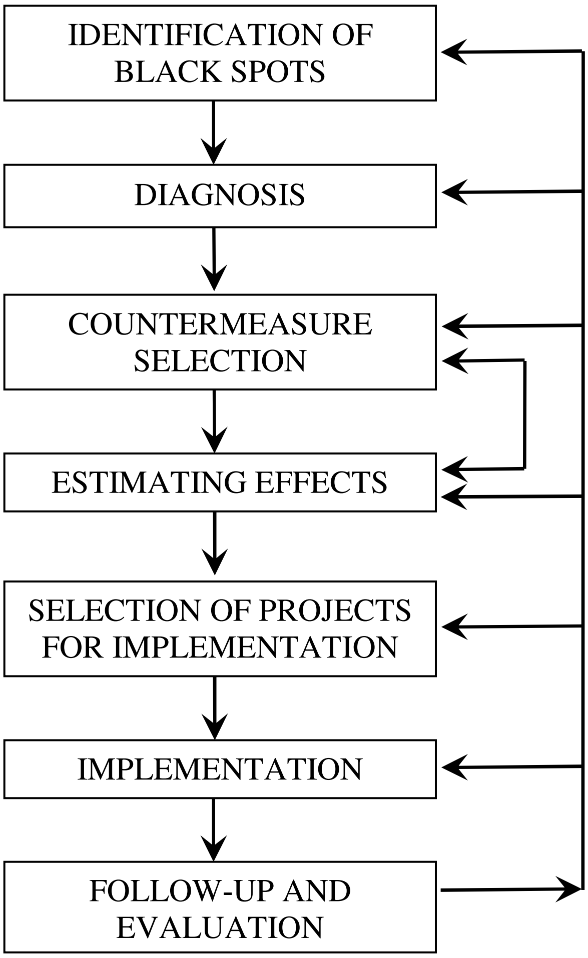

Figure 2-1 Improvement Process for Accident Black Spots [5]

Estimating Effects is the process of estimating the accident reductions likely to result when the countermeasure is applied. These estimations have to be based on the knowledge of the Accident Reduction Factors (ARFs) of different countermeasures. In general ARFs are obtained from the results of completed highway safety improvement projects. Useable and reasonable ARFs can only be developed if the evaluation phases of these projects are successful.

Selection of Projects for Implementation is the process of finding the optimal investment plan, according to expected reductions in accidents, cost of countermeasures and budget restrictions. In other words it is the decision phase for selecting black spots to be improved and the countermeasures for them.

Implementation is the actual realization of the prioritized measures included in the highway safety improvement budget [5].

Evaluation is the last step. Prior to the evaluation process the outcome of countermeasure applications should be monitored. The success levels of countermeasure applications are assessed through this step. The applied countermeasures must be well documented in order to carry out successful before-and-after studies. Evaluation is an assessment of the value of an activity as measured by its success or failure in achieving a predetermined set of goals or objectives [7]. Evaluation involves obtaining and analyzing the quantitative information on the benefits and costs of implemented highway safety improvements. Estimates of benefits and costs increase the ability of planning and implementing future highway safety improvements which have the highest probability for success. The Evaluation step provides information on whether and to what extent past improvements have reduced accidents or accident severity. ARFs are developed based on the results of this step.

This improvement process relies mainly on the availability of accurate and complete records. The availability, completeness and accuracy of accident and traffic exposure data are essential for the black spot improvement process. Inaccurate or incomplete accident information, or unreported accidents introduce uncertainty to the result of the evaluation study.

CHAPTER III

ACCIDENT REDUCTION FACTORS (ARFS)

The principal goal in making improvements to black spots is to reduce the number of accidents and in particular their severity. In evaluating countermeasures associated with road safety projects, the overall effectiveness is normally based on the benefits that are anticipated from a reduction in the frequency and/or severity of accidents. Therefore, the heart of a highway safety management system lies in the ability to estimate the extent of reduction in the number of accidents. This reduction is estimated using Accident Reduction Factors (ARFs) which show the effectiveness of safety improvements.

ARFs are based on the knowledge built up from research and follow-ups of different locations where the measures have been applied. Building up knowledge will take many years and a reliable common databank is required.

Several nations have developed ARFs for various road improvements based on information from previous safety studies. Also a wide range of improvement types have been included in various research reports with sufficient detail to apply

ARFs. On the other hand applicability of these estimates to Turkey is not certain. Since no past studies were carried out in Turkey on this subject, the use of other nations' estimates on ARFs is inevitable.

The default ARF estimates used in BSAP are taken from the research study titled "Development of Accident Reduction Factors" by Agent et al. [11]. This research gives average ARFs for various safety improvements by combining a review of 61 different reports and a survey employed in 43 states in the US. Since this study is based on a wide range of ARF estimates, it provides us with results that can be generalized for common usage. These generalized estimates which are used as default values in BSAP are listed in Appendix-C.

A particular highway improvement often has different reduction effects on fatal, injury and PDO accidents. For this reason; BSAP was prepared to have the capability of using different reduction factors for fatal, injury and PDO accidents when the corresponding ARFs are available. If there is no value identified for fatal and/or injury type of accidents, the default factors for PDO accidents will also be used for them. The user has the chance to change default ARFs as new research and evaluation results become available.

3.1- Development of Accident Reduction Factors

Estimating the reduction in number of accidents is a key element in estimating the benefits that result from a particular improvement or set of improvements on a black spot. When the effectiveness of given countermeasures are known or can be quantified from ARFs, these estimates will be incorporated into the economic analysis for selection of appropriate countermeasures to get the highest benefit.

Traffic accidents are rare and random events and shows statistical variations. Research has shown that the numbers of accidents at a particular site will vary widely from year to year. This means that comparison between before and after accident numbers at improved sites must be made with respect to a fixed time period which should be more than one year. For the development of ARFs, most of the research reports recommend the use of a period of three years if data is available and no significant changes in external factors have occurred [4, 7, 18, 19 and 20]. The main reason of not using more than three years' accident data is to avoid the effects of changes in factors like; traffic flow, behavior, geometry or surface conditions.

The following three types of before-and-after methods for the development of ARFs exist in literature:

1. Simple before-and-after study,
2. Before-and-after study with comparison (control) group method, and
3. Before-and-after study with Empirical Bayes (EB) method.

Each method attempts to accomplish the same objective. That is, to compare the accidents after project implementation with the expected accidents where no improvement had been implemented.

3.1.1- Simple Before-and-After Study

In Simple Before-and-After Study, the safety effectiveness of countermeasure is determined by the difference in the number of accidents occurring before the improvement with those occurring after. The average reduction rates can be developed separately for rural and urban areas if sufficient data are available. There are two basic assumptions involved in this method:

1. without the introduction of the highway safety improvement accident numbers will continue at the same level (see Figure 3-1), and
2. the accident numbers after project implementation is attributable to the improvement.

If the before period exhibits a definable trend, it may be possible to modify the first assumption by using linear regression (see Figure 3-2).

Most of the existing ARFs in practice have been estimated on this simple approach [11, 20]. Unfortunately, such a simple comparison often leads to inaccurate and potentially misleading conclusions because the method is known to be subject to Regression-to-the-Mean factor.

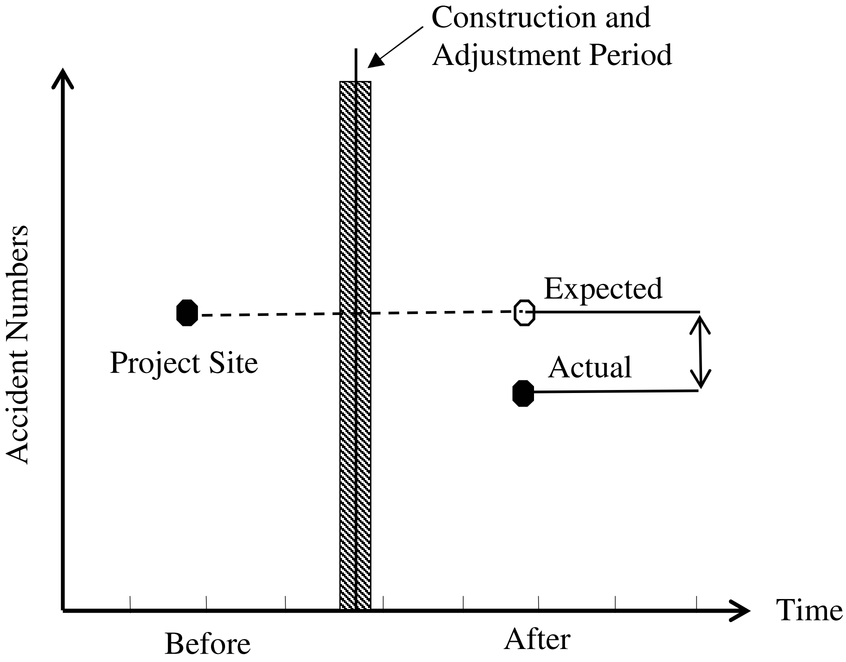

Figure 3-1 Simple before-and-after study [11].

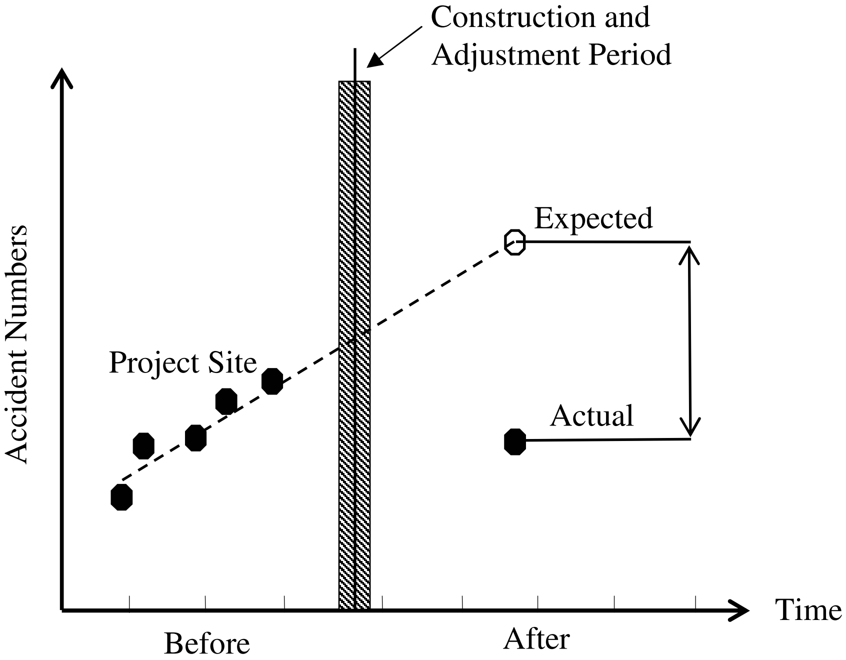

Figure 3-2 Simple before-and-after study (trend analysis) [11].

Regression-to-the-Mean, also known as a “regression artifact” or “bias by selection”, is a statistical phenomenon that occurs whenever a non-random sample is selected from population [20]. It might seem that the improvement has reduced the number of accidents at a certain spot, although the real reason for this reduction can be the fact that the number of accidents at that location is in a tendency to regress to the mean so that a period with a high number of accidents will be followed with a period of a low number accidents. This implies that the accident rates would have been reduced to a lower level even if nothing was done to the site. Therefore, if a safety improvement is implemented and a lower accident rate is found during the after period of the study, the reduction in accident rates may not result from the safety improvement. Thus, ARFs developed from such a site with Simple Before-and-After studies may overestimate the actual effect of the safety improvement.

Council et al. (35) shows the effect of Regression-to-the-Mean with a hypothetical example illustrated in Figure 3-3. In the figure the number of accidents ranges from 8 to 32, with an average of 20. It can be seen that, if an improvement is constructed in 1973 in response to the large number of accidents that occurred in 1972, the results would have shown a 28 percent of accident reduction after treatment. While the treatment may have some effect, some portion of the accident reduction was due to the Regression-to-the-Mean and not the improvement. Consequently, the effectiveness of the treatment will be overestimated. Failing to account for the Regression-to-the-Mean effect in an analysis could thus generate statistically significant results for treatments that are actually ineffective [20].

This Regression-to-the-Mean phenomenon can be properly evaluated by using control sites or the Empirical Bayes method to determine what portion of the accident reduction results from the safety improvement.

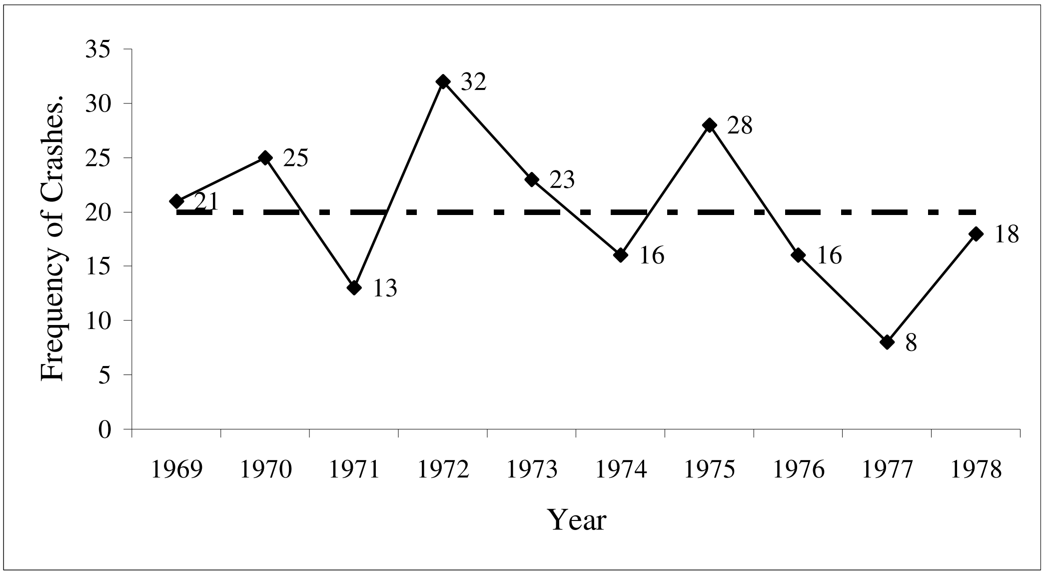

Figure 3-3 Regression-to-the-Mean example [20].

3.1.2- Before-and-After Study with Comparison (Control) Group Method

Some researchers believe that simple comparison of before accidents to the number of after accidents does not provide accurate results due to a bias, making the improvements to appear more effective than they really are [18, 19, and 20]. Making the assumption that the number of accidents that can be expected to occur without treatment is equal to the number of accidents that occurred prior to the treatment is erroneous and may lead to biased results [18]. The best way to debias the result is to use control locations similar to the locations being improved. The Before-and-After with Control Group Method compares the percent change in the accident numbers at the project site (test site) with the percent change in the accident numbers at similar sites (control sites) without the improvement for the same time period. The selection of control sites is the most difficult aspect of this method. Figure 3-4 shows the diagrammatical representation of before-and-after study with comparison groups.

Shen and Gan [20] suggested that a comparison group should meet the following requirements:

1. The length of before and after periods for the treatment and the comparison group should be the same;
2. It should be confident that the change in the factors that affected safety is similar in both groups;
3. The number of accidents in the comparison group should be sufficiently large comparing to the treatment group.

Under these assumptions, it can be assumed that the number of accidents before and after the implementation of countermeasures in the treated sites, if the treatment had not been improved, would have been in the same proportion as in the comparison group.

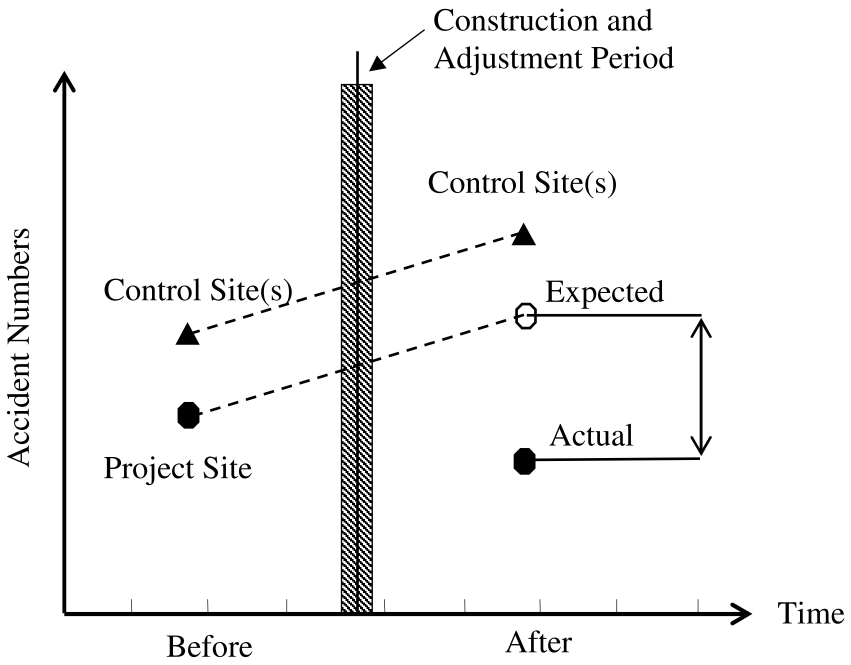

Figure 3-4 Before-and-after study with comparison group [7].

This method yields more accurate results provided that control sites have characteristics (traffic flow, physical characteristics, etc…) similar to the locations those have been improved. However, a suitable number of locations may not always be possible.

3.1.3- Before-and-After Study with Empirical Bayes Method

In order to adjust Regression-to-the-Mean bias, before-and-after study with Empirical Bayes (EB) has been developed. The EB method uses data from a group of similar comparison sites, as well as the before data from the treated site, to estimate how many accidents would have occurred at the treated site had no improvements been made. Formulation of this method is shown in Equation (3-1) [20].

$$\text{Expected accidents at a treated site} = \text{Weight } x \text{ Accidents expected at reference sites} + (1-\text{ Weight}) \, x \text{ Actual accidents at a treated site} \tag{3-1}$$

Where; $0 \leq \text{Weight} \leq 1$

Thus, the expected after accidents with no improvement at the treatment sites is a function of how the 'weight' assigned to the accidents expected on reference sites. 'Weight' factor can be found by statistical analysis (see Shen and Gan [20]).

The method is based on the following three assumptions [21]:

1. The number of accidents at any site follows a Poisson distribution.

2. The means for a population of systems can be approximated by a Gamma distribution.

3. Changes from year to year from different factors are similar for all reference sites.

Al-Masaeid [19] compared the performances of simple before-and-after and EB methods with results obtained by comparison group methods. Results of his analysis indicate that the Simple Before-and-After Method overestimated the effectiveness of safety improvements and led to erroneous conclusions at specific sites. On the other hand; the comparison group method and the EB method provided results comparable to each other. If there is a difficulty in identifying a suitable and large number of comparison locations, EB Method gives more accurate results when compared to Simple Before-and-After Study [19, 20, 21].

3.2- ARFs for Combination of Countermeasures

When several types of improvements are included in a specific project, the factors for these improvements must be combined. A key issue to be addressed is the determination of appropriate ARFs for the combinations of countermeasures. It is well established that accident reduction percentages should not be combined in additive fashion [11, 25]. If one countermeasure reduces accidents by 25 percent and another by 15 percent, their combined effect will not be 40 percent, but would be expected to be less than 40 percent and higher than 25 percent.

Agent et al. [11] recommends that; the largest reduction factor should be considered first with a reduction determined and then any other reductions should be applied to the remaining accidents. The study also suggests a formula which can be used to determine a combined reduction factor for several improvements;

$$ARF_C = 1 - [(1-ARF_1)\,(1-ARF_2)\,(1-ARF_3)] \tag{3-2}$$

Where; ARF_C is the combined accident reduction factor and

ARF_1, ARF_2, ARF_3 are the individual reduction factors

When Equation (3-2) is applied to the reduction values mentioned above;

$$ARF_C = 1 - [(1-0.25)\ (1-0.15)] = 0.36$$

Therefore, combined accident reduction factor of these two countermeasures is equal to 36 percent. In BSAP, when such a combination of countermeasures is selected for a site, this combined countermeasure alternative is included in budget optimization as a new alternative with its reduction factor computed as outlined above.

Equation (3-2) is valid, if the service lives are equal and the opening years are the same for the combined countermeasures. But in practice, usually service lives and opening years of countermeasures are different. To deal with this situation, BSAP compares both the service lives and the opening years of the combined countermeasures. If the service periods of these candidate countermeasures overlap, the combined reduction factor calculated by Equation (3-2) is used; otherwise, the reduction factors of countermeasures will be used in sequential manner.

CHAPTER IV

ACCIDENT COSTS AND CORRECTIONS

The use of cost data associated with reductions in injuries and fatalities is a critical component of the benefit-cost analysis used to asses the effectiveness of safety improvements. In order to determine the effect of safety improvements, a measure of reduced injuries and fatalities must be associated with the proposed safety improvements. To make this association, a cost for each of the reduced injuries and fatalities must be calculated in monetary values. Use of these monetary values for fatalities and for various levels of injuries in combination with accident reduction factors permits an overall assessment of the effectiveness of safety improvements.

4.1- Value of Statistical Life (VOSL)

Accidents cause production losses in the case of injury or fatality. Evaluation of accident costs can help in allocating road safety budgets more efficiently and rationally. The costs of fatal accidents are difficult to calculate since the damage done by fatalities is ‘immaterial’. It is important to assign monetary values to fatalities to be able to include this most harmful accident type in the evaluation of accident costs. In the evaluation of fatal accident costs the availability of an estimate of the economic Value of Statistical Life (VOSL) is pivotal. VOSL in road safety is the value of saving of one life in a large population of road users.

There are two methods for the evaluation of value of statistical life; Human Capital and Willingness-to-Pay (WTP). Actually, the WTP approach contains the results of the Human Capital approach in it, as will be explained in section (4.1.2).

4.1.1- Human Capital

The Human Capital approach consists of valuing damage (death, injury) in accordance with its economic impact, i.e. in terms of production loss, remedial costs (healthcare in the case of injury) and material damage. This method is purely based on the future income and the costs of health care for accidents' victims. The production loss is the value of the amount of goods and services that a person would have been able to produce if that person had not experienced an injury or fatal accident. The present value of production can be calculated using the Serial Present Worth (SPW) factor:

$$PVOP = W * \frac{(1+0.01*i)^A - 1}{i*(1+0.01*i)^A} \quad or \quad PVOP = W(SPW/i/A) \qquad (4\text{-}1)$$

Where:

$PVOP$ = present value of production,

W = average annual income,

A = average years of production lost due to the fatal accident,

$i\ (\%)$ = $(d - p)$, real interest rate,

$d\ (\%)$ = discount rate (capital recovery factor),

$p\ (\%)$ = expected yearly average production increase in the general economy

KGM uses 35 years as average years of production lost (A) due to fatal accidents, which is also used as default value in BSAP. According to the accident statistics of 1998, the average age of fatalities seems to be somewhere between 30-35 years [4], which is in line with the 35 years figure used by KGM. As the average annual income, like suggested by Sweroad, Gross Domestic Product (GDP) per capita is used in BSAP which must be updated every year by the user.

The value of human life is calculated by discounting the earnings of the victim to its present value which implies that the value of human life saved at different years will not be the same. Therefore the argument can be made that a life saved 35 years in the future is worth no less than a life saved next year. This is correct, but the use of present worth factor to convert future accident reduction benefits to their present value is only an economic convention to allow appropriate comparisons of present expenditures and future benefits. Consider, for example, an alternative procedure that performs the economic analysis on annualized basis, rather than a net present value basis. The annual accident cost savings would be unchanged and construction costs would be annualized using discount rate. The net annualized benefits would be computed as the annual accident cost savings minus the annualized construction cost. This approach involves no moral dilemma, because the accident cost savings are constant, but it produces result that will provide exactly the same project ranking as the net present value approach.

More advanced methods, which use injury age and sex of the injured victims exist in literature, but due to lack of necessary data in KGM records, the simple method given as Equation 4.1 is used in BSAP. Users can update all of the default values used in VOSL calculations according to accident statistics or changes in economy.

The European Union currently uses a value of 1 million euros per human life in safety benefit-cost analysis which is known as the “one-million-euro rule” [8]. The use of this specific value also implies that a policy measure or project leading to a reduction of 1 fatality, results in a reduction of 8 serious injuries, 26 slight injuries and 211 damage-only accidents [8]. The one-million-euro rule does not take into account the willingness-to-pay (risk value) for avoiding pain and suffering.

4.1.2- Willingness-to-Pay Approach (WTP)

The Willingness-to-Pay Approach consists of estimating the value; also known as the risk value; that individuals attach to human life by means of surveys aimed at determining the amount of money that individuals would be prepared to pay to reduce the risk of loss of life [4]. The same principle applies to injury, where an attempt is made to determine the monetary value which individuals would be prepared to pay to reduce the risk of injury. To ensure that economic damage is also taken into account, the following are added to the value thus obtained: net production loss, medical costs, administrative costs, etc., which are precisely the values of Human Capital. In other words; The WTP value can also be said to reflect the pain and suffering of the victim as well as the grief and sorrow of his family and friends [4]. The WTP approach yields values far higher than those based solely on the value of Human Capital.

The WTP method is based on individual preferences. These preferences can be determined by Stated or Revealed Preference Methods. The Stated Preference Method uses a questionnaire. In this, the respondents are asked how much they are willing to pay for certain goods (such as a reduction in the fatality risk). Selected groups within the population are given a questionnaire describing situations in which the individual has the choice of spending a certain sum of money or exposing himself to a given risk. The Revealed Preference Method estimates the value of the good by relating it to goods on the market. For example, the price of an airbag can be related to the risks on a fatal accident with and without an airbag. The value of the reduction in fatality risk can thus be calculated.

Blaeij et al. [8] studied literature on the economic valuation of statistical life in road safety. They collected the results from 25 different studies with 71 VOSL estimates in road safety and analyzed them using statistical methods. Results indicate that the VOSL is affected by the presented initial risk level and the reduction of this risk as the result of a safety improvement. It can be expected from the results that the WTP increases with increasing size of the risk reduction. In other words: the more ‘difference it makes’, the more people are willing to pay. It can also be expected that the WTP for a given reduction in fatality risk increases with increasing level of the initial risk, which indicates that the higher the initial fatality risk, the more money people are willing to pay for a given reduction in this fatality risk. The WTP for a given reduction in probability of a fatal accident is an increasing function of the initial risk level. Figure 4-1 shows the relation between the WTP for a given reduction in fatality risk and the initial risk levels. When the risk of involvement in a fatal accident is 1:100,000, the implication is that statistically there is 1 death per 100,000 people per year [8].

It is typically assumed that in a low range of initial risks, the exact risk level does not affect anymore the amount of money people are willing to pay for a given risk reduction; this amount is constant (Figure 4.1). It can be concluded from Blaeij et al. [8] that the VOSL does indeed depend on the initial risk level and the risk decline.

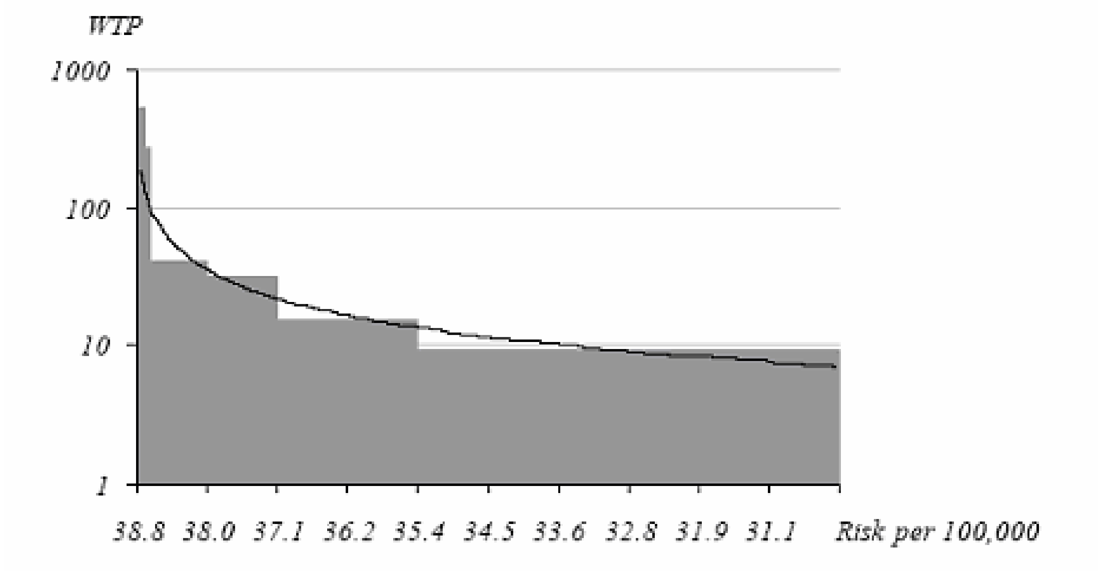

Figure 4-1 WTP (in 1996 U.S. dollars, logarithmic scale) versus risk levels [8].

4.2- Accident Corrections used in BSAP

Since the analysis at KGM is based on the police and gendarme reports, number of fatalities and number of injuries should be multiplied with correction factors for victims who died during the transport to hospital and in the hospital. KGM records accident data as number of property damaged vehicles, number of fatalities, number of injuries and total number of accidents. But due to the statistical uncertainty in the number of fatalities and injuries of KGM records, Sweroad [4] proposes to use average number of fatalities and injuries per fatal and injury accidents. Therefore; BSAP is coded to get accident data in two forms; (1) convenient to KGM accident data records; and (2) convenient to use average values for accident types (fatal, injury or PDO accident) as proposed by Sweroad. The user has the freedom of selecting the appropriate accident data type for his/her work.

Table 4-1 shows the proposed values for the average number of fatalities and injuries per accident (without correction) from the Sweroad study which is based on the police statistics (1995-1999) and statistics from a Pilot Project region (1998-1999).

Table 4-1 Fatalities and Injuries per accident without correction [4].

	Fatalities/ Fatal Acc.	Injuries/ Fatal Acc.	Injuries/ Injury Acc.
Rural Areas	1.50	2.84	2.15
Urban Areas	1.17	1.91	1.45

These average values taken from the police and gendarme reports are corrected with a factor which takes into account the probability of injured victims that will die in the hospital within a period of one year. These correction factors are developed using the Ministry of Health statistics of victims who died in the hospital due to traffic accidents in the period 1998-1999. Table 4-2 shows the corrected values with assuming that those who die in hospital after an accident, twice as often have been involved in a fatal accident as in a severe injury accident [4].

Table 4-2 Fatalities and Injuries per accident with correction [4].

	Fatalities/ Fatal Acc.	Injuries/ Fatal Acc.	Injuries/ Injury Acc.	Fatalities/ Injury Acc.
Rural Areas	2.12	2.22	2.14	0.01
Urban Areas	1.45	1.64	1.43	0.01

When the data compatible with KGM records is used in computations the correction factors proposed by Sweroad are shown in Table 4-3. This table implies that number of fatalities in the police reports should be multiplied by a factor of 1.51; on the other hand, number of injuries should be decreased by a factor of 0.97 in order to take into account the number of injures who die in the hospital in one year.

Table 4-3 Corrections for police and gendarme reporting [4].

	Fatalities	Injuries
Rural Areas	1.51	0.97
Urban Areas	1.51	0.97

These values (Table 4-3) are based on the police and gendarme reported fatalities and injuries of the Pilot Project region. Since the Pilot Project regions are purely rural, corrections for fatalities and injuries in rural and urban areas are identical.

As default, BSAP uses these corrected (Table 4-2, 4-3) values, which are based on a very limited period of analysis. When further information on such data is available the users have the freedom to modify these correction values for their work. The user is also provided to select either corrected or uncorrected values in the analysis.

4.3- Accident Costs used in BSAP

In the economic analysis of improvement projects, it is necessary to assign cost values to accident reductions. BSAP includes property damage costs, production losses from fatalities and injuries with risk values (WTP approach), hospital and administration costs, and correction factors for reported accidents in the calculation of accident costs.

As explained in Section 4.1 the cost of a fatality, VOSL, is based on the risk value and the expected income that the victim loses due to loss of production. The costs of injuries are based on the cost of fatalities. BSAP uses different percentages for injures assuming that they are not able to work for different time periods. These percentages, which are proposed by Sweroad [4], are shown in Table 4-4 and used as default values in BSAP because no other data is available in KGM.

In order find the net present value of production loss, the value of lost consumption must be reduced from PVOP (Equation 4-1) or, as in BSAP, a consumption percentage can be used as a multiplier. BSAPs default consumption is, as proposed by Sweroad, 75 percent of production which means that, the loss of production due to injury or fatality is equal to the 75% of PVOP.

Table 4-4 Out of production percents for injuries of different time periods [4].

Injury Types	%
Percent out of Production for 1 month	40
Percent out of Production for 3 month	30
Percent out of Production for 6 month	20
Percent out of Production for life*	10

* Full disability equals to one person who dies

Since there was no research available for Turkey on the risk value subject, BSAP uses the risk value proposed by Sweroad [4] for Turkey. They developed a risk value for Turkey by using the Swedish values which are corrected in relation to the difference in the GDPs of Sweden and Turkey. These developed risk values for fatality and injury are given below;

Risk Value for an injury	6,025 $
Risk Value for a fatality	175,000 $

The usage of this risk values; however recommended by Sweroad [4], are under debate. Due to results of Blaij et al. [8] study (explained in Chapter 4.1.2), such a transfer approach, where differences in initial risk levels and associated changes in risk levels are not taken into account, is biased. In Value of Statistical Life (VOSL) calculation, BSAP uses the risk value (WTP approach) as default. But it is possible not to use or modify this risk value in VOSL calculation. If the user equates the risk values to zero than this means that Human Capital approach is used in the calculation of VOSL. Actually, carrying out a study for development of risk values for Turkey is the best way to follow because an analysis that ignores the risk value, which reflects the pain and suffering of the victim as well as the grief and sorrow of his/her family and friends, does not give a realistic VOSL estimate.

For finding present value of a fatality and an injury due to production loss, BSAP uses Equation (4.1) and a consumption multiplier (75% [4]). Utilizing parameters of the year 2003, the net production loss including VAT is shown in Table 4.5.

As shown in Table (4-5) the present value of net production loss due to fatality is found to be 14,229 Million TL in 2003 prices. Whenever these parameters change in BSAP, a new value is automatically calculated and used in calculations. Present value of net production loss due to injury with out of production percentages given in Table 4-4, is found to be 5,498 Million TL in 2003 price level.

Table 4-5 The Net Production Loss due to fatality (in price level 2003).

Years, Remaining in Production	35
GDP per Capita (Million TL)	5,044
Economic Growth	5%
Discount Rate	15%
Present Value of Production Loss (Million TL.)	48,645
Consumption	75%
Value Added Tax (VAT)	17%
P.V. of Net Prod. Loss incl. VAT, (Million TL)	14,229

Normally, some kind of "tax factor" needs to be added to the values to obtain the correct results in a benefit-cost analysis. The difference of the production and consumption of the individual will yield the net production of that individual available for the economy. This production will be consumed by other people and therefore the VAT (Value Added Tax) that these people will pay in order to acquire that goods or services should be added to the net production of the person who died in an accident. This is the reason for taking into account a tax factor. The average tax factor used for the case of Turkey is 17% [4].

Because of the high discount rate (15%) and low GDP per capita values for a fatality and an injury, and the difference between them are very low when compared to the one-million-euro rule of European Union.

Table 4-6 shows the corrected cost values for PDO, injury and fatal accidents using the average values shown in Table 4-2. Instead of correcting the accident numbers with the accident correction factors in Tables 4-2 and 4-3, BSAP considers these factors in the calculation of accident cots. In other words, instead of changing the accident data, which will mean a manipulation of the actual figures, the cost of accidents are altered.

Table 4-6 Accident costs, in Million TL, per Police and Gendarme reported accidents (corrected with factors in Table 4-2), incl. VAT, in 2003 prices.

Area Type	Accident Type	Property Damage	Net Prod. Loss	Hosp.&Adm. Costs	Risk Value	Total
Rural Areas	Per PDO Acc.	1,672	-	519	-	2,191
	Per Injury Acc.	3,768	11,908	9,550	21,818	47,044
	Per Fatal Acc.	6,920	42,371	3,736	572,719	625,746
Urban Areas	Per PDO Acc.	588	-	183	-	771
	Per Injury Acc.	1,325	8,004	5,346	26,355	41,030
	Per Fatal Acc.	2,431	29,649	2,330	670,205	704,615

As explained before, KGM uses the number of involvements in accidents; i.e. number of fatalities, number of injuries and number of PDO vehicles; in calculating benefits of black spot improvements. The costs of a fatality and an injury per police and gendarme reported fatalities and injuries; corrected with factors in Table 4-3; are shown in Table 4-7.

Table 4-7 Injury costs, in Million TL, per Police and Gendarme reported accident numbers (corrected with factors in Table 4-3), incl. VAT, in 2003 prices.

Area Type	Accident Type	Property Damage	Net Prod. Loss	Hosp.&Adm. Costs	Risk Value	Total
Rural Areas	Per PD Vehicle	2,090	-	-	-	2,090
	Per Injury	-	5,333	2,777	8,708	16,818
	Per Fatality	-	21,486	1,481	393,732	416,699
Urban Areas	Per PD Vehicle	681	-	-	-	681
	Per Injury	-	5,333	2,777	14,859	22,969
	Per Fatality	-	21,486	1,481	671,775	694,742

Average values for Property Damage costs, Risk Values and, Hospital and Administration cost components are updated from the Sweroad values in 1999 to 2003 values using the ratio between exchange rates (613 000/1 490 000 TL/$).

These values (Table 4-6, 4-7) will automatically change whenever economical values (i.e. GDP per capita, discount rate, exchange rate etc.) in BSAP are updated. For example when a new exchange rate (TL/$) is entered to BSAP, property damage costs, risk values and, hospital and administration costs will automatically change.

In Sweroad reports, the value of property damage calculated for Turkey is based upon estimates of repair costs from policeman making the accident report.

These estimated property damage costs are higher for accidents with fatalities and injuries when compared to accidents with property damage only (PDO) as seen in Tables 4-6, 4-7. Since no statistical study carried out on Hospital and Administration costs of traffic accidents in Turkey, Sweroad develops the cost of this component by assuming to be equally large parts of the material costs (property damage, net production loss) as in Sweden.

Before running the optimization process, the default values used in BSAP should be checked and also revised, if necessary. This concerns, for example, monetary values for accident and casualty reductions, weighting factors for fatal accidents and injury accidents and, property damage only accidents.

CHAPTER V

ECONOMIC ANALYSIS OF TRAFFIC SAFETY IMPROVEMENTS

In order to effectively assign priorities to potential improvements, benefits and costs must be determined. Most of the investments are made because it has been estimated that these improvements will yield larger benefits than costs or larger benefits than other candidate investments.

Economic analysis is the comparison of the economic costs of a candidate countermeasure or set of candidate countermeasures with the economic benefits, and indicates not only whether the countermeasure is worthwhile (i.e., there is a net economic benefit), but also indicates which is the best countermeasure or set of countermeasures to implement. All benefits and costs must be expressed consistently on either an annual or present value basis. BSAP uses the present value basis for comparing different countermeasure alternatives and for the budget optimization process. Conversion of costs or benefits to a present value requires an estimate of the service life of the improvement and a specified discount rate. In this chapter first the parameters used in economical analysis then the evaluation techniques and finally the methodology used in BSAP is described.

5.1- Parameters used in Economical Analysis

5.1.1- Base Year

The use of a consistent basis for comparison is necessary for comparing countermeasures with different service lives. All costs and benefits should be in constant values, as if all costs and benefits occurred in the base year. Therefore the base year can be described as the year to which all costs and benefits are discounted in order to make a comparison between different projects even if the projects are opened in different years.

5.1.2- Discount Rate

In transportation investments, most of the costs are usually incurred in the early years and the benefits from the investments accrue over many years in to the future. The discount rate (minimum attractive rate of return) represents the return that could be made on other projects or investments (i.e., opportunity cost) if the funds were not invested on a highway safety project [1]. The discount rate is used for calculations of discounted values of benefits and costs so that a comparison can be made between different projects in the base year. This process is known as discounting. The discount rate includes the effect of inflation.

The discount rate used for calculations of costs and benefits is very important and has a major influence on all results. At present, KGM uses a discount rate of 15%, which is high when compared to other countries. Many other countries use discount rates in the interval 3% - 8% for road safety investments. High discount rates are because of an uncertain future economic development [5]. Also high discount rates mean that short-term investments are favored when compared to long-term investment [5]. A reduction in the discount rate causes an increase in discounted benefits for long-term investments. For Turkey; Sweroad [4, 5] recommend that a lower discount rate; in the interval 8% - 12%; should be used for road safety investments.

5.1.3- Service Life

Service life is the period of time, in years, in which the components of a program or the project can be expected to actively affect the accident experience. Service lives of the improvements must be known in order to make it possible to calculate the discounted values of future benefits as well as the average annual costs of investment. Typically; transportation improvement projects have a service life of 15 to 20 years. Default service lives of safety improvements used in BSAP are mostly taken from “Highway Safety Evaluation” [7] report of FHWA. The service life estimates of this data source for the improvement types are listed in Appendix-C.

5.2- Evaluation of Improvement Projects

The management techniques available to evaluate highway projects in terms of project costs and safety impacts can be grouped into two broad categories. The basic difference between the two categories is the method of measurement of safety impact. In the first approach, the safety impact is represented by the monetary amount of accident cost savings called Benefit-Cost Analysis, while the second approach considers the cost per expected number of accidents reduced as the measure of safety effectiveness called Cost-Effectiveness Analysis.

5.2.1- Benefit - Cost Analysis (BCA)

When transportation planners are evaluating whether to proceed with a transportation investment, they analyze the benefits and costs of transportation projects. A benefit-cost analysis is a systematic evaluation of the relevant advantages (benefits) and disadvantages (costs) of a set of transportation investment alternatives. A benefit-cost analysis usually compares alternatives although it can be used to decide whether to proceed on a specific project.

Transportation investments typically generate benefits in terms of reduced travel time and vehicle operating costs, and often result in a reduced likelihood of accidents. Costs include initial capital expenditures and maintenance costs. The Benefit-Cost Ratio (BCR) is equal to:

$$BCR = \frac{Benefits}{Costs} \qquad (5\text{-}1)$$

For a candidate improvement to be economically justified, its benefit-cost ratio should be greater than 1.0. The most desired improvements are those with the highest benefit-cost ratios. A BCR value below 1 indicates that the project causes a loss to society. Unlike the cost-effectiveness approach, benefit-cost ratios give explicit consideration to accident severity because accident cost estimates differ by severity level. A disadvantage of the benefit-cost ratio approach is that if there are multiple benefits and cost terms, it is not always clear whether specific terms belong in the numerator or denominator of the benefit-cost ratio. For example, it is not always clear whether some maintenance costs should be treated as a decrease in the annual safety benefit or should be converted to a present value and treated as an increase in the project cost. BSAP treats maintenance costs as a decrease in the annual safety benefit.

5.2.2- Cost - Effectiveness Analysis (CEA)

In evaluating a candidate improvement based upon the cost-effectiveness criterion, the cost effectiveness of the candidate improvement is generally expressed in terms of the money spent per accident reduced. Projects with lower costs per accident reduced are more likely to maximize the benefits of an improvement program then projects with higher cost per accident reduced.

$$Cost\text{-}effectiveness = \frac{Total\ Cost}{Expected\ Number\ of\ Accidents\ \mathrm{Re}duced} \qquad (5\text{-}2)$$

CEA has the advantage of simplicity and may be more accepted than BCA because it does not incorporate any estimates of accident reduction benefits in monetary terms. The primary disadvantages of this analysis are that it does not explicitly consider the severity of the accidents reduced, it is not well suited for deciding among alternative candidate improvements for a given site and it does not explicitly provide a recommended program that maximizes safety benefits [2]. Severity weighting schemes can be incorporated into cost-effectiveness analyses to overcome one of the disadvantages of this approach, but these weights will in some way be identical to assigning monetary values to benefits, which will result in an analysis similar to the BCA approach. In other words, incorporating severity weighting into CEA analysis is against the main idea behind this approach.

5.3- Method Used in BSAP

BSAP uses the BCA approach which requires a monetary estimate for the costs and benefits of each countermeasure. The BCA approach treats accident reductions as economic benefits and converts the amount of future savings to their present values and finally compares them with the countermeasure construction costs. When monetary costs are not attributed to accidents the cost-effectiveness approach can be used. However, the usage of the cost effectiveness approach will not provide the user with the anticipated benefits of the projects. The BCA approach shows whether improvement projects are effective, not only from the safety point of view but also from all other aspects, in monetary terms.

5.3.1- Calculation of Costs in BSAP

The cost of a transportation investment in economic terms is the value of the resources that must be consumed to bring the project about. Cost estimates for improvement alternatives typically rely on results from similar projects recently completed or the expertise of those who have been involved in similar projects. What must be estimated is the total value of the construction costs and any additional operating and maintenance costs. It is important to note that the analysis in BSAP does not distinguish between which component incurs the cost but rather aims to include any and all costs that are involved in bringing about the project.

The construction cost of an improvement project tends to be the most important and the largest component of all costs. Construction cost estimates should be as refined as appropriate for the stage of the development of the project under consideration.

In transportation improvement projects there will be future investments to maintain the serviceability of the facility. When evaluating transportation investments, it is important to estimate the future operating and maintenance costs of the projects. If the project includes a safety measure with a yearly maintenance cost (for example painting or road lighting that has needed to be done every year), the BSAP user can enter this estimated maintenance cost to the corresponding textbox while calculating the cost of that improvement.

The construction cost of projects can be entered to BSAP for different investment years (the years during which the investment is paid for before the project is opened). This is useful when the investment is spread over more than one year. The construction cost can, whenever possible, be estimated from default values of unit costs of the countermeasure incorporated in BSAP. These default values can be changed by the user when the site specific data are available or the user can substitute an available site-specific estimate for the total project cost. In calculating the cost of the investment, BSAP discounts all the construction costs and yearly maintenance costs to the analysis year (base year).

5.3.2- Calculation of Benefits in BSAP

The benefits of a safety improvement can be calculated by determining the expected number of accidents per year and then determining the expected number of accidents reduced per year using the Accident Reduction Factors (ARFs) for the selected countermeasures.

$$Benefit = \text{(Accident Cost without Improvement) - (Accident Cost with Improvement)}$$

The anticipated benefits of improvements are simply evaluated from before-after accident predictions (see Chapter2). The analysis must also include appropriate consideration of the service life of the countermeasure and the time value of money.

In BSAP, Reduction of Total Yearly Accident Cost (RTYAC) is found from Equation (5-3) by simply multiplying the number of avoided fatal, injury and PDO accidents by the corresponding cost.

$$RTYAC = (NF \times ARF_f \times CF) + (NI \times ARF_i \times CI) + (NPDO \times ARF_a \times CPDO) \qquad (5\text{-}3)$$

Where;

NF, NI, NPDO = Number of Fatal, Injury, PDO accidents per year.

These numbers are the total number of the corresponding accident types that occurred during the last 3 years before the analysis year divided by the number of years in this period.

ARF_f, ARF_i, ARF_a = *ARFs* for Fatal, Injury and All accidents.

These percentages represent the accident reduction factors for the corresponding accident type related to the proposed improvement. If reductions for fatal and/or injury accidents are not entered to BSAP, then percent reduction in 'All' accidents is used instead of them.

CF, CI, CPDO = Average Cost of Fatal, Injury, PDO accidents, see Table 4.6.

Average cost of accident types in BSAP. As default, these costs are based on the Sweroad report [4] and updated using the dependencies shown in Table 4.7.

The total benefit of a project is the sum of the RTYAC over its service life, subject to discounting. Therefore; to compare the safety benefits of improvements that occur over its service life, the safety benefits expressed in monetary terms must be reduced to their present value. This is accomplished by multiplying the annual benefits by the Series Present Worth Factor (SPW) (Equation 5-6) and Present Worth Factor (PW) (Equation 5-7). BSAP uses; the SPW to convert the annual benefits of the improvement to its opening year value; and the Present Worth (PW) Factor to convert the benefit value at the opening year to the analysis year. In this manner the Net Present Value of Benefits (NPVB) is calculated.

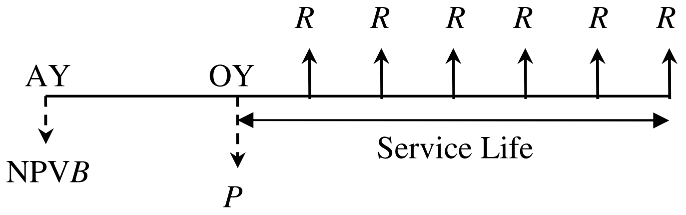

Figure 5-1 SPW and PW Factors

$$P = R \times \frac{(1+i)^n - 1}{i(1+i)^n} \text{ or } P = R(SPW / i / n) \quad (5\text{-}4)$$

$$NPVB = \frac{P}{(1+d)^{(DY)}} \text{ or } NPVB = S(PW / d / DY) \quad (5\text{-}5)$$

Where;

AY = Analysis Year; all effects discounted to this year.

OY = Opening Year; the year in which the project is opened for use.

DY = OY – AY;

R $= RTYAC - (1 + VAT) \times MAINTENANCE$

P = the value of benefits at the opening year of the improvement;

n = service life of the improvement;

d = discount rate;

i = real interest rate; *d* - ATGR; ATGR is subtracted from the discount rate (d); because the annual benefits in the future years are assumed to change according to the change in traffic volume.

ATGR = Annual Traffic Growth Rate

The number of accidents avoided is a function of the predicted total accidents in future years plus the ARF of the improvement. The predicted number of total accidents in the future is a function of observed accidents (average of last three years before the analysis year) plus the accumulated increase in traffic. This approach assumes that the accidents rise linearly with traffic. Sweroad [4] implies that there has not been any correlation between traffic growth and accident growth during the last years (before 1999) in Turkey. Therefore they recommend that no increase/decrease of traffic accidents is made over time in the analysis made in Turkey. If this recommendation is desired to be put in practice by BSAP user, equating ATGR to zero in all black spot locations is the way to follow.

CHAPTER VI

THE RESOURCE ALLOCATION (OPTIMIZATION) PROCESS

At this stage of safety management process, the costs and benefits of projects are known and the problem becomes resource allocation. The term “resource allocation process” implies that the process is intended to allocate limited resources among competing projects. It may also be considered as an optimization process because it is intended to maximize the expected benefits from the investment of the available resources. Since the amount of funds needed to accomplish necessary highway projects far exceed the available funds, the allocation of resources among competing projects becomes the central issue in the programming process. Priority setting has thus been the essential element in highway program administration. The priority ranking of improvements involves economic analysis in the conventional sense of the term, in that the costs and benefits of all proposed improvements in a jurisdiction are considered together for prioritization purposes.

6.1- Objectives of the Resource Allocation Process

The objective of the resource allocation process, as implemented in the BSAP software, is to allow the user to maximize the cost-effectiveness of the funds spent on the improvement projects. In order to do this, the process considers;

1. A specific set of hazardous locations (sections or spots) that are in need of improvement,

2. A specific set of improvement alternatives for each candidate location, including single countermeasures and/or various combinations of safety countermeasures for the site, and

3. A maximum limit on the funds (budget restriction) available for improvements to the set of highway locations.

The result of the process is a recommended improvement alternative for each black spot that results in the maximum net benefit to highway users while not exceeding the available budget. The process addresses the identification of the highest priority improvements, those that should be made during the next construction season.

In BSAP; after identifying the list of potential sites, the user will be able to select the sites with countermeasures and accident data for the budget optimization. This is important because the user can not select sites with no accident data and/or no selected countermeasure for budget optimization.

6.2- Prioritization of Traffic Safety Improvement Projects

There are several approaches to setting priorities for selecting highway improvement and maintenance projects. A procedure based on sufficiency or deficiency ratings has been in use for many decades in highway safety programming. However, this procedure is not capable of dealing explicitly with the problem of the optimal allocation of resources to maximize safety effectiveness. This ranking technique and more advanced optimization process called Binary Integer Programming are described in Sections 6.2 and 6.3, respectively.

An important issue when allocating funds is how those funds are allocated geographically throughout the country. There may be an interest in learning which projects are the best for selection within a particular region of the country. Such calculations can be made by BSAP. For this purpose, only the proposed projects for the particular region of interest should be selected, and then BSAP should be run by changing the budget value to reflect the amount of money to be allocated to that region.

6.2.1- Ranking Projects by Benefit-Cost Ratios (BCR Method)

The easiest way of solving the budget allocation problem is to rank the projects by BCR and then to fund the projects from the top down until the budget is exhausted.

The BCR methodology is easy to grasp. If the BCR of a project is greater than 1, then this means that this project is cost effective and this is a profitable investment. If the BCR is 1 then this means that benefits are equal to costs.

If the user chooses "Ranking Projects by BCRs" as an optimization method, BSAP solves the problem by the following steps;

1. Calculates BCRs for each alternative countermeasures in the selected black spots;
2. Selects the alternative with the highest BCR for each spot;
3. Arranges the magnitude of selected BCRs in descending order;
4. From top to down selects locations until the budget limit is exhausted;
5. Checks if any alternative from the not-included black spots can be included to the action plan with the remaining budget;
6. Determines the benefit value for the last included countermeasure;
7. Checks if any countermeasure alternative among not-included black spots yields a higher benefit when compared to the last included one; if this criterion is satisfied then goes to step 5.
8. Compiles the final plan for implementation of the improvements.

This method often gives a reasonable solution. However, the solution is only approximate and typically fails to use the entire budget. Steps 5 and 7 are used in the algorithm to satisfy the use of the entire budget or to reduce the unspent part of it. The solution can not said to be the 'optimal' solution because the benefits are not maximized. However, when the effect of steps 5 and 7 is omitted, this method gives the highest BCR for the budget allocated. To find the optimal allocation of the budget a more advanced optimization process must be followed.

6.2.2- Binary Integer Programming (BIP)

For an efficient utilization of the resources, it is necessary to evaluate alternative projects for all possible locations *simultaneously*; and the management decision would be to select those projects that, on the whole, optimize the safety effectiveness within the constraint of the available budget. In other words, the allocation of funds should be made in such a way that the question: “What improvement projects should be undertaken in what locations so that the safety effectiveness is maximized?” can be answered.

This problem can be solved by applying a simple Integer Programming technique. Integer Programming (IP) is the name given to Linear Programming (LP) problems which have the additional constraint that all the variables have to be integer. A typical linear program can be illustrated as follows;

Equation (6-1) is the objective function of the linear program; it represents the objective that is to be maximized or minimized. The variables $c_1, \ldots., c_n$ in the objective function are the numerical values appropriate to the particular problem being evaluated. The variables $x_1, \ldots., x_n$ are the decision variables which are limited to non-negative integer values in integer programs. Constraints on decision variables can be provided by using Equations (6-2, 6-3, and 6-4). These constraints can be used to limit total expenditures to a fixed budget amount and to prevent incompatible or infeasible combination of alternatives from being implemented. According to restrictions, these constraints can be either equalities or inequalities. For example, selection of only one alternative for each site can be a limitation which is needed to be restricted with constraints.

Maximize (or minimize) f, where:

$$f = \sum_{i=1}^{n} c_i x_i \tag{6-1}$$

$$\textit{subject to}: \quad \sum_{j=1}^{n} C_{1i} x_i \leq b \; ; \tag{6-2}$$

$$\sum_{j=1}^{n} C_{2i} x_i \leq b \; ; \tag{6-3}$$

$$\vdots$$

$$\sum_{j=1}^{n} C_{mi} x_i \leq b \; ; \tag{6-4}$$

Binary integer programming is a special case of linear programming that is particularly suited to problems involving interrelated “yes” or “no” decisions. BIP models utilized in budget allocations can be used to represent whether a site has been selected or not for improvement. In BIP, the decision variables are restricted to binary (zero-one) constants. The formulation of BIP in budget allocations can be represented as follows:

$$\text{maximize} \rightarrow \sum_{i=1}^{k} \sum_{j=1}^{n} B_{ij} x_{ij} \tag{6-5}$$

$$\text{subject to : } \sum_{i=1}^{k} \sum_{j=1}^{n} C_{ij} x_{ij} \leq b \ ; \qquad (6\text{-}6)$$

$$\sum_{j=1}^{n} x_{ij} \leq 1 \ \forall i = 1 \ldots k; \qquad (6\text{-}7)$$

$$x_{ij} \in \{0,1\} \qquad (6\text{-}8)$$

Equation (6-5) is the objective function; and Equations (6-6, 6-7 and 6-8) are the constraint functions, where;

k : number of candidate black spot locations for improvement;

n : number of countermeasure alternatives for site i (countermeasure combinations included as a new alternative);

B_{ij}: benefit of improvement project j in site i;

C_{ij}: cost of improvement project j in site i;

x_{ij}: an indicator whose value is "1" if countermeasure j at site i is selected as part of the optimum allocation of funds and whose value is "0" if countermeasure j at site i is not selected.

b : improvement budget;

Equations (6-5 to 6-8) indicate that the total number of accidents can be minimized as a result of the system wide implementation of improvement projects. Equation (6-5) is the objective function which implies that the total benefits from all selected countermeasures must be maximized. Equation (6-6) indicates that the total cost of selected improvement projects must be less than or equal to the available budget. Equation (6-7) indicates that only one project (or combinations of projects) can be selected among alternative improvement projects for each candidate site. It is evident that the selection of a project (or combinations of projects) is not necessary for each site since no lower bound is specified in Equation (6-7).

The optimal solution to the integer program is the group of improvement alternatives that provides the maximum total benefit (Equation 6-5) subject to the constraints (Equations 6-6, 6-7, and 6-8). This optimum solution consists of the improvement alternative for each site where the corresponding value of x in the solution vector is equal to 1.

Integer programs can be solved with mathematical techniques such as the Simplex algorithm and various Branch-and-Bound algorithms. BSAP uses a Branch-and-Bound Algorithm for the sake of optimization.

6.2.2.1. Branch-and-Bound (B&B) Algorithm

Branch-and-Bound (B&B) algorithm is an intelligent search method for finding the optimal solution within the space of interest, and has a wide range of applications. This method employs a successive decomposition of the global problem into smaller disjoint or independent sub-problems that are solved recursively until the optimal solution is found.

B&B method begins with obtaining the optimal solution in the absence of integer constraints. If that happens in the first solution, the decision variables whose values are constrained to be ‘integers’ already have integer values, so no further work is required. Otherwise, the relaxation is split into two sub-problems (branches), by fixing a non-integer variable at zero (not fund) or one (fund). This is the start of a tree of sub-problems and called “branching”. A sub problem is selected and the linear programming relaxation of that sub problem is solved. Four outcomes are possible:

1. An integer solution is found and there is no need to divide the problem into sub-problems.

2. The linear programming relaxation is infeasible because of the constraints, in which case the integer sub problem is also infeasible, and the tree can be pruned at this node;

3. The optimal solution has a worse objective function value than a known integer solution to the original problem, in which case any solution to the integer sub problem is also worse than the known solution, and the tree can be pruned at this node;

4. None of these three situations occur, in which case it is necessary to split the node into two further sub-problems.

The sub-problems generated at each stage differ from their parent problem only by the bounds on the integer variables. These sub-problems are solved and the branching process is repeated until a solution is found where all of the variables have integer values (to within a small tolerance due to the potential of round-off errors on digital computers; Appendix-B).

The number of sub-problems may grow exponentially; the "bounding" part of the B&B method is designed to eliminate sets of sub-problems that do not need to be explored because the resulting solutions cannot be better than the solutions already obtained. By the use of bounding, it is possible to examine only some solutions and systematically rule out many others as being infeasible or non optimal. Obviously this may take a great deal of computing time. A node is pruned when its optimal solution is guaranteed to be worse (lower) than some known current best value or when the solution is infeasible. Therefore, the program avoids visiting sub-problems which are known not to contain the optimal solution.

In B&B algorithms it is important to find the optimal solution quickly enough. There are three types of B&B tree search methods;

1 - Depth First method develops the tree on depth, following a route from root through the leave. If the active node is not pruned, this method generates two children nodes and the search continues by exploring the following level in a vertical manner as shown in Figure 6-1-a.

2 - Breath First method develops the tree in breadth, considering first, all the nodes that lie on the same level, and then analyzing these in the following level. Before going to next level, the breath first method explores all nodes at the same level as shown in Figure 6-1-b.

3 - Best First method branches from the node which has the highest resultant value. This search method does not have a standard diagram shape; its shape changes according to the resultant values of the sub-problems.

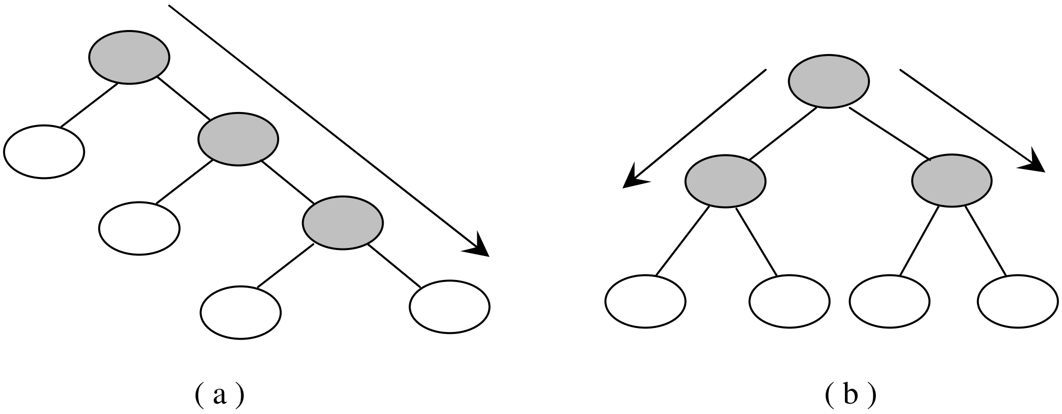

Figure 6-1 Search progressions in (a) Depth First; (b) Breath First
(gray nodes: inactive; white nodes: active)

A program which was coded with B&B algorithm must both decide which variable to branch upon and which problem to solve (branch to follow). It is evident that none of the sub-problems can give a higher resultant benefit value than its parent problem because the sub-problems will be subject to additional constraints. Therefore the parent problem will provide an upper bound to its sub-problems. Relaxation of a sub problem may find an integer solution; however, you can not be sure it is optimal until all upper bounded problems (active nodes) have been examined. Thus, the best integer solution found at any stage of the algorithm provides a bound limiting the problems (branches) to be searched.

Main Analysis Program (MAP) coded in MATLAB for BSAP uses the Best First method due to its quickness in finding the optimal solution. Typically in the Best First method all the active nodes in the B&B tree are rearranged in the order of “upper bound” after each branching. The idea is that active nodes with the highest upper bound stored in the B&B tree are examined with higher priority, in the hope that the global optimum can be found early in the search process, thus allowing later sub-problems that do not possess the global optimum to be quickly pruned before they generate new nodes. For this purpose, MAP of BSAP arranges the upper bounds of all active nodes in descending order and selects the active node with the highest upper bound. MAP continues branching until the decision variables(x) of the selected active node are all binary integers (0-1). If this criterion is satisfied then the optimal solution for the problem is said to be found.

6.3- Comparison of BCR Ranking and BIP by an Example

To illustrate the selection procedures of two methods and differences between their results, a simplified example is introduced below. Suppose that our highway safety improvement budget is 12,000 TL, and we have 4 black spot locations which have various numbers of improvement alternatives as shown in Table 6-1.

The optimal allocation is the solution to:

Maximize:

$$[5.71x_1 + 4.50x_2 + 4.30x_3 + 3.80x_4 + 4.50x_5 + 7.85x_6 + 2.20x_7 + 2.85x_8 + 6.05x_9] \quad (6\text{-}9)$$

Subject to:

$$3.57x_1 + 3.10x_2 + 2.85x_3 + 2.60x_4 + 3.30x_5 + 5.00x_6 + 1.50x_7 + 2.15x_8 + 4.00x_9 \leq 12 \quad (6\text{-}10)$$

$$x_1 + x_2 + x_3 \leq 1\ ;\ x_4 + x_5 \leq 1\ ;\ x_6 + x_7 \leq 1\ ;\ x_8 + x_9 \leq 1\ ; \quad (6\text{-}11)$$

$$x_i = 0 \text{ or } 1, \text{ for } i = 1 \text{ to } 9 \quad (6\text{-}12)$$

Table 6-1 Example – Cost, Benefit and BCR values of black spot improvement projects

Location	Project ID	Cost (TL)	Benefit(TL)	BCR	Decision Variable
A	1	3570	5710	1.60	x_1
A	2	3100	4500	1.45	x_2
A	3	2850	4300	1.50	x_3
B	4	2600	3800	1.46	x_4
B	5	3300	4500	1.36	x_5
C	6	5000	7850	1.57	x_6
C	7	1500	2200	1.46	x_7
D	8	2150	2850	1.33	x_8
D	9	4000	6050	1.51	x_9

The BCR Ranking method as explained in Section 6.2.1, first ranks BCRs of projects in descending order and then adds the costs of projects until the budget is exhausted. Table 6-2 shows the rank based on the BCRs of projects with the highest BCRs from each black spot location, other projects are eliminated.

After adding costs of projects A-1, C-6 and D-9; the budget is exhausted therefore the first two projects (A-1 and C-6) are selected. Then, BSAP searches for candidate projects which can be funded with the remaining budget. At this step the remaining budget is 3,430 TL (= 12,000 – 3,570 – 5,000). With this remaining budget B-4 can be funded. Therefore the remaining budget becomes 830 TL. Since no other black spot location exist (i.e. E, F …) this process can not continue any more. This is the first acceptable alternative which spends 11,170 TL with a resultant benefit of 17,360 TL.

Table 6-2 Project ranking based on BCRs

Rank	Location	Project ID	Cost (TL)	Benefit(TL)	BCR
1	A	1	3570	5710	1.60
2	C	6	5000	7850	1.57
3	D	9	4000	6050	1.51
4	B	4	2600	3800	1.46

For a second try BSAP also excludes the last selected project C-6 from the action plan and searches for the existence of high cost alternatives among discarded locations. In this trial, BSAP finds that A-1, D-9 and B-4 can be funded with 10,170 TL with a resultant benefit of 15,560 TL. However, this allocation is not the optimum selection of the projects for funding.

From these two allocation alternatives, BSAP chooses the first one which costs 11,170 TL with a resultant benefit of 17,360 TL. As a result of this allocation, an amount of 830 TL (=12,000 – 11,170) of the budget remains unspent.

In practice, when a large number of black spot locations are considered in the allocation procedure, the techniques used in BSAP, that are mentioned above, make the BCR Ranking method more efficient in terms of minimizing the unspent part of the budget.

In the solution of this example by using Binary Integer Programming as mentioned in Section 6-2-2; the first step is to solve the problem including the constraint that decision variables lay between zero and one ($0 \leq x_i \leq 1$), instead of Equation (6-13), which means ignoring the integer constraints. Therefore, the problem becomes a linear programming relaxation.

This Linear Programming (LP) relaxation is solved by the MATLAB function called LINPROG as described in Appendix-B in detail. After solving this LP relaxation with LINPROG; the optimal solution becomes;

$$x_1 = 1;\ x_2 = 0;\ x_3 = 0;\ x_4 = 0;\ x_5 = 0;\ x_6 = 1;\ x_7 = 0;\ x_8 = 0;\ x_9 = 0.86$$

which gives a resultant benefit of 18,763 TL. Since the solution is not purely integer, the branching process begins with the non-integer variable "x_9". The problem is divided into two sub-problems with two different additional constraints. The first sub-problem (P_3, Figure 6-2) has an additional constraint which is setting x_9 to one;

Maximize:

$$[5.71x_1 + 4.50x_2 + 4.30x_3 + 3.80x_4 + 4.50x_5 + 7.85x_6 + 2.20x_7 + 2.85x_8 + 6.05x_9] \quad (6\text{-}13)$$

Subject to:

$$3.57x_1 + 3.10x_2 + 2.85x_3 + 2.60x_4 + 3.30x_5 + 5.00x_6 + 1.50x_7 + 2.15x_8 + 4.00x_9 \leq 12 \quad (6\text{-}14)$$

$$x_1 + x_2 + x_3 \leq 1 \; ; \; x_4 + x_5 \leq 1 \; ; x_6 + x_7 \leq 1 \; ; x_8 + x_9 \leq 1 \quad (6\text{-}15)$$

$$0 \leq x_i \leq 1, \text{ for i = 1 to 9 } \& \; \boldsymbol{x_9 = 1} \quad (6\text{-}16)$$

and the second sub-problem (P_2) is created by setting x_9 to zero;

Maximize:

$$[5.71x_1 + 4.50x_2 + 4.30x_3 + 3.80x_4 + 4.50x_5 + 7.85x_6 + 2.20x_7 + 2.85x_8 + 6.05x_9] \quad (5\text{-}17)$$

Subject to:

$$3.57\text{x}1 + 3.10x_2 + 2.85x_3 + 2.60x_4 + 3.30x_5 + 5.00x_6 + 1.50x_7 + 2.15x_8 + 4.00x_9 \leq 12 \quad (6\text{-}18)$$

$$x_1 + x_2 + x_3 \leq 1 \; ; \; x_4 + x_5 \leq 1 \; ; x_6 + x_7 \leq 1 \; ; x_8 + x_9 \leq 1 \quad (6\text{-}19)$$

$$0 \leq x_i \leq 1, \text{ for i = 1 to 9 } \& \; \boldsymbol{x_9 = 0} \quad (6\text{-}20)$$

Based on the solution of the initial (P_1, Figure 6-2) LP relaxation, we know that the integer solutions to each of these sub-problems (P_2 and P_3, Figure 6-2) must have a value less than or equal to the upper bound value 18,763 TL (resultant value of P_1, Figure 6-2). These two sub-problems are solved using LINPROG again. If the decision variables of the sub-problem with the highest resultant benefit are not fully integer, this sub-problem will be divided into two sub-problems again. A sub-problem does not become inactive until either all variables in the solution are integer or there is no feasible solution to it. This branching process continues until a fully integer solution is reached. Figure 6-2 shows the B&B tree of this example. In this figure the index 'i' in P_i, indicates the formation order of branches.

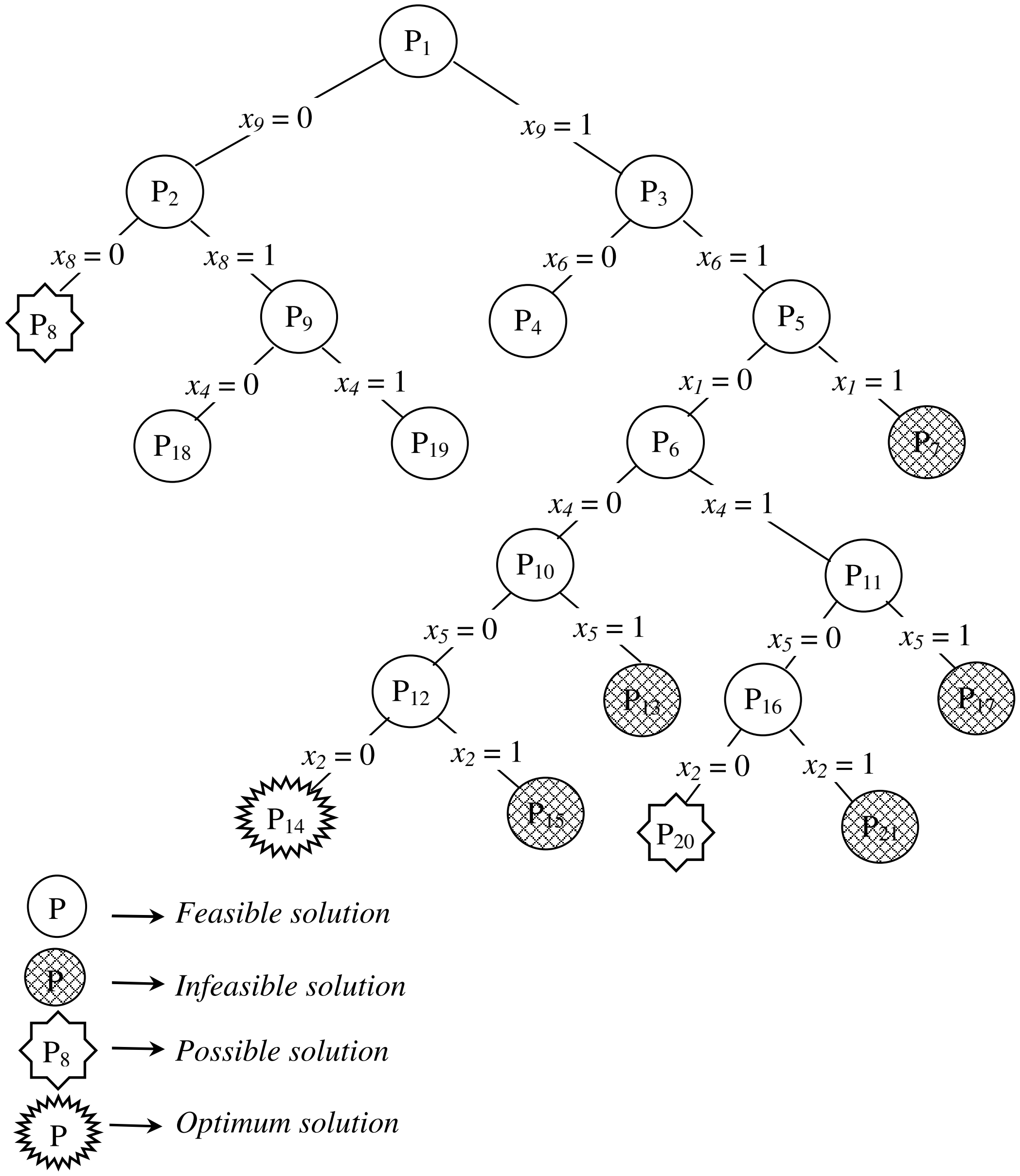

Figure 6-2 B&B tree for example

Table 6-3 Decision variables and corresponding upper bounds (UB) of LP relaxations used in B&B tree of the example.

		Decision Variables								
No	UB	x_1	x_2	x_3	x_4	x_5	x_6	x_7	x_8	x_9
P_1	18748	1	0	0	0	0	1	0	0	0.86
P_2	18460	1	0	0	1	0	1	0	0.39	**0**
P_3	18715	1	0	0	0	0	0.89	0	0	**1**
P_4	18090	1	0	0	0.53	0.47	**0**	1	0	*1*
P_5	18698	0.84	0	0	0	0	**1**	0	0	*1*
P_6	18419	**0**	0	1	0.06	0	*1*	0	0	*1*
P_7	Infeasible	**1**	X	X	X	X	*1*	X	X	*1*
P_8	*18060*	1	0	0	0	0	1	1	**0**	*0*
P_9	18281	1	0	0	0.49	0	1	0	**1**	*0*
P_{10}	18405	*0*	0	1	**0**	0.045	*1*	0	0	*1*
P_{11}	18304	*0*	0	0.14	**1**	0	*1*	0	0	*1*
P_{12}	18320	*0*	0.6	0.4	*0*	**0**	*1*	0	0	*1*
P_{13}	Infeasible	*0*	X	X	0	**1**	1	X	X	1
P_{14}	*18200*	*0*	**0**	1	*0*	*0*	*1*	0	0	*1*
P_{15}	Infeasible	X	**1**	X	*0*	*0*	*1*	X	X	*1*
P_{16}	18281	*0*	0.13	**0**	*1*	0	*1*	0	0	*1*
P_{17}	Infeasible	*0*	X	**1**	*1*	X	*1*	*0*	*0*	*1*
P_{18}	18155	1	0	0	**0**	0.39	1	0	*1*	*0*
P_{19}	18138	1	0	0	**1**	0	0.74	0	*1*	*0*
P_{20}	*17700*	*0*	**0**	*0*	*1*	0	*1*	0	0	*1*
P_{21}	Infeasible	*0*	**1**	*0*	X	X	*1*	X	X	*1*

Table 6-3 shows the decision variables and the corresponding upper bounds (resultant benefit value) of LP relaxations used in the B&B tree. Italic fonts in the decision variables field of Table 6-3 show that the variable is constrained because of its bounds (parent problems). Constrained variables formed at that relaxation are represented by bold fonts. Possible solutions, where decision variables are fully integer, are shown with an italic font in the upper bound value field (UB).

The optimum solution is found at P_{14}, but at this step this node does not give the highest resultant benefit among active nodes (P_4, P_8, P_9, and P_{11}). For this reason the branching process continues until this criterion satisfied. After solving node P_{21}, this criterion is also satisfied. The flowchart used in BSAP and an example which shows the step by step solution of a BIP process with using MATLAB is shown in Appendix-B.

As a result of this B&B process, the example yields the optimum solution (P_{14}):

$$x_1 = 0; x_2 = 0; x_3 = 1; x_4 = 0; x_5 = 0; x_6 = 1; x_7 = 0; x_8 = 0; x_9 = 1$$

which proposes to improve A-3, C-6 and D-9 and provides a resultant benefit of 18,200 TL. To verify that this is the optimal solution, this problem has also been solved with LINGO and the same solution was found. The input file and the solution report of LINGO are presented in Appendix-D.

With this allocation an amount of 150 TL (=12,000 –11,850) of the highway safety improvement budget remains unspent. This allocation yields a higher resultant benefit than the allocation provided by the BCR Ranking method. Table 6-4 shows the results of these two methods.

Table 6-4 Results of BCR Ranking and BIP methods

	BCR Ranking	BIP
Selected Projects	A-1; C-6 and B-4	A-3; C-6 and D-9
Budget Excess	830	150
Budget Expenditure	11170	11850
Expected Benefits	17360	18200
BCR	1.554	1.536

Binary Integer Programming using B&B algorithm finds higher total benefit value and budget expenditure when compared to BCR Ranking method. For every condition, the total benefit value and budget expenditure obtained from BIP are higher than or equal to the ones which are obtained from the BCR Ranking method. In general the BCR Ranking method gives a higher BCR, but in some cases because of the techniques used in this method (i.e. choosing more costly alternative in order to minimize the unspent part of the budget) this value may be smaller then the BCR value obtained from the BIP method. The BCR Ranking method gives approximate solutions but the BIP method always gives the optimum solution in terms of highest resultant benefit.

CHAPTER VII

CONCLUSION AND RECOMMENDATIONS

7.1- Conclusion

Restricted funding for black spot treatments does put a limit to the number of sites that may be treated. Therefore, it is necessary to prioritize between sites and countermeasure alternatives in order to utilize the limited funds as effective as possible. The current practice used by KGM to analyze black spots and determine the priority of improvement projects is based on the BCR Ranking method and methods similar to it. These methods, as mentioned in this study, only yield approximate results therefore more advanced optimization techniques should be employed to allocate the budget among competing improvement projects. In this report, a methodology for optimal allocation of funds to highway safety improvements is presented. Zero-One decision variables are used to represent not-fund and fund decisions respectively, and the problem is formulated as a Binary Integer Programming model. A branch-and-bound algorithm for the solution of the proposed model is summarized.

As a result of this study a computer program called Black Spot Analysis Program (BSAP) is coded. BSAP minimizes the amount of manual work required for safety analysts to optimize the safety improvement budget. BSAP is coded in a flexible manner such that there are no constant values in the program which the user can not change. This provides the safety analyst (user) with the capability to personalize his/her work and to compare results using different parameters without spending much time.

BSAP can also be used in traffic safety management for data storage purposes. The software stores the accident black spot data in an electronic format and thus grants the user the simplicity to access and share the required information in a timely manner. The program was coded by taking into account information and feedback provided by the KGM authorities. Especially data storage functions were developed in accordance with the needs of the authorities so that alliance with the KGM data is ensured.

In order to identify the countermeasure for implementation, the causes and consequences of accidents have to be revised in detail and the required statistical studies have to be performed with care. There is considerable amount of criticism on the reliability of the statistical accident data in Turkey. The maximization of the benefits achieved from traffic safety improvements is subject to the accuracy of the accident data. In order not to cause unfair competition among the candidate black spot locations in the process of prioritization, the data collection process at each spot should be performed with equal importance. The observation of accident figures after the improvement also has critical importance because it will form a basis for future projects. All of these requirements can be achieved with an efficient database built up by a very well functioning management system. After the formation of such a database, the process of prioritization of improvements will become more rational which will yield more reliable results.

Most of the default values used by BSAP, are taken from the results of a study titled “Road Improvement and Traffic Safety Project” conducted in Turkey. This project was carried by the Turkish Government and consulted by a Swedish company called Swedish National Road Consulting AB (Sweroad). As a result of this study Sweroad proposed a long-term Traffic Safety Plan. This plan covers the institutional framework for traffic safety, a mid-term (5 years) program of priority activities and list of performance indicators required for monitoring implementation of the Traffic Safety Plan and related programs [1]. The reports published within the framework of this project propose steps to be taken in order to enhance traffic safety in Turkey and recommend ways of improving the existing methods. Making use of these proposals is very important in order to increase the traffic safety in Turkey.

7.2- Recommendations for Future Study

There are several fields covered by this report for which improvements could be an important future task. The most important ones are:

The reduction figures currently utilized in BSAP are those developed by Kentucky Transport Cabinet [11] which is developed by a survey in the States and a review of literature. Since the accuracy of priority ranking of improvement projects is highly sensitive to the correct application of reasonable ARFs, KGM should perform before-and-after studies in Turkey to develop its own ARFs.

Default accident costs used in BSAP are developed by Sweroad as a result of the study named “National Traffic Safety Program for Turkey”. In this study some values; i.e. risk values and hospital & administration costs are taken from Swedish values and corrected for Turkey; therefore, it is necessary to revise these values by researches whenever an appropriate database is available. Development of such a database should include input from other interested partners, such as General Directory of Security (Police), Ministry of Health.

The official police and gendarme road traffic fatality statistics are being corrected for those injured in a traffic accident that later die in hospital. These correction values are developed from police and gendarme reports only between the years 1998 and 1999. Therefore, it is necessary to develop new correction factors with an accident data which spreads over more than two years (i.e. 10 years) in order to obtain more sensitive accident correction factors.

Safety improvement projects require an evaluation effort to identify the effectiveness of these projects in accident reductions and prevention of fatalities and injuries. Presently at KGM, this phase is not effectively implemented for various reasons. Prominent among these is the lack of an effective tracking (follow-up) system and an accident database. Therefore, an effective project tracking and evaluation process must be developed for all improvement projects. A fully implemented evaluation process would provide accident reduction factors for various strategies that are current and relevant to conditions in Turkey. Furthermore, the evaluation process would provide the information necessary in order to increase the effectiveness of future improvement programs. To be meaningful, evaluations should be performed using data from a period of two to three years following the implementation, depending on the type of improvement.

Default values (accident costs, accident reduction factors, accident correction factors, discount rate, exchange rate, economic growth forecast, GDP per capita, out of production percents for injuries etc.) used in BSAP must be updated whenever appropriate data is available.

For each black spot location more than one improvement alternative should be investigated. The consideration of at least one high and one low cost alternative is essential for the maximization of the expected benefits from the allocated budget. It can be stated that the optimization process will be more efficient in the presence of more improvement alternatives.

To conclude, due to the high social and economical consequences of accidents, traffic safety has become an issue of high priority for Turkey. Therefore Turkey has to start to invest in the researches of certain figures such as ARFs, accident correction factors or accident costs etc., which are currently not available but adapted from international studies. These researches require long term studies which have to be started immediately.

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ABBREVIATIONS

AADT : Average Annual Daily Traffic

ATGR : Annual Traffic Growth Rate

BCA : Benefit-Cost Analysis

BCR : Benefit-Cost Ratio

BIP : Binary Integer Programming

BSAP : Black Spot Analysis Program

B&B : Branch-and-Bound

CEA : Cost-Effectiveness Analysis

EB : Empirical Bayes

KGM : General Directorate of Highways

LP : Linear Programming

NPV : Net Present Value

PDO : Property Damaged Only

PVOP : Present Value of Production

PW : Present Worth Factor

RBV : Resultant Benefit Value

RTYAC : Reduction of Total Yearly Accident Cost

Sweroad : Swedish National Road Consulting AB

SPW : Uniform Series Worth Factor

VAT : Value Added Tax

VOSL : Value of Statistical Life

WTP : Willingness-to-Pay

APPENDIX A

SOFTWARE BSAP

Black Spot Analysis Program (BSAP) is an optimization program that is capable of selecting a set of safety improvements that maximize the system wide safety benefits of a program of improvements with a specific improvement budget.

The Black Spot Analysis Program (BSAP) program is comprised of two separate, but integrated programs: the User Interface Program and the Main Analysis Program. The Main Analysis Program contains the optimization procedure itself and performs all the necessary calculations. The Main Analysis Program is coded in the MATLAB language due to its efficiency in performing scientific calculations. However, the MATLAB language is very poor in terms of user interface. Thus, the user interface is handled through the User Interface Program so that the Main Analysis Program is transparent to the users, i.e., the users do not work directly with the Main Analysis Program. The User Interface Program is coded in MS VISUAL BASIC language, which is more capable at providing a user-friendly environment through the use of windows, screens, and menus.

The User Interface Program provides the users with a simple and structured means to input the data into the BSAP program. The program generates input data files that, together with the default data files, serve as inputs to the Main Analysis Program. After processing by the Main Analysis Program, the User Interface Program then takes the outputs from the Main Analysis Program and presents the results to the users. The transfer of data files between the User Interface Program and the Main Analysis Program is in text format for simplicity and ease of file transfer.

The interface of BSAP is designed as simple as possible. BSAP has a user-friendly interface with Windows-like screens and menus to facilitate easier use of the program. Also an on-screen help is available in BSAP. When the BSAP program is first initiated, the “Select Language” screen will appear which allows the user to select the language of BSAP. BSAP supports two languages; English and Turkish. Turkish language support is added to BSAP due to the request of KGM. After this selection the main screen of BSAP, which provides access to menu items, appears (Figure A-1).

There are six (6) menu items (Project, Search, Countermeasures, Run, Options and Help) in BSAP. Project menu commands allow the user to enter a new project or edit an existing project. Search menu commands are used for searching existing projects and contain five (5) search options. Countermeasures menu commands allow the user to create new countermeasure types or modify existing countermeasure properties. Run menu commands are used for optimizing the budget with the selected sites and creating reports after the execution of the Main Analysis Program. Options menu commands allow the user to modify Economical Values, Accident Corrections and Accident Values used in BSAP. The help menu provides access to the on-screen help file.

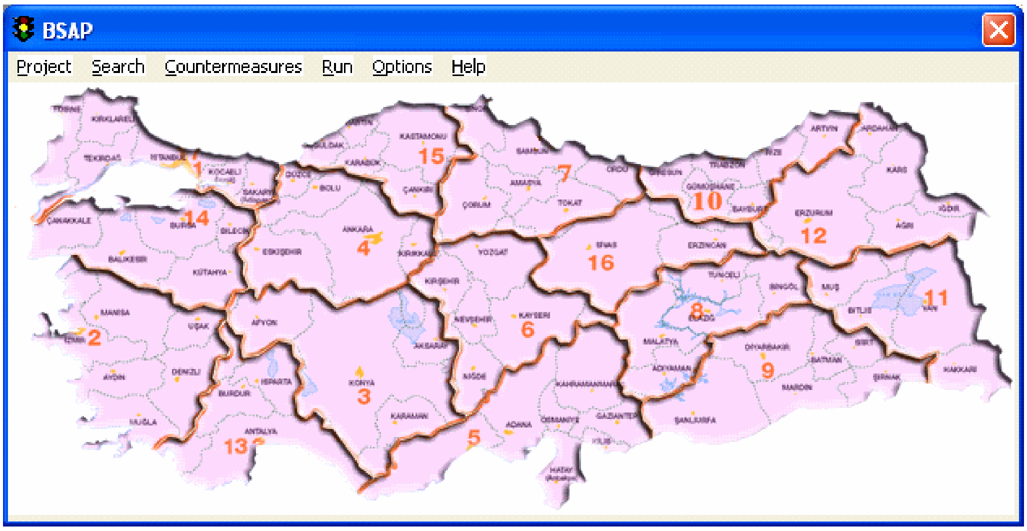


Figure A-1 Main screen of BSAP.

The selection of countermeasures for implementation will be made by the user, not by the software. A list of potential improvements is available from a window in BSAP. The user must also enter the number of fatal accidents or fatalities, injury accidents or injuries, and property damages only (PDO) accidents or PDO vehicles (according to the available accident data) that have occurred at a site over the last three years. Selecting the countermeasure types and entering the number of accidents will be sufficient to calculate the annual project benefits and the present value of project benefits.

The user must also enter an estimate of the project costs. Entering the cost estimate will make it possible to find the BCR of the proposed improvement or improvements at a black spot. A BCR is estimated under default assumptions about the discount rate, accident corrections, the value of fatal accidents or fatalities, injury accidents or injuries and PDO accidents or PDO vehicles. The user, however, will have the option of altering these default assumptions mostly taken from Sweroad Reports [4, 5]. Through the Figures A-2 to A-9, some windows of BSAP are shown.

Use of the software requires the user to enter data for the several following factors, which are listed in Table A-1. After execution of optimization process BSAP gives 5 different report options to the user. The topics included in each of the 5 different reports are as shown below;

Only Budget Allocation Results:

Budget value, Number of spots included in budget optimization, Number of spots proposed to be improved, Unspent part of budget, Total improvement expenditure, Expected benefits from improvements, Benefit/Cost ratio.

Table A-1 Data Entry Requirements

Data Must Be Entered
Project information, highway characteristics
Type of improvement(s) at site
Number of accidents in terms of “persons involved” or “severity type of accident” at site
AADT data and AADT Growth Rate
Estimated improvement costs with opening years
Analysis Year, Budget Value, Exchange Rate (TL/$), GDP per Capita
Optional Data Entry (Default Values Exist)
Discount Rate, Average VAT, Economic Annual Forecast Growth
Components for calculating cost of fatality and injury like; years remaining in production, consumption, out of production percents for injuries
Accident corrections values for police or gendarme reported accidents
Accident and injury costs (based on: Police and Gendarme Reports, Accident Correction Values, and Fatality and Injury Costs)
Accident Reduction Factors (ARFs) and Service Lives of selected countermeasure(s)

Project Name, Project No, Region No/Name, Branch No/Name, Highway-Section No.

Selected Alternatives and (1):

In addition to data given in option (1); “Countermeasure Name, Category Name, Service Life, Opening Year, Expected Accident Reduction Factors, Cost of Countermeasure, Expected Benefit and Benefit/Cost Ratio” of selected countermeasure alternatives are included in the report.

All Alternatives for Selected Spot and (2):

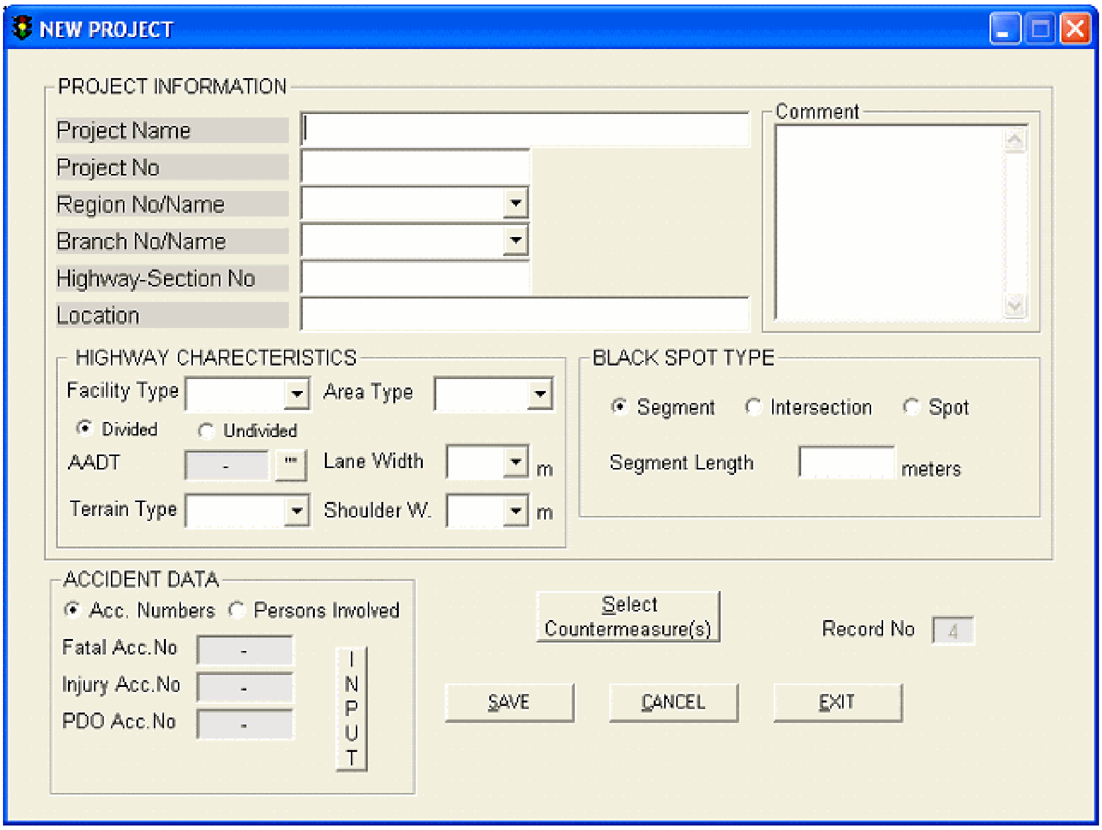
In addition to data given in option (2), properties of all countermeasure alternatives are included in the report.

List spots in terms of Project Name, Number and Region:

Lists all black spot locations included in budget optimization and selected locations after the budget optimization.

List All Alternatives For All Spots:

Lists black spot locations included in budget allocation with all countermeasure alternatives.



● Divided ○ Undivided

AADT -

● Segment ○ Intersection ○ Spot

● Acc. Numbers ○ Persons Involved

Fatal Acc.No -

Injury Acc.No -

PDO Acc.No -

Record No 4

Figure A-2 New Project screen

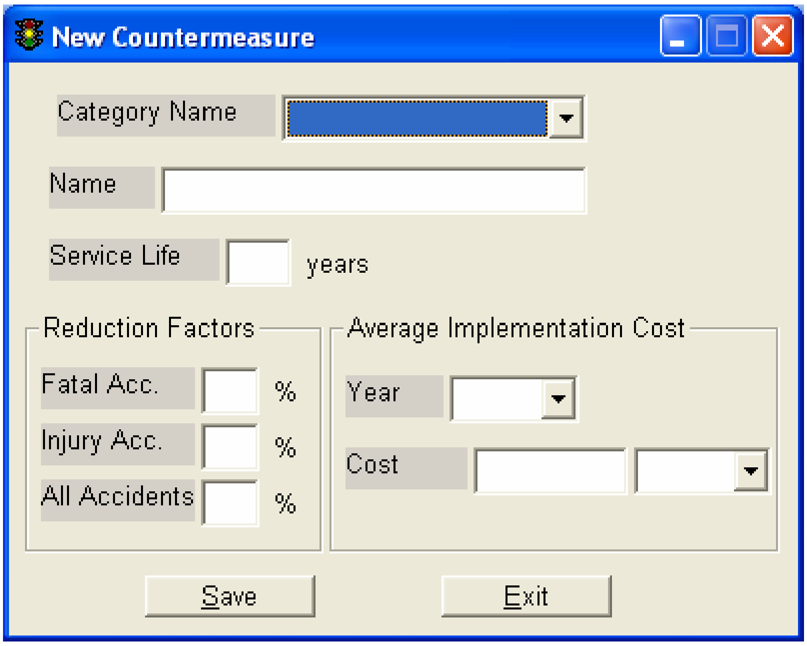
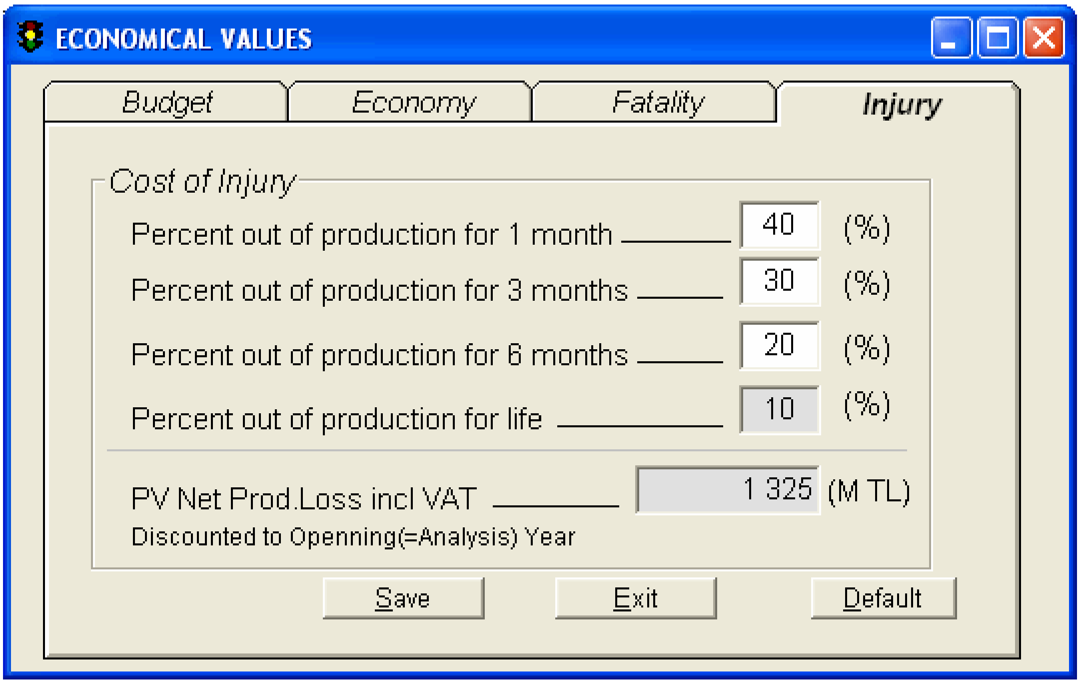


Figure A-3 New Countermeasure screen



Cost of Injury

Percent out of production for 1 month 40 (%)

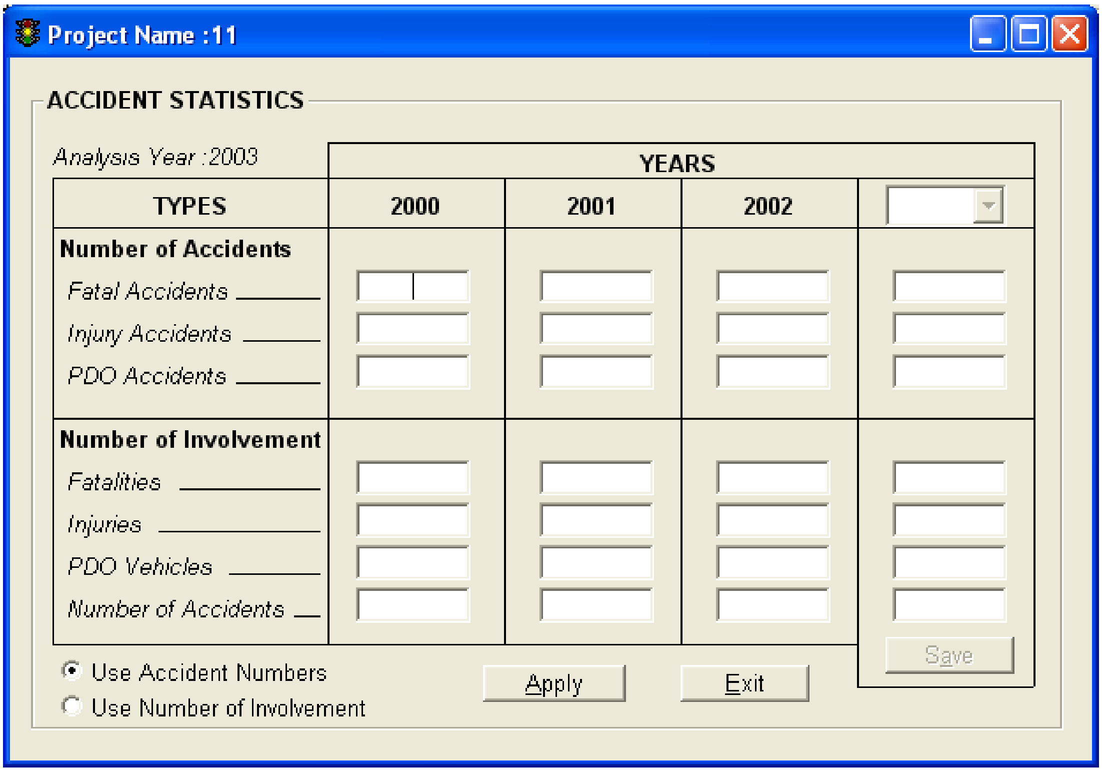
Percent out of production for 3 months 30 (%)

Percent out of production for 6 months 20 (%)

Percent out of production for life 10 (%)

PV Net Prod.Loss incl VAT 1 325 (M TL)
Discounted to Openning(=Analysis) Year

Fig A-4 Economical Values screen



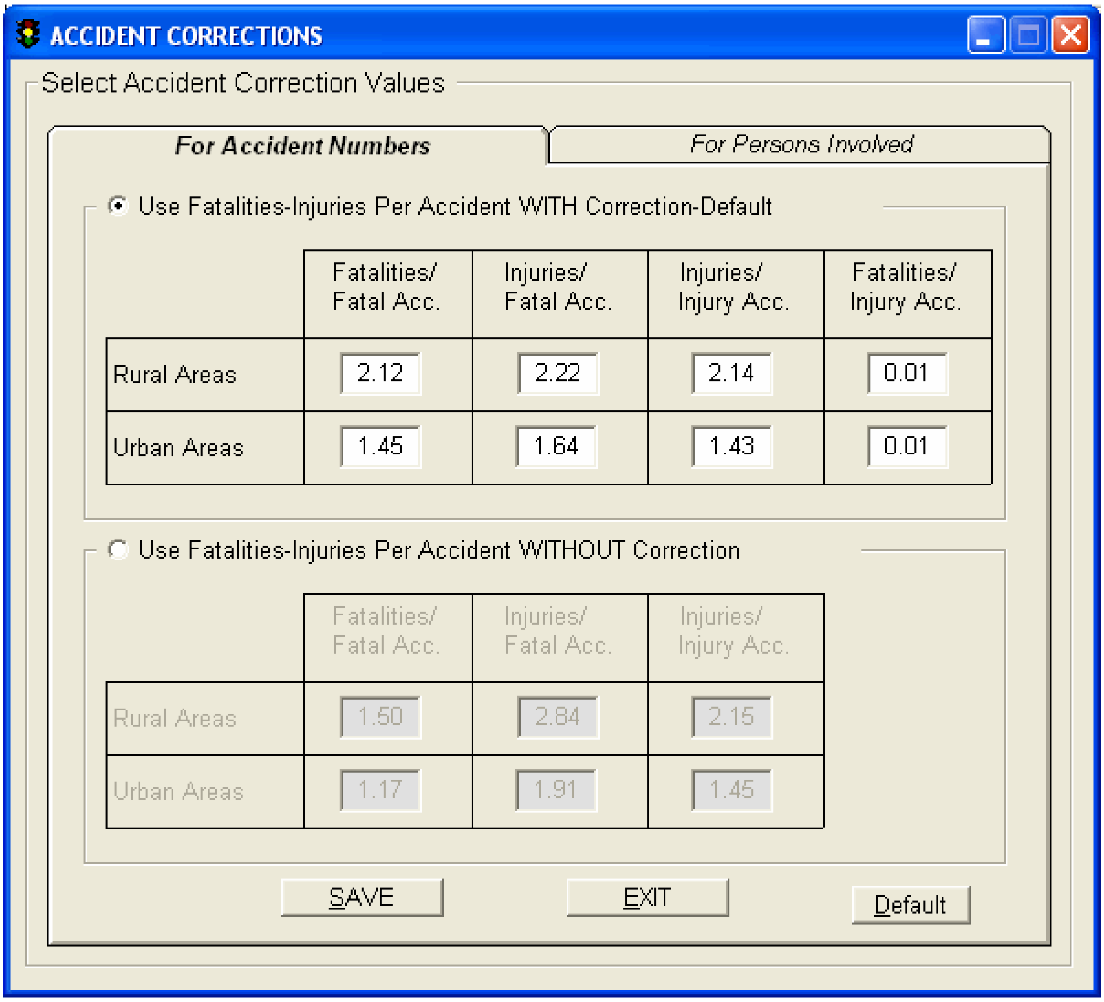
ACCIDENT STATISTICS

Analysis Year :2003

	YEARS			
TYPES	2000	2001	2002	
Number of Accidents				
Fatal Accidents				
Injury Accidents				
PDO Accidents				
Number of Involvement				
Fatalities				
Injuries				
PDO Vehicles				
Number of Accidents				

● Use Accident Numbers
○ Use Number of Involvement

Figure A-5 Accident Statistics screen



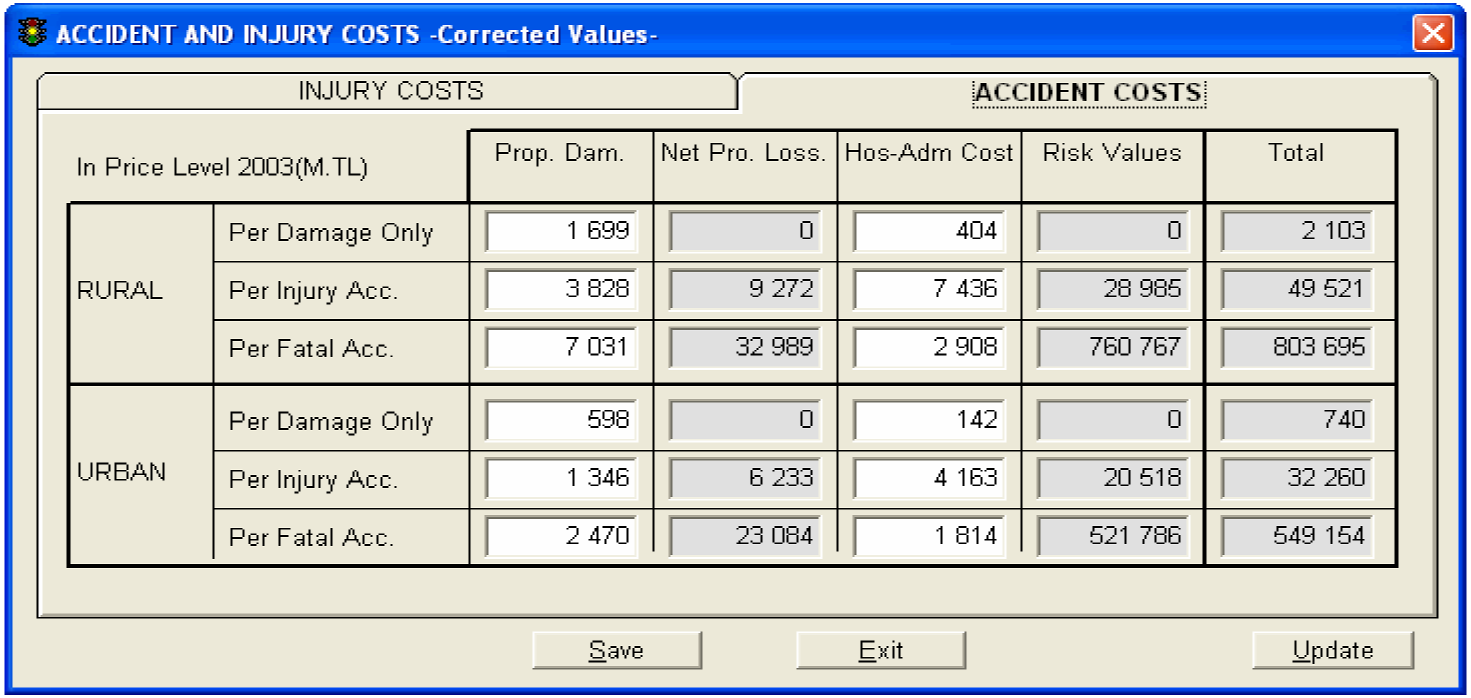
● Use Fatalities-Injuries Per Accident WITH Correction-Default

	Fatalities/ Fatal Acc.	Injuries/ Fatal Acc.	Injuries/ Injury Acc.	Fatalities/ Injury Acc.
Rural Areas	2.12	2.22	2.14	0.01
Urban Areas	1.45	1.64	1.43	0.01

○ Use Fatalities-Injuries Per Accident WITHOUT Correction

	Fatalities/ Fatal Acc.	Injuries/ Fatal Acc.	Injuries/ Injury Acc.
Rural Areas	1.50	2.84	2.15
Urban Areas	1.17	1.91	1.45

Figure A-6 Accident Correction screen



In Price Level 2003(M.TL)		Prop. Dam.	Net Pro. Loss.	Hos-Adm Cost	Risk Values	Total
RURAL	Per Damage Only	1 699	0	404	0	2 103
	Per Injury Acc.	3 828	9 272	7 436	28 985	49 521
	Per Fatal Acc.	7 031	32 989	2 908	760 767	803 695
URBAN	Per Damage Only	598	0	142	0	740
	Per Injury Acc.	1 346	6 233	4 163	20 518	32 260
	Per Fatal Acc.	2 470	23 084	1 814	521 786	549 154

Figure A-7 Accident and Injury Costs screen

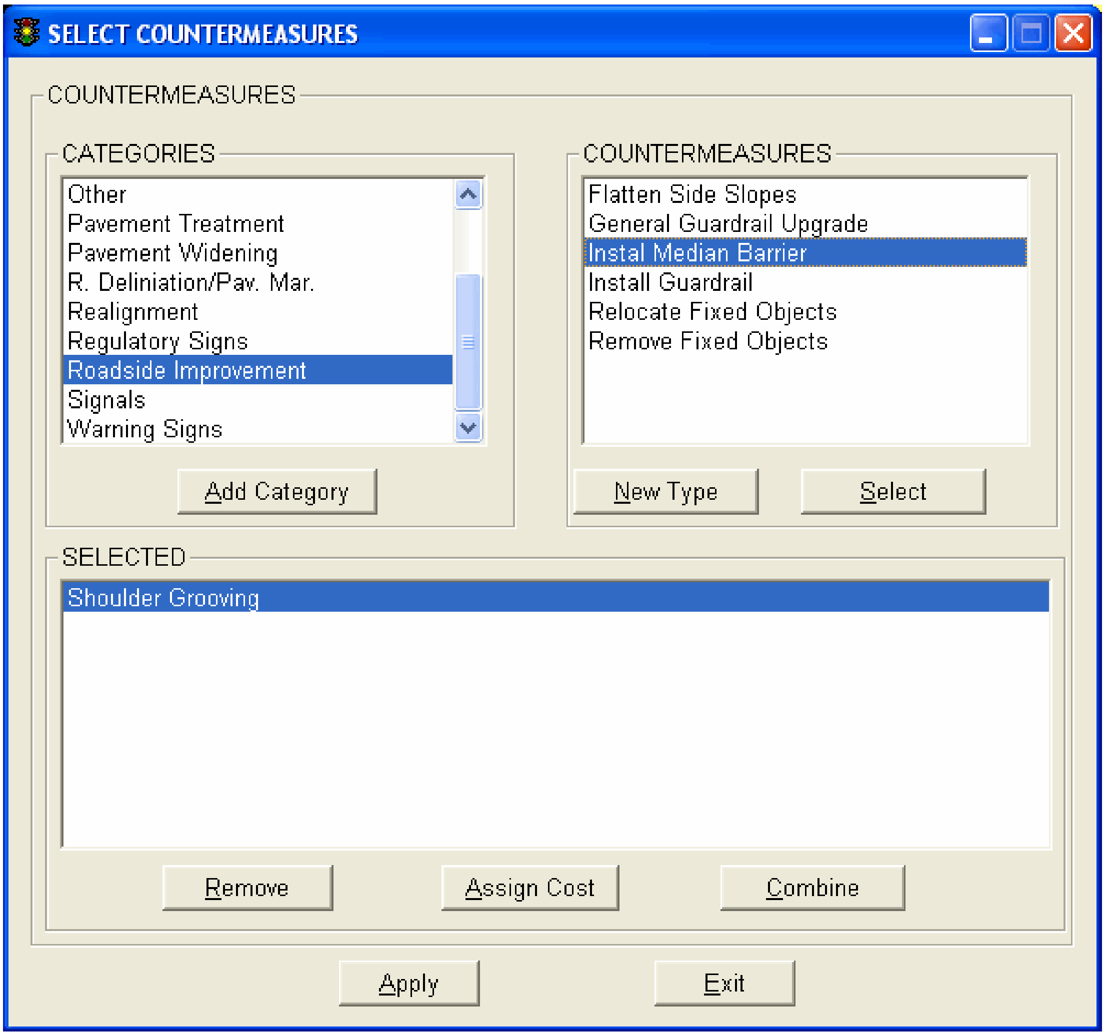
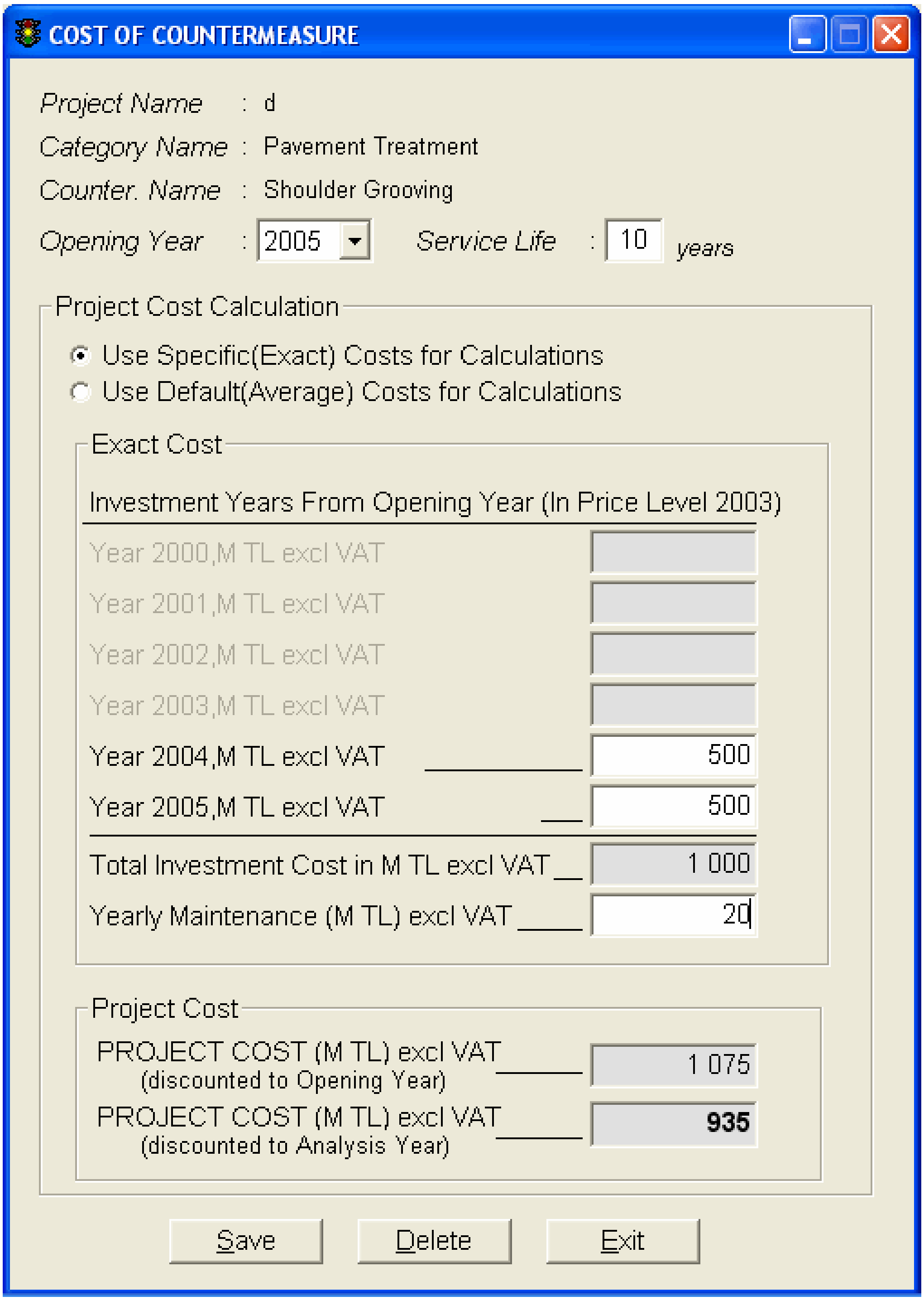


Figure A-8 Select Countermeasure screen



Project Name : d
Category Name : Pavement Treatment
Counter. Name : Shoulder Grooving
Opening Year : 2005
Service Life : 10 years

Project Cost Calculation

● Use Specific(Exact) Costs for Calculations
○ Use Default(Average) Costs for Calculations

Exact Cost

Investment Years From Opening Year (In Price Level 2003)

Year 2000,M TL excl VAT	
Year 2001,M TL excl VAT	
Year 2002,M TL excl VAT	
Year 2003,M TL excl VAT	
Year 2004,M TL excl VAT	500
Year 2005,M TL excl VAT	500
Total Investment Cost in M TL excl VAT	1 000
Yearly Maintenance (M TL) excl VAT	20

Project Cost

PROJECT COST (M TL) excl VAT (discounted to Opening Year)	1 075
PROJECT COST (M TL) excl VAT (discounted to Analysis Year)	**935**

Figure A-9 Cost of Countermeasure screen

APPENDIX B

BINARY INTEGER PROGRAMMING FLOWCHART USED IN BSAP AND A STEP-BY-STEP SOLUTION OF AN EXAMPLE OPTIMIZATION PROBLEM

BSAP uses Binary Integer Programming with Branch and Bound algorithm for the budget allocation process. The flowchart of this optimization procedure which was coded in MATLAB is shown in Figure B-1. Steps of this flowchart are explained in the following paragraphs referring to the corresponding step number in the flowchart.

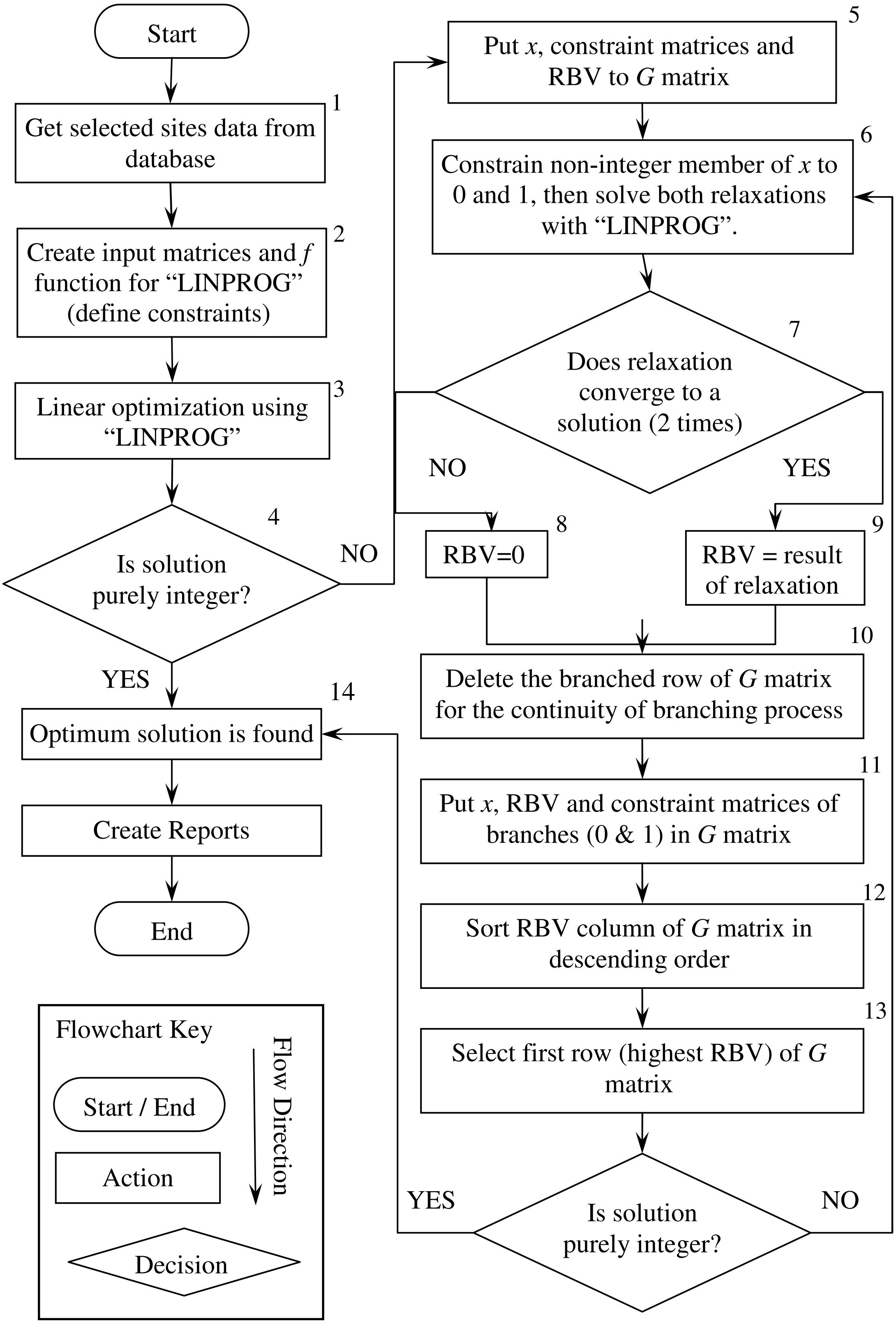


Figure B-1: Binary Integer Programming (BIP) Flowchart used in BSAP

[1] Get selected sites data from database: User Interface Program (UIP) creates necessary input files for Main Analysis Program (MAP) including site ID's, countermeasure ID's, costs and benefits of selected black spots.

[2] Create input (objective and constraint) matrices for LINPROG: LINPROG is a MATLAB function which solves linear programming problems;

$$\max_x f^T x \quad \text{such that} \quad \begin{aligned} A.x &\le b \\ A_{eq}.x &= b_{eq} \\ lb \le x &\le ub \end{aligned}$$

where f, x, b_{eq}, lb and ub are vectors and A and A_{eq} are matrices.

'f' is the objective function of the linear program; it represents the objective that is to be maximized.

'x' is the solution vector found by the LINPROG function. At the end of BIP process all the members of *'x'* becomes binary (zero or one) integers.

A, b: The matrix *'A'* and vector *'b'* are, respectively, the coefficients of the linear inequality constraints and the corresponding right side vector: $A*x \le b$.

A_{eq}, b_{eq}: The matrix A_{eq} and vector b_{eq} are, respectively, the coefficients of the linear equality constraints and the corresponding right side vector: $A_{eq}.x = b_{eq}$.

lb, ub: Lower and upper bound vectors (or matrices).

Contraint matrices : *A, b,* A_{eq}, b_{eq}, *lb, ub*.

Benefit Value : the value of *f* function at the solution *'x'*.

The first row of matrix *'A'* is equated to the cost values of project; other rows (row number = number of sites) are used for satisfying the constraint that there can be only one project (single or combination of projects) selected for one site. The first row of *'b'* vector is equated to the budget value and other rows are 1 (one) because of the same restriction; one project for one site. Therefore; $A.x \leq b$ means that the costs of the selected projects after budget allocation must be smaller than or equal to the budget value and maximum one project can be selected for one site.

In order to perform BIP, the lower and upper constraints must be specified; this is done by equating the lower bound (*lb*) vector to “0 (zero)” and the upper bound (*ub*) vector to “1 (one)”. Therefore; the resultant vector *x*, can not be higher than one or lower than zero ($0 \leq x \leq 1$). But this is not adequate for BIP because ‘*x*’ must be a binary integer.

[3] After creation of constraint matrices, LINPROG function is executed with empty A_{eq} and b_{eq} matrices.

[4] After the first run of LINPROG if all the members of matrix *x* are integer (0 or 1) then the optimum solution is found and execution of the program continues with the creation of reports. Due to the potential for round-off error on digital computers, it is not always possible for BSAP to find exact integer values for the “integer” variables. The Absolute Integrality tolerance is used by BSAP as a test for integrality in matrix ‘*x*’. Due to round-off errors, the integer variables in a solution may not have values that are precisely integer. The absolute integrality tolerance specifies the absolute amount of violation from integrality that is acceptable. Specifically, if $X \in x$ is an “integer” variable and I is the closest integer to X, then X would be accepted as being integer valued if:

$$|X - I| <= \text{Absolute Integrality Tolerance.}$$

The value for the absolute integrality tolerance is 0.00001 in BSAP.

[5] Benefit value, 'x' and constraint matrices of LINPROG are put into 'G' matrix. Matrix 'G' is a storage matrix which is used later for finding the maximum benefit value of active nodes.

[6] If all the members of 'x' are not equal to binary integers (0 or 1) then the branching begins. One of the fundamental operations involved in the branch-and-bound algorithm is branching on non-integer variables. Branching involves forcing a non-integer variable to the next greatest ("1") or the next lowest integer ("0") value. As an example, suppose there is a general integer variable that currently has a value of "0.6". BSAP branches this variable by equating to "1" and "0" by creating the necessary 'A_{eq}' and 'b_{eq}' matrices.

[7, 8, 9] If the exit condition of LINPROG does not converge to a solution then the benefit value; for these constraints; are equated to 'zero' in order not to be selected as a solution. In other case; if the exit condition of LINPROG converges to a solution; the benefit value for these constraints is equated to the value of the objective function (f) at the solution 'x'.

[10] After branching of the non-integer member of 'x' to "0" and "1"; this first row in 'G' matrix is deleted for the continuity of the branching process. If this row is not deleted than after sorting in descending order (step 12) the program always selects this first row for branching because it gives the highest benefit when compared to the other rows of matrix 'G'.

[11, 12, 13, 14] After deleting the first row; benefit value, '*x*' and constraint matrices of "0" and "1" branches; which are created in step 5; are put into the '*G*' matrix and sorted in descending order to find the row with the maximum benefit value. Next, elements of '*x*' in this row are examined if all of them are purely integer or not. If all of them are integer then this means that the optimum solution is found and execution is continued with the creation of necessary reports. If this criterion is not satisfied; a non-integer member is found in the elements of '*x*' vector; then program execution continues with step 6 until all of the members of the '*x*' vector become binary.

B-1 Binary Integer Programming Example

An example which explains the Binary Integer Programming process used in BSAP is introduced below.

Suppose that our highway safety improvement budget is 700 TL and we have 3 black spot locations and each has 3 alternative projects (Table B-1).

The optimal allocation of the budget is the solution to:

$$\text{maximize}:$$
$$f(x) = 360x_{A1} + 350x_{A2} + 235x_{A3} + 500x_{B1} + 340x_{B2} + 760x_{B3} + 300x_{C1} + 400x_{C2} + 590x_{C3}$$
$$\text{subject to}:$$
$$220x_{A1} + 275x_{A2} + 180x_{A3} + 300x_{B1} + 200x_{B2} + 500x_{B3} + 180x_{C1} + 300x_{C2} + 350x_{C3} \leq 700$$
$$x_{RV} = 0 \text{ or } 1 \rightarrow \text{R : A, B, C ; V} = 1, 2, 3$$
$$x_{A1} + x_{A2} + x_{A3} \leq 1 \; ; \; x_{B1} + x_{B2} + x_{B3} \leq 1 \; ; \; x_{C1} + x_{C2} + x_{C3} \leq 1 \; .$$

Table B-1 Example - Cost-Benefit and BCR values of black spot locations

Location	Project ID	Cost (TL)	Benefit(TL)	BCR
A	1	220	360	1.64
A	2	275	350	1.27
A	3	180	235	1.31
B	1	300	490	1.63
B	2	200	340	1.70
B	3	500	760	1.52
C	1	180	300	1.67
C	2	300	400	1.33
C	3	350	590	1.69

BIP process begins with the creation of the input (objective and constraint) matrices for the LINPROG function. For this example these input matrices are shown below;

$$f(\mathrm{x}) = \begin{bmatrix}360 & 350 & 235 & 500 & 340 & 760 & 300 & 400 & 590\end{bmatrix};$$

$$A = \begin{bmatrix}220 & 275 & 180 & 300 & 200 & 500 & 180 & 300 & 350\\ 1 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1\end{bmatrix}; b = \begin{bmatrix}700\\ 1\\ 1\\ 1\end{bmatrix};$$

$$lb = \begin{bmatrix}0\,0\,0\,0\,0\,0\,0\,0\,0\end{bmatrix}; A_{eq} = [\ \ ]$$

$$ub = \begin{bmatrix}1\,1\,1\,1\,1\,1\,1\,1\,1\end{bmatrix};\ b_{eq} = [\ \ ]$$

After creation of these input matrices, the LINPROG function is executed and the solution is found to be;

$x_{A1} = 0.681$; $x_{A2} = 0$; $x_{A3} = 0$; $x_{B1} = 0$; $x_{B2} = 1$; $x_{B3} = 0$; $x_{C1} = 0$; $x_{C2} = 0$; $x_{C3} = 1$

with a resultant benefit value of 1,175 TL. BSAP puts input matrices, benefit value and x vector into the matrix G. Since the solution is not purely integer, branch and bound algorithm creates two new sub-problems by "branching" on the non-integer variable x_{A1}. This branching process is represented diagrammatically in Figure B-2.

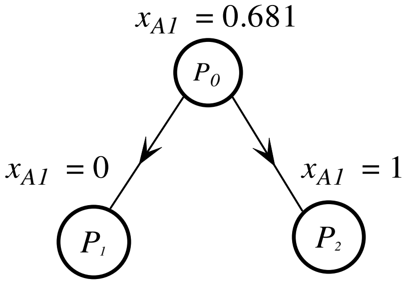


Figure B-2: Example - A tree diagram that shows the Initial LP Relaxation.

This process of taking a fractional variable (variable which takes a fractional value in the LP relaxation) and explicitly constraining it to each of its integer values is known as *branching*. Now we have two new LP relaxations to solve; BSAP first generates a common A_{eq} matrix for these two relaxations.

$$A_{eq} = [1\ 0\ 0\ 0\ 0\ 0\ 0\ 0\ 0];$$

P_1: original LP relaxation (P_o) plus the constraint $x_{A1} = 0$. In order to solve this relaxation we need to define a constraint vector. BSAP uses the b_{eq} = [0]

constraint vector to achieve this goal. As a result of these two constraint matrixes x_{A1} becomes 0 ($A_{eq}.x = b_{eq}$).

P_2: original LP relaxation (P_o) plus the constraint $x_{A1} = 1$; in order to solve this relaxation a constraint vector $b_{eq} = [1]$ created and solved using LINPROG.

Solutions of these two (P_1 -P_2) sub-problems are as follows;

$P_1 \rightarrow x_{A1} = 0$; $x_{A2} = 0$; $x_{A3} =0$; $x_{B1} = 0.75$; $x_{B2} = 0$; $x_{B3} = 0.2$; $x_{C1} = 0$; $x_{C2} = 0$; $x_{C3} = 1$

and the resultant benefit value (RBV) is 1,147 TL;

$P_2 \rightarrow x_{A1} = 1$; $x_{A2} = 0$; $x_{A3} = 0$; $x_{B1} = 0$; $x_{B2} = 1$; $x_{B3} = 0$; $x_{C1} = 0$; $x_{C2} = 0$; $x_{C3} = 0.8$

and the resultant benefit value (RBV) is 1,172 TL.

Both relaxations converge to a solution; therefore, resultant benefit values are not equated to zero. After finding solutions, the branched relaxation (P_o) is deleted from the *G* matrix for the continuity of the branching process. RBVs, '*x*' solution vectors and constraint matrices of P_1 and P_2 relaxations are put into the *G* matrix. After this step, rows of the *G* matrix are sorted in descending order according to their RBVs and the first member with the highest benefit value; P_2; is selected and analyzed. Since the solution vector of P_2 is not purely integer, the problem is "active", and BSAP continues branching. Before the second branching, the sorted *G* matrix looks like this;

$$G = \begin{bmatrix} 1{,}172 & (x)_{\mathrm{P1}} & (A_{eq})_{\mathrm{P1}} & (b_{eq})_{\mathrm{P1}} \\ 1{,}147 & (x)_{\mathrm{P2}} & (A_{eq})_{\mathrm{P2}} & (b_{eq})_{\mathrm{P2}} \end{bmatrix}$$

other constraint matrices (except A_{eq} and b_{eq}) are constant and will not change through the optimization process.

Figure 7-3 shows the B&B tree which is generated by BSAP for solving this optimization problem. BSAP has identified a feasible integer solution with a resultant benefit value 1,150 TL at P_3 but does not stop at this stage because the P_4 branch is still active and gives a higher benefit value when compared with P_3. Since the P_4 solution is not purely integer, BSAP branches P_5 and P_6 from the P_4 bound. Since the P_6 branch does not converge to a solution, this branch is pruned. The P_5 branch converges to a solution and gives a higher RBV (1,162 > 1,150) when compared to P_3 but the solution is not purely integer therefore BSAP creates two more branches (P_7, P_8) from bound P_5. Since the P_8 branch does not converge to a solution, this branch is also pruned. And finally P_7 gives a smaller benefit value when compared to P_3 therefore; the optimum solution for this example becomes P_3 which means improvement projects A-3, B-3 and C-3 are selected after the budget optimization.

Before exiting the optimization process the sorted G matrix looks like this;

$$G = \begin{bmatrix} 1{,}150.0 & (x)_{\mathrm{P3}} & (A_{eq})_{\mathrm{P3}} & (b_{eq})_{\mathrm{P3}} \\ 1{,}147.6 & (x)_{\mathrm{P8}} & (A_{eq})_{\mathrm{P8}} & (b_{eq})_{\mathrm{P8}} \\ 1{,}147.5 & (x)_{\mathrm{P1}} & (A_{eq})_{\mathrm{P1}} & (b_{eq})_{\mathrm{P1}} \end{bmatrix}$$

As seen from the resultant *G* matrix, execution stops when an integer solution is found by BSAP in the first row.

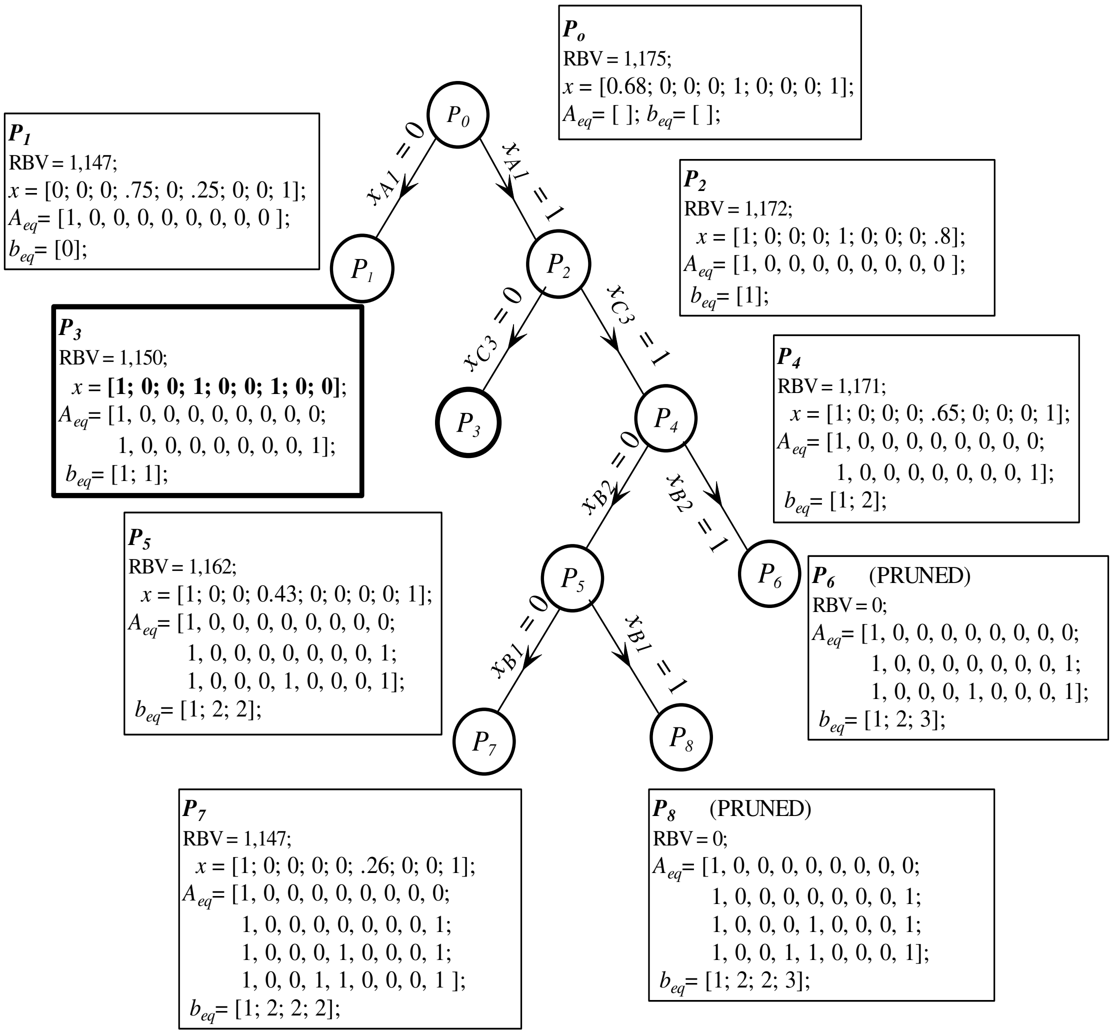


Figure B-3: Example - Branch & Bound process in BSAP

APPENDIX C

DEFAULT ARF AND SERVICE LIFE ESTIMATES OF COUNTERMEASURES USED IN BSAP

Accident Reduction Factors are taken from the research report, Agent, K., Stamatiadis, N., and Jones, S., “Development of Accident Reduction Factors”, Report No. KTC-96-13, Kentucky Transportation Center, 1996. ARFs refers to all accidents unless a specific accident type is noted

Service Lives are taken from the Hazard Elimination Safety (HES) Program, “How to Propose a Highway Safety Project – Fiscal Year 2004-05”, Mobility Management Division Virginia Department of Transportation Richmond, Virginia, March, 2003.

ACCIDENT REDUCTION FACTORS

TYPE OF IMPROVEMENT	Percent Reduction[1]	Service Life[2] (Years)
1-TRAFFIC SIGNS		
Regulatory Signs		
1-1 Install Two-Way Stop Ahead Signs	35	7
1-2 Install All-Way Stop Ahead Signs	55	7
1-3 Install Yield Ahead Signs	45	7
Warning Signs		
1-4 Curve Warning	30	6
1-5 Curve Warning Flashers		6
1-6 Pavement Condition	18	6
1-7 Bridge Related	34	6
1-8 Pedestrian Related	15	6
1-9 School Zone	15	6
2-TRAFFIC SIGNALS		
2-1 Install Signal	25	10
Angle Accidents	65	
2-2 Signal Upgrade - General	20	10
2-3 Improve timing	10	3
2-4 Increase Amber Phase		3
2-5 Add Pedestrian Phase	25	10
Pedestrian Accidents	55	
2-6 Interconnect Traffic Signals	15	10
Railroad Crossings		
2-7 Flashing Lights		
Train Accidents	65	10
2-8 Lights and Gates		
Train Accidents	75	10
2-9 Automatic Gates		
Train Accidents	75	10
3-ROADWAY DELINEATION/PAVEMENT MARKINGS		
3-1 Edgeline Markings	15	2
Off-Road	30	

TYPE OF IMPROVEMENT	Percent Reduction[1]	Service Life[2] (Years)
3-2 Centerline Markings	35	2
3-3 Wide Markings		
Night Accidents	25	2
3-4 No passing Zones		
Passing Accidents	40	2
3-5 Raised Pavement Markers	13	2
3-6 Post Delineators/Curve (night)	23	
3-7 Delineators/Tangent (night)	25	
3-8 Flexible Delineator Post	40	5
4-LIGTHING		
4-1 General	25	15
Night Accidents	45	
4-2 Intersection	30	15
Night Accidents	50	
4-3 Railroad Crossing	30	15
Train Accidents at Night	60	
5-CHANNELIZATION		
5-1 Add Left Turn Lane Physical Separation	35	20
5-2 Add Left Turn Lane with Signal	25	
5-3 Add Right Turn Lane Physical Separation	25	20
5-4 Increase Turn Lane Length	15	20
6-PAVEMENT TREATMENT		
6-1 Resurfacing	25	10
6-2 Pavement Grooving	25	10
6-3 Rumble Strips	25	3
6-4 Shoulder Grooving	25	10
7-ROADSIDE IMPROVEMENT		
7-1 Install Guardrail	5	5
Fatal Accidents	65	
Injury Accidents	40	
7-2 Install Median Barrier	5	5
Fatal Accidents	65	
Injury Accidents	40	

TYPE OF IMPROVEMENT	Percent Reduction[1]	Service Life[2] (Years)
7-3 General Guardrail Upgrade	5	5
Fatal Accidents	50	
Injury Accidents	35	
7-4 Remove Fixed Objects	30	20
Fatal Accidents	50	
Injury Accidents	30	
7-5 Relocate Fixed Objects	25	20
Fatal Accidents	40	
Injury Accidents	25	
7-6 Flatten Side Slopes	30	20
8-CONSTRUCTION/RECONSTRUCTION		
Realignment		
8-1 Horizontal Realignment	40	20
8-2 Curve Reconstruction	40	20
8-3 Vertical Realignment	40	20
8-4 Modify Horizontal and Vert. Realignment	50	20
8-5 Realign Intersection	40	10
8-6 Modify Superelevation	40	20
8-7 Sight Distance Improvement	30	20
Pavement Widening		
8-8 Widen Pavement	25	20
8-9 Widen Shoulder	20	20
8-10 Pave Shoulder	15	20
Additional Lanes		
8-11 Add Passing/Climbing Lane	20	20
8-12 Add Left Turn Lane	25	20
Left Turn Related Accidents	50	
8-13 Add Right Turn Lane	25	20
Right Turn Related Accidents	50	
8-14 Add Acceleration/Deceleration Lane	10	20
Median		
8-15 Add Mountable Median	15	10
8-16 Add Non-mountable Median	25	20
Bridge		
8-17 Widen Bridge	45	20

TYPE OF IMPROVEMENT	Percent Reduction[1]	Service Life[2] (Years)
8-18 Replace Bridge	45	30
8-19 Bridge Deck Repair	15	10
Pedestrian		
8-20 Construct Pedestrian Grade Separation		
Pedestrian Accidents	90	30
8-21 Add Sidewalks		
Pedestrian Accidents	65	5
8-22 Crosswalks		
Pedestrian Accidents	25	2
Other		
8-23 Drainage Improvements		
Wet Pavement	20	20
8-24 Install Animal Fencing		
Animal Related	90	10

[1] Refers to all accidents unless a specific accident type is noted. Factors are from the Kentucky Transportation Center Report “Development of Accident Reduction Factors”, June 1996.

[2] Service Lives are from Virginia Department of Transportation Report "Hazard Elimination Safety Program".

APPENDIX D

INPUT AND OUTPUT FILES OF LINGO RELEATED TO CHAPTER 6.3

LINGO is a tool for utilizing the power of linear and nonlinear optimization to formulate large problems concisely, solve them, and analyze the solution [LINGO Help]. Figure D-1 and D-2 show the input and solution report of LINGO for the example problem illustrated in Chapter 6-3. As can be seen in Figure D-2 the LINGO solution is the same as the BSAP solution.

```
MAX
=5710*X1+4500*X2+4300*X3+3800*X4+4500*X5+7850*X6+2200*X7+2850*X8+6050*X9;

3570*X1+3100*X2+2850*X3+2600*X4+3300*X5+5000*X6+1500*X7+2150*X8+4000*X9<=
12000;
X1+X2+X3<=1;
X5+X4<=1;
X6+X7<=1;
X8+X9<=1;
@BIN (X1);
@BIN (X2);
@BIN (X3);
@BIN (X4);
@BIN (X5);
@BIN (X6);
@BIN (X7);
@BIN (X8);
@BIN (X9);
```

Figure D-1 Input file of LINGO for the example in Chapter 6-3

```
  Global optimal solution found at iteration:             0
  Objective value:                                 18200.00

                     Variable           Value        Reduced Cost
                           X1        0.000000           -5710.000
                           X2        0.000000           -4500.000
                           X3        1.000000           -4300.000
                           X4        0.000000           -3800.000
                           X5        0.000000           -4500.000
                           X6        1.000000           -7850.000
                           X7        0.000000           -2200.000
                           X8        0.000000           -2850.000
                           X9        1.000000           -6050.000

                          Row    Slack or Surplus      Dual Price
                            1        18200.00            1.000000
                            2        150.0000            0.000000
                            3        0.000000            0.000000
                            4        1.000000            0.000000
                            5        0.000000            0.000000
                            6        0.000000            0.000000
```

Figure D-2 Solution report of LINGO for the example in Chapter 6-3