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ANALYSIS OF COST-EFFECTIVENESS MODELS USED TO DETERMINE THE PRIORITY OF ROADSIDE ACCIDENT COUNTERMEASURE PROJECTS.

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Ce projet intitulé:

ANALYSIS OF COST-EFFECTIVENESS MODELS USED TO DETERMINE THE PRIORITY OF ROADSIDE ACCIDENT COUNTERMEASURE PROJECTS.

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Abstract

The prime objective of this research is to analyze the three resource allocation programs i.e., Incremental Benefit-Cost Analysis, Integer Programming and Dynamic Programming. These techniques are aimed at maximizing the net benefit of highway safety improvement projects for a given budget constraint by selecting the optimal mix of accident locations and the preferred countermeasure alternatives at these locations. The three computer models are collectively termed the "Safety Resource Allocation Programs" (SRAP).

This project discusses the objective function of the three models, the calculation technique of the input data, and the use of the ROADSIDE program to calculate the present worth of net benefits arising from the implementation of a safety project alternative, which is an important input data for the SRAP program. This project also presents the use of Microsoft EXCEL's "SOLVER" tool (version 5.0) to solve this type of problems. "SOLVER" yields the same optimal solutions as the Integer programming approach.

The three resource allocation programs are compared twice. Firstly, with the Simple Benefit-Cost method and secondly among themselves to determine the advantage of keeping the three models in the SRAP program. A sensitivity test is made to examine the impact of the misestimation of the initial project costs in the selection of the projects. A detailed description of the SRAP program is presented before concluding with model advantages and limitations.

Résumé

Le projet consiste à analyser les trois modèles d'allocation des ressources financières soit: l'analyse bénéfice-coût incrementale, la programmation dynamique et la programmation linéaire à nombres entiers. Ces trois techniques utilisées pour la sélection optimale des variantes de projets en sécurité routière maximisent les bénéfices nets en tenant compte des contraintes budgétaires. Les trois modèles sont regroupés dans le logiciel "Safety Resource Allocation Programs" (SRAP).

Ce projet traite de la fonction objectif, des algorithmes, ainsi que des données nécessaires pour ces techniques d'optimisation. De plus, le logiciel ROADSIDE est présenté pour calculer la valeur actuelle des bénéfices nets résultant de l'implantation du projet retenu. Ces bénéfices représentent une donnée importante pour effectuer les calcules dans le logiciel "SRAP". Ce projet présente également l'utilisation de l'outil SOLVER du chiffrier "EXCEL" (version 4.0, ou 5.0) pour résoudre le même type de problème. La solution optimale obtenue par SOLVER est la même que celle de la programmation linéaire à nombres entiers.

Deux type de comparaisons sont faites avec les trois modèles, premièrement, avec l'analyse bénéfice-coût simple, et deuxièmement, les trois

modèles sont comparés entre eux pour identifier leurs forces et faiblesses et les raisons pour lesquelles ils ont été retenus dans le logiciel SRAP.

Une analyse de sensibilité est effectuée pour examiner l'impact d'un changement dans l'estimation du coût initial des variantes sur la sélection optimale. Puis, une description détaillée du logiciel SRAP est présentée avant de conclure avec ses avantages et ses inconvénients.

Condensé en Français

Introduction.

La procédure de la gestion de la sécurité routière comporte les quatre éléments essentiels suivants.

1. L'identification des sites dangereux (les points noirs).
2. Les spécifications des variantes des projets proposés à chaque site pour réduire le nombre et la gravité des accidents.
3. L'estimation des coûts et des bénéfices pour chaque projet.
4. Le classement selon l'ordre de priorité de réalisation des projets.

La présente recherche a permis de faire la lumière sur le dernier élément de la liste précédente, qui est la sélection optimale des projets sous contrainte budgétaire. Le problème est assez complexe, étant donné que plusieurs variantes peuvent être proposées pour chaque site dangereux à améliorer.

Il s'agit donc d'identifier pour chaque site la variante la plus intéressante dans le but de maximiser les bénéfices nets tout en respectant les limites budgétaires. La solution exacte du problème peut être trouvée par la programmation linéaire à nombres entiers. Il y a cependant d'autres méthodes utilisées traditionnellement par les ingénieurs.

Les méthodes disponibles pour prioriser les projets de sécurité routière en tenant compte des contraintes budgétaires, sont :

1. L'analyse bénéfice - coût simple (SEMBEN).
2. L'analyse incrementale du bénéfice-coût (INCBEN).
3. La programmation dynamique (DYNPROG).
4. La programmation linéaire à nombres entiers (INTPROG).

Ces techniques sont utilisées pour répondre à la question: " Quel site dangereux doit-on améliorer en priorité, et quelle variante proposée à ce site doit-on choisir?". Le FHWA (Federal Highway Administration) en 1988 a regroupé les méthodes d'analyse (INCBEN, DYNPROG, INTPROG) dans le logiciel SRAP (Safety Resource Allocation Programs). Ces méthodes s'avéraient plus avantageuses que l'ancienne méthode utilisée, soit, la méthode de bénéfice-coût simple(SIMBEN).

La fonction objectif.

Le problème d'allocation des ressources est un problème d'optimisation. Chacune des trois méthodes de coût - efficacité, inclut dans le logiciel "SRAP", a la même fonction objectif. Cette fonction est la maximisation de la valeur actuelle du bénéfice net résultant de la réalisation des projets retenus à l'intérieur du budget imposé . Le bénéfice net, suite à la réalisation d'une variante, est la différence entre les bénéfices (la réduction des coûts des accidents et les autres bénéfices d'usagers) et les coûts (le coût d'entretien annuel, le coût de la réparation et le coût d'opération).

Une description détaillée des algorithmes utilisés dans ces méthodes est présentée dans le rapport.

Les données nécessaires.

Les trois méthodes requièrent les mêmes données pour effectuer la sélection des projets. Ces données sont:

1. Le nombre de sites dangereux à considérer.
2. Le nombre de variantes à considérer à chaque site.
3. De plus, pour chacune des variantes :
    - le coût initial de la construction .
    - la valeur actuelle du bénéfice net annuel.
4. Le budget maximal alloué pour réaliser les projets de sécurité.

Les données précédentes peuvent être obtenues de manière directe sauf pour la valeur actuelle du bénéfice net annuel.

ROADSIDE est la version informatique de la procédure de la sélection coût - efficacité (1988 AASHTO Roadside Designe Guide), qui peut être employé pour calculer les valeurs actuelles des bénéfices nets qui résulteraient de l'implantation de chacune des variantes. Ces données sont considérées parmi les plus difficiles et longues à obtenir par calcul manuel.

Comparaison entre les méthodes.

Les conclusions suivantes ont été obtenues en analysant les résultats produits par les quatre méthodes déjà mentionnées.

1. Le modèle de programmation linéaire à nombres entiers (INTPROG) propose la solution optimale absolue.
2. Le modèle de la programmation dynamique (DYNAPROG) donne une solution approchant l'optimale dépendant de la précision utilisée.
3. Le modèle du bénéfice-coût incremental a l'avantage de classer tous les projets à tous les sites en ordre décroissant du rapport bénéfice-coût incremental. Ce classement est valable dans le cas d'analyse de plusieurs niveaux de budget. Bien que la solution proposée par le modèle bénéfice-coût incremental ne soit pas la solution optimale absolue, il peut parfois être intéressant d'améliorer un plus grand nombre de sites.
4. Le modèle de bénéfice-coût simple est une bonne méthode pour classer les sites seulement si une variante est envisagée à chaque site; ou encore pour

choisir la variante intéressante dans le cas où seulement un site est étudié. Mais dans les situations où il y a plusieurs variantes à chaque site toutes les autres méthodes proposent de meilleures solutions.

5. La performance des trois méthodes par rapport à la méthode de bénéfice-coût simple, augmente avec la taille du problème, l'augmentation du niveau du budget, et aussi avec l'augmentation de la différence entre le coût initial individuel des variantes et le budget utilisable.

Finalement, les méthodes peuvent être classées selon leurs performances dans l'ordre décroissant suivant :

INTPROG ≥ DYNPROG≥ INCBEN ≥ SEMBEN.

L'utilisation du Solver d'EXCEL.

Le chiffrier EXCEL version 5.0 possède un outil de résolution des problèmes d'optimisation appelé SOLVER. Cette facilité permet d'effectuer des itérations sur une ou plusieurs cellules du chiffrier afin d'atteindre un objectif concernant une cellule-cible. L'algorithme de résolution employé par le SOLVER est celui de Newton (la programmation linéaire) qui propose la même solution optimale que celle proposée par la programmation linéaire à nombres entiers.

Un exemple numérique est présenté dans le rapport avec les solutions calculées avec les différents modèles (manuellement, et avec le logiciel SRAP) et aussi avec le SOLVER d'EXCEL.

Le logiciel SRAP (Safety Resource Allocation Programs).

Le logiciel est une intégration informatique qui contient les trois modèles d'allocation des ressources pour la sécurité routière suivant (INCBEN, INTPROG et DYNPROG). Ce logiciel a été développe par le FHWA, en 1988, pour aider le planificateur à prendre les décisions pour la sélection des projets, servant à améliorer la sécurité, basés sur leurs coûts et leurs bénéfices. le logiciel SRAP peut analyser jusqu'à 150 sites dangereux, comptant chacun un maximum de sept variantes.

Une analyse de sensibilité a été faite pour examiner l'impact d'une erreur dans l'estimation du coût initial sur la sélection des projets. Les résultats suivants ont été obtenus :

1. Le modèle INTPROG est plus sensible que DYNPROG et INCBEN aux changements des coûts initiaux. Si l'estimation des coûts initiaux est

imprécise jusqu'à 5%, pour tous les projets, la solution optimale demeure la même.

2. Une erreur d'estimation de pourcentage inégale a plus d'effet sur les solutions qu'une erreur de pourcentage équivalent sur tous les projets.
3. Un changement proportionnel du coût initial des projets et du budget utilisable sans changer le bénéfice, n'affecte pas la sélection des projets.

<u>Conclusion.</u>

L'objectif principal de ce rapport était de présenter et d'analyser le logiciel SRAP (Safety Resource Allocation Programs) ainsi que ses trois modèles de priorisation de projets développé par FHWA (Federal Highway Administration). Ces modèles maximisent le bénéfice net en tenant compte des contraintes budgétaires en choisissant la meilleure combinaison des sites dangereux et la maillure variante à chaque site choisi. Le modèle INTPROG propose toujours la solution optimale. L'outil SOLVER d'EXCEL version 5.0 est capable de résoudre le même type de problème et de proposer la même solution optimale mais le logiciel SRAP Safety Resource Allocation Programs est plus rapide et plus facile à utiliser.

Les avantages et les limitations de SRAP Safety Resource Allocation Programs sont:

Les avantages:

1. Facile à utiliser, structure d'entrée de données simple et résultats clairement présentés.
2. Une performance supérieure à la méthode du bénéfice - coût simple.
3. Permet d'encourager et de promouvoir la formulation et développement de variantes possibles pour les projets de sécurité routière.

Les inconvénients:

1. Manque de compatibilité avec l'environnement "WINDOWS".
2. L'entrée des données peut être faite seulement par "SRAP". Le logiciel SRAP n'accepte pas des fichiers des données préparés par d'autre logiciels, par exemple "EXCEL".
3. Plus de ressources humaines sont requis pour estimer les coûts initiaux ainsi que les bénéfices des variantes.

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Chapter 1

Introduction

A major problem faced by traffic safety planners seeking to reduce fatalities, injuries, and property damages due to accidents occurring at hazardous highway locations is how to allocate a given budget among various countermeasures in order to produce the maximum possible reduction in losses due to accidents.

According to the Transportation Research Board (TRB,1975), the highway safety planning process includes four elements :-

1. Identification of hazardous locations .
2. Specification of appropriate accident countermeasures at each location.
3. Estimation of the benefits and costs of each countermeasure at specific location.
4. Establishment of project priorities.

A Federal Highway Administration study of cost-effectiveness methods published in April 1988, documented three improved resource allocation models for use in selecting accident countermeasures and locations for highway safety

programs. These models perform the final step of the preceding list using the input data generated in the first three steps. The budget considered in these models usually consists of funds for the initial costs of countermeasures.
The three models are;

Incremental Benefit-Cost analysis, (INCBEN).

Dynamic Programming, (DYNPROG).

Integer Programming, (INTPROG).

These three improved optimization techniques are used to address the previous question which is, " Which safety improvement or accident countermeasure should be installed and Where?". They are a decision making tool for maximizing the net benefit of highway safety improvement projects for a given budget, by selecting the optimal mix of accident locations and the preferred countermeasure alternatives at those locations.

The three computer models, are collectively termed the "Safety Resource Allocation Programs (SRAP)" (FHWA - TS - 88 -19).

The three improved cost -effectiveness methods were tested against the commonly practiced Simple Benefit-Cost method (SIMBEN). It is clearly seen that the three improved models gave significantly higher benefits than the simple benefit cost analysis.

The objective of this research was to analyze the three improved optimization techniques and compare them with The Simple Benefit-Cost Method. This paper discusses their objective function, the calculation technique for their input data, the use of the ROADSIDE program (Encroachment - Probability Formula and Severity Indices) to calculate the reduction in accident costs and other user benefits due to employing an accident countermeasure. A detailed description of the SRAP program is presented before concluding with advantages and limitations of these techniques.

Chapter 2

Cost- Effectiveness Methods

Four methods are used to determine project priority within the available budget for highway safety programs. They are:

1- Simple Benefit-Cost Ratio.

2- Incremental Benefit-Cost Analysis.

3- Dynamic Programming.

4- Integer Programming.

The analysis of these four methods indicates that the Simple Benefit-Cost Ratio technique is a fairly good technique for ranking the accident locations if only one alternative is considered at each location, but usually several alternatives are considered at most accident locations. In this case the Simple Benefit-Cost Ratio method cannot be used to select the optimal set of projects and locations. The other three techniques, however, can be used to select the "optimal" set of projects. They differ from the commonly practiced simple benefit-cost ratio method in the following two respects:

- First, multiple countermeasure alternatives are explicitly formulated and evaluated at each high-accident location and are carried forward to the optimization stage.
- Secondly, the optimization techniques allow for simultaneous determination of preferred locations and the preferred alternatives at these locations to obtain the best system or program-wide solution.

The purpose of this chapter is to describe the four methods of choosing alternatives and to indicate the benefits of using the improved methods.
Prior to the description of these methods, the objective function assumed to be used in all of these methods is discussed.

2.1 Choice of an objective function

The resource allocation problem is formulated as an optimization problem where one attempts to find the best combination of countermeasure alternatives and accident locations for improvement, under the constraint of a given budget of initial project costs .
Each of the three improved cost-effectiveness methods (Incremental Benefit-Cost Analysis, Dynamic Programming , Integer Programming) is designed to have the same objective function : to maximize the present worth of net benefits for a given budget of initial project costs.

It is assumed that there is a large number of accident locations, and that each location has one or more alternatives for reducing accident damages. The present worth of net benefits for each alternative is calculated by using the following formula: (FHWA 1985)

$$B=\sum_{t=1}^{SL}\left(\frac{AC_t}{(1+r)^t}+\frac{OUB_t}{(1+r)^t}-\frac{MC_t}{(1+r)^t}-\frac{RC_t}{(1+r)^t}\right)+\frac{SV}{(1+r)^{SL}}$$

Where;

B = Present worth of net benefits over the service life of the alternative.

SL = Service life of the alternative, in years.

r = discount rate.

AC_t = expected reduction in accident costs from employing the alternative, in year t.

OUB_t = other expected user benefits from employing the alternative, in year t.

MC_t = increase in annual maintenance and operating costs from employing the alternative (excluding RC defined below), in year t.

RC_t = annual increase in repair costs from employing the alternative, in year t.

SV = salvage value of the alternative at the end of its service life.

The important aspect to note about this net benefit formulation is, that net benefit for each year is estimated as the difference between the benefits (reduction in accident costs and other user benefits)and the costs (annual maintenance, operating, and repair costs) which result due to the improvement made. Thus, the objective function used in the optimization programs is to maximize the present worth of these net benefits subject to a constraint on total initial cost (i.e., the budget).

2.2 Brief description of the four methods

2.2.1 Simple Benefit- Cost Ratio (SIMBEN)

The simple Benefit- Cost Ratio program (FHWA 1985) ranks alternatives at accident locations by first calculating the ratio of benefits to costs for each alternative at a given location. The alternative with the highest benefit-cost ratio at each location is designated as the preferred alternative at the location, and the other alternatives at that location are discarded.

Next, the preferred alternatives at each location are ranked in descending order from the highest to lowest benefit- cost ratio . For a fixed budget problem, the analyst goes down this list, selecting the projects that can be fitted within the available budget.

All projects are selected in descending order. If the addition of a project makes the cumulative cost exceed the budget, then it is skipped, and other projects down the list are selected until no additional projects can be added without exceeding the budget.

2.2.2 Incremental Benefit- Cost (INCBEN)

The incremental benefit-cost algorithm for which a program was developed can be used to arrange projects in an order such that a preferable ordering of projects can be obtained for the same cumulative cost. (This method gives approximately the same choice of projects as does the Integer programming method).

The unique aspect of this algorithm is its procedure for discarding some increments while averaging together increments of expenditure at a location if there are increasing ratios of incremental benefits to incremental costs. An array of increments of expenditure in decreasing order of incremental benefit-cost ratios is produced. After an initial solution is selected from this array, a "Switching" rule is used. That sometimes makes marginal improvements in the initial solution (FHWA 1985). This method will be described in the following pages and illustrated by a practical example.

As described in FHWA-RD-79-53 (FHWA1979), The Incremental Benefit- Cost algorithm is outlined below;

where;

i = number of locations (1, 2, 3,...........,m).

j = number of alternatives at location (1, 2, 3,.........., n).

$A_{i,j}$ = alternative (project) j at location i.

$C_{i,j}$ = initial construction cost of $A_{i,j}$.

$MC_{i,j}$ = the marginal or incremental cost of $A_{i,j}$.

= $C_{i,j}$ when, (j =1).

= $C_{i,j} - C_{i,(j-1)}$ (j = 2, 3,......,n).

$B_{i,j}$ = present value of net benefits of $A_{i,j}$ over its service life.

$MB_{i,j}$ = the marginal or incremental benefit of $A_{i,j}$

= $B_{i,j}$ when, (j =1).

= $B_{i,j} - B_{i,(j-1)}$. (j = 2, 3,......,n).

$R_{i,j}$ = the incremental benefit- cost ratio of $A_{i,j}$.

$= MB_{i,j} / MC_{i,j}$

The steps of the algorithm are as follows:

Step 1:- Calculation of the incremental benefit- cost ratios.

1a. For each location i, array the $A_{i,j}$, with its cost and benefits, in increasing order of $C_{i,j}$.

1b. If, at any given location i, $C_{i,j} = C_{i,(j+1)}$ and $B_{i,j} \geq B_{i,(j+1)}$,then delete $A_{i,(j+1)}$ from the array. Renumber all $A_{i,j}$ at location i, so that there are no "missing" j values.

1c. At each location i, calculate $MC_{i,j}$ for each $A_{i,j}$, which equal to $C_{i,j}$ when j=1, and $C_{i,j} - C_{i,(j+1)}$, for the other values, (j= 2, 3,.....,n).

1d. At each location i, calculate $MB_{i,j}$ for each $A_{i,j}$, which equal to $B_{i,j}$ when $j=1$, and $B_{i,j}-B_{i,(j+1)}$, for the other values, ($j= 2, 3,.....,n$).

1e. Calculate $R_{i,j}$ for each $A_{i,j}$, which equal ($MB_{i,j}/ MC_{i,j}$).

1f. For each location i, delete from the array any $A_{i,j}$ for which $R_{i,j} \leq 1$.

If $A_{i,j}$ is deleted, then recompute $R_{i,(j+1)}$ by using $B_{i,(j-1)}$, $C_{i,(j-1)}$, $B_{i,(j+1)}$, and $C_{i,(j+1)}$. renumber all $A_{i,j}$ at location i, so that there are no missing j values.

1j. For each location i, compare $R_{i,1}$ to $R_{i,2}$. If $R_{i,2}>R_{i,1}$, then combine these two increments to form the average benefit- cost ratio $R^*_{i,2} = MB^*_{i,2}/ MC^*_{i,2} = (MB_{i,1} +MB_{i,2}) / (MC_{i,1} +MC_{i,2})$. Leave $A_{i,1}$ in the array and Continue the comparison between $R_{i,j}$ or $R^*_{i,j}$ and $R_{i,(j+1)}$, If $R_{i,j}$ or $R^*_{i,j} < R_{i,(j+1)}$, then repeat the same procedure, forming $R^*_{i,(j+1)}= (MB_{i,j} +MB_{i,(j+1)})/(MC_{i,j} +Mc_{i,(j+1)})= MB^*_{i,(j+1)}/ MC^*_{i,(j+1)}$, as long as $R_{i,j}$ is greater than the immediately preceding incremental ratio ($R_{i,(j-1)}$ or $R^*_{i,(j-1)}$). The asterisk indicates that the incremental benefit-cost ratio for an alternative has been recalculated. If any ($R_{i,j}$ or $R^*_{i,j}$) is less than the relevant preceding increment, then no combination is necessary.

For the alternatives from $A_{i,2}$ to $A_{i,n}$, $R^*_{i,(j+1)}$ must now be compared with the incremental benefit- cost ratio for the next lower cost alternative to $A_{i,j}$, i.e. , $R_{i,(j-1)}$, to see whether the marginal benefit ($MB_{i,j} + MB_{i,(j+1)}$) and the marginal cost ($MC_{i,j} + MC_{i,(j+1)}$) for $A_{i,(j+1)}$ must be combined with previous increments of benefits and costs to calculate another ratio for $A_{i,(j+1)}$, (i.e., $R^*_{i,(j+1)}$ is compared to $R_{i,(j-1)}$). If $R_{i,(j-1)} < R^*_{i,(j+1)}$,then combine the incremental costs and benefits for $A_{i,(j+1)}$, $A_{i,j}$ and $A_{i,(j-1)}$ and calculate $R^{**}_{i,(j+1)}$, where the asterisks indicate a second recalculation of the incremental benefit-cost ratio for $A_{i,(j+1)}$.

Step 2:- Selection of alternatives.

2a. Arrange all alternatives, along with their relevant corresponding marginal costs ($MC_{i,j}$,$MC^*_{i,j}$, etc.) , in decreasing order of their relevant incremental benefit- cost ratios ($R_{i,j}$, $R^*_{i,j}$, etc.).

2b. Calculate the cumulative marginal cost (ΣMC) for all the alternatives in the same order as step 8, except $A_{i,(j-1)}$, if $A_{i,j}$ is superier in the order ($R_{ij} > R_{i,(j-1)}$).

2c. Choose alternatives in descending order of incremental benefit-cost ratios, accumulating corresponding marginal costs, to determine which alternatives to include in the budget. If some $A_{i,j}$ cannot be accepted without exceeding the budget limit, then exclude that $A_{i,j}$ from consideration and proceed until another alternative or alternatives can be accepted. Selection ends when no more alternatives can be added without exceeding the budget limit. Chose the alternative which has the bigger value of j In the selected list , for each location. Delete from selection other alternatives at the same location.

Step 3:- Evaluation of the solution.

In case of very large numbers of projects, a switching rule is applied after the previous selection process ends, The last $A_{i,j}$ selected, say $\grave{A}_{i,j}$, is dropped from the array of chosen projects, and the selection process continues, adding as many projects as the remaining budget (after dropping $\grave{A}_{i,j}$) will allow. After this process is completed, the total net benefits of the initial set of projects (including $\grave{A}_{i,j}$) are compared with the benefits of the second set of projects (excluding $\grave{A}_{i,j}$). The set having the greater amount of total net benefits is selected as the optimal set.

To summarize, the steps of the incremental benefit- cost algorithm are;

Step 1:- Calculation of the incremental benefits - cost ratios.

- Arrange the alternatives at each location in order of increasing initial cost, to give the priority of the less expensive alternatives.
- Delete from consideration, those projects that have equivalent cost but have no more benefits to be gained from spending additional money at a location.
- Calculate the marginal cost, the marginal benefit and the incremental benefit-cost ratio, for each alternative, which reflects the additional benefits to be gained from spending additional money at a location.

- Delete from consideration projects that yield additional benefits less than the additional cost required to implement them (instead of a less expensive project) at the particular location.
- Adjust marginal benefit - cost ratio when the ratio for one project exceeds the ratio for the next less expensive project at the same location, to ensure that, each alternative is presented in the selection list with either its total cost or its marginal cost over the previous alternative.

Step 2:- Selection of alternatives.

- Rank all projects in the data set in decreasing order of their incremental benefit-cost ratios (as adjusted in step 1).
- Calculate the cumulative marginal costs in the same order made above.
- Select the highest ranking project and continue in descending order until the budget is exhausted. Alternatives with initial costs exceeding the remaining budget are excluded. If an alternative is selected at a location, less expensive alternatives are excluded from the solution since only one alternative for each location can be implemented.

Step 3:- Evaluation of the solution.

In case of large size problems, evaluate the final solution, when the addition of another alternative would cause the cumulative cost to exceed the specified budget, by dropping the last chosen project from the solution and adding additional projects until the budget is exhausted. The total benefit for this second solution is compared with the total benefit for the initial solution and the solution yielding the largest total benefit is selected.

2.2.2.1 Notes on the algorithm:-

1. This algorithm will not necessarily give the best possible solution for a fixed budget because the last part of step 2, which states that if an alternative is selected at a location, less expensive alternatives are excluded from the solution.
2. This algorithm has the advantage of ranking the increments of expenditure from best to worst with only one iteration.

2.2.3 Dynamic programming (DYNPRG)

Dynamic Programming is a mathematical technique dealing with the optimization of multistage processes which can be decomposed into a sequence of interrelated but separate decisions. Multiple alternatives exist within each decision set, with one being the do - nothing alternative. The basic concept of the dynamic programming is contained in the "principle optimality" which ensures that the optimal set of decisions in a multistage process is reached. It operates such that, regardless of the initial decision, the remaining decisions must constitute an optimal sequence of decisions for the remainder of the problem.

In general, the problem is solved in a sequential manner. Each alternative within a decision set is evaluated in terms of its contribution to the overall objective, with the optimum alternative always being selected.

David B. Brown has applied the Dynamic Programming to traffic safety budget allocation problems (FHWA -TS-88-19). In Brown's formulation, each location is considered as a stage, and the set of alternative safety projects at each stage constitutes the set of decision alternatives at that location. Each stage includes the "do nothing" alternative, implying that none of the available alternatives are chosen. Dynamic Programming considers the cost and benefit information for every feasible combination of alternatives and systematically eliminates each alternative that is suboptimal until only the optimal set of alternatives remains.

In Brown's Dynamic Programming model (which is used in the SRAP program), the allowable allocation of the budget is approximated by a series of discrete points or increments. This increment is calculated as being the maximum allowable budget divided by 300. The choice of 300 increments is a compromise between a high number, which would improve numerical accuracy, and a low number which would decrease computing costs and require less computer memory. The Dynamic Programming model will choose exactly one alternative at any location . If the expenditure will produce a greater return if invested at other locations, the "do-nothing" alternative will be selected.

The principle of optimality is best explained in the following numerical example which is presented in section 2.3 of this paper.

2.2.3.1 Notes on the algorithm:-

The only two constraints that may keep the Dynamic Programming solution from being the best possible solution for a fixed budget are:

1. The budget must be divided into increments to be considered in the Dynamic Programming algorithm.
2. Project costs must be rounded to the same increment or some multiple of this increment. This increment can be made quite small, causing the calculation time to increase substantially as the increment is made smaller, when there are many alternatives.

   Example: if the project costs are $490, $1200, $3,010, with using increment of $1000 the costs will be $1000, $2000, $4000. But with using increments of $500 the costs will be $500, $1500, $3500 which are more accurate but increase the calculation time.

2.2.4 Integer programming (INTPROG)

Another method for solving the capital budget problem, is the Modified

0-1 knapsack algorithm developed by Robert M. Nauss.(FHWA-TS-88-19).

In general, this procedure depends on the choice of one project for each combination of projects which maximizes the total benefits, while acting under a budgetary constraint. The optimization problem is mathematically stated as follows:-

$$Max\sum_{i=1}^{N}\sum_{j=1}^{M_i} b_{ij}x_{ij}$$

s.t. $$\sum_{i=1}^{N}\sum_{j=1}^{M_i} c_{ij}x_{ij} \le B$$

$$\sum_{j=1}^{M_i} x_{ij} \le 1$$ for i = 1, 2, ..., N

and $x_{i,j}$ = 0, 1 for all i, j

where :

N = the number of locations.

M_i = the number of alternatives at location i.

B = the total amount of resource available (budget).

b_{ij} = the benefit associated from employing the alternative j at location i.

c_{ij} = the cost associated from employing the alternative j at location i.

x_{ij} = variable set

= 1 if alternative j has been chosen at location i.

= 0 otherwise.

The second constraint ($\sum_{j=1}^{M_i} x_{ij} \leq 1$) is known as the multiple choice or generalized upper bound (GUB) constraint. It assumes that only one alternative is chosen at each location. The "do nothing" alternative is included for each GUB constraint, so that at each location, the algorithm must chose an alternative. Within a GUB constraint, exists the possibility of eliminating one or more alternatives. If an alternative has a lower benefit coefficient but a higher cost coefficient then another alternative within the same GUB constraint, than that alternative may be eliminated from the problem without affecting the optimal solution.

The program (INTPROG) uses "the Branch and Bound algorithm" , which is the most widely used method for solving the pure binary integer programming problems in practice (FHWA-RD-79-53). The algorithm is basically an efficient enumeration procedure for examining all possible integer feasible solutions. The Branch and Bound algorithm is as follows:

1. Let (P) be the optimization problem.
2. If (P) cannot be solved, then it is divided into two or more subproblems.
3. A candidate problem (cp) is chosen from the candidate list of subproblems.
4. The problem (cp) can be fathomed, by either finding an optimal solution or showing that there is no feasible solution which is better than the incumbent solution.

5. If (cp) cannot be fathomed, then it is separated further.

6. The best integer solution obtained at a fathomed subproblem becomes the optimal solution to the original integer problem.

- A lower bound of the total benefit must be subjected.

This algorithm is presented as a flow-chart in Figure 2.1.

Notes on the algorithm:-

1. There are many iterations to add projects to the solution which in turn spend more of the budget and adding more to cumulative benefits.
2. The higher the benefit lower bound is set, the fewer the number of iterations.
3. The optimal solution is the set of projects which yields the maximum total annual net benefit for the available budget .
4. If the final solution indicates that the total cost is zero, this indicates that the lower bound was set too high, which exceeds the maximum benefit that can be produced for the available budget .
5. The algorithm accepts any form of cost or benefit coefficients, including costs and / or benefits expressed in dollars and cents.
6. This algorithm guarantees an optimal solution .

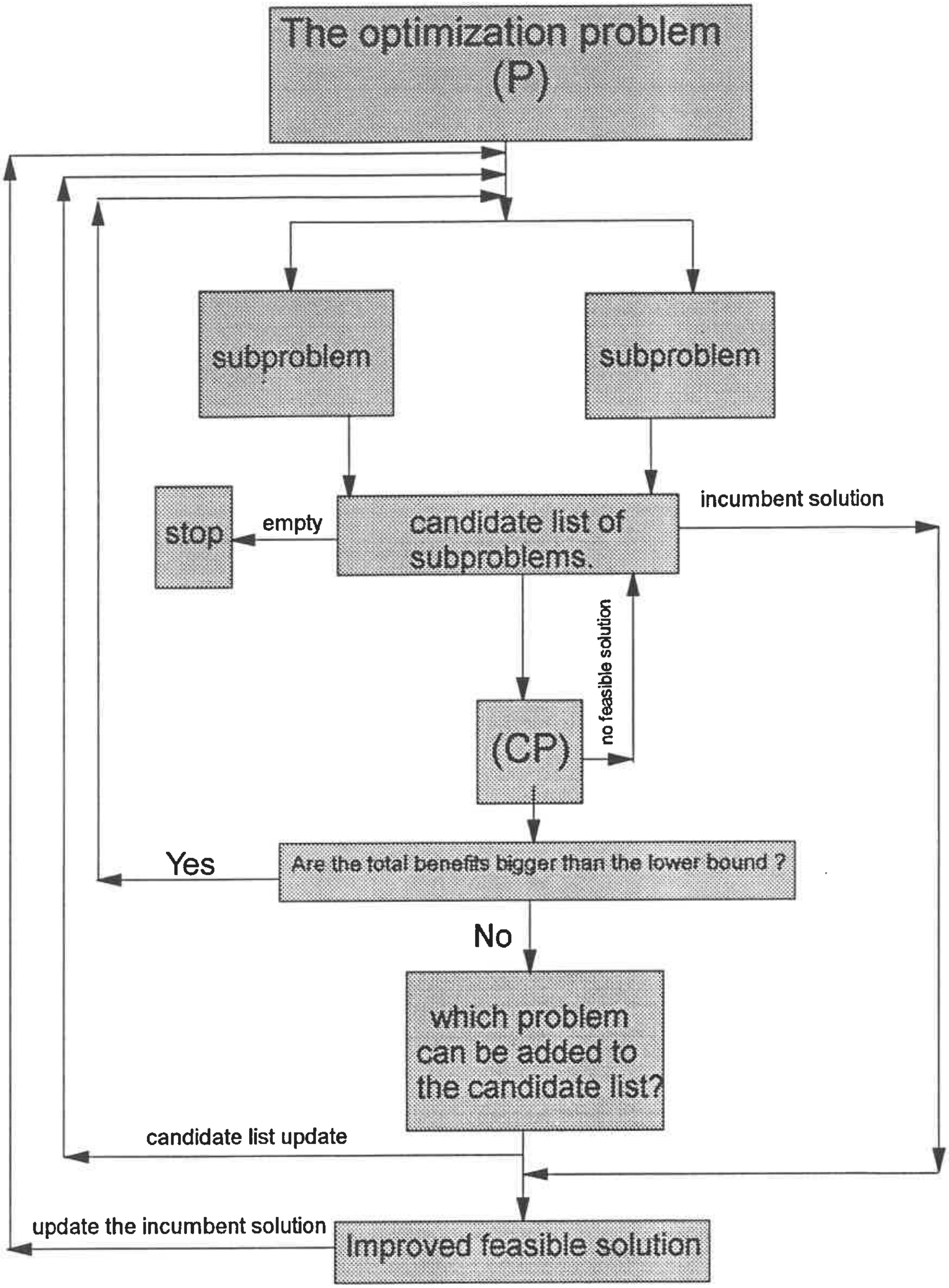


Figure 2.1: Branch and Bound algorithm

2.3 Numerical example for the cost-effectiveness methods

The example problem below is taken from FHWA (RD-79-53), and is presented for the purposes of obtaining a better understanding, and for comparing the four methods of solving the problem of allocating a fixed budget. This example was completed and reviewed prior to the writing of this report by hand calculations.

2.3.1 Example problem

Consider the following set of projects recommended for consideration at four different locations, assuming that the available budget is $9,000.

Table 2.1: Example problem.

Location	Alternative	Benefit	Cost
1	1-A	40,000	11,000
	1-B	32,000	9,000
	1-C	10,000	2,500
2	2-A	35,000	5,200
	2-B	20,000	3,010
3	3-A	10,000	1,000
	3-B	30,000	4,600
4	4-A	5,000	490
	4-B	12,000	1,200

2.3.2 Simple Benefit- Cost (SIMBEN) solution

Following the procedure described in section 2.2.1, the benefit- cost ratio "Rij" is calculated for each of the alternatives, as shown in Table 2.2. The alternative with the greatest benefit- cost ratio is selected for each location. These alternatives are arranged in order of decreasing benefit- cost ratios, as shown in Table 2.3. The selected alternatives exhausting the available budget ($9,000) are: 4-A, 3-A, and 2-A with an associated benefit of $ 50,000 and unexpended funds of $ 2,310.

Table 2.2: Simple benefit- cost method.

Location	Alternative	Cost (C)	Benefits (B)	B/C Ratio
1	1 A	11 000	40 000	3.64
	1 B	9 000	32 000	3.56
	1 C	2 500	10 000	4.00
2	2 A	5 200	35 000	6.73
	2 B	3 010	20 000	6.64
3	3 A	1 000	10 000	10.00
	3 B	4 600	30 000	6.52
4	4 A	490	5 000	10.20
	4 B	1 200	12 000	10.00

Table 2.3: Selection of projects.

Location	Alternative	B/C Ratio	Cost (C)	Sum C
4	4 A	10.2	490	490
3	3 A	10	1000	1490
2	2 A	6.73	5200	6690
1	1 C	4	2500	9190

Total cost =	6 690
benefit	50 000

budget = $9 000 - $6 690 = $ 2 310.

2.3.3 Incremental Benefit- Cost (INCBEN) solution

Using the same example as before and following the first step of the improved incremental benefit- cost algorithm outlined in Section 2.2.2 , the following listing is obtained.

Table 2.4: Incremental benefits,costs and ratios.

$A_{i,j}$	project	$C_{i,j}$	$B_{i,j}$	$MC_{i,j}$	$MB_{i,j}$	$R_{i,j}$	$R^*_{i,j}$
$A_{1,1}$	1-B	2,500	10,000	2,500	10,000	4.00	
$A_{1,2}$	1-C	9,000	32,000	6,500	22,000	3.38	
$A_{1,3}$	1-A	11,000	40,000	2,000	8,000	4.00	3.53
$A_{2,1}$	2-B	3,010	20,000	3,010	20,000	6.64	
$A_{2,2}$	2-A	5,200	35,000	2,190	15,000	6.85	6.73
$A_{3,1}$	3-A	1,000	10,000	1,000	10,000	10.0	
$A_{3,2}$	3-B	4,600	30,000	3,600	20,000	5.56	
$A_{4,1}$	4-A	490	5,000	490	5,000	10.2	
$A_{4,2}$	A-B	1,200	12,000	710	7,000	9.86	

The two last columns give the incremental and the average incremental benefit-cost ratios. In two cases, the incremental benefit- cost ratio of a more costly alternative was higher than the next lower alternative. The first case is the project 1-A with an incremental benefit- cost ratio of 4.0 which is higher than the

3.38 of the project 1-C . Therefore, these increments are combined for an average incremental benefit- cost ratio of 3.53, which is shown in the last column $R_{i,j}$* and is the ratio used for ranking this combined increment. Similarly, the two projects 2-A and 2-B are combined to give a ratio of 6.73.

Following step 2 of the algorithm, the following ranking is produced.

Table 2.5: Incremental Benefit-Cost Analyze.

project	$A_{i,j}$	$MC_{i,j}$	$R_{i,j}$	ΣC
4-A	$A_{4,1}$	490	10.2	490
3-A	$A_{3,1}$	1,000	10.0	1,490
4-B	$A_{4,2}$	710	9.86	2,200
2-A	$A_{2,2}$	5,200	6.73	7,400
2-B*	$A_{2,1}$*	3,010*	6.64*	*
3-B	$A_{3,2}$	3,600	5.56	11,000
1-B	$A_{1,1}$	2,500	4.00	13,500
1-A	$A_{1,3}$	8,500	3.53	22,000
1-C*	$A_{1,2}$*	6,500*	3.38*	*

Note that Table 2.5 contains the two averaged entries 2-A (which is a combination of the 2-B and 2-A increments) and 1-A (combination of 1-C and 1-A). The lower cost parts of these averaged increments have been included in the listing with stars, 2-B* and 1-C*. These increments actually are already included in the array since they are averaged in with 2-A and 1-A . They are included with stars to signify that they are not added separately in cumulative cost and will only be included in the budget if it is insufficient to include the more costly, averaged increments that include them. For example, 2-B would be included only if there were not enough funds for 2-A but were enough for 2-B* , i.e., a budget equal to or greater than $5,210 but less than $7,400.

For a budget of $9,000, the optimum increment benefit- cost solution is derived by first noting that expenditure increments 4-A, 3-A,4-B and 2-A have a cumulative cost of $7,400, but if the next increment ,3-B is included, the budget is exceeded by $2,000. Since there are no increments further down the list that cost $1,600 or less, the solution as outlined in the algorithm is complete. The alternatives included in the solution are 2-A, 3-A, and 4-B(the most expensive alternative at location 4, found in the selection list) with total cost of $7,400, total benefits of $ 57,000, and unspent funds of $1,600.

Since, the number of alternatives is relatively small, there is no need to apply step 3 of the algorithm in this case.

The point that was previously emphasized several times with respect to the increment benefit cost algorithm yielding the best solution for a given cumulative cost can be illustrated with reference to the last column in Table 3b, "ΣC" . It is not possible to get a better solution for \$490 than 4-A; for \$1,490 than 4-A and 3-A; for \$2,200 than 3-A and 4-B; for \$7,400 than 3-A, 4-B, and 2-A; for \$11,000 than 4-B,2-A and 3-B ; and so forth. Thus, even though the incremental benefit- cost algorithm does not assure selection of the best projects for a fixed budget, it does assure the best ranking and the best solution for the cumulative cost of the increments of expenditure.

2.3.4. Dynamic Programming(DYNPROG) solution

For solving the same example using the Dynamic Programming algorithm explained in Section 2.2.3, at the beginning, consider that the decisions at locations 4, 3, and 2 had already been made, and decisions at location 1 were to be examined, assume that no information was available concerning those previous decisions. So an optimal decision must be determined for each one of the ten budget levels from \$0 to \$9,000 (maximum available budget) when an increment of \$1,000 will be chosen for this process.

Let : **stage 1** = location 1

$\mathbf{S_1}$ = budget level (\$0, \$1,000,............, \$9,000).

$\mathbf{d_1}$ = set of alternatives at location 1 (projects 1-A, 1-B, 1-C, and 1-D which is "do nothing" alternative).

B_1 (S_1, d_1) = the benefit associated with decision d_1 at budget level S_1.

d_1* = the optimal decision , yielding the maximum benefit, at a given budget level S_1.

Max. $B_1(S_1)$ = the maximum benefit for a given budget level S_1.

Hence, **Max. $B_1(S_1)$** = $\max_{d1}$ { **B_1 (S_1, d_1)** }.

The table 2.6 represent the Dynamic program process at stage 1 (location 1). Each entry in this table is the benefit associated with each decision at each budget level.

Table 2.6: Dynamic Programming calculation at stage 1.

d_1 S_1	1-A C = 11,000 b = 40,000	1-B C = 9,000 b = 32,000	1-C C = 2,500 b =10,000	1-D C = 0 b = 0	d_1*	max. $B_1(S_1)$
0				0	1-D	0
1 000				0	1-D	0
2 000				0	1-D	0
3 000			10 000	0	1-C	10 000
4 000			10 000	0	1-C	10 000
5 000			10 000	0	1-C	10 000
6 000			10 000	0	1-C	10 000
7 000			10 000	0	1-C	10 000
8 000			10 000	0	1-C	10 000
9 000		32 000	10 000	0	1-B	32 000

Note that:-

1. the maximum budget is $9,000 .
2. there are ten possible budget levels using a $1,000 increment.
3. Some decisions are not possible because they cost more than the budget level.

4. The "do nothing" alternative costs "zero" dollars and also carries a return of "zero dollars.

At the last budget level (if all \$9,000 is still available) the decisions 1-B, 1-C, 1-D are feasible with returns of \$32,000, \$10,000, and \$0 respectively. The decision 1-A is not feasible (it costs \$11,000), then decision 1-B is optimal with a benefit of \$32,000. Similar logic leads to **d_1*** and **Max. $B_1(S_1)$** for each budget level **S_1.**

Now, suppose we extend this logic and assume that location 2 is being considered . Again, the amount of money spent at locations 3,4 is unknown, so an optimal decision must be determined for each increment of budget from \$0 to \$9,000.

Define:

stage 2 = location 2

S_2 = budget level (\$0, \$1,000,............, \$9,000).

d_2 = set of alternatives at location 2 (projects 2-A, 2-B, and 2-C which is "do nothing" alternative).

B_2 (S_2, d_2) = the benefit associated with decision d_2 at budget level S_2.

d_2* = the optimal decision , yielding the maximum benefit, at a given budget level S_2.

Max. B_2 (S_2) = the maximum benefit for a given budget level S_2.

Note that at this stage; $\mathbf{Max.\ B_2(S_2)} = \max._{d2} \{ \mathbf{B_2 (S_2, d_2) + Max.\ B_1 (S_1)} \}$.

But S_1 is the amount of money left for stage 1 (location 1) after money at stage 2 (location 2) has been spent. This amount is determined by the following formula: $S_1 = S_2$ - (cost of decision d_2)

Note that once a decision d_2 has been considered at budget level S_2, Max. $B_1(S_1)$ is already known from the stage 1 analysis for $1,000 budget increments. The calculations are summarized in the following table.

Table 2.7: Dynamic Programming calculation at stage 2.

d_2 S_2	2-A C=5,200 b=35,000	2-B C=3,010 b=20,000	2-C C=0 b=0	d_2*	Max. $B_2(S_2)$
0			0	2-C	0
1 000			0	2-C	0
2 000			0	2-C	0
3 000			10 000	2-C	10 000
4 000		20 000	10 000	2-B	20 000
5 000		20 000	10 000	2-B	20 000
6 000	35 000	20 000	10 000	2-A	35 000
7 000	35 000	30 000	10 000	2-A	35 000
8 000	35 000	30 000	10 000	2-A	35 000
9 000	45 000	30 000	32 000	2-A	45 000

For example consider an available budget of $9,000. If one chooses alternative 2-A, then this costs $5,200 and leaves $3,800 for stage 1. However, with $1,000 increments one must use the lower increment figure of $3,000. From the stage 1 analysis (Table 4a) at S_1 =$3,000, one can obtain Max. $B_1(S_1)$ = Max. B_1(3,000) = $10,000.

This yields a total benefit of $35,000 (2-A) plus $10,000 (1-C) = $45,000.

The other alternatives are calculated in the same manner.

That is present the general formulation for the optimal benefit at stage n in the following form.

Max. $B_n(S_n)$ = max. d_n [B_n ($S_{n,}d_n$) + Max. $B_{n-1}(S_{n-1})$

where (S_{n-1}) = S_n -Cost of d_n .

using this notation we proceed with stage 3 (location 3).

Table 2.8: Dynamic Programming calculation at stage 3.

d_3 S_3	3-A C=1,000 b=10,000	3-B C=4,600 b=30,000	3-C C=0 b=0	d_3*	Max. B_3 (S_3)
0			0	3-C	0
1 000	10 000		0	3-A	10000
2 000	10 000		0	3-A	10000
3 000	10 000		10 000	3-A&3-C	10000
4 000	20 000		20 000	3-A&3-C	20000
5 000	30 000	30 000	20 000	3-A&3-B	30000
6 000	30 000	30 000	35 000	3-C	35000
7 000	45 000	30 000	35 000	3-A	45 000
8 000	45 000	40 000	35 000	3-A	45000
9 000	45 000	50 000	45 000	3-B	50000

At stage 4 (location 4) the budget level is known to be $9,000. This simplifies the calculations to a single line. and Max. $B_4(S_4)$ represent the optimal Dynamic Programming return, which is equal to $57,000.

Table 2.9: Dynamic Programming calculation at stage 4.

d_4 S_4	4-A C=490 b=5,000	4-B C=1,200 b=12,000	4-C C=0 b=0	d_4*	Max. B_4 (S_4)
9 000	50 000	57 000	50 000	4-B	57 000

The sequence of decisions is recovered by working backwards through each stage. At stage 4, the optimal decision is 4-B which costs \$1,200 and leaves \$7,800. Hence, stage 3 is entered at a level of \$7,000 due to the \$1,000 increments. This yields an optimal decision 3-A, which costs \$1,000 and leaves \$6,000 for stages 1 and 2. At stage 2 with S_2 = \$6,000, the optimal decision is 2-A which costs \$5,200 and leaves \$800. This sets S_1 = 0. The only feasible decision at stage 1 is 1-D (do nothing).

The results are summarized in the following table.

Table 2.10 : Dynamic Programming results

Stage	Decision	Cost	Benefit	Excess Budget
4	4-B	1200	12000	7000
3	3-A	1000	10000	6000
2	2-A	5200	35000	0
1	1-D	0	0	0

Total costs = \$ 7,400.
Excess budget = \$ 1,600.

2.3.5 Integer Programming (INTPROG) solution

The optimal solution of the capital budget problem can be obtained by using the branch and bound technique for pure binary integer programming (Hiller and Liebeman 1986). In maximization form the problem as presented in section 2.2.4 is:

The objective function : Maximize $Z_u = \sum_{i=1}^{N} \sum_{j=1}^{M_i} b_{ij} x_{ij}$

subject to $\sum_{i=1}^{N} \sum_{j=1}^{M_i} c_{ij} x_{ij} \le B$

$\sum_{j=1}^{M_i} x_{ij} = 1$ for i =1, 2, ………, n

x_{ij} is binary for all i, j

This algorithm allows to eliminate from further consideration the solution if it passes any one of the usual three tests presented below.

First test $\sum_{j=1}^{M_i} x_j =$

Only one alternative must be chosen at each location in the solution.

Second test $\sum_{i=1}^{N} \sum_{j=1}^{M} c_{ij} x_{ij} \le B$

The total cost of the chosen projects in the solution, must be either equal to or lower than the available budget.

Third test $Z_u \ge Z_L$

Where ; Z_U = the value of the objective function for the chosen alternatives in the solution.

Z_L = Lower bound on total benefits.

Returning to the previous example, due to the complexity of the algorithm, the problem was simplified to a more moderate size by eliminating location 1 and its alternatives from the hand solution. This was acceptable since none of the alternatives at location1 were chosen in the Integer Programming computer solution. Also, a "do nothing" alternative was added to each location. The modified problem, therefore, takes the form shown in Table 2.11 and the available budget is again $9000.

Table 2.11: Moderate size example problem.

Location (i)	Alternative	(Aij)	cost (cij)	Benefit (bij)
2	2 a	A_{21}	5,2000	35,000
	2 b	A_{22}	3,010	20,000
	2 c	A_{23}	0	0
3	3 a	A_{31}	1,000	10,000
	3 b	A_{32}	4,600	30,000
	3 c	A_{33}	0	0
4	4 a	A_{41}	490	5,000
	4 b	A_{42}	1,200	12,000
	4 c	A_{43}	0	0

We shall now illustrate the algorithm by applying it to this problem.

Z_u= 35,000 x_{21}+20,000 x_{22}+10,000 x_{31}+30,000 x_{32}+5,000 x_{41}+12,000 x_{42}

s.t.

$x_{21}+x_{22}+x_{23} = 1$

$x_{31}+x_{32}+x_{33} = 1$

$x_{41}+x_{42}+x_{43} =1$

5,200 x_{21} + 3,010 x_{22} + 1,000 x_{31} + 4,6000x_{32} + 490x_{41} + 1,200 x_{42} $\leq$ 9000

Assume $Z_L = \sum_{i=1}^{N}\sum_{j=1}^{M_L} b_{ij}x_{ij}$ where *xij* =1 if bj minimum for each location i.

Z_L = 20,000+10,000+5,000=35,000.

The solution procedure consists of the following steps:-

1. Create the tree of all the feasible solutions that passes the first test ($\sum_{j=1}^{M_L} x_j =$), as shown in figure 2.2.
2. Eliminate from the tree of all the feasible solutions, all the branches which cannot pass the second test ($\sum_{i=1}^{N} \sum_{j=1}^{M} c_{ij}x_{ij} \leq B$), as shown in figure 2.3.
3. Eliminate from the resulted tree, all the branches which cannot pass the third test ($Z_u \geq Z_L$). Now we have the initial solutions tree, as shown in figure 2.4.

Select from the initial solutions tree the optimal solution branch, which has the maximum value of total benefits. The optimal solution is found in Table 2.12.

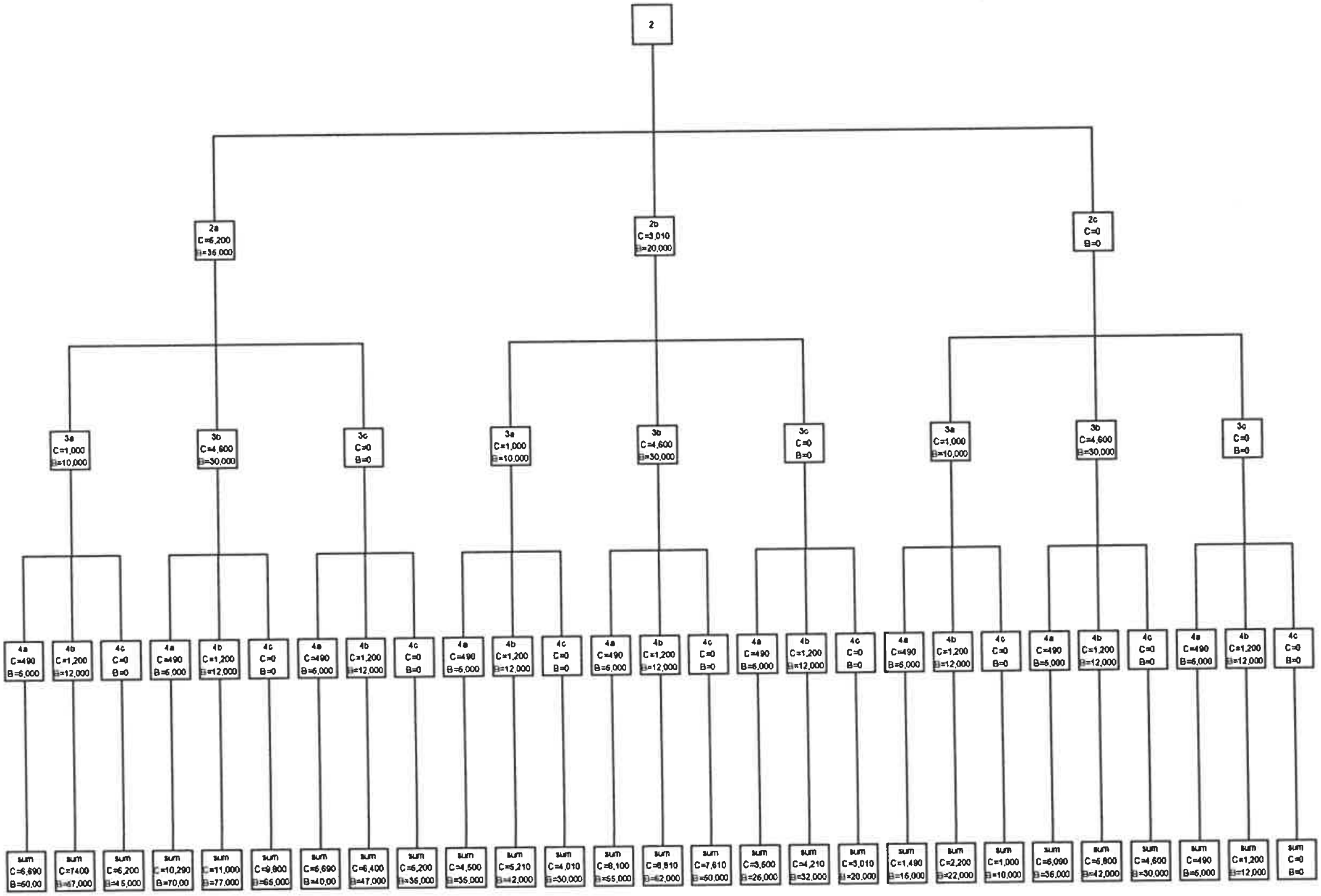


Figure 2.2: The tree of all- feasible solutions.

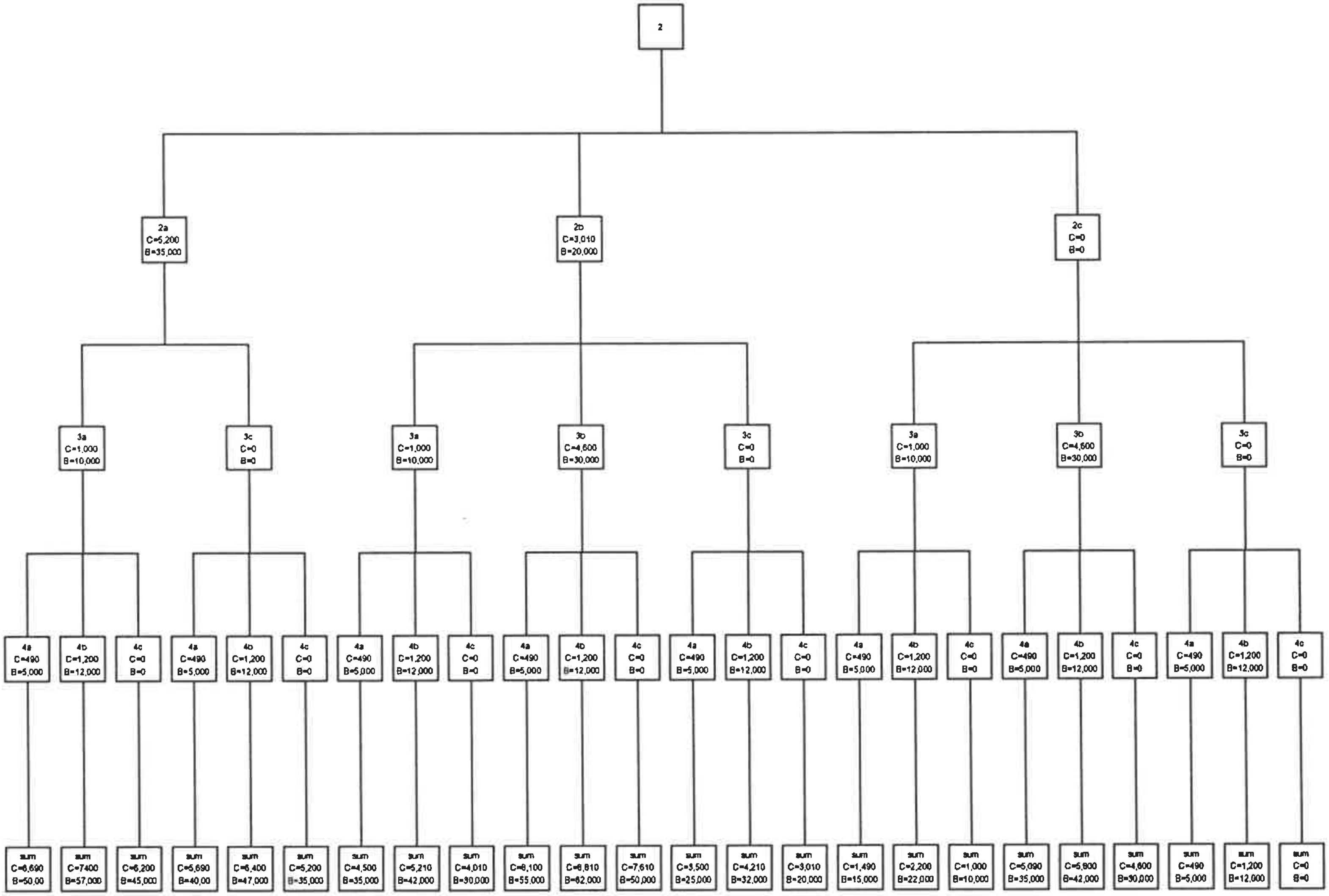


Figure 2.3: Resulting tree after the budget constraint.

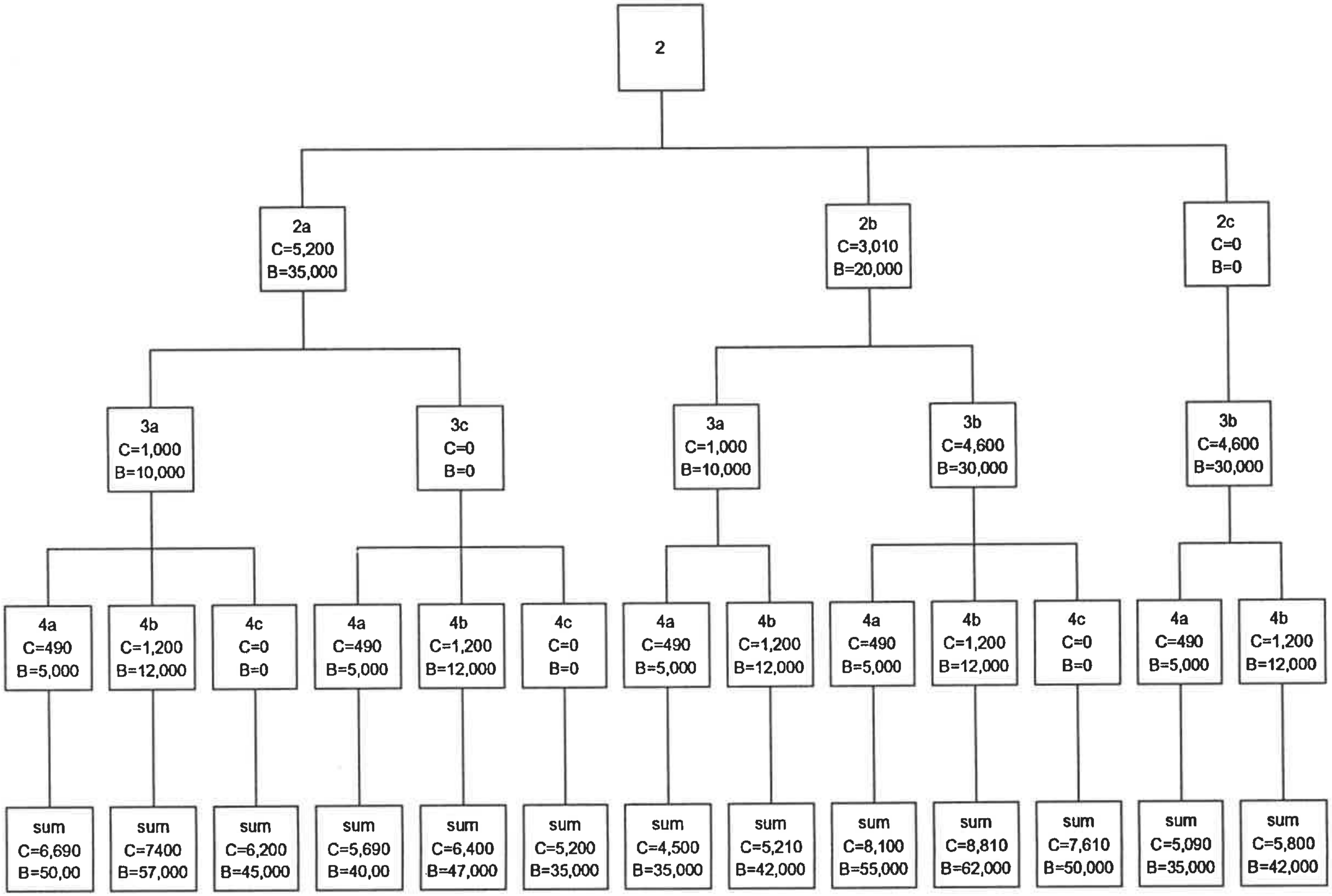


Figure 2.4: The initial solutions tree.

Table 2.12: Integer Programming solution

A_{ij}	Alternative	cost	benefit
A_{22}	2 B	3,010	20,000
A_{32}	3 B	4,600	30,000
A_{42}	4 B	1,200	12,000
	SUM	8,810	62,000

It is clearly seen, that this solution is superior to the others, it realizes the maximum total benefit ($62,000) from employing the above alternatives, also, the overall budget excess is only $190.

Again, the same solution can be generated by using Microsoft EXCEL. The following section, discusses the EXCEL solution, which applies the same principals, as the Integer Programming .

2.3.6 Microsoft EXCEL solution

One of the tools available with Microsoft EXCEL version 4.0 or 5.0 is SOLVER which solves optimization problems. This facility is developed to carry out many iterations on one or more cells, in order to realize the objective function. In this example, SOLVER uses the Newton algorithm which is :-

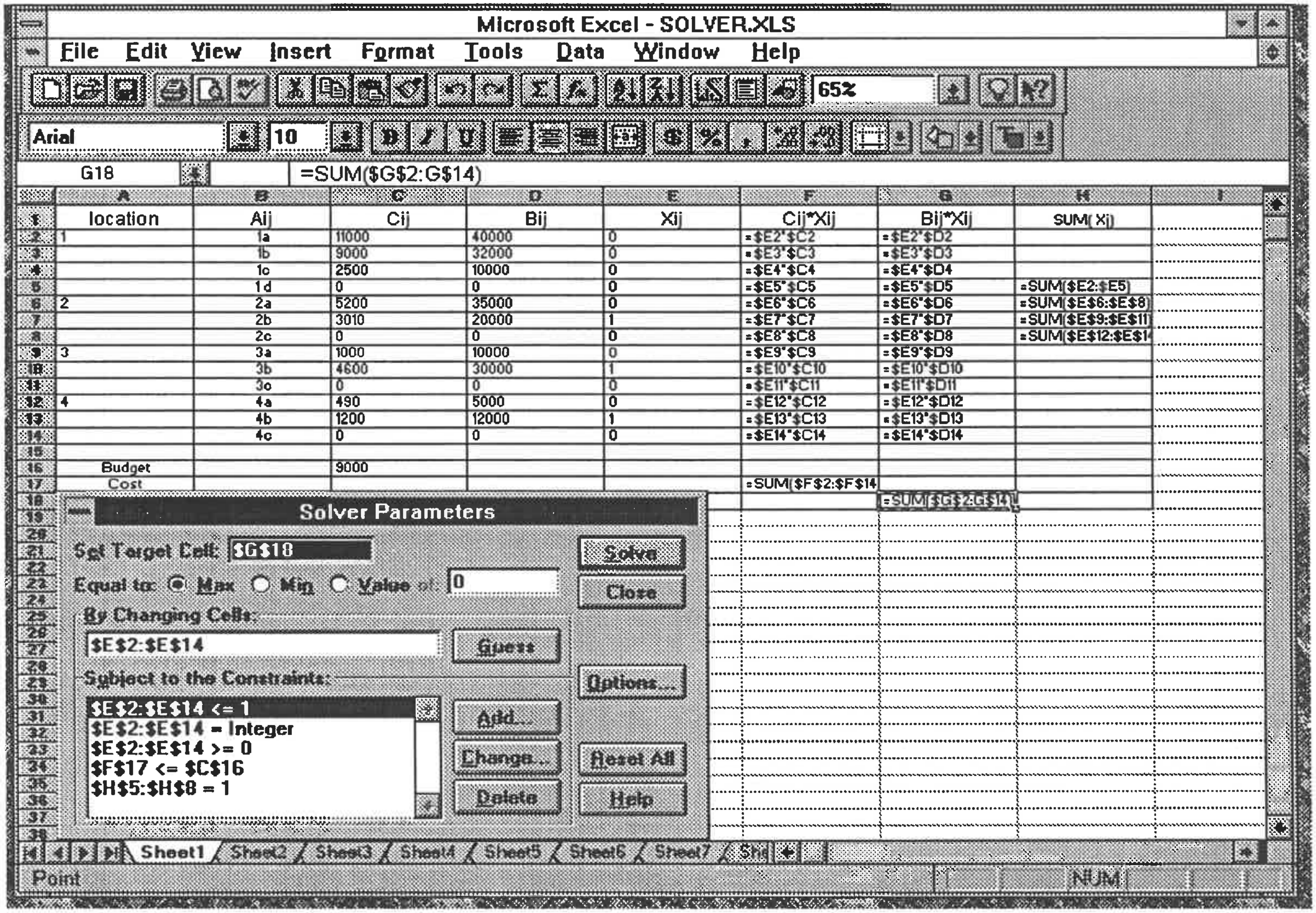
$$X_{n+1} = X_n - \frac{f(X_n)}{f'(X_n)}$$

Where the derivative *f'* was determined by an approximate tangent linear model. The accuracy used is 0.000001 and tolerance chosen was 5%, which may be considered sufficient taking into account the size of the problem. EXCEL calculations are presented in the tables 2.13.

Table2.13: SOLVER solution.

location	Aij	Cij	Bij	Xij	Cij*Xij	Bij*Xij	SUM(Xj)
1	1a	11 000	40 000	0	0	0	
	1b	9 000	32 000	0	0	0	
	1c	2 500	10 000	0	0	0	
	1 d	0	0	1	0	0	1
2	2a	5 200	35 000	0	0	0	1
	2b	3 010	20 000	1	3 010	20 000	1
	2c	0	0	0	0	0	1
3	3a	1 000	10 000	0	0	0	
	3b	4 600	30 000	1	4 600	30 000	
	3c	0	0	0	0	0	
4	4a	490	5 000	0	0	0	
	4b	1 200	12 000	1	1 200	12 000	
	4c	0	0	0	0	0	
Budget		9 000					
Σ Cost					8 810		
Σ Benefit						62 000	

The used equations (EXCEL calculation sheet) and also SOLVER options and parameters including all the constraints are presented in figures 2.5 and 2.6.



G18 =SUM($G$2:G$14)

	A	B	C	D	E	F	G	H
1	location	Aij	Cij	Bij	Xij	Cij*Xij	Bij*Xij	SUM(Xj)
2	1	1a	11000	40000	0	=$E2*$C2	=$E2*$D2	
3		1b	9000	32000	0	=$E3*$C3	=$E3*$D3	
4		1c	2500	10000	0	=$E4*$C4	=$E4*$D4	
5		1d	0	0	0	=$E5*$C5	=$E5*$D5	=SUM($E2:$E5)
6	2	2a	5200	35000	0	=$E6*$C6	=$E6*$D6	=SUM($E$6:$E$8)
7		2b	3010	20000	1	=$E7*$C7	=$E7*$D7	=SUM($E$9:$E$11
8		2c	0	0	0	=$E8*$C8	=$E8*$D8	=SUM($E$12:$E$1
9	3	3a	1000	10000	0	=$E9*$C9	=$E9*$D9	
10		3b	4600	30000	1	=$E10*$C10	=$E10*$D10	
11		3c	0	0	0	=$E11*$C11	=$E11*$D11	
12	4	4a	490	5000	0	=$E12*$C12	=$E12*$D12	
13		4b	1200	12000	1	=$E13*$C13	=$E13*$D13	
14		4c	0	0	0	=$E14*$C14	=$E14*$D14	
15								
16	Budget		9000					
17	Cost					=SUM($F$2:$F$14		
18							=SUM($G$2:G$14)	

Solver Parameters

Set Target Cell: $G$18

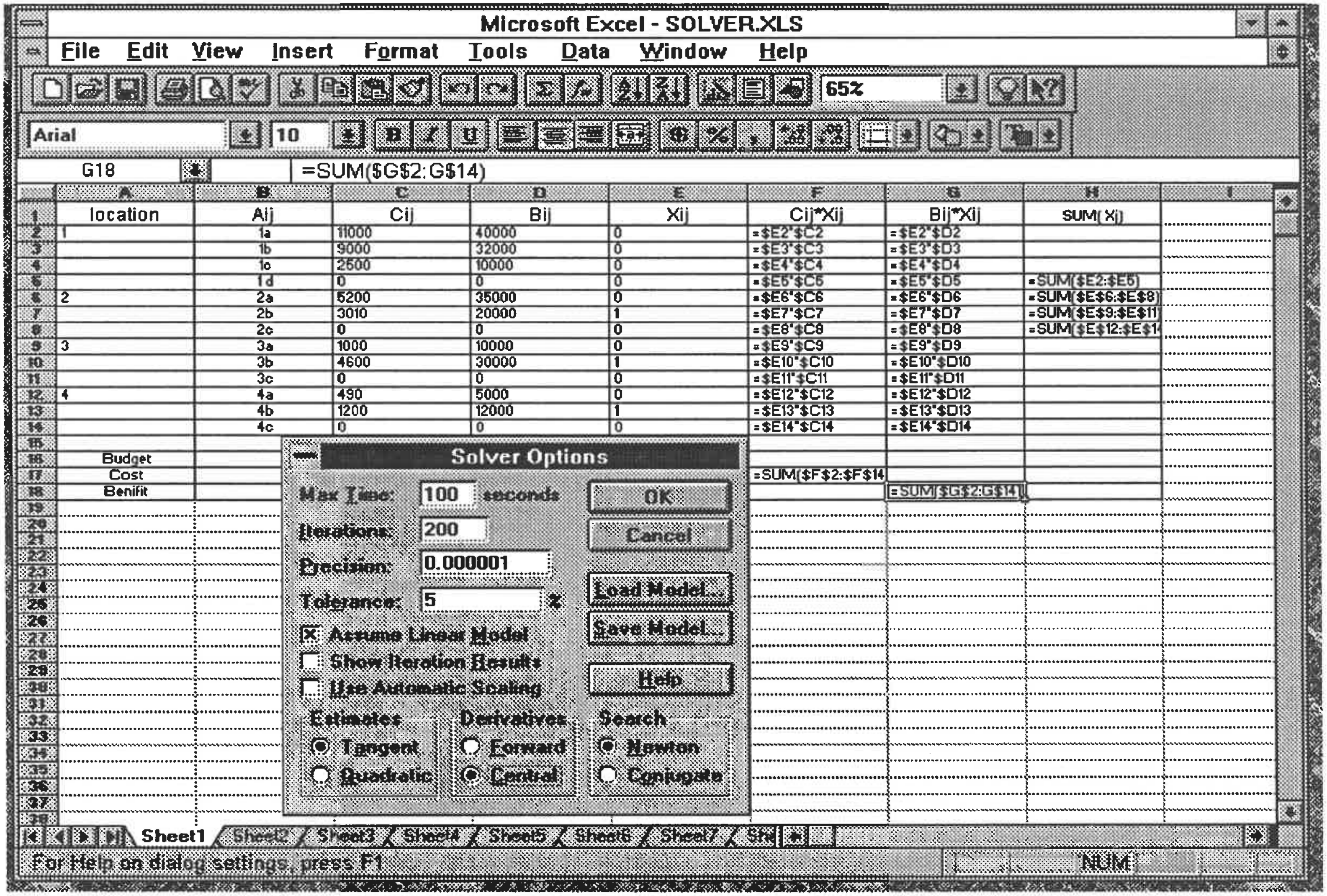
Equal to: ● Max ○ Min ○ Value of: 0

By Changing Cells: $E$2:$E$14

Subject to the Constraints:

$E$2:$E$14 <= 1
$E$2:$E$14 = Integer
$E$2:$E$14 >= 0
$F$17 <= $C$16
$H$5:$H$8 = 1

Figure 2.5: Solver Parameters.



G18 =SUM($G$2:G$14)

	A	B	C	D	E	F	G	H
1	location	Aij	Cij	Bij	Xij	Cij*Xij	Bij*Xij	SUM(Xj)
2	1	1a	11000	40000	0	=$E2*$C2	=$E2*$D2	
3		1b	9000	32000	0	=$E3*$C3	=$E3*$D3	
4		1c	2500	10000	0	=$E4*$C4	=$E4*$D4	
5		1d	0	0	0	=$E5*$C5	=$E5*$D5	=SUM($E2:$E5)
6	2	2a	5200	35000	0	=$E6*$C6	=$E6*$D6	=SUM($E$6:$E$8)
7		2b	3010	20000	1	=$E7*$C7	=$E7*$D7	=SUM($E$9:$E$11
8		2c	0	0	0	=$E8*$C8	=$E8*$D8	=SUM($E$12:$E$1
9	3	3a	1000	10000	0	=$E9*$C9	=$E9*$D9	
10		3b	4600	30000	1	=$E10*$C10	=$E10*$D10	
11		3c	0	0	0	=$E11*$C11	=$E11*$D11	
12	4	4a	490	5000	0	=$E12*$C12	=$E12*$D12	
13		4b	1200	12000	1	=$E13*$C13	=$E13*$D13	
14		4c	0	0	0	=$E14*$C14	=$E14*$D14	
15								
16	Budget							
17	Cost					=SUM($F$2:$F$14		
18	Benifit						=SUM($G$2:G$14)	

Max Time: 100 seconds

Iterations: 200

Precision: 0.000001

Tolerance: 5 %

☒ Assume Linear Model

☐ Show Iteration Results

☐ Use Automatic Scaling

Estimates: ● Tangent ○ Quadratic

Derivatives: ○ Forward ● Central

Search: ● Newton ○ Conjugate

For Help on dialog settings, press F1

Figure 2.6: Solver Options.

It should be noted that, in order to get a reliable solution, it is necessary to correlate the initial cells to the target cell. The target cell is the cell that will be maximized by the objective function.

The procedure used as shown in the Excel calculation sheet (Figure 5) is:

1- All the alternatives (Aij) including the do-nothing alternative for each of the four locations are defined with their costs (Cij) and benefits (bij) in the range of cells from B2 to D14.

2- The cells E2 to E14 are reserved for the variable set (Xij) which are changed by SOLVER. The Xij value is equal to either 1, if alternative j has been chosen at i or 0 otherwise as seen in the constraints. That is mean that, Xij represents the choice of alternatives made by SOLVER.

3- Columns F and G represent the multiplication of Cij*Xij and Bij*Xij.

4- The total cost and the total benefit of the chosen alternatives are presented in cells F17 (sum of the range of calls F2 to F14), and G18 (sum of the rang of calls G2 to G14).

5- The available budget of $9,000, is found in cell C16.

6- The cells H5 to H8 are reserved for the sum of the variable Xj for each location i, each cell must have a value equal to one, that means, that an alternative must be chosen at each location, either a project or the "do nothing" alternative.

As shown in the SOLVER Parameters sheet, it must respect certain constraints to realize the objective function (maximize the total benefits) found in the Target cell (G18) by changing the range of cells E2 to E14). These constraints are the same used by the integer programming model.

After several iterations, a maximum total benefit of $62,000 was determined. SOLVER chose the same alternatives as the Integer Programming solution. The selected alternatives, found in Table 6a are those with a value of 1 in the column Xij. the results are presented in Table 2.14.

Table2.14: SOLVER Results.

Location	Alternative	Cost	Benefit
1	1d	0	0
2	2b	3,010	20,000
3	3b	4,600	30,000
4	4b	1,200	12,000
Sum		8,810	62,000

Similar results were obtained using the SRAP program. The output of the three improved safety resource allocation computer models are shown in Appendix A.

2.3.6.2 Using the Keyboard to operate the SOLVER.

The following keys substitute for actions with the mouse to realized the SOLVER solution. Letter keys are not case sensitive. The uses of these keys are especially important when creating macros with Windows Macro Recorder.

Alt **T**, **v**, **e** ($G$18), Alt **M**, Alt **B** ($E$2:$E$14), Alt **u**, **A** ($E$2:$E$14<=1), **A** ($E$2:$E$14= Integer), **A** ($E$2:$E$14>=0), **A** ($F$17<=$C$16), **A** ($H$5:$H$8=1), Alt **O**, Alt **T** (100), Alt **I** (200), Alt **P** (0,000001), Alt **e** (5), Alt **M**, Alt **a**, Alt **C**, Alt **N** ↵ Alt **S**↵.

Another example was solved using SOLVER in 200 seconds (the computer used was a IBM- PC compatible " 486 DX 50" with 8 Mb of RAM). The sample problem consisted of 24 locations, and 47 alternatives . The results are shown in Appendix B.

SOLVER maximum capacity is 200 alternatives for each problem (including the "do nothing" alternatives) without limit of maximum number of alternatives at each location.

All the information about SOLVER is found in EXCEL user's guide Chapter 29, "Using Solver To Analyse Multiple- Variable Problems", and also in the "Help" file of the Microsoft EXCEL.

2.3.7 Comparison between the different methods

The following conclusions can be derived, from the analysis of the results using the four models presented in Table 2.15.

1- The Integer programming model(INTPROG) will always yield the optimal solution and is insensitive to the form of cost/benefit coefficients.

2- The Dynamic programming model (DYNPROG) will not yield feasible results in its present form unless budget coefficients are in units of the budget increments. Further, the current procedure will only yield an optimal solution if the individual budget expenditures and the budget increments are both in the same basic units.

However, in that case the Dynamic programming results will coincide with the Integer programming results.

3- The Incremental benefit- cost model has the advantage of ranking from best to worst, all increments of expenditures, instead of specifying the best group of projects for a given budget, which is valuable when different budget levels are analyzed.

4- The Simple benefit- cost ratio model is a fairly good technique for ranking accident locations if only one alternative is considered at each location. But in the situation where there exists several alternatives at each location, the improved techniques are always superior to it. In the above table, the percent improvement for each of the improved methods over the simple benefit cost ratio are presented.

5- The performance of the three improved resource allocation models relative to the simple benefit-cost method improved with the increase in budget level, the increase in the size of data. The models' performance also improved when the cost of individual alternatives were small relative to the available budget, and when there was a small variance in the costs between different alternatives.

Table 2.15: Comparison between the different results .

MODEL	No. of Alternatives in solution	Total Cost $	Unspent Budget	Total Benefits	% improvement over SIMBEN
SIMBEN	3	6,690	2,310	50,000	0
INCBEN	3	7,400	1,600	57,000	14
DYNPROG	3	7,400	1,600	57,000	14
INTPROG	3	8,810	190	62,000	24

Finally, with regard to the choice of projects which maximize the total returns for a fixed budget, the following inequality will usually hold:

B/C Ratio ≤ IB/C Ratio ≤ Dynamic Programming ≤ Integer Programming.

Chapter 3

Calculation Techniques for Input Data

In this chapter, calculation techniques are given for each component of the net benefit formula given at the beginning of Chapter 2.

The net benefit of employing an alternative is equal to the difference between the gross benefits and the total costs. The gross benefits are comprised of the sum of the expected reduction in accident costs, other expected user benefits from employing the alternative and its salvage value at the end of its service life. The total costs are made up of the increase in maintenance, operating, and repair costs from employing the alternative.

3.1 Calculation of reduction in accident costs

Two techniques can be used for calculating the expected reduction in accident costs for a countermeasure alternative. These techniques are :-

1- The use of percentage reduction factors .

2- The use of an encroachment- probability model (cost-effectiveness selection procedure).

Each of these techniques is discussed below.

3.1.1 Use of percentage reduction factors

The percentage reduction factor is a principal method used to estimate the reduction in accident costs from employing a countermeasure alternative.

Accident costs are calculated as being the sum of the costs derived by multiplying the number of accidents during a certain period of time for each degree of severity, by their respective average costs. (FHWA - RD -84 -011)

$$AC_M = (F_M * C_F) + (I_M * C_I) + (PDO_M * C_{PDO})$$

where:

AC_M = total accident cost during M years of accidents.

F_M = actual number of fatal accidents during M years.

I_M = actual number of injury accidents during M years.

PDO_M = actual number of property damage only accidents during M years.

C_F = average accident cost per fatal accident.

C_I = average accident cost per injury accident.

C_{PDO} = average accident cost per property damage only accident.

The actual number of accidents at a high accident location is taken over M years, where M is typically 2 to 5 years.

To estimate the expected reduction in accident costs per year due to the implementation of an accident countermeasure, percentage reduction factors are used .

The formula is : -

$$ACR = \left[\left(F_M * C_F * R_F \right) + \left(I_M * C_I * R_I \right) + \left(PDO_M * C_{PDO} * R_{PDO} \right) \right] / M$$

where:

ACR = accident costs reduction per year for an alternative.

F_M, I_M, PDO_M = actual number of fatal, injury, property damage only type accidents for M years.

C_F, C_I, C_{PDO} = average accident cost for fatal, injury, or property damage only type accident.

R_F, R_I, R_{PDO} = percentage reduction factor for an alternative for (respectively) fatal, injury, or property damage only type accident .

M = time, typically 2-5 years.

It is possible also, to use the above formula to estimate the reduction in accident cost per cause (like: safety lighting accidents, wet weather accidents,....) . In this case the number of accidents at a location and the average accident costs, by cause, are used in the calculation.

It is recommended that accident costs be calculated not only according to severity class but also for each type of area (rural, urban), type of accident and other cross-classifications. The expected percentage reduction factors are usually obtained from lists used for the different accident countermeasure alternatives. For example, Table 54 (FHWA - RD - 84 -011), P 120 -125 , presents the percentage reduction factors for 19 categories of accident countermeasures.

3.1.2 Use of encroachment - probability model

Most roadside obstacles have a relatively low probability of being hit by a motor vehicle within a short time period such as 2 to 5 years. In addition, many countermeasures for roadside hazards may be expected to change the severity of accidents in ways that are difficult to estimate with percentage reduction factors. For these reasons the encroachment probability formula has been used for predicting the number of accidents with roadside obstacles.

The formula for calculating the expected reduction in accident costs using this model is:-(FHWA-RD-84-011)

$$ACR = \left(E(f)_E - E(f)_A\right) * C(f) + \left(E(I)_E - E(I)_A\right) * C(I) + \left(E(P)_E - E(P)_A\right) * C(P)$$

Where:

ACR = expected reduction in accident cost per year.

$E(f)_E, E(I)_E, E(P)_E$ = expected number of fatal, injury, or PDO accident per year with existing roadside obstacle.

$E(f)_A, E(I)_A, E(P)_A$ = expected number of fatal, injury, or PDO accident per year after improvement

$C(f), C(I), C(P)$ = average cost per fatal, injury, or PDO accident.

$E(i)_E$ *and* $E(i)_A$ are the expected numbers of accidents with severity type *i*, *(where i* is fatal, injury, or PDO),per year before and after employing a countermeasure alternative, within section L of the roadway estimated by using the following encroachment probability formula.(NCHRP-NO. 148)

$$E(i) = V * P(E) * P(C/E) * P(i/C)$$

where:-

i = severity type, fatal, injury, or PDo.

E(i) = expected number of accidents, with severity type *i*, per year.

V = traffic volume, (vehicles per year).

P(E) = probability that the vehicle will encroach on the roadside within section L, (encroachments per vehicle).

P(C/E) = probability of a collision, given that an encroachment has occurred, (accidents per encroachment).

P(i/C) = probability of an accident, with severity type *i*, given a collision has occurred, (severity type *i* accidents per total accidents).

Both of P(E) and P(C/E) account for the frequency of collision, but P(i/C) indicates the severity of the collision determined from a severity index. The P(i/C) represents the probability of a certain severity given that a collision has occurred.

An encroachment probability model is based on the concept that the run-off-the road accident frequency can be directly related to the encroachment frequency ,i.e., the number of vehicles inadvertently leaving the traveled portion of the road way. It is also assumed that the encroachment frequency is a function of roadway and traffic characteristics and the severity of run-off -the road accidents is related to encroachment characteristics, such as speed and angle of encroachment .

There are three major components to the encroachment probability model: (King K. Mak (TRC ,No.416, 1993)

1. An algorithm to predict the frequency of accidents.
2. An algorithm to predict the severity of accidents.
3. A procedure to estimate accident costs.

A brief description of each of these components follow;

3.1.2.1 Accident frequency prediction

The accident frequency prediction algorithm is based on the probability of an encroachment, P(E), and the probability of an accident given an encroachment, P(C/E).

The model starts with a base or average encroachment rate, which is either a fixed rate as used by the "Roadside Design Guide" AASHTO 1988 (0.0005 encroachment / mile / year / ADT), or different base encroachment rates for the various highway types and the different ADT levels as used by "The Cost - Effectiveness Techniques (FHWA- RD- 84- 011).

This base encroachment rate is then adjusted for specific site conditions, such as geometric and roadway cross-section characteristics. The rationale for these adjustment factors is that encroachment rates are affected by certain geometric and roadway cross-sectional characteristics and the base encroachment rate should be adjusted to account for these characteristics.

The encroachment characteristics, such as speed, the angle of encroachment, and the extent of lateral encroachment, are expressed in terms of probability distributions so that the probability of an errant vehicle to have a certain combination of encroachment characteristics can be determined from these distributions. The probability and impact condition of an errant vehicle impacting with a roadside obstacle are determined from the encroachment characteristics, after accounting for the trajectory of the vehicle subsequent to leaving the roadway. The trajectory of the vehicle refers to the path of the vehicle, driver inputs, and roadside conditions such as presence or absence of shoulder, shoulder width, roadside slope, lateral offset, roadside obstacle, etc.

The probability of an accident given an encroachment is estimated using an impact envelope, which is defined as the region along the roadway within which a vehicle leaving the travelway at a prescribed angle will impact the roadside obstacle. The impact envelope is a function of the encroachment angle, and the physical dimensions and lateral offset of the roadside obstacle.

Other factors influencing the probability of an impact is the encroachment speed and the vehicle trajectory. Some vehicles may stop or recover and return to the roadway prior to impact with the roadway object.

3.1.2.2 Accident severity prediction

The severity of an accident which is defined as the probability of injury given an accident P(i/C), is a function of several factors, which include impact conditions (impact speed, angle and vehicle orientation), the size and weight of the impacting vehicle, and the nature of the impacted roadside obstacle.

Accident severity is typically expressed in terms of a severity index, which is a surrogate measure of injury probability and severity. The severity indices are developed from various sources including accident data, simulation and full-scale test results.

3.1.2.3 Accident cost estimation

The recommended technique in roadside obstacle cases to estimate the average accident costs is to assign a severity index to each obstacle and to use this value together with the curve that relates cost to the severity index. This curve is scaled from zero for null damage accidents to ten for fatal accidents which have a large impact on the economic analysis.

For many years, there have been different accident costs developed by different governmental agencies and by the National Safety Council. For example, the following table taken from "Roadside Design Guide" (AASHTO 1988) and "Roadside Safety Manual" (Ontario 1993) presents the accident costs in dollars.

Table 3.1: Accident cost according to severity

Accident type	AASHTO, 1988	Ontario, 1993
Fatal	500,000	750,000
Severe Injury	110,000	50,000
Moderate Injury	10,000	10,000
Minor Injury	3,000	
Property damage only 1	2,500	6,000
Property damage only 2	500	

Without discussing the merits of specific accident costs, this paper will focus on the appropriate use of whatever accident costs are selected by the user.

The expected reduction in accident cost can be determined now, after obtaining the accident frequency, severity and cost before and after employing the countermeasure safety alternative.

3.2 Calculation of other user benefits

The second item considered in the net benefit formula is the other user benefits or the reduction in other user costs. Many types of countermeasures do not only affect motorist comfort but also vehicle speeds and, thus, vehicle operating and time costs. For example, using crash cushions at gore areas on the freeways, changes many fatal and injury accidents to hit -and -run accidents, thus, reducing motorists costs associated with traffic delays at the time of the accident. This reduction may more than offset traffic disruption during repair of crash cushions. Other accident countermeasures gave a relatively small effect on other motorists benefits than accident costs. For example, the removal of a roadside obstacle, such as trees ,or the use of improved culvert designs.

3.2.1 How can other user benefits be considered?

Two inputs must be provided to determine the effects of the countermeasures on other user benefits:-

1. The decrease in vehicle operating costs per 1,000 vehicles resulting from employing the countermeasure .

The decrease in motorist time costs per 1,000 vehicles resulting from employing the countermeasure.

The above two values are inputted as positive values (benefits)when user costs are decreased but if the countermeasure increases one of these costs, then a negative value is used.

It further can be assumed that these inputs are estimated for the first year the countermeasure is being employed and remain constant for 1,000 vehicles over the analysis period.

3.3 Adjustments to accident cost reductions and other user benefits

Accident cost reductions and other user benefits may change over time because of :-

1. Changes in traffic volumes.
2. Changes in countermeasure effectiveness.
3. Other changes.

At least two types of adjustments should be made. The first is, the proportioning of the future expected reduction in accidents to average daily traffic (ADT).

- If percentage reduction factors are used for a countermeasure alternative and the user inputs M years of accident data, the ADT at this location averaged over the years also must be inputted to calculate the expected reduction in accident costs per vehicle.
- If an encroachment -probability model is used, it can be presumed that accident reductions are calculated for the first year of the analysis period.

Future average daily traffic (ADT_N) can be calculated at a location for each year N by specifying, the actual average daily traffic (ADT_0) and the traffic growth rate per year (TGR). The formula for the future average daily traffic (AASHTO 1988) is:-

$$ADT_N = ADT_0 + (1 + TGR / 100)^N$$

The second adjustment accounts for the possible decline in countermeasure effectiveness over time. For most of the countermeasure alternatives, the last year's effectiveness probability will be as good as the first year's effectiveness. Some countermeasures ,however, such as skid resistance alternatives, may be expected to decline in effectiveness over time.

3.4 Countermeasure costs and salvage value

The costs associated with each accident countermeasure alternative comprise the following:

- Initial cost which is equal to the total cost for installing a safety feature, modifying or removing an existing hazard.
- Annual maintenance and operating costs for each alternative, are assumed to be constant over an alternative's service life.

- Repair cost, per accident for each alternative, depends on the number of accidents estimated by the encroachment-probability model.

A salvage value may be inputted for each alternative, which includes the price of some of its materials at the end of the project life .

3.5 Discount rate and service life

Since the present worth of net benefits is calculated over the expected service life of each countermeasure using a specified discount rate, the service life and discount rate both are important inputs in the net benefit formula.

The service life for each accident countermeasure alternative is the useful life of the design and is an input value selected by the user.

The discount rate is also a basic input to the economic analysis. It is recommended to use a discount rate of 3 to 5 percent in future cost and benefits calculations.

This same procedure used to calculate the present worth of net benefits over the service life of an alternative is used by the ROADSIDE program which has been written for IBM compatible personal computers. The following chapter describes the ROADSIDE application.

Chapter 4

ROADSIDE Program

ROADSIDE is the microcomputer version of the cost effectiveness selection procedurein the (AASHTO1988) "Roadside Design Guide",Appendix A.

The object of this chapter is not to explain in detail how the ROADSIDE Program works, but to present it as a tool that can be used to calculate the « Present worth of net benefit ».

As seen in Chapter 2, the present worth of net benefits is the objective function to maximize in all the cost effectiveness techniques and also an important input data for the Safety Resource Allocation Programs (SRAP) which will be presented in Chapter 5.

4.1 ROADSIDE summary outlines

The cost effectiveness computer program is written in Quick Basic 4 and consists of two sets of variables. The first set, consists of the following default values :-

- Accident cost per severity category (fatal, injury, PDO).
- Encroachment characteristics (rate, angle, swath width).
- Limiting traffic volume.

The user of the program has the option to change any default value as deemed appropriate for new data or location conditions.

The second set of variables consists of the input variables which include:-

- Traffic volume(two-way ADT).
- Roadway characteristics (type, number of lanes, width of lane, curvature and grade).
- Design speed .
- Hazard definition (length, width and offset from driving lane).
- Severity index .
- Project life and discount rate.
- Highway agency costs (installation, repair, maintenance cost and salvage value).

The methodology of ROADSIDE is presented in Appendix A of "Roadside Design Guide" (AASHTO 1988).

The ROADSIDE output data are, the present worth and the annualized value for installation cost , repair and maintenance costs, and the salvage value for the accident countermeasure alternative.

4.2 Calculation of the present worth of net accident benefits

The cost effectiveness selection procedure is a rational method that can be used to predict the present worth of net benefits (B), for each alternative, using the following formula:-

$$B = RA_c - M_c - R_c + SV$$

where:

B = the present worth of net accident benefits.

RA_c = the present worth of expected reduction in accident cost due to employing an accident countermeasure alternatives by using, the encroachment probability model as shown in Chapter 3.

= A_C(before improvement) - A_C (after improvement)

M_c = the present worth of alternative annual operation and maintenance costs.

R_c = the present worth of project annual repair cost per accident.

SV = the present worth of project salvage value.

The first term in the above formula (RA_c) is equal to the difference between the present worth of annual accident before and after the improvement that can be obtained by creating two different ROADSIDE scenarios; one to calculate the accident cost before (do-nothing)and a second one to calculate the cost after employing the project. The others items of the formula(M_c , R_c ,SV) are found in the ROADSIDE output for the second scenario (after improvement).

The sample problem below is taken from (AASHTO 1988 "Roadside Design Guide" Appendix A, page A-23), and is presented for the purpose of calculating the present worth of net benefits for an accident countermeasure alternative.

4.3 Sample problem.

Consider an existing 10 feet concrete box culvert within the project limits of a rehabilitation project. This unshielded culvert is ten feet from the edge of the driving lane, has a 12 inch protecting head wall, and wing walls with a 2:1 taper. The roadway is a 2 lane undivided facility, with a lane width of 12 feet, design speed of 60 miles per hour and an average daily traffic volume of 7,000 vehicles.

- The proposed project is to shield the culvert with a longitudinal traffic barrier. The associated costs to this project are:-
- Initial cost = $5,000 .
- Repair cost = $500.
- Maintenance cost per year = $0.
- Salvage value = $0.

The barrier dimensions are:-

length = 290 feet.

Width = 1 feet.

Offset from driving lane = 8 feet.

The output calculation of ROADSIDE Program in the two cases before and after the installation of the barrier are found in Appendix C. The ROADSIDE results are in the following table.

Table 4.1:- The ROADSIDE Program Results.

The present worth of	Do-nothing (Before improvement)	Use traffic barrier (After improvement)
accident cost	$ 28,003	$ 11,662
installation cost	0	$ 5,000
repair cost	0	$ 693
maintenance cost	0	0
salvage value	0	0

Now the present worth of net benefits can be obtained from the previously formula,

B = (28,003 - 11,662) - 693 - 0 + 0

= $ 15,648

As shown the present worth of net benefits from employing a traffic barrier at this location is $15,648.

It should be noted, that the use of the ROADSIDE program to calculate this factor is very easy, efficient and practical, which can help in safety resource allocation problems where there are a large number of locations and one or more alternatives at each location.

All the information about ROADSIDE program is found in Appendix A of the AASHTO 1988, «READ ME» file of the ROADSIDE computer program and FHWA, 1991.

A new National Cooperative Highway Research Program (NCHRP) study (project 22-9) is underway to develop a new version of ROADSIDE program. It is expected to be completed in august 1995. Texas A&M University is the research agency of this project (NCHRP, summary of progress, 1993).

Chapter 5

Safety Resource Allocation Programs (SRAP)

The Safety Resource Allocation Programs (SRAP) is an integrated microcomputer program package which contains the Federal Highway Administration's (FHWA) three safety resource allocation programs presented in Chapter 2. They are the incremental benefit-cost analysis (INCBEN), the integer programming (INTPROG) and the dynamic programming (DYNPROG).

The SRAP program was developed by the FHWA in 1988 to aid highway safety planning decisions by prioritizing projects based on their costs and benefits.

5.1 Model overview

In all three models (INCBEN, INTPROG, DYNPROG), the resource allocation problem is formulated as an optimization problem in which one attempts to find the best combination of countermeasure alternatives and accident locations for improvement, under the constraint of a given budget of initial costs. The selection of locations and the appropriate alternative at each location (which may be do-nothing) is made on a basis of the present value of annual net benefits and the initial cost of each countermeasure alternative. The same objective function is used in all three formulations, is maximize the present worth of net benefits over all selected alternatives as previously maintained in Chapter 2. It is noted that in estimating the net benefits, the annual maintenance, operating, and repair costs less the salvage value, should be specifically included as "disbenefits". This ensures that the optimization models maximize the net benefits subject to a constraint on total initial cost (budget). However, if annual maintenance, operating and repair costs and salvage value are lumped with the construction cost, the cost constraint would not be the "budget" for initial cost, but would be a budget for present worth of all costs less the salvage value. The optimization algorithms used in the three models are detailed in Chapter 2.

5.2 Data requirements

The input data required by the three safety resource allocation programs are similar and include the following:-

1-The number of hazardous locations to be considered.

2-The overall budget available for safety projects in dollars.

3-The number of countermeasure alternatives to considered at each location.

4- For each alternative at each location:-

a- The initial construction cost in dollars.

b- The present worth of annual net benefit, in dollars.

All the input items can usually be obtained in a straightforward manner, except, the last item, the present worth of net benefits for each alternative which should be estimated as described in Chapter 4.

For the integer programming model (INTPROG) only, three additional data items are required in the input stream. They are:-

1- The lower bound on the total benefits expected, in dollars.

2- A print option to show calculation in the algorithm's LP (linear program) relaxation.

3- A print option to trace the search of the optimal solution.

The two print options generally are not activated and not easily comprehended.

The lower bound of the total benefits can be estimated, as the sum of the minimum benefit that can be realized by an improvement made at each location, or, as being approximately twice the budget level.

The input processor of SRAP is available which relieves the user of all the "clerical" requirements of running models (FHWA-IP-88-20).

5.3 The SRAP microcomputer system

SRAP is an integrated microcomputer program package which contains FHWA's three safety resource allocation programs and an interactive input processor for developing and modifying input data files. The package, with its menu structure and full-screen data entry feature is extremely user friendly. No prior microcomputer experience is required from the user.

SRAP system is composed of four independed programs working under an integrated, coordinated environment. The input processor program and the three safety resource allocation programs (incremental benefit cost analysis, integer programming and dynamic programming) make up the four programs. An overview of SRAP system structure is given in Figure 5.1.

The three resource allocation models were originally written in FORTRAN for the main frame computer. They were converted to run in the DOS operating system on IBM, PC. and compatible microcomputers. The input processor was programmed in turbo Pascal. The current version of the SRAP program has the capability of analyzing up to 150 accident locations per given run. Each location can contain up to seven accident countermeasure alternatives. The only exception is the dynamic programming (DYNPROG) model, which is limited to no more than 85 accident locations per run, due to the larger memory requirement of the DYNPROG model (FHWA-IP-88-20).

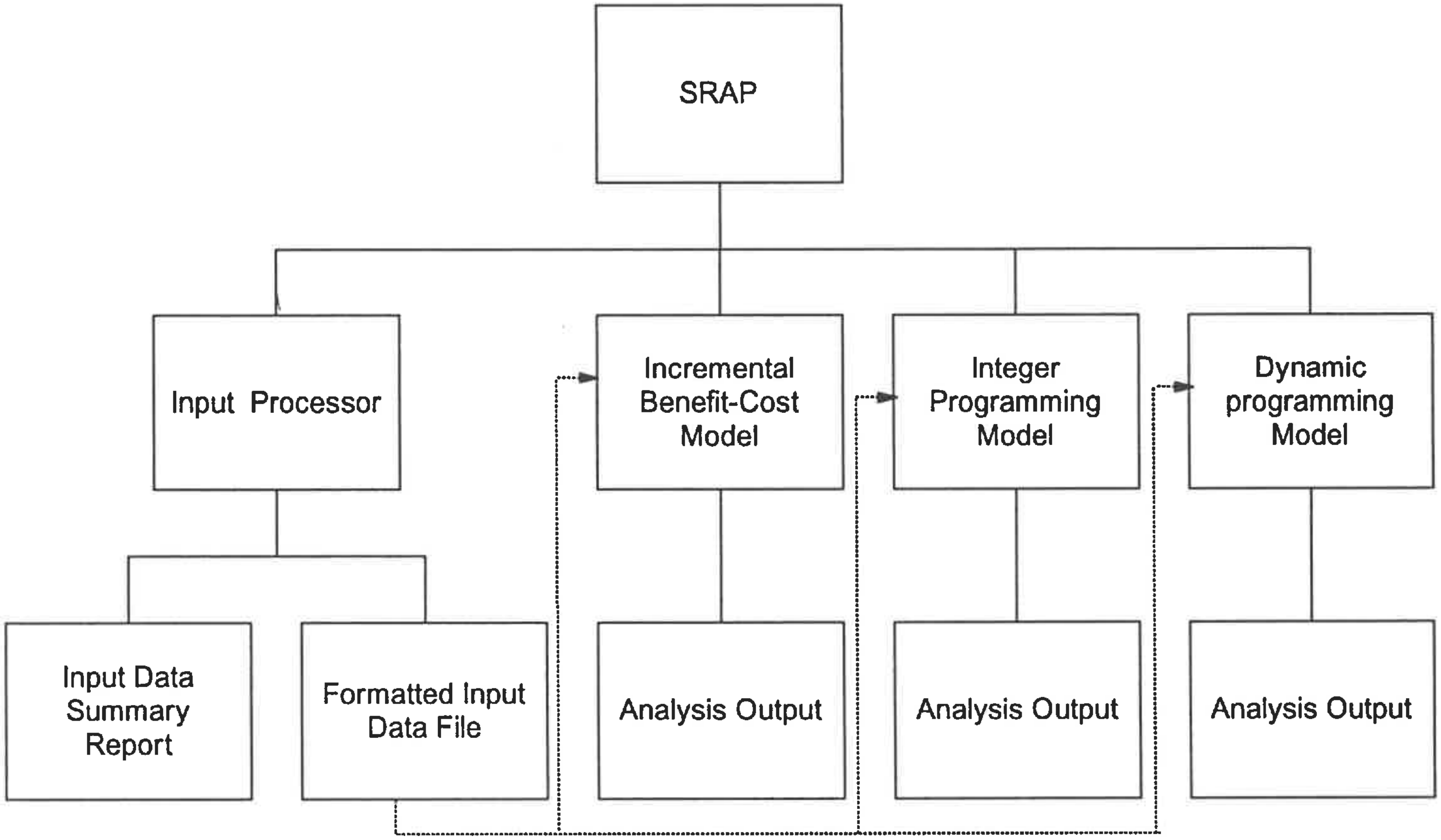


Figure 5.1: The SRAP prgram structure overview .

5.4 Output interpretation

Output from each of the three safety resource allocation models is briefly discussed below.

5.4.1. Incremental benefit cost analysis(INCBEN)

The output from INCBEN consists of the following six parts as shown in appendix A.

1. The listing of input data showing the total number of location, the available budget, and each countermeasure alternative along with its respective initial cost and present value of annual net benefit over its service life. This portion of the output simply prints out the input data.
2. The listing of projects deleted from the array of alternatives due to equal initial cost, but not greater than net benefit when comparing one alternative at a given location with the immediately preceding alternative.
3. The results of the incremental benefit-cost procedure, where project costs, benefits, incremental costs, incremental benefits, and incremental benefit-cost ratios are calculated.
4. The listing of projects deleted by the procedure due to incremental benefit-cost ratios less than one.
5. The listing of the remaining alternatives ranked by incremental benefit-cost ratios, with the cumulative cost of projects for some alternatives. The symbol "**"

appears in the cumulative cost column, indicating that the incremental cost for such an alternative is not included because the incremental cost of a higher cost alternative(with a greater incremental benefit cost ratio) at the same location has already been included in cumulative cost.

6. The listing of an optimal solution of selected projects for the available budget, based on the ranking described in part 5.

5.4.2 Integer programming (INTPROG)

The output from INTPROG consists of the following three parts:-

1. The listing of input data, as explained for the INCBEN model, in addition a lower bound of total net benefits from the project selection is added.
2. The intermediate calculation, depending on the values of the two print options.
3. The optimal solution, or that set of projects which yields maximum total annual net benefits for the available budget.

5.4.3 Dynamic programming(DYNPROG)

The output from model DYNPROG consist of two parts :-

1. The listing of input data, as explained for the INCBEN model.
2. The selection of projects showing the optimal set of projects which maximizes total annual net benefits for the available budget.

5.5 output analysis

A large problem containing 80 high-hazard locations and a total of 146 countermeasure alternatives spread among the locations was solved by the SRAP program for the purpose of analyzing the output solutions of three models (INCBEN, INTPROG, and DYNPROG). The input data and the three models' results are found in the Appendix D. Their solutions are summarized in Table 5.1.

Table 5.1: The 80 locations problem results.

Model	No. Of alternatives in solution	Total initial costs	Total benefits	Unspent budget	% of unspent budget over the total budget
INCBEN	58	748,680	3,476,566	1320	0.17%
INTPROG	57	749,680	3,477,677	320	0.04%
DYNPROG	59	746,180	3,473,163	3820	0.9%

By analyzing the output solutions from the previous example, it is found that, the INTPROG solution is the preferable, absolute optimum solution which yields the maximum total benefits with the minimum unspent budget. In certain cases the INCBEN solution is also interesting since an extra projects can be undertaken with little differences in total benefits and total initial costs. In other words more accidents locations can be improved.

In the above example, the INTPROG solution contained 57 projects and the INCBEN proposes 58 projects with a negligible difference in the total benefits (-0.03%) and in the unspent budget (+0.13%).

The INCBEN has the advantage of ranking from best to worst all the projects according to their incremental benefit cost ratios. This advantage helps to provide an argument for justification of discarding any project.

Since there is no difference between the three models run time and memory space, and since the solution proposed by the DYNPROG is relatively approximate due to the default increment, there is no need to keep the DYNPROG solution.

5.6 Sensitivity test

A sensitivity test was performed on the numerical example presented in Chapter 2, Section 2.3 in order to evaluate the sensitivity of project selection to changes in the project's initial costs. An error in the initial costs may accur due to an inaccurate estimation of these costs. The results of the sensitivity analysis aid a decision makers' ability to respond to problems posed by assumptions about this parameter. These assumptions may hamper the effective utilization of the SRAP program.

The sensitivity of project selection to changes in the initial cost of all projects in the 4 locations was tested for ± 15 percent variation in cost and fixed the available budget which was always $9000, also the benefits are unchanged. A base array of projects for each computer model (INCBEN, DYNPROG, INTPROG) used as a base for comparison, was determined by running the SRAP program before doing any changes to the project initial costs (% cost =100%), which found in Appendix A. The test results which present the SRAP program selected projects at the different cases are shown in Tables 5.2,5.3, 5.4.

Highlight of the results are as follows:-

When SRAP was run several times using different percentages of project initial costs with always the same available budget $9000, different behavior occurred with the three models.

The INCBEN model, the project selection is not effected, only minor changes appear when the assumed initial cost dropped to 85% or 90% of the base case. In these cases the available budget permitted to add another project.

The DYNPROG model exhibits the same behavior like the INCBEN. The results change only with the decrease of the initial cost to 85% and 90% of the base case.

The INTPROG model is more sensitive to changes in the initial costs. The list of selected projects is still constant within a maximum range of 5% of cost.

Table 5.2: INCBEN Sensitivity results.

% Cost	Selected projects	Benefits	Cost	Unspent budget
85%	1B, 2A, 3A, 4B	67 000	8 415	585
90%	1B, 2A, 3A, 4B	67 000	8 910	90
95%	2A, 3A, 4B	57 000	7 030	1 970
100%	**2A, 3A, 4B**	**57 000**	**7 400**	**1 600**
105%	2A, 3A, 4B	57 000	7 770	1 230
110%	2A, 3A, 4B	57 000	8 140	860
115%	2A, 3A, 4B	57 000	8 510	490

Table 5.3: DYNPROG Sensitivity results.

% Cost	Selected projects	Benefits	Cost	Unspent budget
85%	2A, 3B, 4A	70 000	8 747	253
90%	2A, 3B	65 000	8 820	180
95%	2A, 3A, 4B	57 000	7 030	1 970
100%	**2A, 3A, 4B**	**57 000**	**7 400**	1 600
105%	2A, 3A, 4B	57 000	7 770	1 230
110%	2A, 3A, 4B	57 000	8 140	860
115%	2A, 3A, 4B	57 000	8 510	490

Table 5.4: INTPROG Sensitivity results.

% Cost	Selected projects	Benefits	Cost	Unspent budget
85%	1B, 2A, 3A, 4B	67 000	8 415	585
90%	1B, 2A, 2A, 4B	67 000	8 910	90
95%	2B, 3B, 4B	62 000	8 370	630
100%	**2B, 3B, 4B**	**62 000**	**8 810**	**190**
105%	2A, 3A, 4B	57 000	7 770	1 230
110%	2A, 3A, 4B	57 000	8 140	860
115%	2A, 3A, 4B	57 000	8 510	490

The following conclusions are obtained:

1. The project selection for both of INCBEN and DYNPROG models is minimally effected by the changes of the estimated project initial costs. The INTPROG model which always yields the optimal solution is more sensitive to the changes in the estimated project costs. But the project selection is not effected by changing in the initial costs within a maximum range of 5%.
2. Accurate estimation of the relative costs of projects is important in determining the optimal solution (INTPROG solution).
3. Changing the initial cost for all projects **with an identical change in the budget**, and no change in the benefits, will not alter the project selection.

Chapter 6

Conclusion

The objective of this report was to present and analyse the Safety Resource Allocation Programs (SRAP) which contain three computerized methodologies for prioritizing safety improvement projects. The three safety resource allocation models are: Incremental Benefit-Cost Analysis, Integer Programming, and Dynamic Programming. These models were developed by the Federal Highway Administration and aimed at maximizing the total benefits under a given budget constraint by selecting the optimal mix of accident locations and the preferred countermeasure alternatives at these locations. A brief description of these three methods and comparison of the Simple Benefit-Cost Ratio method with them are presented .

The objective function of any of the three methods is to maximize the present worth of net benefits for a given budget of initial project costs. The present worth of net benefits is important input data for the SRAP program. The ROADSIDE program is a useful tool which supplies the SRAP program with this data for each countermeasure alternative, by using the probability encroachment model (manual calculation would be very long) .

Therefore, the optimal solution is always obtained by using the Integer programming approach. The "Solver" tool available with the Data Analysis tool pack in Microsoft EXCEL version 5.0 can be used with these types of problems and gives the same optimal solution. But it is clearly noted that, the SRAP program is always faster, more easy to use and proposes three solutions for the same problem by using its three computerized methodologies. The Integer Programming solution is usually the preferable, absolute optimal solution, however in certain cases the Incremental Benefit-Cost solution is also interesting since the letter allows for more accident locations to be improved. Also, the Incremental Benefit-Cost solution provides an argument for the justification of discarding any project from the selected list by ranking all the projects according to their incremental benefit- cost ratios. Nothing further is added by the Dynamic Programming solution.

Proportionate over- or underestimation of the initial cost of all projects does not greatly affect project selection, except to the extent that underestimation allows more projects to be chosen while overestimation precludes the selection of some projects. There is no effects in the optimal solution within an error range of 5% of the initial costs. Selection would be more significantly affected if initial costs were disproportionately misestimated for different types of projects, since the relative cost-effectiveness estimates of the projects would be affected.

The major findings regarding the Safety Resource Allocation Programs (SRAP) may be summarized as follows:-

Model advantages.

1. Easy to use, simple input structure and clear output.
2. Superior performance over the Simple Benefit-Cost Ratio method.
3. Encouraging and promoting the formulation and development of possibly more cost-effective countermeasure alternatives.

Model limitations.

1. Additional manpower requirement to develop and estimate the cost of multiple countermeasure alternatives .
2. Extra human resources are required to conduct continuous accident location reviews to maintain a project backlog.
3. Incompatible with other operating systems like WINDOWS and software such as EXCEL for data inputting (data entry has to be done by SRAP. Data prepared differently , for example by EXCEL, cannot be used).

References

AASHTO. (1977). Guide for selecting locating, and designing Traffic Barriers, American Association of State Highway and Transportation Officials, Washington D.C.

AASHTO. (1988). Roadside Design Guide, American Association of State Highway and Transportation Officials, Washington D.C.

BROWN, D. B., BULFIN, R. and DEASON, W. (1990). Allocating Highway Safety Funds, Transportation Research Record, 1270 Transportation Research Board, National Research Council, Washington D.C.

CALCOTE, L.R. (1977). Development of a cost effectiveness Model for Guardrail Selection, Volumes I & II, final report FHWA contract DOT- FH-11-8927, Southwest Research Institute.

FHWA. (1991). Supplemental information for use with The Roadside Computer Program. Federal Highway Administration Washington D.C.

GLEMNON, J. C. (1974). Roadside Safety Improvement Programs On Freeways. A Cost-Effectiveness Priority Approach, Technical Report, NCHRP 148, Transportation Research Board, Washington D.C.

HILLIER, F. S. and LIEBERMAN, G. J. Introduction to Operations Research. Forth edition Holden-Day inc. Oakland. California.

KING, K. M. (1993). Cost-Effectiveness evaluation of roadside safety improvement. Transportation research circular No. 416 Transportation Research Board, Washington D.C.

LAUGHLAND, J.C., HOEFNER, L. E., HALL, J.W. and CLOUGH, D.R. (1975). Methods for evaluating Highway Safety Improvements. Technical report, NCHRP-162, Transportation Research Board, Washington D.C.

LIU, C.C. (1988) Safety Resource Allocation programs implementation technique. Rapport No. FHWA-TS-88-19, Federal Highway Administration, Washington D.C.

LIU, C.C. and CHEN, H. (1988). Safety Resource Allocation Programs and Input Processor. Users Manual. Rapport No. FHWA-IP-88-20, Federal Highway Administration Washington D.C.

MC FARLAND, F. W. and ROLLINS, J. B. (1981). Sensitivity of improved Cost-effectiveness techniques. Texas transportation institute. Texas transportation institute, Texas A&M University, college Station, Texas.

MC FARLAND, W.F. and ROLLINS, J. B. (1984). Cost-effectiveness techniques for Highway Safety :final report, Texas transportation institute. Texas transportation institute, Texas A&M University, college Station, Texas.

MC FARLAND, W.F. et al. (1979). Assessment of Techniques for Cost-effectiveness Technique of Highway Accident counter measures, report No. FHWA-RD-79-53, Federal Highway Administration Washington D.C.

MC FARLAND, W.F. and ROLLINS, J.B. (1985). Cost-effectiveness Technique for Highway Safety; Resource Allocation - final report, report No. FHWA-RD-84-011, Federal Highway Administration Washington D.C.

Ministry of Transportation of Ontario, 1993. Road Side Safety Manual (section 2.14: Cost Analysis), Quality Standards Division.

NAUSS, R.M. (1978). The 0-1 Knapsack Problem With Multiple Choice Constraints. European Journal Of Operational Research, Vol.2.

NCHRP, 1993. Summary of Progress December 31, 1993. National Cooperative Highway Research Program, NATIONAL ACADEMY PRESS, Wasington D.C.

TROXEL, L. A. (1993). Severity Models for Roadside Objects. Transportation Research Circular No. 416 , Transportation Research Board, Washington D.C.

Appendix A

The example problem output from the SRAP

A.1 INCBEN Output

```
********************************************
*                                          *
*                F H W A                   *
*                                          *
*  SAFETY RESOURCE ALLOCATION PROGRAMS     *
*                                          *
*  INCREMENTAL BENEFIT-COST TECHNIQUE      *
*                                          *
********************************************



                   INPUT DATA
                   **********



THE NUMBER OF LOCATIONS =      4
THE BUDGET LEVEL        =       9000.00



    LOC   PROJ NO          COST          BENEFIT



     1       1 A        11000.00        40000.00

     1       1 B         9000.00        32000.00

     1       1 C         2500.00        10000.00



     2       2 A         5200.00        35000.00

     2       2 B         3010.00        20000.00
```

```
   3        3 A          1000.00        10000.00

   3        3 B          4600.00        30000.00


   4        4 A           490.00         5000.00

   4        4 B          1200.00        12000.00
```

```
PROJECTS OF SAME COST BUT LESS BENEFIT DELETED
**********************************************


REF   PROJ NO             COST           BENEFIT

         NO PROJECT IS DELETED
```

```
                    AN INCREMENTAL BENEFIT-COST ANALYSIS
                    ************************************


LOC   PROJ NO       COST       BENEFIT      INC COST    INC BENEFIT   INC BC-RATIO   AVG BC-RATIO


 1      1 C       2500.00     10000.00      2500.00      10000.00        4.00            .00

 1      1 B       9000.00     32000.00      6500.00      22000.00        3.38            .00

 1      1 A      11000.00     40000.00      2000.00       8000.00        4.00           3.53


 2      2 B       3010.00     20000.00      3010.00      20000.00        6.64            .00

 2      2 A       5200.00     35000.00      2190.00      15000.00        6.85           6.73


 3      3 A       1000.00     10000.00      1000.00      10000.00       10.00            .00

 3      3 B       4600.00     30000.00      3600.00      20000.00        5.56            .00


 4      4 A        490.00      5000.00       490.00       5000.00       10.20            .00

 4      4 B       1200.00     12000.00       710.00       7000.00        9.86            .00



                          PROJECTS DELETED
                          ****************


   LOC   PROJ NO        COST        BENEFIT       INC COST     INC BENEFIT    INC BC-RATIO
```

```
                         SELECTION OF PROJECTS
                         *********************


PROJ NO        COST        BENEFIT        INC COST    BC-RATIO     CUM COST


  4 A         490.00       5000.00         490.00      10.20        490.00

  3 A        1000.00      10000.00        1000.00      10.00       1490.00

  4 B        1200.00      12000.00         710.00       9.86       2200.00

  2 A        5200.00      35000.00        5200.00       6.73       7400.00

  2 B        3010.00      20000.00        3010.00       6.64         **

  3 B        4600.00      30000.00        3600.00       5.56      11000.00

  1 C        2500.00      10000.00        2500.00       4.00      13500.00

  1 A       11000.00      40000.00        8500.00       3.53      22000.00

  1 B        9000.00      32000.00        6500.00       3.38         **

THE PREFERRED SOLUTION OF PROJECTS FOR A FIXED BUDGET OF     9000.00   IS :


PROJ NO        COST        BENEFIT


  2 A        5200.00      35000.00

  3 A        1000.00      10000.00

  4 B        1200.00      12000.00


THE TOTAL COST IS          7400.00

THE TOTAL BENEFIT IS      57000.00

THE EXCESS BUDGET IS       1600.00
```

A-2 DYNPROG OUTPUT

```
**********************************************
*                                            *
*               F H W A                      *
*                                            *
*  SAFETY RESOURCE ALLOCATION PROGRAMS       *
*                                            *
*     DYNAMIC PROGRAMMING TECHNIQUE          *
*                                            *
**********************************************


                    INPUT DATA
                    **********


  THE NUMBER OF LOCATIONS =      4
  THE BUDGET LEVEL        =      9000.00

LOC   ALT        PROJECT       COST     BENEFIT      BEN/COST



  1      1           1 A        11000.     40000.        3.64

  1      2           1 B         9000.     32000.        3.56

  1      3           1 C         2500.     10000.        4.00


  2      1           2 A         5200.     35000.        6.73

  2      2           2 B         3010.     20000.        6.64


  3      1           3 A         1000.     10000.       10.00

  3      2           3 B         4600.     30000.        6.52
```

```
4     1          4 A          490.       5000.      10.20

4     2          4 B         1200.      12000.      10.00
```

```
                      SELECTION OF PROJECTS
                      ***********************

             PROJ NO             COST           BENEFIT



               4 B            1200.00          12000.00

               3 A            1000.00          10000.00

               2 A            5200.00          35000.00


      THE OPTIMAL RETURN IS       57000.00
      THE TOTAL COST IS            7400.00
      THE ORIGINAL BUDGET IS       9000.00
```

A-3 INTPROG OUTPUT

```
********************************************
*                                          *
*              F H W A                     *
*                                          *
*  SAFETY RESOURCE ALLOCATION PROGRAMS     *
*                                          *
*     INTEGER PROGRAMMING TECHNIQUE        *
*                                          *
********************************************


                             INPUT DATA
                             **********

THE NUMBER OF LOCATIONS =                  4
THE BUDGET LEVEL        =            9000.00
THE LOWER BOUND         =           20000.00

                  PROJ NO            COST            BENEFIT



                     1 A         11000.00           40000.00

                     1 B          9000.00           32000.00

                     1 C          2500.00           10000.00



                     2 A          5200.00           35000.00

                     2 B          3010.00           20000.00



                     3 A          1000.00           10000.00

                     3 B          4600.00           30000.00



                     4 A           490.00            5000.00

                     4 B          1200.00           12000.00
```

```
THE UNCONVERGED OPTIMUM SOLUTION AT ITERATION   1  IS


                    PROJ NO           COST           BENEFIT

                       2 A          5200.00         35000.00

                       3 A          1000.00         10000.00

                       4 B          1200.00         12000.00


      THE TOTAL BENEFIT IS        57000.00


      THE TOTAL COST IS            7400.00


      THE ORIGINAL BUDGET IS       9000.00



THE UNCONVERGED OPTIMUM SOLUTION AT ITERATION   2  IS


                    PROJ NO           COST           BENEFIT

                       2 B          3010.00         20000.00

                       3 B          4600.00         30000.00

                       4 B          1200.00         12000.00


      THE TOTAL BENEFIT IS        62000.00


      THE TOTAL COST IS            8810.00


      THE ORIGINAL BUDGET IS       9000.00
```

```
THE OPTIMUM SOLUTION IS

                    FINAL SELECTION OF PROJECTS
                    ***************************


               PROJ NO          COST          BENEFIT

                 2 B          3010.00         20000.00

                 3 B          4600.00         30000.00

                 4 B          1200.00         12000.00


     THE TOTAL BENEFIT IS      62000.00


     THE TOTAL COST IS          8810.00


     THE ORIGINAL BUDGET IS     9000.00
```

Appendix B

24 locations problem's Solver solution

location	Aij	Cij	Bij	Xij	Cij*Xij	Bij*Xij	SUM(Xj)
1	1a	765 000	1 132 200	0	0	0	
	1b	815 000	1 132 900	0	0	0	
	1c	1 625 000	3 607 500	0	0	0	
	1 d	154 000	750 000	0	0	0	
	1 e	0	0	1	0	0	1
2	2a	221 000	908 300	0	0	0	1
	2b	259 000	909 100	0	0	0	1
	2c	0	0	1	0	0	1
3	3a	365 000	927 100	0	0	0	1
	3b	440 000	1 020 800	0	0	0	1
	3c	0	0	1	0	0	1
4	4a	864 500	2 039 000	0	0	0	1
	4b	1 203 300	2 334 400	0	0	0	1
	4c	0	0	1	0	0	1
5	5 a	748 000	9 140 600	1	748 000	9 140 600	1
	5 b	1 653 200	3 637 000	0	0	0	1
	5 c	0	0	0	0	0	1
6	6 a	778 000	5 780 500	1	778 000	5 780 500	1
	6 b	781 000	2 975 600	0	0	0	1
	6 c	0	0	0	0	0	1
7	7 a	1 725 000	2 777 300	0	0	0	1
	7 b	2 641 700	3 064 400	0	0	0	1
	7 c	0	0	1	0	0	1
8	8 a	556 000	795 100	0	0	0	1
	8 b	572 000	1 538 700	0	0	0	1
	8 c	0	0	1	0	0	1
9	9 a	66 000	440 200	1	66 000	440 200	1
	9 b	169 100	270 600	0	0	0	1
	9 c	0	0	0	0	0	
10	10 a	3 100 000	4 867 000	0	0	0	
	10 b	3 350 000	4 857 500	0	0	0	
	10 c	4 150 000	4 855 500	0	0	0	
	10 d	0	0	1	0	0	
11	11 a	65 000	279 200	0	0	0	
	11 b	115 000	349 000	1	115 000	349 000	
	11 c	0	0	0	0	0	
12	12 a	1 461 200	4 407 300	0	0	0	
	12 b	2 750 000	8 827 500	0	0	0	
	12 c	0	0	1	0	0	
13	13 a	200 000	604 000	0	0	0	
	13 b	290 000	597 400	0	0	0	
	13 c	0	0	1	0	0	

14	14 a	260 000	3 211 000	0	0	0	
	14 b	310 000	4 808 100	1	310 000	4 808 100	
	14 c	0	0	0	0	0	
15	15 a	2 650 000	7 950 000	0	0	0	
	15 b	0	0	1	0	0	
16	16 a	160 000	1 062 400	0	0	0	
	16 b	326 000	2 314 600	1	326 000	2 314 600	
	16 c	0	0	0	0	0	
17	17 a	439 000	2 458 400	1	439 000	2 458 400	
	17 b	660 000	2 277 000	0	0	0	
	17 c	0	0	0	0	0	
18	18 a	31 900	2 392 500	1	31 900	2 392 500	
	18 b	74 400	2 461 000	0	0	0	
	18 c	0	0	0	0	0	
19	19 a	50 000	519 500	1	50 000	519 500	
	19 b	552 200	2 275 100	0	0	0	
	19 c	0	0	0	0	0	
20	20 a	1 055 000	91 300	0	0	0	
	20 b	0	0	1	0	0	
21	21 a	84 000	22 200	0	0	0	
	21 b	171 000	64 400	0	0	0	
	21 c	0	0	1	0	0	
22	22 a	130 000	767 000	1	130 000	767 000	
	22 b	0	0	0	0	0	
23	23 a	2 094 300	2 408 500	0	0	0	
	23 b	3 600 000	2 772 000	0	0	0	
	23 c	0	0	1	0	0	
24	24 a	249 800	699 400	0	0	0	
	24 b	0	0	1	0	0	
Budget		3 000 000					
Cost					2 993 900		
Benifit						28 970 400	

Appindex C

Sample problem output from ROADSIDE

C-1: Do-nothing case

```
1. TITLE:    befor improvement

2. INITIAL TRAFFIC VOLUME =    7,000 VEHICLES PER DAY
   TRAFFIC GROWTH RATE =  2.0 % PER YEAR     DESIGN YEAR ADT =    10,402
   LIMITING TRAFFIC VOLUME PER LANE   =    10,000

3. UNDIVIDED HIGHWAY  LANE(S) OF ADJACENT TRAFFIC =    1.  LANE WIDTH = 12.0 FT.

4. CURVATURE =    0.0 DEGREES            GRADE (PERCENTAGE) =    0.0

5. INITIAL ENCROACHMENT FREQUENCY = 0.0005000 * (TVeff ^ 1.000000)
             TRAFFIC   BASELINE   CURVATURE   GRADE    USER     TOTAL
             VOLUME      ENC.       FACTOR    FACTOR   FACTOR    ENC.
   ADJACENT   3,500     1.7500      1.00       1.00     1.0     1.7500
   OPPOSING   3,500     1.7500      1.00       1.00     1.0     1.7500

6. DESIGN SPEED = 60 MPH   ENCROACHMENT ANGLE =   13.0   SWATH WIDTH =   12.0

7. LATERAL PLACEMENT (A)    =       10. FT.
   LONGITUDINAL LENGTH (L) =       12. FT.
   WIDTH OF OBSTACLE        =       20. FT.
                      ZONE1         ZONE2         ZONE3
   ADJACENT          0.0287        0.0177        0.0040    ENCROACHMENTS/YEAR
   OPPOSING          0.0287        0.0177        0.0040    ENCROACHMENTS/YEAR

8. INITIAL COLLISION FREQUENCY =       0.018 IMPACTS PER YEAR
   EXPECTED IMPACTS OVER PROJECT LIFE =      0.439
   ADJACENT    CFT=  0.0120  CF1 =  0.0041  CF2 =  0.0061  CF3 =  0.0018
   OPPOSING    CFT=  0.0059  CF4 =  0.0019  CF5 =  0.0031  CF6 =  0.0009

9. SEVERITY INDEX =   5.50          5.50         6.00         6.00        4.80
                    SIDEUP       SIDEDOWN    UP CORNER   DOWN CORNER      FACE
   ACCIDENT COST = $   86,545  $   86,545  $  116,555  $  116,555   $   50,298
   INITIAL COST/YEAR IMPACTS WITH  UPSTREAM SIDE       OF HAZARD = $       354
   INITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM SIDE     OF HAZARD = $       169
   INITIAL COST/YEAR IMPACTS WITH  UPSTREAM CORNER     OF HAZARD = $       706
   INITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM CORNER   OF HAZARD = $       356
   INITIAL COST/YEAR IMPACTS WITH  FACE                OF HAZARD = $       138
                                     TOTAL INITIAL ACCIDENT COST = $     1,723.
```

```
10. PROJECT LIFE =  20 YEARS       DISCOUNT RATE =  4.0 %
    KT =   13.590    KJ =    0.456    CRF =   0.074    KC  =  16.252

11. COST OF INSTALLATION            = $        0.
12. COST OF REPAIR  $ SU=       0  SD=       0  CU=       0  CD=       0  F=      0

13. MAINTENANCE COST PER YEAR       = $        0.
14. SALVAGE VALUE                   = $        0.

15. TOTAL PRESENT WORTH             = $   28,003.    ANNUALIZED $    2,060.
    HIGHWAY DEPARTMENT COST         = $        0.    ANNUALIZED $        0.

    INSTALLATION COST =               $        0.    ANNUALIZED $        0.
    REPAIR COST       =               $        0.    ANNUALIZED $        0.
    MAINTENANCE COST  =               $        0.    ANNUALIZED $        0.



   SALVAGE VALUE     =               $        0.    ANNUALIZED $        0.
   ACCIDENT COST     =               $   28,003.    ANNUALIZED $    2,060.
```

C-2 Use traffic barrier

```
1. TITLE:    after improvement

2. INITIAL TRAFFIC VOLUME =   7,000 VEHICLES PER DAY
   TRAFFIC GROWTH RATE =  2.0 % PER YEAR    DESIGN YEAR ADT =   10,402
   LIMITING TRAFFIC VOLUME PER LANE   =   10,000

3. UNDIVIDED HIGHWAY  LANE(S) OF ADJACENT TRAFFIC =   1.  LANE WIDTH = 12.0 FT.

4. CURVATURE =   0.0 DEGREES          GRADE (PERCENTAGE) =   0.0

5. INITIAL ENCROACHMENT FREQUENCY = 0.0005000 * (TVeff ^ 1.000000)
             TRAFFIC   BASELINE   CURVATURE   GRADE    USER    TOTAL
             VOLUME      ENC.      FACTOR     FACTOR   FACTOR   ENC.
   ADJACENT  3,500      1.7500      1.00      1.00      1.0     1.7500
   OPPOSING  3,500      1.7500      1.00      1.00      1.0     1.7500

6. DESIGN SPEED = 60 MPH   ENCROACHMENT ANGLE =  13.0  SWATH WIDTH =  12.0

7. LATERAL PLACEMENT (A)   =        8. FT.
   LONGITUDINAL LENGTH (L) =      290. FT.
   WIDTH OF OBSTACLE       =        1. FT.
                    ZONE1        ZONE2        ZONE3
   ADJACENT        0.0014       0.0177       0.0961   ENCROACHMENTS/YEAR
   OPPOSING        0.0014       0.0177       0.0961   ENCROACHMENTS/YEAR

8. INITIAL COLLISION FREQUENCY =       0.085 IMPACTS PER YEAR
   EXPECTED IMPACTS OVER PROJECT LIFE =      2.092
   ADJACENT    CFT=  0.0568  CF1 =  0.0004  CF2 =  0.0068  CF3 =  0.0496
   OPPOSING    CFT=  0.0285  CF4 =  0.0002  CF5 =  0.0034  CF6 =  0.0249

9. SEVERITY INDEX =   3.00         3.00        3.00        3.00        2.70
                     SIDEUP      SIDEDOWN   UP CORNER  DOWN CORNER     FACE
   ACCIDENT COST = $   10,295  $   10,295  $   10,295  $   10,295  $    8,147
   INITIAL COST/YEAR IMPACTS WITH  UPSTREAM SIDE      OF HAZARD = $        4
   INITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM SIDE    OF HAZARD = $        2
   INITIAL COST/YEAR IMPACTS WITH  UPSTREAM CORNER    OF HAZARD = $       70
   INITIAL COST/YEAR IMPACTS WITH  DOWNSTREAM CORNER  OF HAZARD = $       35
   INITIAL COST/YEAR IMPACTS WITH  FACE               OF HAZARD = $      606
                                      TOTAL INITIAL ACCIDENT COST = $      718.
```

```
10. PROJECT LIFE =  20 YEARS       DISCOUNT RATE =  4.0 %
    KT =    13.590    KJ =    0.456    CRF =    0.074    KC  =  16.252

11. COST OF INSTALLATION           = $    5,000.
12. COST OF REPAIR  $ SU=     500  SD=     500  CU=     500  CD=     500  F=     500

13. MAINTENANCE COST PER YEAR      = $        0.
14. SALVAGE VALUE                  = $        0.

15. TOTAL PRESENT WORTH            = $   17,354.    ANNUALIZED $    1,277.
    HIGHWAY DEPARTMENT COST        = $    5,693.    ANNUALIZED $      419.

    INSTALLATION COST =              $    5,000.    ANNUALIZED $      368.
    REPAIR COST       =              $      693.    ANNUALIZED $       51.
    MAINTENANCE COST  =              $        0.    ANNUALIZED $        0.



   SALVAGE VALUE     =              $        0.    ANNUALIZED $        0.
   ACCIDENT COST     =              $   11,662.    ANNUALIZED $      858.
```

Appendix D

80 locations problem's input and results from SRAP

D-1 Input data

```
THE NUMBER OF LOCATIONS =    80
THE BUDGET LEVEL        =    750000.00


    LOC   PROJ NO           COST          BENEFIT



     1       101A          600.00         10710.00

     1       101B         2300.00         42892.00

     1       101C         2900.00         53603.00

     1       101D        19100.00        157894.00

     1       101E        22000.00        185170.00


     2       102A        10800.00         20438.00

     2       102B        12700.00         31622.00

     2       102C        23500.00         71470.00


     3       103A         2000.00          2360.00

     3       103B         5000.00          4739.00

     3       103C         7000.00          7359.00


     4       104A          200.00          1523.00

     4       104B          800.00          9803.00

     4       104C         1000.00         13829.00
```

5	105A	15000.00	1120.00
5	105B	20000.00	16293.00
5	105C	35000.00	17413.00
6	106A	450.00	4442.00
6	106B	90000.00	65301.00
7	107A	600.00	558.00
7	107B	1650.00	32900.00
7	107C	2250.00	3858.00
8	108A	210.00	1472.00
8	108B	390.00	7386.00
8	108C	600.00	8858.00
9	109A	2000.00	1994.00
9	109B	28000.00	7490.00
9	109C	30000.00	10015.00
10	110A	300.00	8172.00
10	110B	1100.00	22317.00
10	110C	3000000.00	93714.00
11	111A	15000.00	52446.00

12	112A	25.00	7842.00
12	112B	2000.00	36250.00
13	113A	2000.00	17413.00
13	113B	1500000.00	70286.00
14	114A	2000.00	52587.00
15	115A	1500.00	5909.00
15	115B	3000.00	11818.00
16	116A	20000.00	109229.00
17	117A	700.00	36434.00
18	118A	24000.00	70636.00
19	119A	40000.00	28850.00
20	120A	150000.00	35136.00
21	121A	8000.00	6861.00
21	121B	30000.00	49350.00

22	122A	3300.00	4479.00
22	122B	89600.00	142129.00
23	123A	3300.00	3514.00
23	123B	64600.00	111036.00
24	124A	1500.00	71892.00
25	125A	850.00	6332.00
25	125B	4650.00	47413.00
26	126A	730.00	3077.00
27	127A	8700.00	5620.00
27	127B	80000.00	130726.00
28	128A	12575.00	101467.00
29	129A	195.00	10661.00
30	130A	1980.00	849.00
30	130B	32600.00	2510.00
31	131A	335.00	10661.00

32	132A	20000.00	52124.00
33	133A	15000.00	144903.00
34	134A	400.00	33205.00
34	134B	2000400.00	79009.00
35	135A	400.00	25290.00
35	135B	2000.00	54826.00
36	136A	200.00	14363.00
36	136B	500.00	23089.00
37	137A	3000.00	18687.00
37	137B	9000.00	59730.00
37	137C	12000.00	78417.00
38	138A	2000.00	305443.00
38	138B	16000.00	423668.00
38	138C	73000.00	1020076.00
39	139A	15000.00	24860.00
39	139B	30000.00	37264.00

40	140A	500.00	13745.00
40	140B	1000.00	14324.00
40	140C	1500.00	28069.00
41	141A	2000.00	2780.00
41	141B	4000.00	10703.00
42	142A	2000.00	32201.00
43	143A	10000000.00	577863.00
44	144A	500.00	967.00
44	144B	5000.00	6730.00
44	144C	250000.00	12088.00
45	145A	2500000.00	392740.00
46	146A	3000.00	10159.00
46	146B	35000.00	49848.00
46	146C	2300000.00	85646.00
47	147A	20000.00	17606.00
48	148A	43000.00	34644.00

49	149A	1000.00	7588.00
49	149B	250000.00	42620.00
50	150A	8000.00	191.00
50	150B	150000.00	2679.00
51	151A	10000.00	191.00
51	151B	200000.00	2679.00
52	152A	70000.00	10043.00
53	153A	11000.00	5519.00
53	153B	24000.00	36327.00
54	154A	4500.00	3312.00
54	154B	15000.00	29971.00
55	155A	50000.00	27091.00
55	155B	2500000.00	137830.00
56	156A	15000.00	7490.00
56	156B	30000.00	12780.00
56	156C	45000.00	14247.00
57	157A	15000.00	15827.00
57	157B	3000000.00	38695.00

58	158A	30000.00	11061.00
58	158B	3000000.00	46421.00
59	159A	100000.00	10866.00
59	159B	150000.00	25111.00
59	159C	250000.00	31467.00
60	160A	50000.00	4645.00
60	160B	1500000.00	68915.00
61	161A	30000.00	19199.00
61	161B	3000000.00	67606.00
62	162A	400000.00	297779.00
63	163A	1000.00	4711.00
63	163B	50000.00	52108.00
64	164A	3600.00	735.00
64	164B	18000.00	25111.00
64	164C	21600.00	25983.00

65	165A	28000.00	36264.00
66	166A	1200.00	7538.00
67	167A	2500.00	9404.00
67	167B	5000.00	29036.00
68	168A	300.00	5526.00
69	169A	300.00	335.00
69	169B	750.00	3811.00
70	170A	5000.00	13378.00
70	170B	106000.00	29046.00
70	170C	111000.00	45823.00
71	171A	700.00	9048.00
72	172A	200.00	10640.00
73	173A	6350.00	56204.00

74	174A	775.00	20695.00
75	175A	17600.00	84368.00
76	176A	1500.00	27336.00
77	177A	720.00	4093.00
78	178A	300000.00	121498.00
79	179A	50000.00	125521.00
80	180A	20000.00	18864.00

D-2INCBEN Results

PROJ NO	COST	BENEFIT
101E	22000.00	185170.00
102C	23500.00	71470.00
104C	1000.00	13829.00
106A	450.00	4442.00
107B	1650.00	32900.00
108C	600.00	8858.00
110B	1100.00	22317.00
111A	15000.00	52446.00
112B	2000.00	36250.00
113A	2000.00	17413.00
114A	2000.00	52587.00
115B	3000.00	11818.00
116A	20000.00	109229.00
117A	700.00	36434.00
118A	24000.00	70636.00
121B	30000.00	49350.00
122B	89600.00	142129.00
123B	64600.00	111036.00
124A	1500.00	71892.00
125B	4650.00	47413.00
126A	730.00	3077.00
127B	80000.00	130726.00

128A	12575.00	101467.00
129A	195.00	10661.00
131A	335.00	10661.00
132A	20000.00	52124.00
133A	15000.00	144903.00
134A	400.00	33205.00
135B	2000.00	54826.00
136B	500.00	23089.00
137C	12000.00	78417.00
138C	73000.00	1020076.00
139A	15000.00	24860.00
140C	1500.00	28069.00
141B	4000.00	10703.00
142A	2000.00	32201.00
144B	5000.00	6730.00
146A	3000.00	10159.00
149A	1000.00	7588.00
153B	24000.00	36327.00
154B	15000.00	29971.00
157A	15000.00	15827.00
163A	1000.00	4711.00
164B	18000.00	25111.00
165A	28000.00	36264.00
166A	1200.00	7538.00
167B	5000.00	29036.00
168A	300.00	5526.00

```
   169B          750.00         3811.00

   170A         5000.00        13378.00

   171A          700.00         9048.00

   172A          200.00        10640.00

   173A         6350.00        56204.00

   174A          775.00        20695.00

   175A        17600.00        84368.00
   176A         1500.00        27336.00

   177A          720.00         4093.00

   179A        50000.00       125521.00


THE TOTAL COST IS              748680.00

THE TOTAL BENEFIT IS          3476566.00

THE EXCESS BUDGET IS             1320.00
```

D-3 DYNPROG Results

```
SELECTION OF PROJECTS
**********************

PROJ NO          COST            BENEFIT


179A          50000.00          125521.00
177A            720.00            4093.00
176A           1500.00           27336.00
175A          17600.00           84368.00
174A            775.00           20695.00
173A           6350.00           56204.00
172A            200.00           10640.00
171A            700.00            9048.00
170A           5000.00           13378.00
169B            750.00            3811.00
168A            300.00            5526.00
167B           5000.00           29036.00
166A           1200.00            7538.00
165A          28000.00           36264.00
164B          18000.00           25111.00
163A           1000.00            4711.00
157A          15000.00           15827.00
154B          15000.00           29971.00
153B          24000.00           36327.00
149A           1000.00            7588.00
146A           3000.00           10159.00
```

144A	500.00	967.00
142A	2000.00	32201.00
141B	4000.00	10703.00
140C	1500.00	28069.00
139A	15000.00	24860.00
138C	73000.00	1020076.00
137C	12000.00	78417.00
136B	500.00	23089.00
135B	2000.00	54826.00
134A	400.00	33205.00
133A	15000.00	144903.00
132A	20000.00	52124.00
131A	335.00	10661.00
129A	195.00	10661.00
128A	12575.00	101467.00
127B	80000.00	130726.00
126A	730.00	3077.00
125B	4650.00	47413.00
124A	1500.00	71892.00
123B	64600.00	111036.00
122B	89600.00	142129.00
121B	30000.00	49350.00
118A	24000.00	70636.00
117A	700.00	36434.00
116A	20000.00	109229.00

```
                    115B          3000.00             11818.00

                    114A          2000.00             52587.00

                    113A          2000.00             17413.00

                    112B          2000.00             36250.00

                    111A         15000.00             52446.00

                    110B          1100.00             22317.00

                    108C           600.00              8858.00

                    107B          1650.00             32900.00

                    106A           450.00              4442.00

                    104C          1000.00             13829.00
                    103A          2000.00              2360.00

                    102C         23500.00             71470.00

                    101E         22000.00            185170.00

THE OPTIMAL RETURN IS       3473163.00
THE TOTAL COST IS            746180.00
THE ORIGINAL BUDGET IS       750000.00
```

D-4 INTPROG Results

```
               FINAL SELECTION OF PROJECTS
               ***************************


PROJ NO             COST              BENEFIT

  138C          73000.00           1020076.00

  133A          15000.00            144903.00

  128A          12575.00            101467.00

  116A          20000.00            109229.00

  124A           1500.00             71892.00

  179A          50000.00            125521.00

  175A          17600.00             84368.00

  114A           2000.00             52587.00

  173A           6350.00             56204.00

  118A          24000.00             70636.00

  125B           4650.00             47413.00

  117A            700.00             36434.00

  111A          15000.00             52446.00

  134A            400.00             33205.00

  127B          80000.00            130726.00

  123B          64600.00            111036.00

  122B          89600.00            142129.00

  107B           1650.00             32900.00

  142A           2000.00             32201.00

  135B           2000.00             54826.00
```

132A	20000.00	52124.00
102C	23500.00	71470.00
112B	2000.00	36250.00
176A	1500.00	27336.00
101E	22000.00	185170.00
174A	775.00	20695.00
167B	5000.00	29036.00
137C	12000.00	78417.00
113A	2000.00	17413.00
110B	1100.00	22317.00
140C	1500.00	28069.00
121B	30000.00	49350.00
154B	15000.00	29971.00
129A	195.00	10661.00
172A	200.00	10640.00
131A	335.00	10661.00
136B	500.00	23089.00
171A	700.00	9048.00
170A	5000.00	13378.00
153B	24000.00	36327.00
149A	1000.00	7588.00
139A	15000.00	24860.00
166A	1200.00	7538.00
141B	4000.00	10703.00
168A	300.00	5526.00
115B	3000.00	11818.00

```
              106A          450.00          4442.00
              104C         1000.00         13829.00
              163A         1000.00          4711.00
              177A          720.00          4093.00
              169B          750.00          3811.00
              165A        28000.00         36264.00
              126A          730.00          3077.00
              108C          600.00          8858.00
              146B        35000.00         49848.00
              103A         2000.00          2360.00
              144B         5000.00          6730.00

THE TOTAL BENEFIT IS       3477677.00

THE TOTAL COST IS           749680.00

THE ORIGINAL BUDGET IS      750000.00
```