Development of Computational Tool for Highway Asset Management of a Flexible Pavement

FINAL YEAR PROJECT UG 2014

Thesis By:

Mohsin Ali Riaz (G.L)	(NUST201432223)
Muhammad Ahmed Javed	(NUST201432130)
Muhammad Talha Sandhu	(NUST201432166)
Nauman Ahmad	(NUST201433731)

Project Advisor: Lec Kamran Shakir

NUST Institute of Civil Engineering
School of Civil and Environmental Engineering
National University of Sciences and Technology, Islamabad, Pakistan

2018

CERTIFICATION

This is to clarify that thesis entitled

Development of Computational Tool for Highway Asset Management of a Flexible Pavement

Submitted By:

Mohsin Ali Riaz	(NUST201432223)
Muhammad Ahmed Javed	(NUST201432130)
Muhammad Talha Sandhu	(NUST201432166)
Nauman Ahmad	(NUST201433731)

Has been accepted towards fulfillment

of the requirements

For Bachelors in Civil Engineering

____

Lec. Malik Kamran Shakir

Lecturer

NUST Institute of Civil Engineering, NICE

School of Civil and Environmental Engineering, SCEE

DEDICATION

This thesis is dedicated to our parents.
And to the people who are working hard for the development and prosperity of Pakistan

DECLARATION

We hereby declare that the thesis entitled "Development of a computational tool for Highway Asset Management of Flexible Pavement", submitted by us is based on the study and work by us. Any references to work done by any other person, institutions or sources have been duly cited. We further clarify that this thesis has not been published or submitted for publication anywhere else.

ACKNOWLEDGEMENT

We are thankful to Almighty Allah, who gave us the courage and strength to complete this work. We would like to pay a debt of gratitude to our advisor, Lec Malik Kamran Shakir for his profound encouragement, support, motivation and valuable time he provided for this research. We would also like to pay our solemn and honest gratitude to our parents for their absolute support, encouragements, prayers, and patience.

ABSTRACT

Poor planning, defective design strategies and selection of inappropriate maintenance and operations plan are few major problems in getting best worth out of the money spent on highway projects. Similarly during planning phase of developing highway infrastructure their overall summative impact on community, road users, environment, future concerns about quality and capacity, economics and many more is not considered. In any highway planning process there are always more then on alternative available, these alternatives may vary in route alignment, design strategies or maintenance and operational plan. The above mentioned problems can be solved by equipping the planners with analysis tool that can analyses different alternative economically, environmentally and on the basis of performance. This project is about to make such a computational tool which evaluate and compare the different alternatives of project and aid the planners in making a right decision. The tool will aid designers and planners to evaluate alternatives in project level assessment economically, environmentally and to determine the benefits provided to the users. It will also aid at the end to compare the alternatives by the process of multi criterion decision making to select the best alternative.

TABLE OF CONTENTS

LIST OF FIGURES ix
LIST OF TABLES x
KEY TO ABBREVIATIONS xi
1. CHAPTER 1 1
INTRODUCTION 1
1.1 Preamble 1
1.2 Background 2
1.3 Problem Statement 2
1.4 Objectives 3
1.5 Scope 3
1.6 Software 3
1.7 Organization of Thesis 4
2. CHAPTER 2 5
LITERATURE REVIEW 5
2.1 Introduction to Study 5
2.2 Pavement Asset Management PAM 5
2.2.1 Industry and PAM Tool 5
2.2.2 Life Cycle Analysis 6
2.3 Agency Costs 6
2.4 Safety Costs 6
2.5 Vehicle Operating Costs 6
2.5.1 Tangible Costs 7
2.5.2 Intangible Costs 7
2.8 Multi Criteria Decision Making 7
2.8.1 Equal weighting 7
2.8.2 Direct Weighting 7
2.8.3 Pairwise Comparison Method 7
2.9 Research Gap 8
CHAPTER 3 9
METHODOLOGY 9
3.1 Introduction 9
3.2 Economic Evaluation 9
3.2.1 Agency Cost 10
3.2.2 User Cost 11
3.2.3 Safety Cost 13
3.2.4 Equivalent Uniform Annual Cost (EUAC) 14

3.3 Environmental Impact Analysis 15
3.4 Pavement Performance 16
3.4.1 Effectiveness (short term) 16
3.4.2 Effectiveness (long term) 17
3.5 Measures of Long Term Effectiveness 17
3.5.1 Performance Jump (PJ) 17
3.5.2 Effectiveness 18
3.5.3 Area over Performance Curve (AOC) 18
3.6 Multi Criterion Decision Making 19
3.7 Establishing weights of Criterion 21
3.7.1 Pairwise Comparison Method 21
3.7.2 Consistency Check 23
CHAPTER 4 26
IMPLEMENTATION 26
4.1 Introduction 26
4.2 Compiler 26
4.3 P-PAVE 28
4.3.1 Project Details 29
4.4 Domains 30
4.4.1 Environment Impact 31
4.4.2 Economic Evaluation 33
4.4.3 Performance Evaluation 36
4.4.4 Best Alternative Selection 38
4.5 System of Units 39
CHAPTER 5 40
Results and Conclusion 40
5.1 Introduction 40
5.2 Procedure for Selecting Best Alternative 40
5.3 Software logic 41
5.4 Limitations 42
5.4 Conclusion 42
5.5 Recommendations 43
5.6 Summary 44
ANNEX A 45
TABLES 45
REFERENCES 48

LIST OF FIGURES

Chapter 1

Figure 1.1 Process of LCCA 1

Chapter 3

Figure 3.1 Agency Cost 10
Figure 3.2 Factors Affecting VOC 11
Figure 3.3 Hepburn's VOC speed model 12
Figure 3.4 VOC Cash Flow Diagram 12
Figure 3.5 Fatality and Injury rate by FHWA 13
Figure 3.6 Safety Cost Cash Flow Diagram 14
Figure 3.7 Final Cash Flow Diagram 14
Figure 3.8 Table of Emissions by TRCP 15
Figure 3.9 World Bank IRI threshold matrix 16

Chapter 4

Figure 4.1 Compiler 27
Figure 4.2 Coding 27
Figure 4.3 User Information 29
Figure4.4 Project Details 29
Figure 4.5 Domains 30
Figure 4.6 Environmental Impact 31
Figure 4.7 EIA Summary 32
Figure 4.8 Economic Evaluation (Agency) 33
Figure 4.9 Economic Evaluation (User) 34
Figure 4.10 Economic Evaluation (Safety) 35
Figure 4.11 Economic Evaluation (Summary) 36
Figure 4.12 Performance Evaluation (Inputs) 37
Figure 4.13 Performance Evaluation (Summary) 37
Figure 4.14 Analysis Report 38

LIST OF TABLES

Chapter 4
Table 4.1 Input Units 39
Table 4.2 Outputs Units 39
Chapter 5

Table 5.1The summary of the results, guidelines and method used 44
Chapter 6

Table 6.1 Motor fatality and injury rates by functional class per 100 million.............45
Table 6.2 Parameters for Hepburn Speed VOC model (2005-cents)...........................46
Table 6.3 Pollution Emission by mode (g/VMT), source TCRP 2003........................46
Table 6.4 Summary for Critical IRI Values and treatment effectiveness measures 47
Table 6.5 KABCO scale 47

KEY TO ABBREVIATIONS

PAM	Pavement Asset Management
LCCA	Life Cycle Cost Analysis
AASHTO	American Association of State Highway and Transportation Officials
FHWA	Federal Highway Administration
MCDM	Multi Criterion Decision Making
VOC	Vehicle Operating Cost

CHAPTER 1

INTRODUCTION

1.1 Preamble

Road construction is evolving like any other industry, whether it is road design ,road construction or road maintenance industry is trying to move toward new and innovative techniques due increasing travel demand and need for economic efficiency.

Pavement Asset Management (PAM) is a strategic and systematic process of maintaining, operating and improving physical assets cost efficiently, incorporating both engineering and economic analysis. Life cycle cost analysis (LCCA) is an appraisal technique in PAM that assist in total cost comparison of competing design or preservation alternatives and determining the lowest cost alternative to accomplish the project. The American Association of State Highway Officials (AASHO) introduced the concept of life-cycle cost-benefit analysis in its ‘‘Red Book” in 1960 and now it is being practiced in developed countries. The biggest benefit performing LCCA before selecting a maintenance and rehabilitation strategy is that user gets best value of money spent and save millions of dollars by selecting most economically efficient strategy.

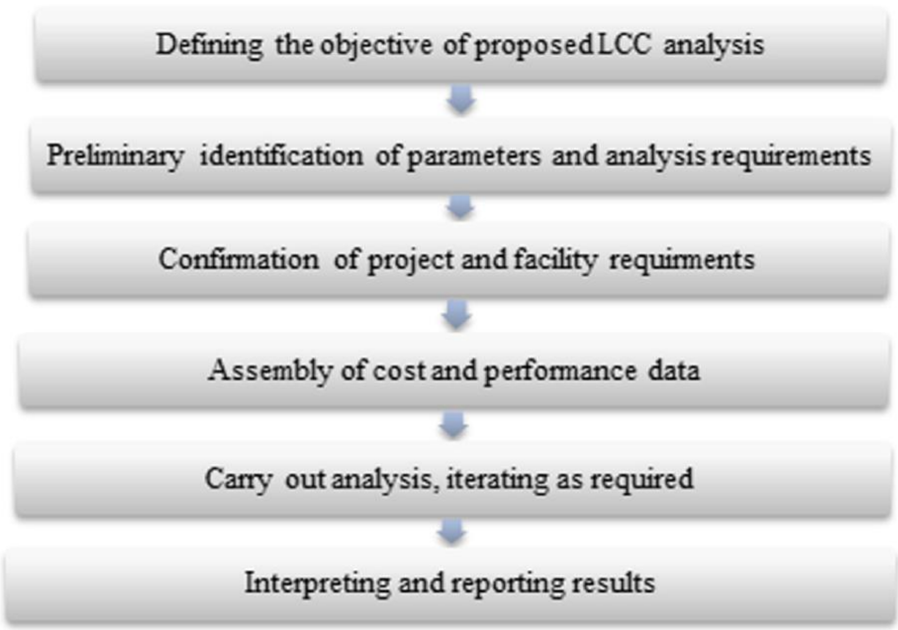


Figure 1.1 Process of LCCA

1.2 Background

Pakistan is under the development process and its ability to cope with the increasing number of vehicles now demands that new methods or researches be started so that overall cost incurred in life of road can be minimized. It also addresses the current civil engineers to introduce new ways and new techniques in pavement design, construction and maintenance so that the roads designed and constructed in near future are economical to construct, don't fail prematurely and to easy maintain.

Currently there is a boom in road construction industry due to ongoing projects of CPEC which include both construction of new highways and rehabilitation and maintenance of existing highways. These Rehabilitation and maintenance operation should be done such a way that user receive fair level of service (LOS) from facility.

In today's world, there preservation of nature and reduction in environmental pollution are of prime focus. Design procedure of every newly purposed project must ensure minimum interference with ecosystem.

Construction of Roads in Pakistan is still very traditional, concept of economic evaluation of road and environmental analysis are not followed on a large scale. These new methods include cost saving techniques, increasing life of pavement structure and allowing roads to provide desired level of service to users.

1.3 Problem Statement

As we all know Roads are built at great expense and effort but like any other asset highway infrastructure needs to be regularly taken care of, preserved, elevated (quality) and renewed in order to keep on providing the citizens with the level of service they are entitled to expect and to keep value its value for the community. So when to repair a road and when to renew it is important decision. Selection of maintenance and rehabilitation strategy must be backed by an economic study because in the current climate of increasingly urgent infrastructure needs and shrinking funding, it is important for agencies to identify strategy that is both cost effective and environment friendly.

Therefore a simplified analysis tool incorporating both economic and environmental evaluation is needed to effectively solve these problems.

1.4 Objectives

The aim of this study is to achieve the following objectives through this project:

a) To facilitate public and private administrations to perform economic evaluation of total cost involved in Life-Cycle of road and select most cost effective flexible pavement procurement strategy.
b) To facilitate construction Firms to evaluate the effectiveness of asphaltic treatment in rehabilitation and maintenance operations and select best treatment strategy from available alternatives

1.5 Scope

To achieve the above mentioned research objectives a research plan was prepare and for the gratification of plan following tasks were outlined:

a) Literature review of previous research findings about pavement asset management and multi criteria decision making
b) Extraction and revising of different factors involved in planning phase of any highway project
c) Preparation of methodological flow charts
d) Conversion of methodological flowcharts into machine language using NetBeans IDE 8.1
e) Interface design of software using JFrames.
f) Testing and validation of software

1.6 Software

Following is the list of software used for this study

a) Edraw Mind Map
b) NetBeans IDE 8.1

The purpose and details of each of the above mentioned software will be provided in the section in which they are used

1.7 Organization of Thesis

The study was divided in six chapters which is outlined as:

a) Chapter 1 includes brief introduction of Highway Asset Management, Economic and Performance analysis procedures of Flexible Pavement
b) Chapter 2 includes a literature review on findings of previous studies on Highway Asset Management, Economic and Performance analysis procedures of Flexible Pavement
c) Chapter 3 includes the methodology selected to achieve the study goals
d) Chapter 4 includes user interface and guide of software
e) Chapter 5 is concerned with conclusion and future recommendations

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction to Study

The overall global ambition towards construction with minimum economical aspect has led to the need to consider developments in terms of sustainability and life cycle cost entanglement of road construction and has incited designers to combine technical advances in fields of mechanics with traditional methods.

2.2 Pavement Asset Management PAM

PAM (Pavement Asset Management) has been in use worldwide for a decade and it also finds its application in evaluation of economic sustainability of road. Some of

Published work in this field is mentioned

Flexible Pavements are naturally prone to a variety of distresses as a result of the environment and repeated traffic loads if there is not a well-defined and executed maintenance and rehabilitation plan. (FHWA (1998) LCCA in pavement design)

The LCCA methodology allows the total cost comparison of competing design alternative, route alternatives, maintenance and preservation strategies, operational strategies, each of which is applicable for enactment of a transportation project (US Dep. Of Transportation (2002) LCCA Primer)

All of the relevant costs that is spent during the life of an alternative, not simply the original expenses, are included in LCCA i.e., maintenance cost rehabilitation cost, user cost. (Babashamsi et al., 2016)

2.2.1 Industry and PAM Tool

Stake holders of large municipal authorities such as federal departments, provincial departments, and construction industry have responsibility over a diverse set of facilities. These assets range from complex network of roads, bridges, tunnels and airports to simple buildings, parks and other equipment required to maintain these facilities. These infrastructures cannot be protected by deterioration due to its extensive use, changing climatic effects. Furthermore because of inadequate funding and support from technologies certain components are ignored which have long term bad effects.

2.2.2 Life Cycle Analysis

This type of analysis includes the facts of what happened what is current situation and what will be the expected forecast. How the road has been constructed, how it is performing now and after and what are the impacts on surrounding. The answer to all these questions will be given by Life cycle analysis. It has many types depending on the scope of study such as Life Cycle Cost Analysis (LCCA), Life Cycle Benefits Analysis (LCBA) and Life Cycle Overall Impact Analysis (LCOIA) etc.

2.3 Agency Costs

Agency costs include Initial cost (design costs, construction, contract costs, etc.), yearly maintenance and operating costs and major rehabilitation costs throughout design life of road

2.4 Safety Costs

Safety cost is the cost paid by the society in case of vehicular accident on the highway

2.5 Vehicle Operating Costs

James Luk and Hepburn established a VOC model in 1994 that considers the sum of four vehicle operating cost (VOC) components (Fuel, maintenance, vehicle depreciation, and Tire Cost) as a function of two VOC factors: Vehicle Class and speed limit for urban roadways (Luk et al., 1994). This cost is incurred by the road users in form of above mentioned VOC components throughout their travelling or life.

2.5.1 Tangible Costs

Tangible costs are those costs that are monetary but paid indirectly as expenses associated with vehicular use of asset

2.5.2 Intangible Costs

Tangible costs are those costs that are non-monetary except some cases

2.8 Multi Criteria Decision Making

By using a process named as sensitivity analysis the results of deterministic analysis can be enhanced. This procedure involves changing a single input limitation of interest while holding all other inputs constant, and estimating a series of output values (Audu et al., 2015). It also includes the selecting the best output depending the criterions affecting decision. Many methods are available to give the weightage and power of criterions to be finally used for decision. Few of them are described here:

2.8.1 Equal weighting

In this method equal weightage is given to all factors. This can be done only in case in which impacts of different factors are same.

2.8.2 Direct Weighting

The weights for the domain are determined by individual judgmental experience. It varies from case to case and person to person.

2.8.3 Pairwise Comparison Method

This method involves assigning the weightage to multiple criterions based on their relative importance. This method is best in a case where the impacts of factors are different.

2.9 Research Gap

Very limited work has been done in the field of Highway asset management. There is a huge gap in planning and analysis of alternative pavement design strategies. There are no set procedures or methods in industry to carry out proper planning before the start of highway project which result in many unrectifiable problems in future. In a country like Pakistan where it is an immense need of study in this area for the development of highway infrastructure from minimum available resources.

CHAPTER 3

METHODOLOGY

3.1 Introduction

For development of comprehensive software application research was divided in three main domains.

1. Economic Evaluation
2. Environmental Impact Analysis
3. Pavement Performance

3.2 Economic Evaluation

For any transportation problems/project, there are quite a lot of design alternative decisions or actions, each corresponding to their unique set of costs and benefits. The collective cost (including initial construction cost, operation and maintenance cost, intervention cost, road users cost, community cost etc) of each alternative can be represented by a measure known as economic efficiency, which is derived using the principles of economic analysis. Economic analysis is a decision-making tool that assesses the economic viability of investments from a pecuniary position and integrates costs and benefits related with each design alternative.

Across all alternatives, differences in pavement design strategies are the combination of initial pavement design and necessary supporting maintenance and rehabilitation activities. These can be forecasted values/activities estimated by designers. Every design strategy impacts factors like environment, safety and vehicle operating cost differently. Mostly decisions to select the best from several alternatives, actions are often made on the basis of economic contemplations. But how to gauge the economic efficiency of a proposed project?:

There are several criteria for doing this:

1. Present Worth of Costs (PWC)
2. Equivalent Uniform Annual Cost (EUAC)
3. Equivalent Uniform Annual Return (EUAR)

4. Net Present Value (NPV)
5. Benefit – Cost Ratio (BCR)

We selected method of **Equivalent Uniform Annual Cost (EUAC)** also termed as annual worth analysis for checking the economic efficiency of different alternatives by the computational tool. This method is selected because it can be used in a case where time span of alternatives are different. For using method of Equivalent Uniform Annual Cost (EUAC) three different costs are calculated.

1. Agency Cost
2. User Cost
3. Safety Cost

3.2.1 Agency Cost

Agency cost is the cost born by the constructing agency throughout the lifecycle of pavement. It further includes three costs:

1. Capital Cost:

It is the sum of all the expenditures company has to bear on ROW purchase, Asset Construction, Utilities Relocation etc. taken as single cash flow at year zero.

2. Maintenance and Operation Cost:

Cost paid by agency in term of yearly maintenance and crack sealing

3. Rehabilitation or Preservation Cost:

Cost paid by agency in term of major rehabilitation and preservation activities

Cash flow diagram for agency cost is shown below

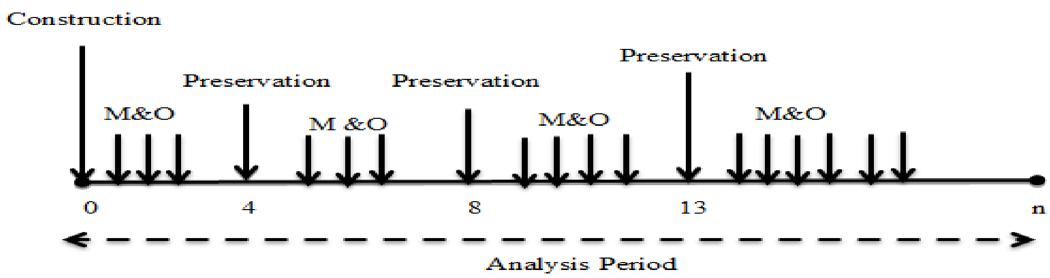


Figure 3.1 Agency Cost

3.2.2 User Cost

User costs are straight expenses that comprise the costs of vehicle ownership (fixed) and vehicle operation (variable) by the owner or user using highway facility. The latter category, characteristically referred to as vehicle operating costs (VOC's), varies with vehicle use and it is expressed in unit cents per mile traveled by a vehicle. Factors affecting VOC are as follows:

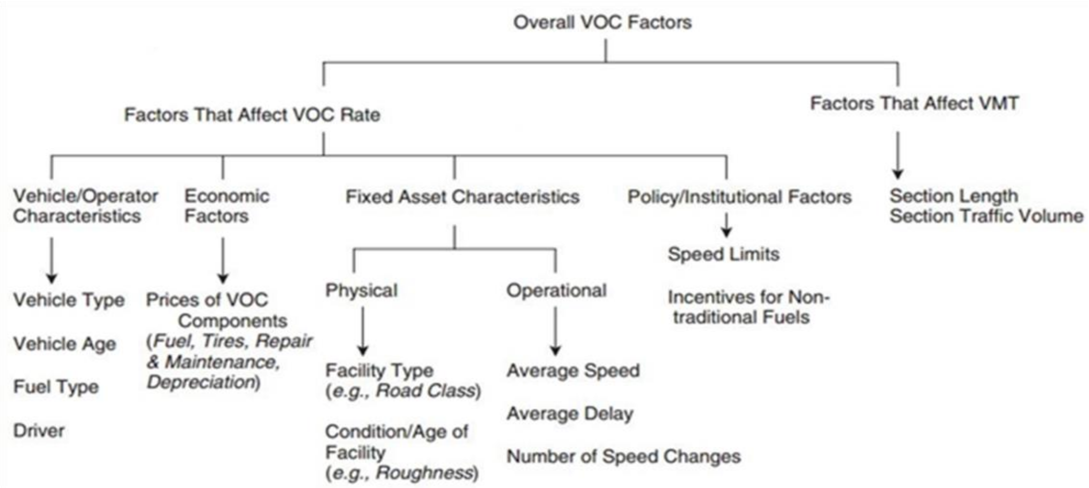


Figure 3.2 Factors Affecting VOC

This software uses Hepburn model to calculate VOC

1. HEPBRUN MODEL:

For evaluating user cost incurred on specific alternatives we selected Hepburn model. Hepburn established a VOC model in 1994 that considers the sum of four vehicle operating cost (VOC) components (Fuel, maintenance, vehicle depreciation, and Tire Cost) as a function of two VOC factors: Vehicle Class and speed limit for urban roadways (Luk et al., 1994). This cost is incurred by the road users in form of above mentioned VOC components throughout their travelling or life.

The Hepburn function which is converted in programing language is as follows:

For "low" average travel speeds (< 50 mph):

$$VOC = C + \frac{D}{S}$$

For "high" average travel speeds (> 50 mph):

$$VOC = a_o + a_1S + aS^2$$

Where VOC is in cents/mile, S is speed (mph) and;

C, D, a0, a1, and a2 are coefficients that are functions of vehicle class. The coefficient values are provided in Table 7.3 from Sinha & Labi Text Book.

Table 7.3 Parameters for Hepburn's VOC–Speed Model (2005 Cents)

Vehicle Type	C	D	a_0	a_1	a_2
Small automobile	24.8	45.5	27.2	0.035	0.00021
Medium-sized automobile	28.5	95.3	33.5	0.058	0.00029
Large automobile	29.8	163.4	38.1	0.093	0.00033

Figure 3.3 Hepburn's VOC speed model

Our tool automatically selects equation by comparing the speed limit. Table is saved in software directory in .csv format which is read by using while loop

Yearly VOC is calculated by formula

$$\mathbf{Yearly\ VOC} = \mathbf{AADT} \times \mathbf{l} \times \mathbf{365} \times \mathbf{Unit\ VOC}(\mathbf{Table\ 7.3})$$

This formula will give value of OC in 2005 Dollars. Software converts this value to Rupee of 2017 by using formula

$$\mathbf{Yearly\ VOC}(\mathbf{Rs}) = \mathbf{Yearly\ VOC}(\$) \times \frac{CPI_{2017}}{CPI_{2005}} \times (\$ - \mathbf{Rs})_{conversion\ rate\ 2017}$$

Final shape of cash flow diagram for VOC is shown below.

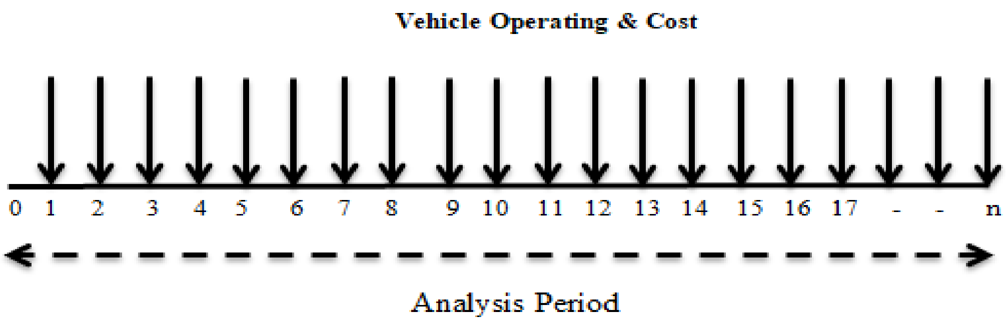


Figure 3.4 VOC Cash Flow Diagram

3.2.3 Safety Cost

Transportation Engineers generally take serious note of safety component in transportation planning and try to reduce the rate or severity of crashes. The economic cost of transportation crashes, which is endured by individuals, insurance companies, community, other road users and government, consists of loss of human life, property damage, loss of domestic yield and workplace costs.

The primary unit for measuring transportation safety is a crash. A crash is a collision involving at least one moving transportation vehicle (car, truck, plane, boat, railcar, etc.) and another vehicle or object (stationary or moving). Number of expected fatal and Non-Fatal crashes is calculated based on functional class of road and yearly VMT. In mathematical for it can be written as:

$$\textbf{Crashes per year} = \textbf{AADT} \times \textbf{l} \times \textbf{365} \times \textbf{crashes per million}(\textbf{Table 6.3})$$

The Crash Rates are taken from Table 6.3 from Sinha & Labi Text Book

Table 6.3 Motor Vehicle Traffic Fatality and Injury Rates by Functional Class

Area Class	Functional Class	Number of Crashes (per 100 million VMT) Fatal	Non-Fatal
Rural	Interstate	1.05	25.08
	Other principal arterial	1.96	50.87
	Minor arterial	2.33	70.52
	Major collector	2.51	86.79
	Minor collector	3.16	106.02
	Local	3.52	147.79
Urban	Interstate	0.56	46.56
	Other freeway & expressway	0.75	68.60
	Other principal arterial	1.30	124.69
	Minor arterial	1.08	126.89
	Collector	1.00	104.95
	Local	1.33	194.40

Source: FHWA (1998).

Figure 3.5 Fatality and Injury rate by FHWA

Fatal Crash Cost = 8.01 Million PKR (Calculated Value form Unit Crash Cost on the basis of KABCO Scale converted to 2017 PKR).

Non-Fatal Crash Cost = 1.6 Million PKR (Calculated Value form Unit Crash Cost on the basis of KABCO Scale converted to 2017 PKR).

Now yearly safety cost in 2017 Rupee is calculated by using formula

$$\textbf{Yearly Cost} = \mathbf{8.01}(\textbf{Fatal Crashes per year}) \times \mathbf{1.6}(\textbf{Non Fatal Crashes per year})$$

General shape of cash flow diagram for VOC is shown below:

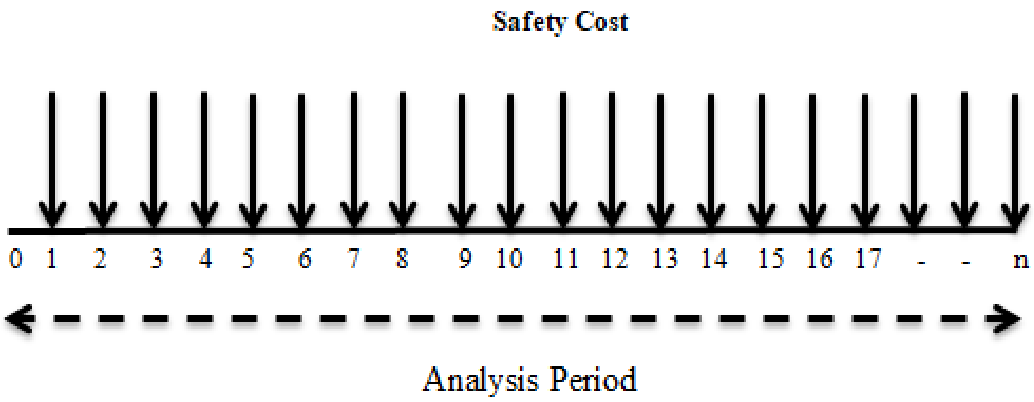


Figure 3.6 Safety Cost Cash Flow Diagram

3.2.4 Equivalent Uniform Annual Cost (EUAC)

After calculating all three costs the software then combines all three cash flow to form a single cash flow for each design alternative. Modified general cash flow diagram is shown below

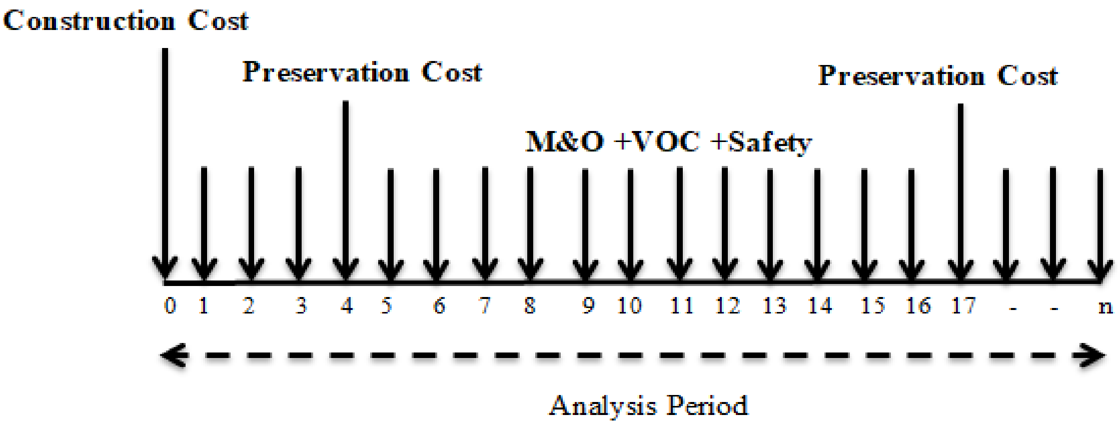


Figure 3.7 Final Cash Flow Diagram

Now, software applies Annual worth Analysis which is a principle of economics to calculate Equivalent Annual Cost of each alternative. In this method both Construction cost and Preservation cost are converted to equivalent annual cost and added to sum of M&O,VOC and Safety Cost. Alternative with least annual cost is declared economically efficient.

3.3 Environmental Impact Analysis

Transportation is also called mobile sources of air pollution. Motor vehicles are a primary source of local air pollutant problems which is emitted due to burning of fossil fuels during travelling and are considered the main cause of excess regional photochemical oxidant concentrations. Vehicles typically emit oxides of carbon, nitrogen oxides, small particulate matter, and other toxic substances that can cause health problems when inhaled. Air pollution also has adverse effects on forests, lakes, and rivers. The contribution of transportation vehicle use to global warming remains a cause for much concern as its impacts on the upper atmosphere become increasingly evident.

This software calculates emission of Carbon monoxide, Carbon dioxide and NOx using following formulae. (Note: evaluation of alternative in this domain does not indicate the complete environment impact assessment of project)

$$\mathbf{CO\ emited} = \mathbf{AADT} \times \mathbf{l} \times \mathbf{CO\ emission\ factor}(\mathbf{Table\ 8.3})$$

$$\boldsymbol{CO_2}\ \mathbf{emited} = \mathbf{AADT} \times \mathbf{l} \times \boldsymbol{CO_2}\ \mathbf{emission\ factor}(\mathbf{Table\ 8.3})$$

$$\boldsymbol{NO_x}\ \mathbf{emited} = \mathbf{AADT} \times \mathbf{l} \times \boldsymbol{NO_x}\ \mathbf{emission\ factor}(\mathbf{Table\ 8.3})$$

Carbon monoxide, Carbon dioxide and NOx emission factors are calculated from Pollution Emissions by Mode (g/VMT) table 8.3

	VOC	CO	NO_x	CO_2
Small Automobile	1.88	19.36	1.41	415.49
Medium Automobile	2.3	11.6	1.84	521.63
Large Automobile	2.51	25.29	11.9	2386.9
Source: TCRP (2003).				

Figure 3.8 Table of Emissions by TRCP

3.4 Pavement Performance

Performance of a road is a main objective of any Highway. It also termed as a benefits provided to the user in form of mainly riding quality. Approaches involved cost only considers the fact that different investments result in a highways with a same quality and all the available alternatives will provide same level of service to users. So to counter this fact, pavement performance evaluation along with the treatment performance evaluation is carried out.

The basic output of performance is riding quality. Different indices are available to represent the riding quality such as IRI, PSI and PCR etc. we have selected IRI (international roughness index) as main unit to perform our performance evaluation of different alternatives. The reason to select this index over others is because of direct and easy measurement of bumpiness of pavement by many available instruments. Test parameters and different threshold values are given by World Bank.

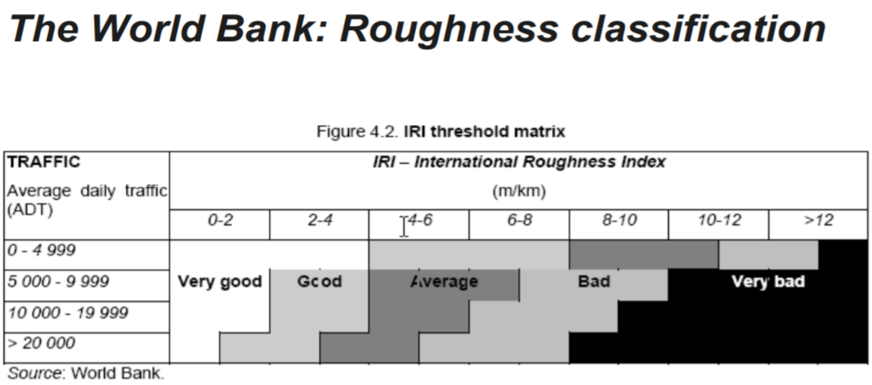


Figure 3.9 World Bank IRI threshold matrix

There are two evaluation methods for measure of benefits only i.e.

1. Effectiveness (short term)
2. Effectiveness (long term)

3.4.1 Effectiveness (short term)

The summary of this evaluation method of pavement evaluation criteria are:

- Performance measures are performance jump (PJ) of treatment and deterioration rate reduction (DRR).
- Pre-and Post-treatment condition values are required.
- Highly recommended for short term analysis.

3.4.2 Effectiveness (long term)

The summary of this evaluation method of pavement evaluation criteria are:

- Performance measures are increased pavement condition over treatment life (effectiveness) of treatment and area bounded by treatment curve (AOC).
- Post-treatment conditions and performance model values are required.
- Highly recommended for long term analysis.

3.5 Measures of Long Term Effectiveness

Long term benefits and effectiveness of treatments is evaluated by calculating following parameters:

1. Performance Jump (PJ)
2. Effectiveness
3. Area over performance curve (AOC)

3.5.1 Performance Jump (PJ)

Instantaneous improvement in pavement condition after rehab or any pavement intervention.

$PJ = IRI_{(n)} - IRI_{(o)}$

Whereas

$IRI_{(n)}$ = condition after intervention

$IRI_{(o)}$ = condition before intervention

3.5.2 Effectiveness

Effectiveness is intervention effectiveness defined as percent increase in average pavement condition (APC) after rehab/intervention. It is measured as compared to average condition value of pavement before the first interventions/rehab.

$$perf = \frac{1}{tc}(yo + y1)$$

$$effectiveness = 100 \times \frac{Perf(avg) - Perf(ini)}{Perf(ini)}$$

The above modified equation for first intervention in software is:

$$eff = \frac{[100 \times \left(\frac{1}{2RY - 1RY} \times (Yo + Y1)\right) - \frac{1}{1RY}(\text{IRIn} + \text{IRIo})]}{\frac{1}{1RY}(\text{IRIn} + \text{IRIo})}$$

For second intervention:

$$eff = \frac{[100 \times \left(\frac{1}{3RY - 2RY} \times (Yo + Y1)\right) - \frac{1}{1RY}(\text{IRIn} + \text{IRIo})]}{\frac{1}{1RY}(\text{IRIn} + \text{IRIo})}$$

For third intervention:

$$eff = \frac{[100 \times \left(\frac{1}{tc - 3RY} \times (Yo + Y1)\right) - \frac{1}{1RY}(\text{IRIn} + \text{IRIo})]}{\frac{1}{1RY}(\text{IRIn} + \text{IRIo})}$$

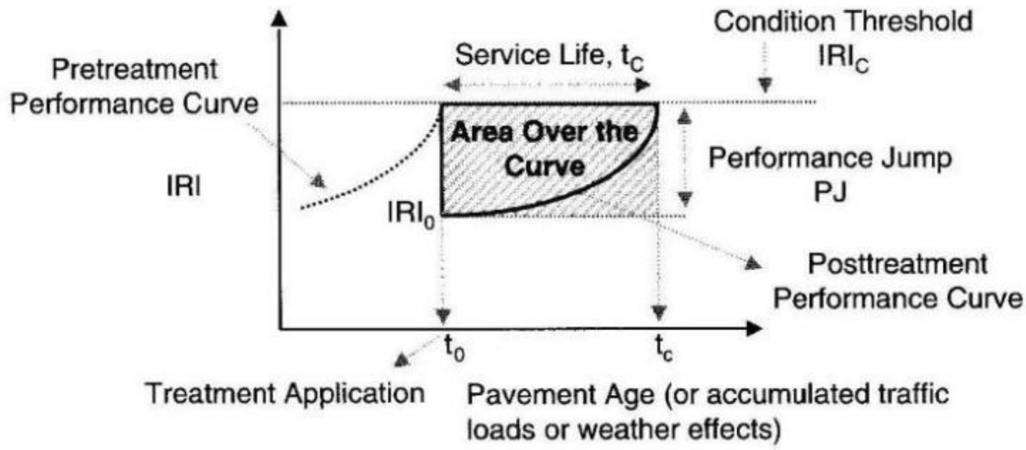
RY=Rehab Year, Yo=IRI after treatment, Y1=IRI before next intervention, IRIn=threshold value, IRIo=Value after initial construction, tc=service life

3.5.3 Area over Performance Curve (AOC)

Area bounded by performance curve and threshold line, includes both pavement condition and service life into account. It is calculated by different means either graphically or mathematically. Value depends on the performance relation or function used in analysis. In our case, we used simply used exponential relation between IRI reductions over time. Mathematical eq for AOC calculation is:

$$AOC = (\mathrm{IRI(n)} + \mathrm{IRI(o)}) + (e^{(2RY)} - e^{(1RY)}) + \mathrm{IRI(n1)} + (2RY - 1RY) + (e^{(3RY)} - e^{(2RY)}) + \mathrm{IRI(n2)} + (3RY - 2RY) + (e^{(SL)} - e^{(3RY)})$$

Following figure (Khurshid, 2009) represent the above measures of long term effectiveness graphically.



3.6 Multi Criterion Decision Making

The first task in multiple criteria valuation is to check how decision makers attach relative levels of importance (or weights) to these criteria. The next assignment in multi criteria evaluation is scaling where each criterion is converted from its original dimension to one that is to proportionate all performance criteria.

After all performance criteria have been weighted and scaled, the next step is to combine the impacts for each transportation alternative. After the economic, Performance and environment evaluation of different alternatives is done it is required to select the best alternative depending on the above calculated factors. The factors contributing in final decision are shown below in tabular form.

S.no	Factors	Domains
1	CO emission	Environment
2	Nox emission	Environment
3	CO2 emission	Environment
4	Agency Cost	Economics
5	Safety Cost	Economics
6	User Cost	Economics
7	Performance Jump 1	Performance
8	Performance Jump 2	Performance
9	Performance Jump 3	Performance
10	Effectiveness 1	Performance
11	Effectiveness 2	Performance
12	Effectiveness 3	Performance
13	Area Over Curve (AOC)	Performance

Funneling of above factors is done after the selection which involves the neglecting of least important criterion and arranging criterions in descending order of their relative importance. There is no set procedure available in literature for this process but it is recommended to do on the basis of designer experience, brainstorming among planning team and survey results from general public or specifically road users. Our arrangement of criterion in descending order after funneling is shown below in tabular form:

S.no	Factors	Domains
1	Agency Cost	Economics
2	Safety Cost	Economics
3	User Cost	Economics
4	Area Over Curve (AOC)	Performance
5	Performance Jump 1	Performance
6	Performance Jump 2	Performance
7	CO emission	Environment
8	Nox emission	Environment
9	CO2 emission	Environment

The above table also shows the different impact intensity. CO and CO2 may be emitted in same quantity but impact of CO on environment is worse than CO2.

Similarly, Agency cost is of prime importance because initiation of any project trigger depending on initial construction cost, available resources etc.

3.7 Establishing weights of Criterion

In multi criteria decision making, an important step is the explicit or implicit assignment of relative weights to each performance criterion to reflect its importance compared to other criteria; for example, to what extent is performance improvement more important than cost reduction, increase in facility condition than environment safety and improved aesthetics, and so on? The following methods can be used to establish the weights:

1. Equal Weighting
2. Direct Weighting
3. Regression-Based Observer-Derived Weighting
4. Delphi Approach
5. Gamble Method
6. Pairwise Comparison
7. Value Swinging.

Pairwise Comparison method is selected for establishing weights for our criterions.

3.7.1 Pairwise Comparison Method

Pairwise comparison is the technique used in this study to establish weights for the performance criteria. Weight depicts the power of criterion in establishing final decision. Weighting can be done by using pairwise comparison of performance criteria. It is a common tool for doing this also known as analytical hierarchy process (AHP). AHP establishes the weights of performance criteria by allowing the decision maker to consider objective and subjective factors in assessing the relative importance of each criterion (Saaty, 1977). Using AHP, decision maker can develop weights by using their experience and knowledge in a natural and intuitive manner. Inputs can be taken from the stakeholders of the decision. We have taken out a general survey to determine the average road user experience in Pakistan. First step of this method is to develop a Relative importance matrix showing the precedence of one criterion over other and vice versa. Relative importance of criterions was determined by brainstorming and with the help of survey done through Google forms. Responses collected were from general public of different education backgrounds i.e. Environmental Engineering, Mechanical Engineering, and Students of Economics etc. Matrix of our criterions is:

	Agency Cost	Safety Cost	User Cost	AOC	PJ1	PJ2	CO emission	Nox emission	CO2 emission
Agency Cost	1	2	3	4	5	6	7	8	9
Safety Cost	0.5	1	2	3	4	5	6	7	8
User Cost	0.333	0.5	1	2	3	4	5	6	7
AOC	0.25	0.333	0.5	1	2	3	4	5	6
PJ1	0.2	0.25	0.33	0.5	1	2	3	4	5
PJ2	0.167	0.2	0.25	0.33	0.5	1	2	3	4
CO emission	0.143	0.167	0.2	0.25	0.33	0.5	1	2	3
Nox emission	0.125	0.143	0.167	0.2	0.25	0.33	0.5	1	2
CO2 emission	0.111	0.125	0.143	0.167	0.2	0.25	33	0.5	1
Total	2.829	4.718	7.593	11.447	16.280	22.1	61.500	36.500	45.000

Criterions are arranged in descending order of their relative importance e.g. Agency Cost is 2 times important than safety cost hence 2 is written in ist row second column as shown similarly C02 emissions are 0.25 times Performance Jump2 (PJ2) and so on. Relativity is determined from brainstorming among teachers and in light of road user survey responses. After establishing the pairwise comparison matrix, the next step is to calculate the relative weights. For this, Saaty (1994) proposed a procedure using matrix theory. Each cell of reciprocal matrix is determined by dividing cell of pair wise matrix with their total added value of column. Normalized weight is the ratio of sum of row and total of sum column. By this matrix theory, reciprocal matrix and normalized weights are:

	Agency Cost	Safety Cost	User Cost	AOC	PJ1	PJ2	CO emission	Nox emission	CO2 emission	Sum	Normalized Weight
Agency Cost	0.353	0.424	0.395	0.349	0.307	0.272	0.114	0.219	0.200	2.634	0.293
Safety Cost	0.177	0.212	0.263	0.262	0.246	0.226	0.098	0.192	0.178	1.853	0.206
User Cost	0.118	0.106	0.132	0.175	0.184	0.181	0.081	0.164	0.156	1.297	0.144
AOC	0.088	0.071	0.066	0.087	0.123	0.136	0.065	0.137	0.133	0.906	0.101
PJ1	0.071	0.053	0.044	0.044	0.061	0.091	0.049	0.110	0.111	0.633	0.070
PJ2	0.059	0.042	0.033	0.029	0.031	0.045	0.033	0.082	0.089	0.443	0.049
CO emission	0.050	0.035	0.026	0.022	0.020	0.023	0.016	0.055	0.067	0.315	0.035
Nox emission	0.044	0.030	0.022	0.017	0.015	0.015	0.008	0.027	0.044	0.224	0.025
CO2 emission	0.039	0.026	0.019	0.015	0.012	0.011	0.537	0.014	0.022	0.695	0.077
										9.000	1.00

These normalized weights depict the percentage of influence of each factor in final decision e.g. Agency Cost has 29.3% contributing power in selecting the best alternative and average riding quality to users (AOC) has 10.1% contribution. Similarly total emissions from daily traffic over service life have total of 13.1% influence in setting final decision.

3.7.2 Consistency Check

Consistency checks assess the degree of randomness in the judgments used to develop the reciprocal matrix. The standard deviation of λ_{max} from n (n=order of reciprocal matrix) is used as a measure of the consistency with the reciprocal matrix developed. The logical consistency of the comparisons is then measured by taking ratio of consistency index (CI) and random index (RI), which is defined as:

$$CR = \frac{CI}{RI} = \frac{\lambda_{max} - n}{(n-1)}$$

Consistency index (CI) represents the inconsistency which occurred during comparison or in reciprocal matrix. The consistency index is then compared with the average consistency index of reciprocal matrices (referred to as the random index RI). RI also depicts the level of inconsistency that can be expected from matrix of order n operations. Following Table shows the random indices for matrices of order 1 to 10 (Saaty, 1994).

Order of Matrix (n)	Average Random Index
1	0.00
2	0.00
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

The overall consistency of AHP judgments can be determined using the consistency ratio (CR), which is computed as follows:

$$CR = \frac{CI}{RI} = \frac{\lambda_{max} - n}{(n-1)(RI)}$$

A consistency ratio of 0.1 or lower is considered acceptable (Saaty, 1994). If the ratio exceeds 0.1, then judgments are considered random and the reciprocal matrix should be recomputed.

Consistency check for our reciprocal matrix is as following:

$$CR = \frac{CI}{RI} = \frac{\lambda_{max} - n}{(n-1)(RI)} = \frac{0.977 - 9}{(9-1)(1.32)} = -0.7 < 0.1$$

$$(weights\ are\ perfectly\ consistent)$$

Following are the summary points of consistency check:

1. $CR = \frac{CI}{RI} = \frac{\lambda_{max}-n}{(n-1)(RI)} < 0.1$
2. $RI = Random\ Index = level\ of\ incosistency\ expected.$
3. The maximum order of reciprocal matrix that can be checked is of 10×10.
4. λ_{max}=Standard deviation of product matrix of relative importance matrix and Normalized weight. Product matrix of in our case is:

$$A \times W = \begin{vmatrix} 3.323 \\ 2.4695 \\ 1.81667 \\ 1.32892 \\ 0.9666 \\ 0.69636 \\ 0.49384 \\ 0.3405 \\ 1.36651 \end{vmatrix}$$

5. If Consistency Ratio CR > 0.1 then method is repeated and values are recomputed.
   - Repeat Funnelling
   - Change relative importance

CHAPTER 4

IMPLEMENTATION

4.1 Introduction

One of our objectives is to develop a computational tool to make asset management and cumbersome procedure of selecting best alternative convenient, accurate and easy to use. For this computer software named P-PAVE is developed. Coding language used is Java because of its syntax adaptability with graphic user interface (GUI). GUI templates were designed on JFrame. This chapter includes the screenshots in a series of Graphic User Interface (GUI) of P-PAVE showing the steps to evaluate the flexible pavement project and to select the best one by method described in chapter 3.

4.2 Compiler

The compiler software used for programming is NetBeans IDE 8.1. Code is written and GUI is designed on this software. Following figure is showing the designing of GUI in JFrame of NetBeans IDE 8.1.

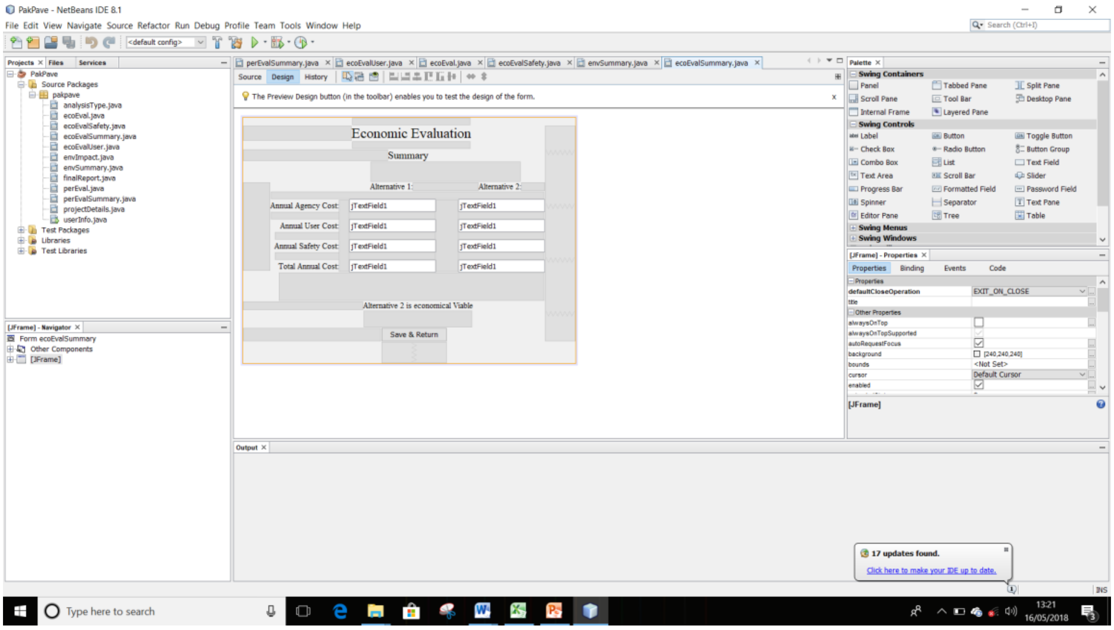


Figure 4.1 Compiler

Following figure shows the development of code in compiler:

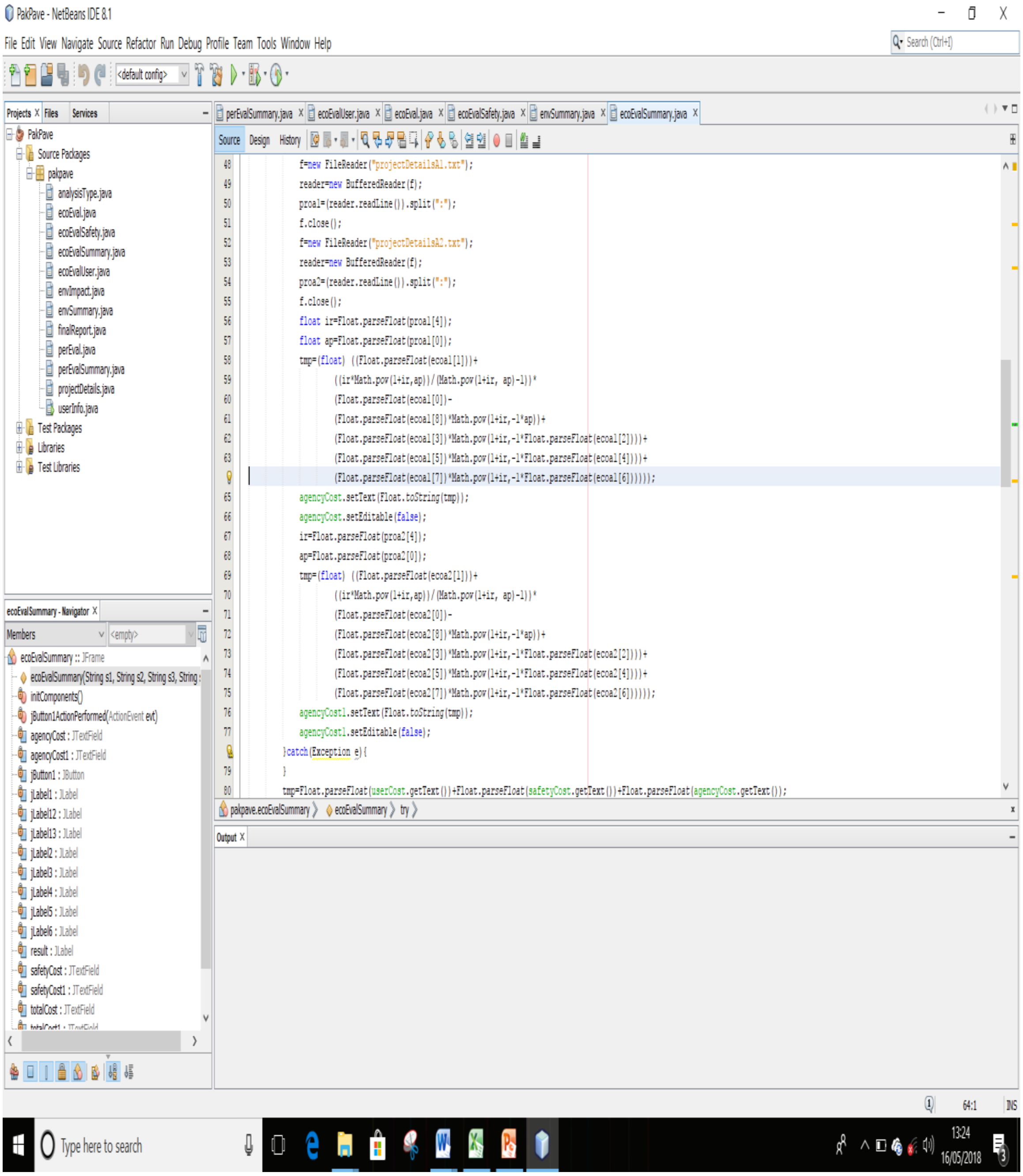


Figure 4.2 Coding

4.3 P-PAVE

Initially user has to put user information for a record. This input screen stores the data about person who is running an analysis.

Figure 4.3 User Information

4.3.1 Project Details

It is also an input screen in which user puts the general project details for both alternatives as:

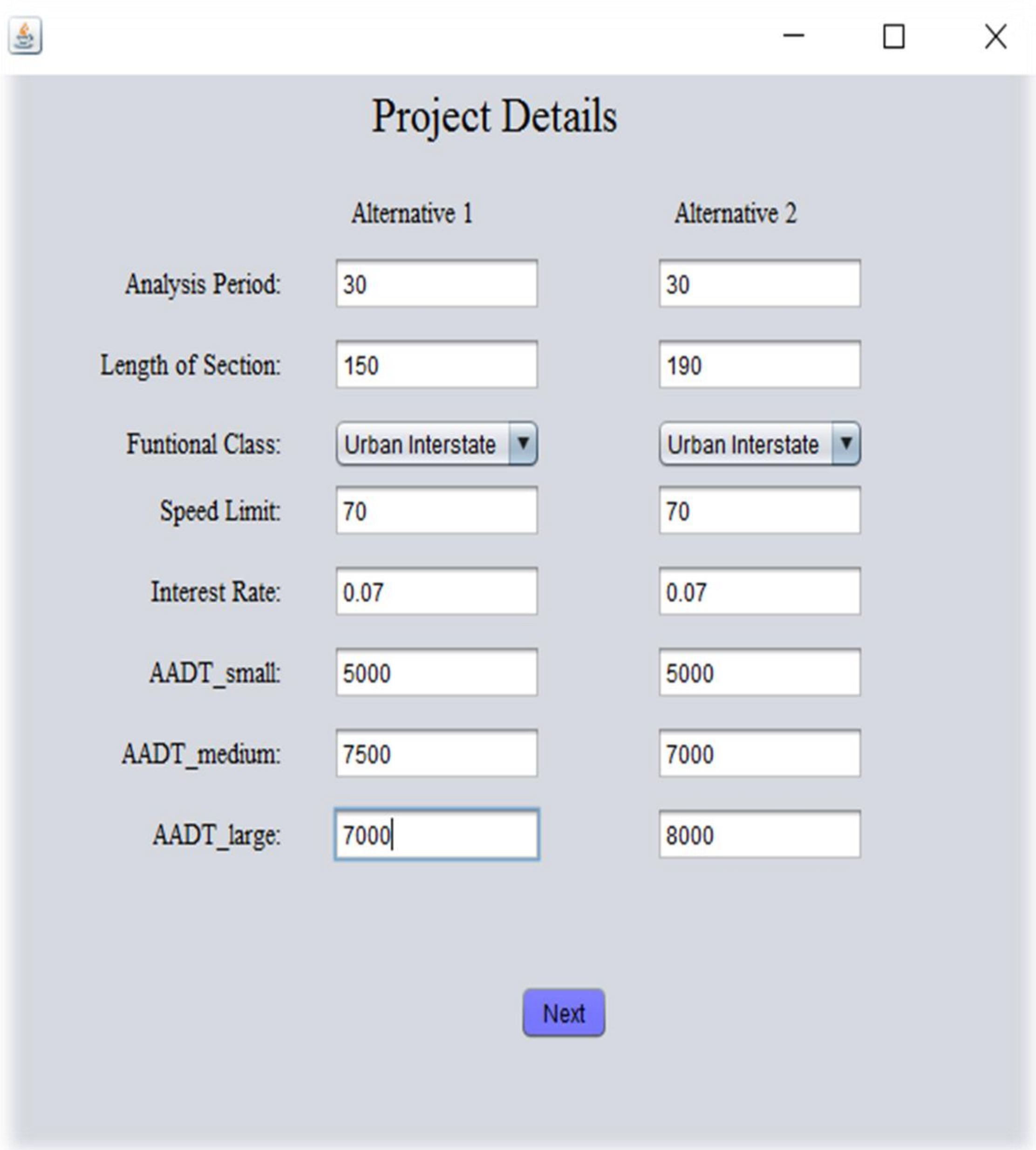


Figure4.4 Project Details

4.4 Domains

Three type of analysis based on the evaluation types i.e. environment, economics, performance and multi criterion decision making as described in chapter 3 is shown and selected from this screen:

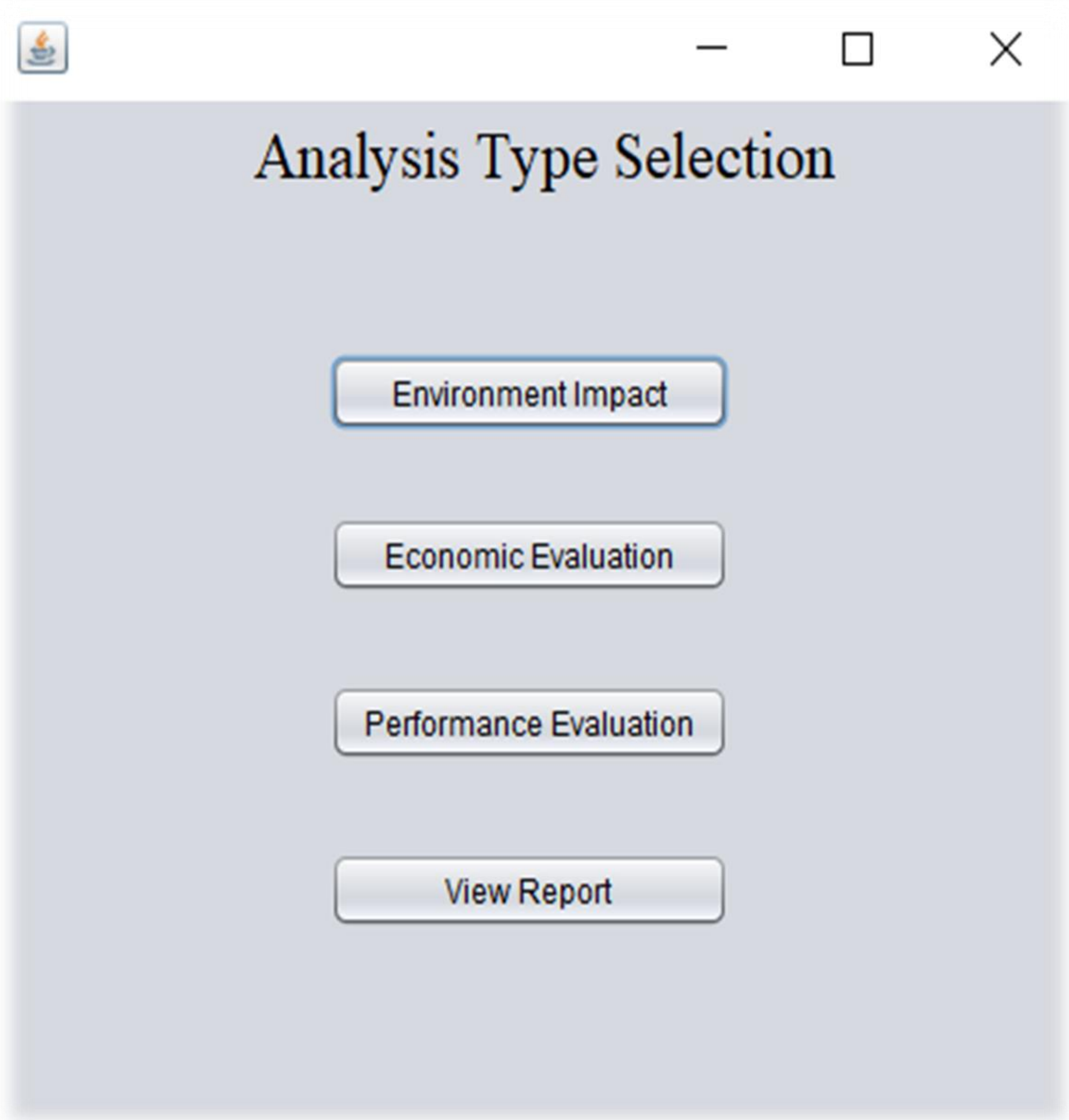


Figure 4.5 Domains

4.4.1 Environment Impact

Output screen showing the emissions of air pollutants:

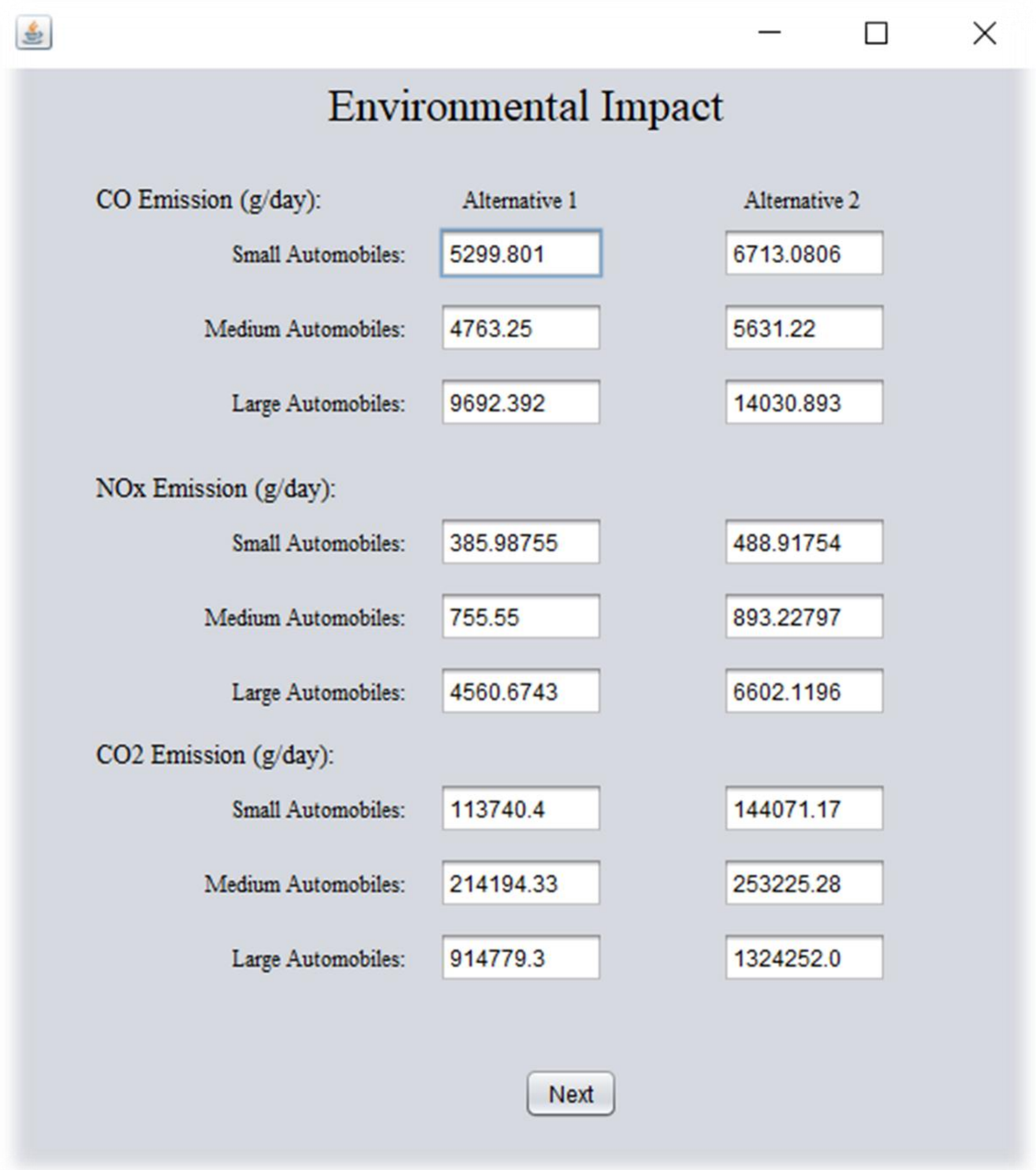


Figure 4.6 Environmental Impact

Summary of the results of environment impact analysis:

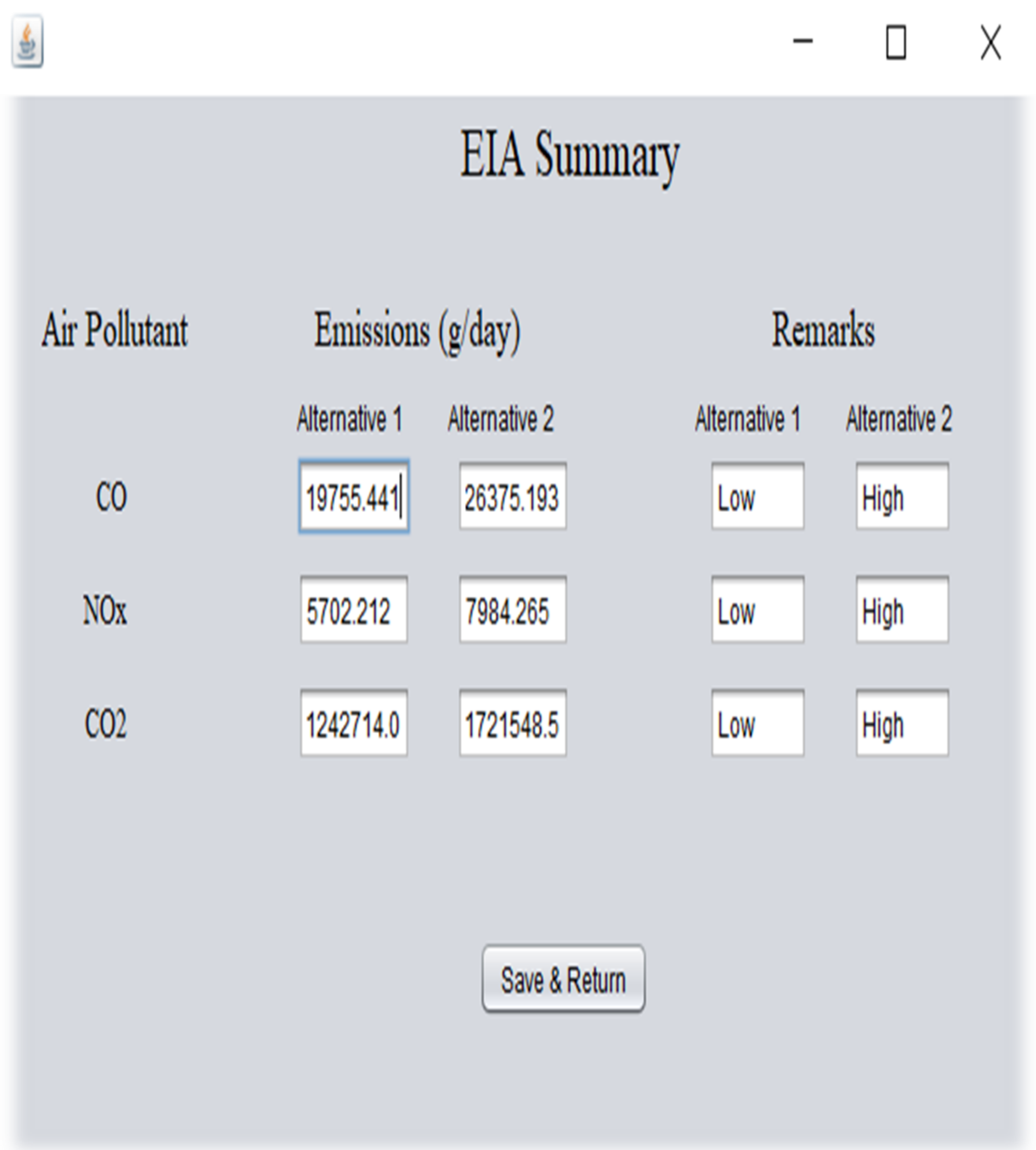


Figure 4.7 EIA Summary

4.4.2 Economic Evaluation

For this analysis to be run in this domain initially values of agency cost is inputted:

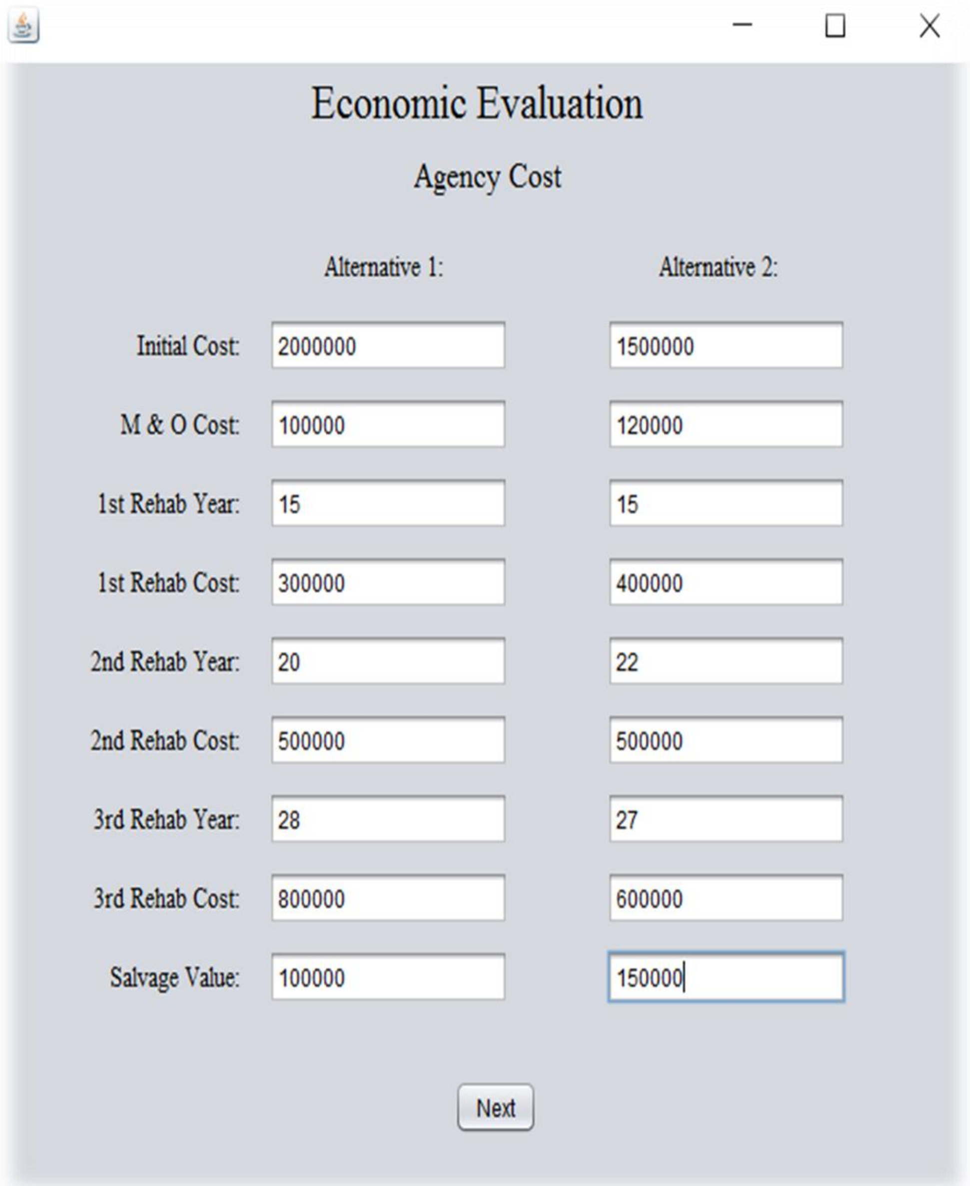


Figure 4.8 Economic Evaluation (Agency)

Output screen for user cost:

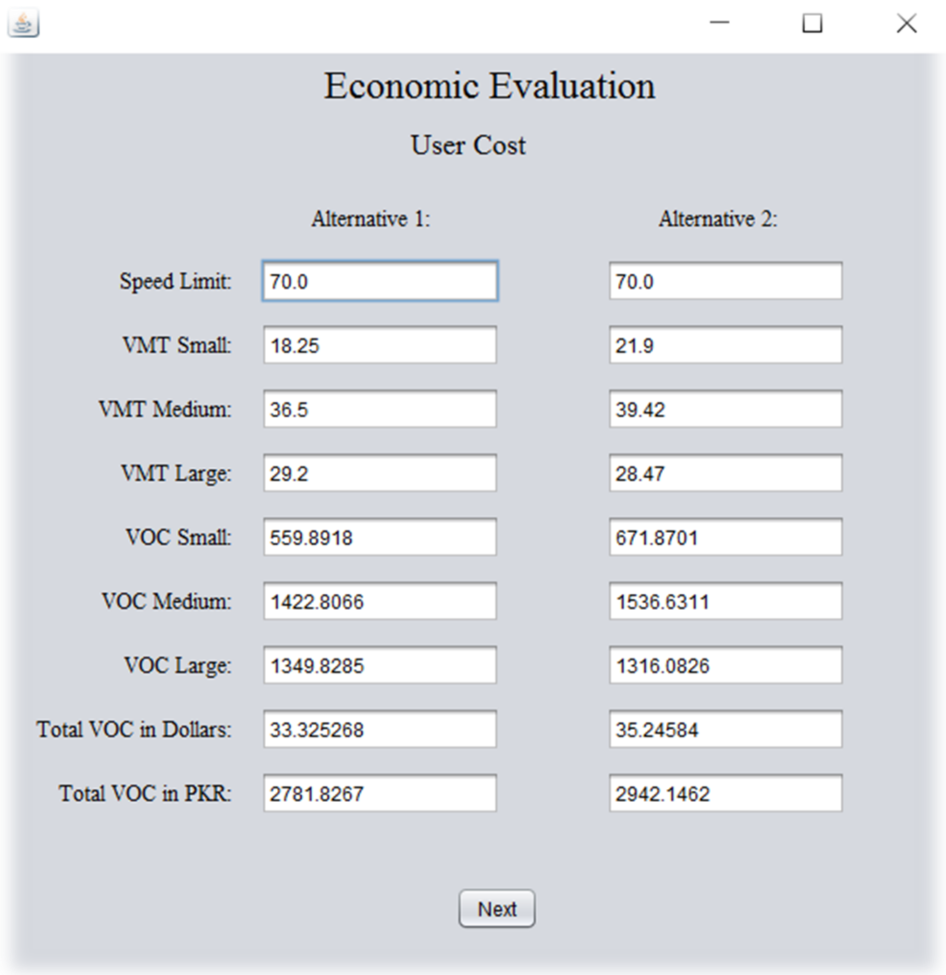


Figure 4.9 Economic Evaluation (User)

Output screen for safety costs:

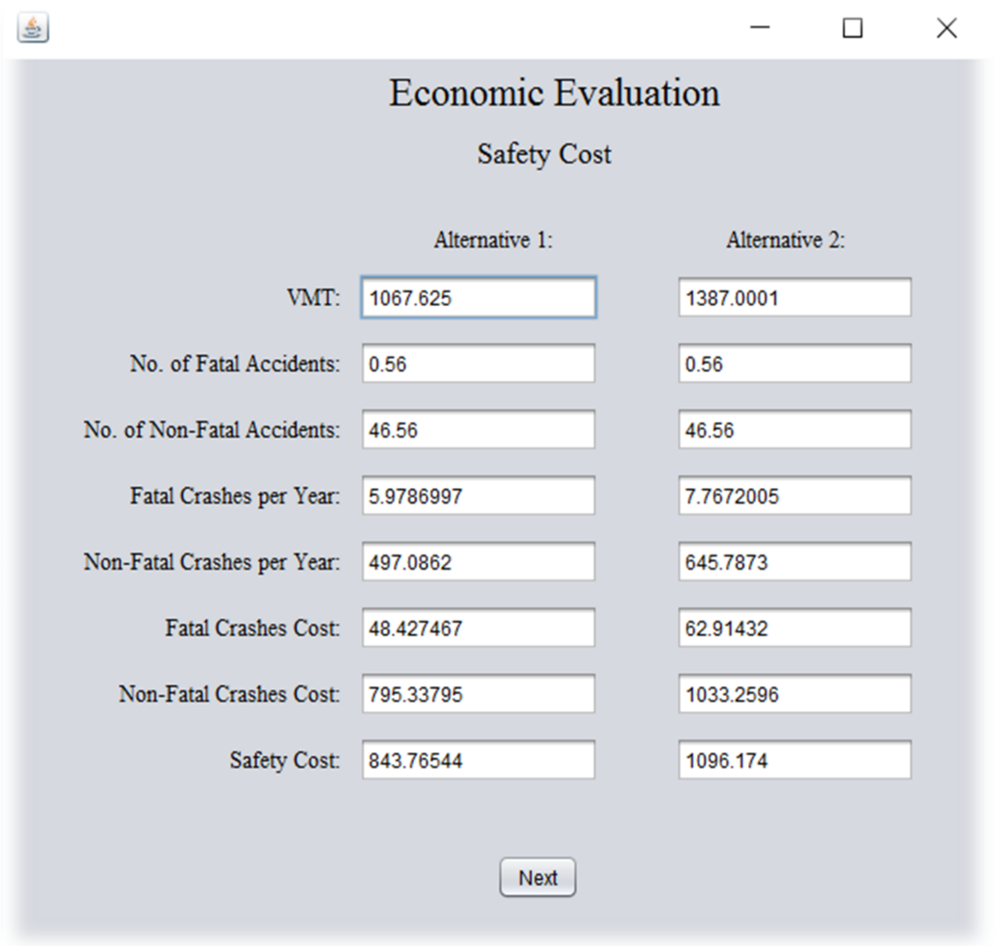


Figure 4.10 Economic Evaluation (Safety)

Annual costs of alternatives after computed after annual worth analysis:

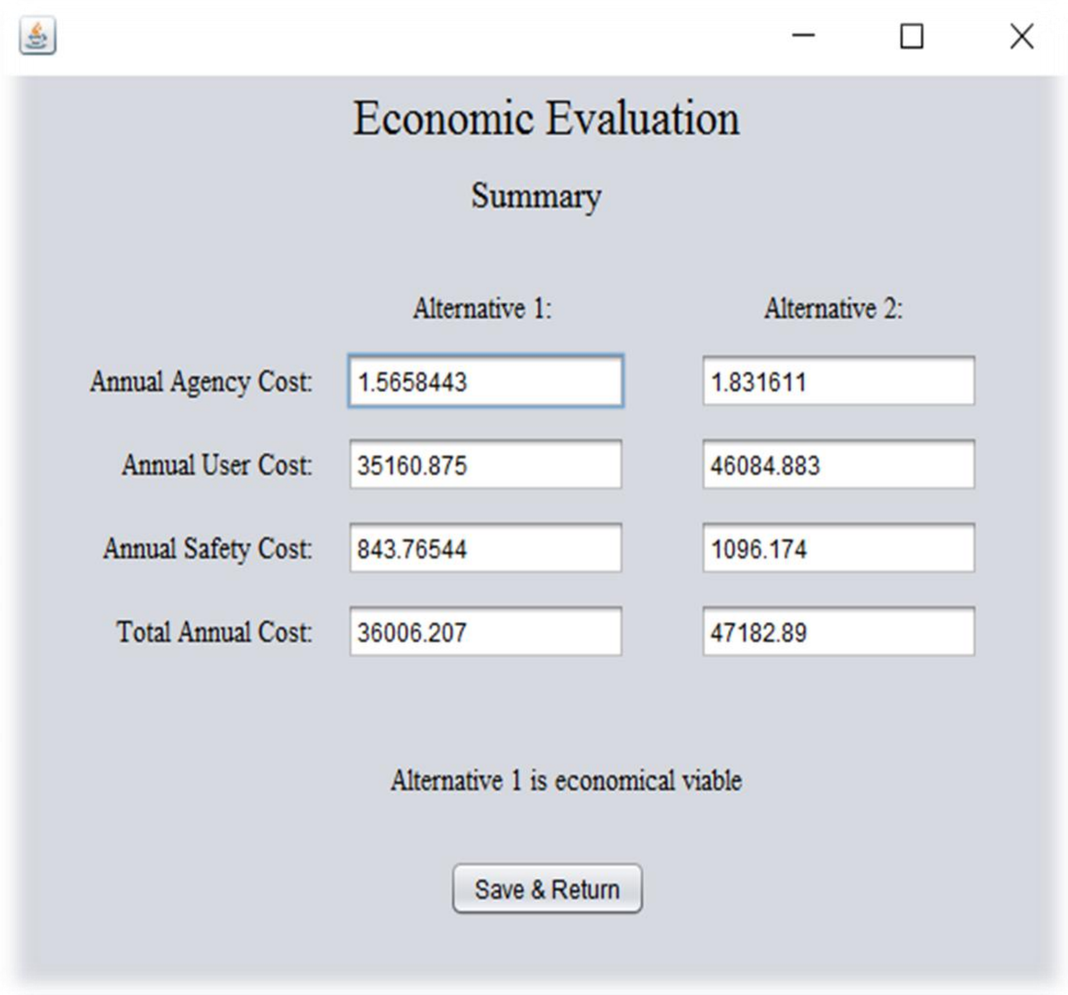


Figure 4.11 Economic Evaluation (Summary)

4.4.3 Performance Evaluation

Initial and threshold values of IRI and intervention types are selected by user in this screen:

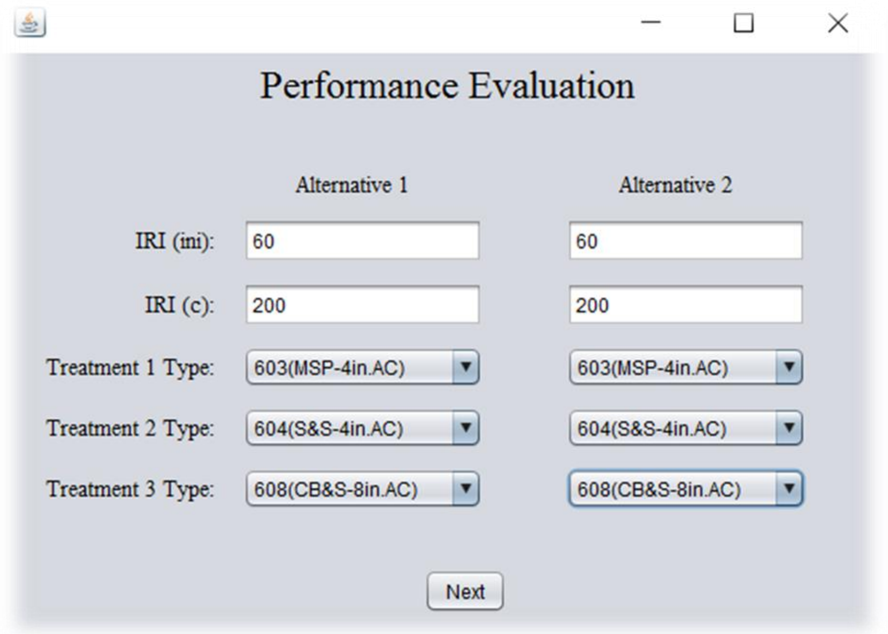


Figure 4.12 Performance Evaluation (Inputs)

Results of performance evaluation analysis are shown as:

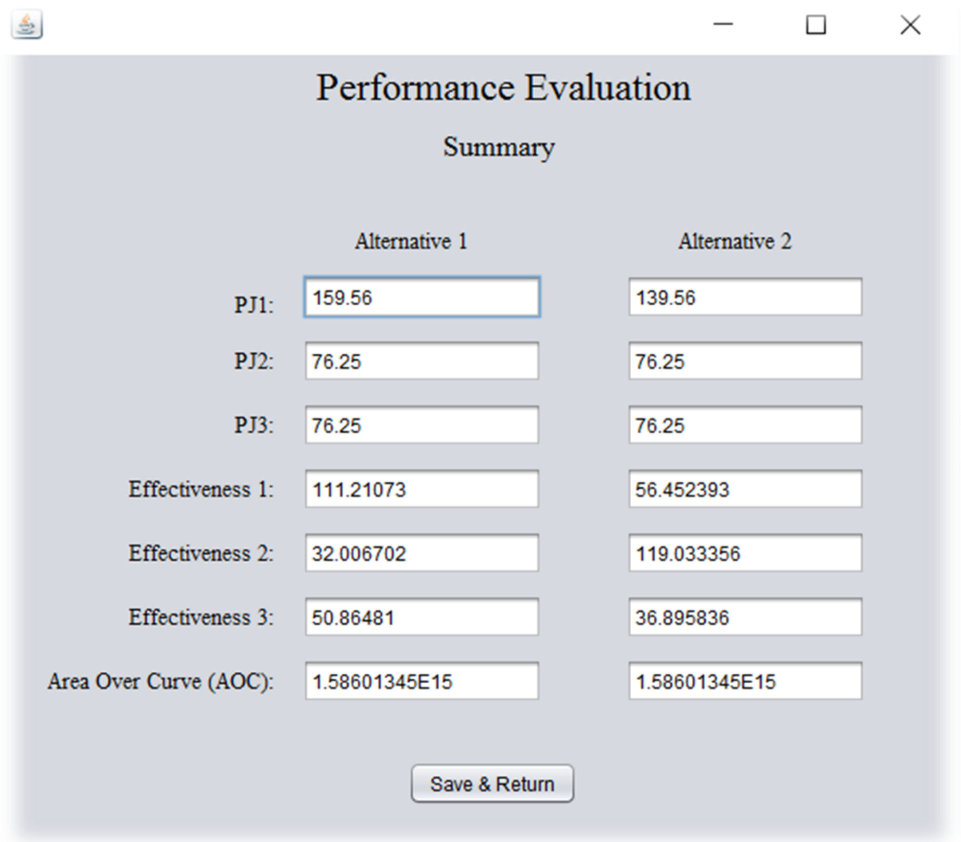


Figure 4.13 Performance Evaluation (Summary)

4.4.4 Best Alternative Selection

By the principles of multi criterion decision making, AHP, and according to the relative weights given to criterion final decision shown as:

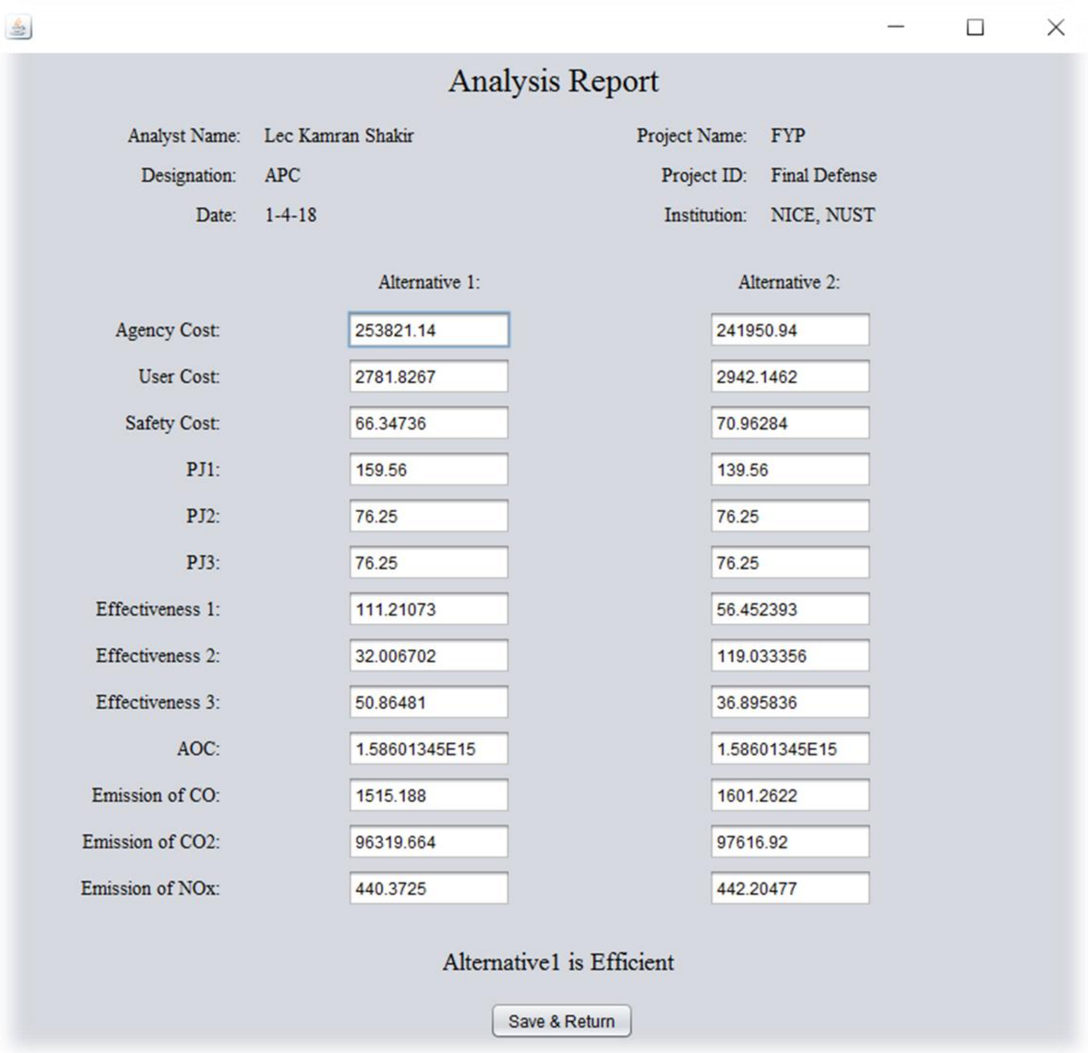


Figure 4.14 Analysis Report

4.5 System of Units

Following tables show the system of units in which software works:

INPUTS	
Analysis Period	years
Length	Miles
Speed	mph
Interest Rate	Decimal
AADT	veh/day
Costs	millions USD
IRI	inch/mile

Table 4.1 Input Units

OUTPUTS	
Costs	million PKR/year
VMT	million miles/year
VOC	million PKR/year
Crashes Cost	million PKR/year
AOC	IRI-years
PJ	inch/mile
Emissions	g/day

Table 4.2 Outputs Units

CHAPTER 5

Results and Conclusion

5.1 Introduction

During our research and no of studies on pavement asset management, Economics of project, impacts of traffic on environment and decision-making principles involving Multi criterions we recommend the procedure/method of selecting best alternative which may differ in route alignment, operational strategies and maintenance and rehab strategies. This chapter involves method and procedure of selection, logic behind the working of software, limitations of software, conclusions and recommendations for future study.

5.2 Procedure for Selecting Best Alternative

Following is the proposed method of selecting best alternative during planning phase of project:

1. Economic Evaluation of available alternatives of a project to determine annual expenditure over service life. This is described in detail under heading 3.
2. Performance based Evaluation of available alternatives to forecast average pavement condition or average riding quality to road users over complete life cycle of project. This is described in details under heading 3..
3. Environment based Evaluation of available alternatives to determine their impacts in form of emissions from traffic over complete life of project. This is described in details under heading 3..
4. Selecting the criterions computed from above methods and arranging it in descending order of their relative importance after funneling. This is described in details under heading 3..
5. Pair Wise Comparison of selected criterions by on the basis of relative weights of corresponding criterions. This is described in details under heading 3.
6. Summation of points assigned to all selected criterions in above point. Alternative with more point value is best to choose. Comparison will be based

on point values obtained from total 1.00. Total point value of alternative cannot be more than 1.

5.3 Software logic

Running principle and logic behind P-PAVE are:

1. Economic, Performance and Environmental Impact evaluation is done separately. Length of section, speed limit, interest rate, and other details are taken from the users. All the parameters/criterions such as emissions, annual agency accost, annual safety cost, annual user cost, total annual expenditures, Performance jump and area over curve etc. are computed and shown in the form of output.
2. Comparison of alternatives is done according to the relative weights and multi criterion decision making defined previously. Every selected criterion is compared and assigned a point value. Values are assigned in such a way to optimize the result of final decision i.e. less value economic and environmental parameters is given a point value and higher value of performance parameters is given assigned value.
3. All the tables used and shown in Annex A is saved in software directory in .csv format.
4. Individual results of evaluation and overall result of analysis can be printed from .txt format.
5. Screenshots of software showing the graphic user interface and working environment is shown in chapter 4.

5.4 Limitations

Limitations of software are:

1. Comparison of alternative can only be done in project level assessment not of network level assessment.
2. Analysis of 2 alternatives can only be compared at one time.
3. Rehab treatment or intervention type can only be selected which is specified in software.
4. Maximum number of treatment or pavement intervention is 3.
5. Dollar’s value is used as in year 2005 and Rs value as in 2017.
6. Units system of software cannot be changed.
7. Utility, bridges, tunnels; specialized structures assets are not included.

5.4 Conclusion

Following are the few points which are concluded from our study:

1. Taking adverse effects on environment into consideration have little but good impact on final decision e.g. Weightage of environment impact parameters is 13.6% effect on our final decision.
2. Considering all the parameters/criterions equally is wrong. It is because of the fact that different criterions have different impact.
3. Decision based on cost-only is a bad approach. (Alternative economical viable may not be overall efficient).
4. P-PAVE is a quick option to solve all this cumbersome method easily.

5.5 Recommendations

Recommendations for the future study which should be kept in mind are:

1. In order to make this software more comprehensive Delay Time Savings can be added in Economic Evaluation Tab.
2. Environmental Impact Analysis can also be enhanced by addition of impacts of different alternatives by Noise Pollution.
3. Results of Environment Analysis will be more accurate and reliable if this is done by proper procedure of Environment impact Assessment.
4. Environmentally viable alternative may need mitigation measures to preserve ecosystem more efficiently. Mitigation measures may include revise in design, traffic control measures and use of environment friendly materials and practice.
5. Normalized Weights of decision criterion can be computed by more than one method for more accuracy.
6. Relation between road quality (IRI) and user cost can be considered because bad performance of pavement result in more user cost.
7. Network level assessment is necessary before doing any project level assessment.

5.6 Summary

The summary of the results, guidelines and method used to achieve objective is shown in following tabular form:

S.no	**Objectives**	**Method**	**Guidelines**
1	Quick evaluation of different alternatives of project economically.	LCCA Procedure	FHWA, NCHRP
2	Assessment of alternatives based on their Environment Impact	EIA Procedure	Literature
3	Evaluation of available options based on Performance/Benefits (Long Term)	Effectivenes s	Literature
4	To select the best design and operational strategy	MCDM Method	Literature
5	To develop software which incorporate the above procedure to be solved with ease by designers/planners?	Java	Netbeans IDE 8.1

Table 5.1The summary of the results, guidelines and method used

ANNEX A

TABLES

Functional class	Fatal	Non-Fatal
rural interstate	1.5	25.08
rural arterial	1.96	50.87
rural collector	2.51	86.79
rural local	3.52	147.79
urban interstate	0.56	46.56
urban arterial	0.75	68.6
urban collector	1.08	126.89
urban local	1.33	194.4

Table 6.1 Motor fatality and injury rates by functional class per 100 million

Vehicle Types	C	D	a0	a1	a2
small automobile	24.8	45.5	27.2	0.035	0.00021
medium automobile	28.5	95.3	33.5	0.058	0.00029
large automobile	29.8	163.4	38.1	0.093	0.00033

Table 6.2 Parameters for Hepburn Speed VOC model (2005-cents)

	CO	Nox	CO2
small automobile	19.36	1.41	415.49
medium automobile	11.6	1.84	521.63
large automobile	25.29	11.9	2386.9

Table 6.3 Pollution Emission by mode (g/VMT), source TCRP 2003

Treatment type	IRI(n)	IRI(o)	IRI(avg)	PJ	SL	Effectiveness	AOC(IRI-years)
603(MSP-4in.AC)	136.69	60.44	94.88	76.25	27	30.59	1217.84
604(S&S-4in.AC)	140.01	60.82	96.59	79.18	25	31.01	1134.07
606(ISP-4in.AC)	145.98	61.78	100.51	84.21	29	31.15	1415.29
607(CB&S-4in.AC)	132.08	61.08	92.75	71	26	29.77	1105.17
608(CB&S-8in.AC)	141.32	61.71	91.82	79.61	30	35.02	2233.81

Table 6.4 Summary for Critical IRI Values and treatment effectiveness measures

Code	Severity	Unit Cost (2005 $)
K	Fatal	3654299
A	Critical	181276
B	Severe	46643
C	Serious	22201
PDO	Moderate	2116

Table 6.5 KABCO scale

REFERENCES

Sustainable Pavement Asset Management Based on Life Cycle Models and Optimization **Methods (**Han Zhang)

Life-Cycle Cost Analysis Primer (U.S. Department of Transportation Federal Highway Administration Office of Asset Management)

Real Cost of Car Travel and Congestion **Pricing (**Luk et al., 1994)

www.elsevier.com/locate/IJPRT

Life-Cycle Cost Analysis of **Pavements (**Peterson et al., 1985)

Mechanistic Empirical Pavement Design **Guide (**Federal Highway Administration)

https://www.researchgate.net/publication/281446870

Network level pavement asset management system integrated with life-cycle analysis and life-cycle optimization (Gregory A. Keoleian, Micheal D Lepech)

LCCA Analysis in Pavement Design (FHWA, Publication No. FHWA-SA-98-079)

LCCA analysis for indot pavement design procedures (Geoffrey Lamptey, FHWA/IN/JTRP-2004/28, 2005)

Multi criterion decision making for margalla avenue bypass project a term project.(masud, MS Transportation Engineering course, 15)

LCCA Analysis of pavements (Dale E Peterson. nchrp, 1985)

Comparison of methods for evaluating pavement intervention (Khurshid, 2009)

Why industry need asset management tools by D.J. Vanier

Transportation Decision Making: Principles of Project evaluation and programming (Sinha,Labi 2007)

Transportation Asset Management Overview (Jaosn Bittner and Howard Rosen, 2004)