LIFE CYCLE COST ANALYSIS ON AIRPORT PAVEMENT DESIGN WITH DIFFERENT TYPES OF MATERIALS

B. M. Assaduzzaman Nur

MASTER OF SCIENCE IN CIVIL ENGINEERING

DEPARTMENT OF CIVIL ENGINEERING
BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY
DHAKA, BANGLADESH

January 2022

Life Cycle Cost Analysis on Airport Pavement Design with Different Types of Materials

by

B. M. Assaduzzaman Nur
Student No. 0416042427

A thesis submitted to the
Department of Civil Engineering
in partial fulfillment for the degree of
MASTER OF SCIENCE IN CIVIL ENGINEERING
(Transportation)

Department of Civil Engineering
Bangladesh University of Engineering and Technology
Dhaka, Bangladesh

January 2022

BOARD OF EXAMINERS

The thesis titled "Life Cycle Cost Analysis on Airport Pavement Design with Different Types of Materials", submitted by B. M. Assaduzzaman Nur, Roll No.: 0416042427F, Session: April-2016, has been accepted as satisfactory in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering (Transportation) on 8th January 2022.

Dr. Md. Mizanur Rahman Professor Department of Civil Engineering BUET, Dhaka	Chairman (Supervisor)
Dr. Md. Delwar Hossain Professor and Head Department of Civil Engineering BUET, Dhaka	Member (Ex-Officio)
Dr. Hasib Mohammed Ahsan Professor Department of Civil Engineering BUET, Dhaka	Member
Parimal Kumar Karmakar Executive Engineer HSIA Expansion Project (Phase-I) CAAB, Kurmitola, Dhaka	Member (External)

DECLARATION

I hereby declare that this thesis is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or have been accepted for the award of any other degree or diploma at Bangladesh University of Engineering and Technology (BUET) or any other educational institution, except where due acknowledgement is made. I also declare that the intellectual content of this thesis is the product of my own work and any contribution made to the research by others, with whom I have worked at BUET or elsewhere, is explicitly acknowledged.

B. M. Assaduzzaman Nur

DEDICATION

This work is dedicated to my parents, Mr. Md. Saiful Islam Bhuyan and Mst. Rokeya Khatun, who have always loved me unconditionally and whose good examples have taught me to work hard for the things I aspire to achieve. I also dedicate this to the memory of my late uncle, Mr. Mohammad Arifur Rahman, P.Eng. Finally, I'd like to thank my beloved wife, Shayeda Shoulin, and son, Abdullah Bin Nur, who have always been a constant source of support in my life. I am truly grateful to have both of you in my life.

ACKNOWLEDGEMENT

In the name of Allah, the Most Beneficent, Gracious, and Merciful. All praise to Allah and his blessings for the completion of this thesis. I thank Allah for all of the opportunities, trials, and strength that have been bestowed upon me in order for me to complete the thesis.

I would like to express my heartfelt gratitude, sincere appreciation, and indebtedness to my supervisor, Dr. Md. Mizanur Rahman, Professor, Department of Civil Engineering, Bangladesh University of Engineering and Technology (BUET), for his constant supervision, continuous guidance, constructive criticism, affectionate encouragement, invaluable suggestions, generous help, and unfailing enthusiasm at all stages of my work. My inspiration came from his active interest in this topic and valuable advice. I am extremely grateful that you took me as a student and continued to have faith in me over the years.

I would also like to thank the rest of my thesis committee, Professor. Dr. Md. Delwar Hossain, Professor. Dr. Hasib Mohammed Ahsan, and Executive Engineer Parimal Kumar Karmakar, for taking time out of their busy schedules to attend my master's defense presentation and help make this presentation possible.

I’d like to thank Gary L. Mitchell, P.E., Vice President, Airports and Pavement Technology, American Concrete Pavement Association, USA, for his helpful advice via email.

Finally, I am grateful to my friends and family members for their constant encouragement and support, which has provided me with the necessary strength to complete this study.

ABSTRACT

This study is about airport pavement design using a life-cycle cost analysis. Secondary data collected for the pavement design includes: (i) annual air traffic; (ii) traffic growth factor; (iii) sub-grade strength of 12,000 Psi; and (iv) design life of 20, 30, and 40 years. FAARFIELD software is used to design flexible and rigid pavements, using alternative materials for different layers as prescribed by FAARFIELD. The initial costs and life-cycle costs of the pavements are determined using AirCost software's material unit price. For the long-term (40-year) analysis period, overlay design incorporates primarily selective pavements: (i) asphalt and concrete overlays on flexible pavement, and (ii) asphalt and concrete overlays on rigid pavement. Pavement life-cycle cost analysis was done using two methods: (i) Net Present Value method and (ii) Deterministic and Normal Probabilistic method in AirCost software. A single discount rate was used for the analysis.

The study identifies cost-effective flexible and rigid pavement design materials. Another significant finding was the use of recycled concrete aggregate as a subbase design material on both pavements. The life-cycle cost analysis determines flexible pavement has lower initial costs of 12.4%, 13.88%, and 14.93% but higher maintenance and rehabilitation costs of 7.82%, 8.73%, and 8.08% than rigid pavement. Therefore, the rigid pavement with a single Portland cement concrete overlay is the most cost-effective pavement alternative (NPVs of 4.41%, 4.45%, 3.73%, and AirCosts of 19.09%, 19.24%, and 18.45%, respectively) and has the highest chance of success with less simplified risk. Furthermore, sensitivity analysis reveals that as the discount rate rises, the life cycle cost falls.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBRAVIATIONS

$	Dollar
°C	Celsius
AAPTP	Airfield Asphalt Pavement Technology Program
ACNs	Aircraft Classification Numbers
APSDS	Airport Pavement Structural Design System
CAAB	Civil Aviation Authority of Bangladesh
CBR	California Bearing Ratio
CDF	Cumulative Damage Factor
EUAC	Equivalent Uniform Annual Cost
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FWR	Dynamic Falling Weight Reflectometer
HMA	Hot Mix Asphalt
HSIA	Hazrat Shahjalal International Airport
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
in	Inch
kg	Kilogram
lb.	Pound
LCA	Life Cycle Cost
LCCA	Life Cycle Cost Analysis
m	Meter
MPa	Mega Pascal
NAPTF	National Airport Pavement Test Facility
NPV	Net Present Value
PCC	Portland Cement Concrete
PCI	Pavement Condition Index
Psi	Pounds per square inch
sq. ft.	Square Feet
sq. yd.	Square Yard

CHAPTER 1

INTRODUCTION

1.1 General

Air transport is a critical enabler of the country's economic growth and development. It integrates into the global economy and establishes extensive connectivity on a national, regional, and international scale. Nowadays, airplanes are advanced, and the rapid growth of air travel demand has resulted in an airport being evaluated as a dynamic system.

The runway is one of the most critical components of an airport, and it is critical to ensure the quality of the pavement. It must be built with enough strength to carry a moving aircraft and with a high resistance to skidding and aquaplaning. Typically, pavement is classified into two types: flexible and rigid. This pavement design software has been developed and released by aviation authorities all over the world, including LEDFAA, PCASE, APSDA, FAARFIELD, and TKUAPAV.

Pavement life cycle cost analysis (LCCA) is a well-known economic analysis process that uses the net present value (NPV) method to assess the cost-efficiency of alternatives. The analysis method has been developed over decades by agencies and institutions from various countries. Some organizations developed computer programs for their LCCA approaches for analysis, such as AirCost, LCCA2002, RealCost, APA LCCA, etc.

1.2 An Overview of Aviation Sector in Bangladesh

1.2.1 Air Travel Demand

The distances between major cities are insufficient for air transportation to be effective, and roadways are congested and prone to accidents, whereas railways and waterways are inefficient and slow. With fewer improvements to roads, railways, and waterways, as well as the country's imbalanced socio-political conditions, people are becoming more interested in air travel.

Bangladesh Parjatan Corporation has a great responsibility to look after the tourism sector. The Sundarban, the historic mosque in the city of Bagerhat, and the ruins of the Buddihist Vihara at Paharpur are three world heritage sites in the country among 1,007.

In 2012, approximately six lakh tourists visited our country, contributing 4.4 percent to GDP, increasing employment by 3.8 percent, and opening up 1.5 percent of investment opportunities [1].

Bangladesh has a population base of 160 million people, with ten million people working outside the country, and over one million people visiting Saudi Arabia for Hajj. This has made Bangladesh a lucrative destination for all foreign airlines. Some far eastern airlines, owned by Malaysia and Thailand, are offering budget air packages and making brisk business utilizing the huge air travel market of Bangladesh.

At present, aviation activities are carried out from three international and five domestic airports, and about twenty airlines are now operating in and out of the country. By 2020, it is expected that passenger volume will increase from 5.8 million to 10.2 million, and air cargo volume will increase from 230,000 to 360,000 metric tons [2]. Figure 1.1 shows that over the past 45 years, this indicator reached a maximum value of 5,984,155 in 2018 and a minimum value of 431,400 in 1974 [3].

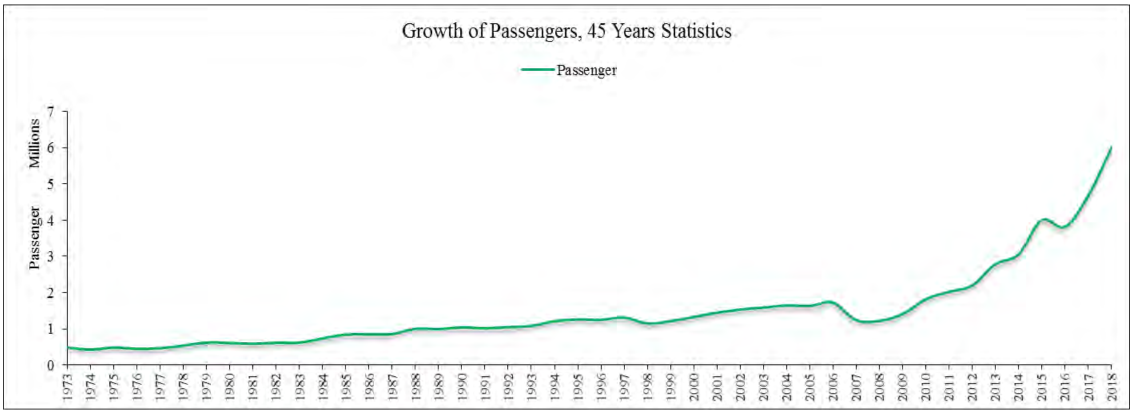

Figure 1.1: Passenger growth statistics in Bangladesh [3].

Domestic and international air passenger traffic increased by 1,433.89 percent in 2018 to 8,896,571. The growth of air cargo from 39,359 tons in 1990 to 384,291 tons in 2018 represents a growth of 876.37 percent. In the first two decades after independence, between 1972 and 1992, the number of air passengers increased by 188.6 percent, from 58,000 to 1,645,035. A decade later, passenger traffic increased by 79.25 percent a decade later, reaching 2,948,880. In the next decade, in 2012, passenger numbers increased by 109.34 percent to 617,323,423 from 2,948,880. Over the previous six years, passenger traffic increased 441.12 percent, from 6,173,423 in 2012 to 8,896,571 in 2018.

The International Air Transport Association (IATA) predicts that the number of air travelers in Bangladesh will reach 21 million by 2035. The commercial aviation sector will employ 3.3 million people, a 145 percent increase over 2014. Commercial aviation's contribution to GDP would be USD 8 billion, a 142 percent increase over 2014 [4].

1.2.2 The Airport’s Current Status

The air transportation network of Bangladesh includes three international, seven domestic, five STOL (Short Take-off and Landing) ports, and nine other underutilized airports. With the exception of a significant portion of the ground facilities, all airports are public. Table 1.1 shows the current status of airports.

Table 1.1: The current airport status in Bangladesh [5].

International Airports	
1. Hazrat Shah Jalal International Airport, Dhaka (HSIA)	
2. Shah Amanat International Airport, Chittagong (SAIA)	
3. Osmani International Airport, Sylhet (OIA)	
Domestic Airports	**STOL ports**
Operational:	1. Comilla STOL port
1. Saidpur Airport	2. Bogra STOL port
2. Shah Makhdum Airport, Rajshahi	3. Thakurgaon STOL port
3. Jessore Airport	4. Lalmonirhat STOL port
4. Barisal Airport	5. Shamshernagar STOL port
5. Cox's Bazar Airport	**Unused Airports:**
Non-operational:	1. Sandwip Airport
1. Tejgaon Airport	2. Chakaria Airport
2. Ishurdi Airport	3. Feni Airport
Under Construction:	4. Rajendrapur Airport
1. Khan Jahan Ali Airport, Bagerhat	5. Maulvi Bazar Airport
2. Noakhali Airport	6. Rasulpur Airport
	7. Sirajganj Airport
	8. Bajitpur Airport
	9. Pahar Kanchanpur Airport

1.3 Statement of the Problem

Airport pavement is considered a mega-construction, and due to a lack of funds and time, the scope of new pavement design, construction, or reconstruction is quite difficult. The allocation of developmental expenditure for the aviation sector is comparatively low in comparison to other transportation sectors. However, air travel demand is rapidly increasing and is contributing significantly to the country's GDP.

The standard design life of an airport pavement is 20 years. There are no plans for long-term (30 or 40-year) pavement design, construction, or reconstruction. The selection of construction materials is important and plays a significant role during the design phase. For example, if a locally available, suitable material is not chosen, it may require importing, so construction can be hampered and project costs can skyrocket. The project's strategic alternative options, as well as their life cycle costs and profitability, are not well analyzed at the beginning of a new project investment. That is why decision-makers are unable to make rational decisions and, at times, simply blindly accept them as a political commitment and public support. As a result, our country's economy suffers, as do development programs. Hence, both local and foreign investors are refusing to invest.

1.4 Background of the Study

Modern aircraft are larger, with a higher gross weight and tire load. The FAA used a real-scale field experiment linked to a real-time simulation to simulate various types of airplane movements in terms of wheel load. Some members of the FAA's airport engineering department used LEDFAA and FEDFAA software to conduct these studies in 1989 [6]. Brill (2004) also conducted a study on three pieces of software, LEDFAA, FEDFAA, and FAARFIELD, and stated the capabilities of each in the analysis and design of airport pavement. Their work was validated by the results of National Airport Pavement Test Facility (NAPTF) field experiments [7]. The study finds that airplanes with 4 and 6 wheels, such as the B-777 and A-340, gained from the design of FAARFIELD software were more reliable with the values acquired from field trials on a real scale.

The FAARFIELD software can operate using elastic layer theory and the 3D finite element method, as well as the standard thickness design accompanying AC 150/5320-6F, 2016 Airport Pavement Design and Evaluation. The current free version of the software is FAARFIELD 1.42, which stands for FAA flexible and rigid iterative elastic layered design utilizing failure mode [8] [9]. A comprehensive study was conducted on the LEDFAA, PCASE, APSDA, FAARFIELD, and TKUAPAV software. This study finds FAARFIELD software makes the prediction of the behavior of airplanes loading on runway pavement more realistic and economical [10].

The FAA's NextGen program is a multi-agency, multi-year effort to modernize today's national airspace system. It conducts research and development on the technologies, methods (for example, switching from a 20-year to a 40-year pavement design) and materials required to safely accommodate increased traffic. Recycled concrete aggregate and reclaimed asphalt pavement can be used in an unbound base course on pavement. It can reduce the need for virgin materials, preserve the environment, and save landfill space. Sustainable airfield pavement engineering solutions address all aspects of airport pavement design, construction, and evaluation, including mix design, material selection, environmental factors, maintenance, sustainability, and life-cycle cost analysis procedures [11].

Life cycle cost analysis is a useful decision making tool. When selecting a pavement type, life cycle cost analysis is used to determine the most effective method and timing for all new construction, reconstruction, and maintenance projects. A life cycle cost analysis was carried out on the Hazrat Shah Jalal International Airport pavement in Dhaka. The study finds the initial cost of rigid pavement is 20.98 percent higher than flexible pavement, but maintenance and rehabilitation costs are 78.26 percent lower than flexible pavement. At the end of the analysis, rigid pavement was 4.58 percent more cost-effective compared to flexible pavement [12].

The AirCost LCCA software was developed by the Airfield Asphalt Pavement Technology Program (AAPTP) and is used as a decision-making tool in the planning and construction of low-cost airport pavement. The life cycle cost analysis period for new construction will be 40 years, and 30 years for rehabilitation or overlay [13].

1.5 Objectives of the Study

The specific objectives of this study are outlined below.

i. To design structural thickness of airport pavements by FAARFIELD software using alternative materials in different layer for same design criteria.
ii. To estimate the pavements' initial construction cost.
iii. To determine the pavements' life cycle cost by Net Present Value method and AirCost software for long term analysis period.
iv. To find out the most cost effective design alternative and quick decision making option.

1.6 Scope of the Study

The study will extend existing knowledge about airport pavement design and its life cycle cost analysis according to the FAA standards. There are many potential benefits that researchers and airport authorities can gain through successful competition of this study. It will also assist the decision-maker in making a quick, rational decision. This type of analysis is not new all over the world, but the authorities keep practicing and upgrading to reach the ultimate goal.

1.7 Limitations of the Study

The study has some restrictions; without them, the study could be more precise if these limitations were not present. This limitation includes

i. If another airport pavement design software is used, the study's possible outcomes may change.
ii. Any change in the price of a material unit may have an effect on the final outcome of this analysis.
iii. The possible outcomes of the analysis might change if different life cycle cost analysis methods and software are used.
iv. In Bangladesh, no significant research on this topic has been conducted. So, the study has been following the airport pavement design guidelines of the FAA Standard.

v. This study is based on secondary data. However, sufficient relevant data is not found in the second source. It is necessary to make some assumptions in order to carry out this study.

1.8 Thesis Organization

The thesis consists of eight chapters and eight appendices. A brief commentary on these chapters is presented below.

Chapter 1 deals with the background of the study relating to the thesis topic, which is tailed by the present status of airports and air travel demand in Bangladesh, a problem statement, aims and objectives, methodology, scope and limitations, and finally, the organization of the thesis.

Chapter 2 includes a general literature review of airport pavement design and evaluation related to FAA standards, FAARFIELD software and methods of construction, life cycle cost analysis with the NPV method and Air Cost software, and international case studies of previous research relevant to the topic of study.

Chapter 3 consists of data collection, airport pavement design by FAARFIELD software, pavement material and initial cost estimation.

Chapter 4 discusses the results of pavement design thickness, associated pavement's initial costs, and the selection of economic pavement with materials.

Chapter 5 briefly describes the pavement overlay designs, which are based on long-term maintenance and rehabilitation strategies, and a summary of the design results.

Chapter 6 includes the pavement life cycle cost analysis using the Net Present Value method and Air Cost software, and a summary of the analysis result.

Chapter 7 covers economical pavement selection, selected pavements' entire life span costing scenario, and sensitivity analysis.

Chapter 8 presents the conclusions and recommendations of the study.

CHAPTER 2

LITERATURE REVIEW

2.1 General

This chapter provides an overview of the literature on airport pavement design. It briefly discusses the flexible and rigid pavement design procedures. It also discusses the procedures for pavement life cycle cost analysis in a global context. Some relevant case studies and international practice are also discussed in relation to the study.

2.2 Airport Pavement

The airport pavement consists of the runway, taxiway, shoulder, and apron. Some of these components' parts are identified as critical, and others are identified as non-critical. A critical area is defined as a location where the aircraft's speed is low or the aircraft is at rest. This part of the pavement requires a thicker structural thickness. The non-critical area is considered the runway's center where the aircraft is partially airborne; additionally, due to greater lateral wander, the stress repetitions at a particular spot are small [3]. Aside from high speed, the asphalt has greater strength than slow speed movement. As a result, the design thickness for non-critical areas is less than for critical areas.

2.3 Different Types of Airport Pavements

The airport pavement is a sophisticated engineering structure. It is classified into two types: flexible and rigid [14].

Flexible pavement consists of a bituminous surface course over a base course and sub-base course. The total pavement structure bends or deflects due to traffic loads. Since the stress induced by traffic loading is highest at the top, the surface layer has the maximum stiffness. The below layers have less stiffness but are equally important for the pavement composition.

Rigid pavement consists of a concrete surface course over a base course. The most common type of rigid pavement contains dowel bars and tie bars. Dowel bars are the shortest steel bars that provide a mechanical connection between slabs without restricting horizontal joint movement. Tie bars are either deformed steel bars or connectors used to hold the faces of abutting slabs in contact.

2.4 Airport Pavement Structures

A surface course, base course, subbase course, and subgrade are common components of airport pavement structures. Figure 2.1 shows the typical airport pavement structure.

i. Surface courses usually include Portland Cement Concrete (PCC) and Hot Mix Asphalt (HMA).
ii. Base courses are generally categorized into two classes, namely stabilized and unstabilized bases. Unstabilized bases consist of crushed and uncrushed aggregates. Whereas stabilized bases consist of crushed and uncrushed aggregates stabilized with cement or asphalt,
iii. Subbase courses comprise granular material that may be stabilized or unstabilized.
iv. Subgrade consists of natural or modified soils.

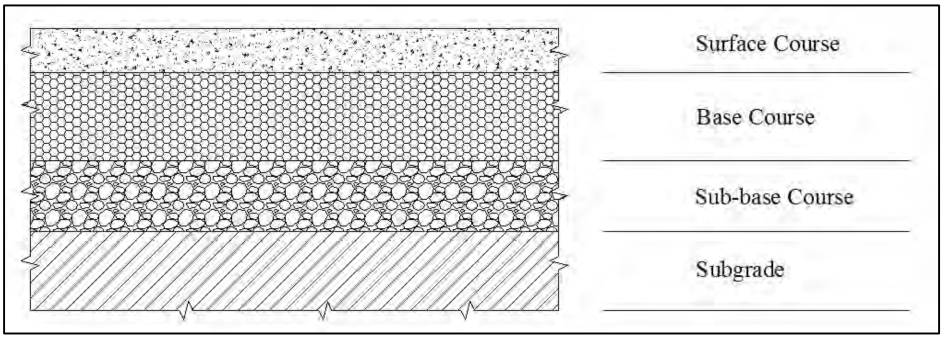

Figure 2.1: Typical airport pavement structure.

2.5 Aircraft Historical Evaluation

In 1903, the Wright brothers first invented sustained, controlled, powered, heavier-than-air airplane flight and, later in 1905, developed the first practical fixed-wing aircraft. In 1909, the military closely saw the advantages of airplanes, and they were used and played a minor role in World War I in 1914. Because the aircraft were light in weight, airfield pavements were unimportant, and they could operate from any relatively flat and clear paddock.

In the middle of the World War, I and II aircraft were technologically improved. Famous World War II aircraft include the P-51 Mustang, Lancaster Bomber, and B-29

Superfortress. At the end of the war, these aircraft became too heavy to continue to operating unprepared ground. For the first time, the US Army Corps of Engineers is interested in airport pavement design.

The DC-8-50 was invented in 1958 and it had the most damaging of all relative aircraft with 19 tons of wheel load. During World War II, commercial aircraft technology initiatives were developing. This development enhanced the escalation of the cold war between the USA and Russia. Between 1940 and 1950, military aircraft tire pressures increased from 0.6 MPa to 1.2 MPa.

The commercial aircraft industry has developed slightly more than the military aviation sector in recent years. In 2004, Airbus introduced the extended body A340-600 commercial passenger jet, which was built with advanced technology for one of the most demanding pavements. In 2005, it also introduced the world's largest passenger aircraft, the A380-800. Airbus and the Boeing industry are developing commercial and military aircraft side by side.

Airport pavement that has evaluation on airport pavement design and technology requirements could have a significant impact on how much fuel is burned per kilometer flown. Currently, modern aircraft manufacturers are focused on attaining the lowest fuel burn per passenger per kilometer flown.

2.6 Existing Pavement Assessment

Airport pavement projects do not always involve the design and construction of new pavement; some involve the evaluation and improvement of existing pavement. Pavement evaluation is related to pavement design and describes the structural capacity of a pavement; it is based on reverse design concepts. Existing pavement evaluation includes existing pavement and subgrade conditions to determine the long-term serviceability of future aircraft traffic, also known as pavement remaining life.

The assessment of the existing pavement structure includes the following components:

i. Documentation: Existing pavement was previously documented as being constructed.

ii. Non-destructive Field Testing: A range of non-destructive field testing methods are available, with the dynamic falling weight reflectometer (FWD) being useful up to 1.5 m.

iii. Intrusive Test: This test uses core cutting to determine different layers, materials, and thicknesses. The samples are subjected to laboratory testing for plasticity, crushed or uncrushed gravel, subgrade moisture content, and CBR, etc.

2.7 Conventional Airport Pavement Design Software

Airport pavement is a complex engineering challenge for designers, and it can be very difficult to design the right kind of pavement for an airport. Some pieces of flexible and rigid pavement design evaluation software are built on the basis of conventional design guidelines [10].

2.7.1 LEEDFAA

LEDFAA is an airport flexible and rigid pavement thickness design software. It was designed by the FAA, and its final version presented in 2004. The operating system is the basis of elastic layer theory. The ability to transfer loads through the joints of this software is 25 percent, which is based on the assumptions of Westergaurd.

2.7.2 FAARFIELD

FAARFIELD is an airport flexible and rigid pavement thickness design software. The operating system was based on elastic layer theory and the finite element method. The core of the program is a structural response model comprised of LEAF and NIKE3D. Both programs can be used when a FARFIELD program is needed, but their contents are not visible to the users.

2.7.3 COMFAA

The COMFAA is an airport pavement design software that was designed by the FAA. It can compute flexible and rigid aircraft classification numbers (ACNs) and pavement thickness. This software has the ability to calculate aircraft classification numbers in accordance with the International Civil Aviation Organization (ICAO) procedure.

2.7.4 PCASE

PCASE is an airport pavement design software designed by the U.S. Army Corps of Engineers association. Since 2005, the software has been considered public information and has easy accessibility for all users. The software's most recent version was released in 2010. It has the ability to design and evaluate airports with flexible and rigid pavement, railroads, and roads.

2.7.5 TKUAPAV

TKUAPAV is an airport's rigid pavement thickness design software. It was developed at Tamkang University in Taiwan by Shao-Tang Yen under the supervision of Professor York Ying-Haur. This software is used to design airport rigid pavement based on the theory of Westergaurd and choose the right airplanes in the LEDFAA program.

2.7.6 APSDS 5.0

The airport pavement structural design system (APSDS) is a new airport pavement design software. It was manufactured by an Australian company named Mincad in 2010. APSDS 3.0 and APSDS 4.0 software entered the market and became available for users in 1995 and 2000. The main capability of the software was to calculate the amount of pavement cost according to the volume of materials used in the design. The software is used for flexible pavement design based on the theory of elastic layers. Moreover, economic design is the main advantage of this software.

2.8 Software Design Process

The design process of this software is almost similar. At first the intended aircrafts along with their number of annual flight are selected. Then the characteristics of pavement materials are determined, and design process is performed based on the cumulative damage factor (CDF) of each aircraft to the extent that cumulative value of this factor is equal to 1 [10]. This ratio represents the pavement failure rate and depends on many factors such as aircraft weight, wheel placement, the percentage of aircraft weight on the main wheels, axles distance, and pavement type. The CDF value is from zero to one and is split among the planes in the complex traffic list as a cumulative manner and each plane has a part in this amount. This factor indicates the amount of damage caused by complex traffic on the pavement and this enables the designer that the plane has the maximum force to the pavement and put the system under loads on the threshold of pavement failure. The CDF value is obtained through the following equation 2.1 [9]:

$$CDF = \frac{\text{(annual deparatures) x (life in years)}}{\text{(pass/coverage ratio) x (coverage to failure)}} \qquad 2.1$$

Coverage is the number of times when the aircraft passes unit area of flight path, one wheel of a plane main wheels that passes through it. And pass is the distance of a plane passing to the loading location until it flies or the distance from where the aircraft touches the ground to the discharge site.

If CDF<1, it means some time is remained from pavement life and the pavement does not suffer from fatigue.

If CDF=1, all the useful life of the pavement is used.

If CDF>1, the useful life of pavement is finished and pavement suffers from some damages. Also substrate elasticity modulus calculation in flexible pavement using any software is based on the following relation-

$$E_{SG}=1500 \text{ x } CBR \text{ (psi)} \qquad 2.2$$

This method is based on flexible pavement design method of subtracting the value of CBR. For rigid pavement, modulus value considers the subtraction of K value which is equal to-

$$E_{SG}=26 \text{ x } k^{1.284} \qquad 2.3$$

$$K=\left[\frac{1500 \text{ x } CBR}{26}\right]^{0/778} \qquad 2.4$$

The subtract elasticity Modulus (psi) = E_{SG}

Soil reaction index (psi) = k

In addition, E_{SG} can be obtained from laboratory tests or other non-destructive tests. Equations for converting CBR to modulus are based on empirical data that are used in the method of elastic layer's theory.

2.8.1 Pavement Design Life

The standard design life of airport flexible and rigid pavement is 20 years. A larger hub airport may choose a longer design life, but this requires FAA approval [9]. Pavement design lives of 20 to 30 years are used in the United Kingdom. The upper end of this range is for rigid pavements, while the lower end is for flexible pavements [15]. In Australia, the design life of flexible pavements is 20 years, whereas rigid pavements are 40 years [16].

2.8.2 Pavement Long-term Service Life

The expected service life of airport pavements varies with pavement type. The FAA announced in 2011 that the pavement expected life of large hub airports would be increased from 20 to 40 years [17]. In Australia, flexible pavement life expectations are unlimited and can be periodically reset by an asphalt overlay, while rigid pavement life expectations range from 40 to 60 years [16].

2.8.3 Pavement Minimum Layer Thickness

The FAA classified airplane weight into three categories: less than 12,500 pounds, less than 100,000 pounds, and more than 100,000 pounds. The minimum thickness requirements are determined by the gross weight of the heaviest airplane in the design traffic mix, regardless of traffic level. The minimum layer thickness requirements are determined automatically by software based on the traffic mix. Tables 2.3 and 2.4 show the FAA's minimum layer thicknesses for flexible and rigid pavements, respectively [9].

Table 2.1: Minimum layer thickness for flexible pavement structures [9].

Layer Type	FAA Specification Item	Maximum Airplane Gross Weight Operating on Pavement, lbs. (kg)		
		<12,500 (5,670)	< 1,00,000 (45,360)	≥1,00,000(45,360)
HMA Surface	P-401	3 in. (75 mm)	4 in. (100 mm)	4 in. (100 mm)

Table 2.1: Minimum layer thickness for flexible pavement structures [9] (continued).

Layer Type	FAA Specification Item	Maximum Airplane Gross Weight Operating on Pavement, lbs. (kg)		
		<12,500 (5,670)	< 1,00,000 (45,360)	≥1,00,000(45,360)
Stabilized Base	P-401 or P-403; P-304; P-306	Not Required	Not Required	5 in. (125 mm)
Crushed Aggregate Base	P-209	3 in. (75 mm)	6 in. (150 mm)	6 in. (150 mm)
Aggregate Base	P-208	3 in. (75 mm)	Not Used	Not Used
Subbase	P-154	4 in. (100 mm)	4 in. (100 mm) (If required)	4 in. (100 mm) (if required)

Table 2.2: Minimum layer thickness for rigid pavement structures [9].

Layer Type	FAA Specification Item	Maximum Airplane Gross Weight Operating on Pavement, lbs. (kg)		
		<12,500 (5,670)	< 1,00,000 (45,360)	≥ 1,00,000 (45,360)
PCC Surface	P-501	5 in. (125 mm)	6 in. (150 mm)	6 in. (150 mm)
Stabilized Base	P-401 or P-403; P-304; P-306	Not Required	Not Required	5 in. (125 mm)
Base	P-208, P-209, P-211, P-301	Not Required	6 in. (150 mm)	6 in. (150 mm)
Subbase	P-154	4 in. (100 mm)	As needed for frost or to create working platform	As needed for frost or to create working platform

2.9 Pavement Maintenance and Rehabilitation Schedule Plan

The pavement is maintained and rehabilitated on a regular basis to ensure a smooth riding surface and to extend its service life. A typical pavement maintenance and rehabilitation schedule plan is presented as follows [16].

Flexible pavement

i. An asphalt surface requires an overlay every 10 to 12 years.
ii. Joint sealing commences after 5 years and continues until resurfacing.
iii. Boney surface filling has minor requirements for intermediate construction and reconstruction every 5 years thereafter.
iv. Asphalt patching works for 6 years and is increasing for the remainder of the surface's life.
v. Asphalt preservation is typically performed every 6 to 8 years, and potentially again approximately 3 years later.

Rigid pavement

i. A severe minor crack is repairs after 20 years and will increase for the remainder of the pavement's life.
ii. Repairing minor spalls after five years, with an increase after 20 years.
iii. Reinstatement of joint sealants every 10 to 15 years
iv. Partial and full slab replacement are needed after 30 years, and this is increasing for the remainder of the pavement's life.

Historical pavement maintenance records are stored in a pavement management database, and this does not indicate a rigid timeframe for the application of maintenance. The North Carolina Department of Transportation (NCDOT), Division of Aviation, has developed a typical pavement maintenance schedule plan [18]. Flexible pavement's asphalt overlay is applied at the age of 15 years, and crack sealing is done every 6 to 7 years. The NCODT has insufficient information for rigid pavement maintenance. The joint seal between concrete slabs is replaced every 10 years on average, but in many cases, the joint resealing is not required until the 15th year. A concrete slab replacement of 5 percent is required at the end of the 20th year. The 5 percent slab replacement is recommended for general aviation use.

Rigid pavements in the United Kingdom require less maintenance and can last for 25 to 35 years. Flexible pavements typically require slurry sealing maintenance every 7 to 10 years and more substantial restoration work after 20 to 25 years, and resurfacing is required every 15 years in the case of friction [15].

2.10 Construction Practice

In this modern era, there are several airport pavement construction standards available. The basic construction procedures are almost the same, and some extra precautions are taken depending on geographical location, climate, etc. This section has been furnished as per the study materials used in the design. Constructive construction procedures are concisely illuminated here [19].

2.10.1 Flexible Pavement

2.10.1.1 Surface

Item P-401, Hot Mix Asphalt (HMA), is used for flexible pavement's top surface. The preparation bed of the underlying HMA course shall be cleaned of all dust and debris. Afterward, tack coat P-603 at a spray rate of 0.05 to 0.10 gallons per square yard is applied. If the underlying surface temperature is 4 °C, an HMA compacted layer thickness of 75 mm or greater can be used. For a thicker HMA layer construction, compaction and surface smoothness control are very difficult, particularly while an adjustable layer thickness is required. The HMA layer thickness used in Australia generally varies from 35 mm to 80 mm [16]. Also, if the compacted layer thickness is greater than 75 mm, a one-layer tack coat with a spraying rate of 0.05 to 0.10 gallons per square yard is used between the two layers.

The HMA is mixed at a very hot temperature of 160–175 °C. The laying temperature is 130–150 °C, and the steel rolling temperature is 90–130 °C. But below the temperature of approximately 90°C, rolling asphalt is largely ineffective. HMA has been laid using a mechanical paver and a combination of pneumatic tires and steel drum rollers. The level of the mechanical paver is automatically controlled by computer software, based on the existing and designed surface levels. Also, the top surface is grooved (P-401-B) and road markings (P-100-14) are applied.

2.10.1.2 Stabilized Base

Item P-403, Hot Mix Asphalt (HMA), is laid on top of the subbase. The preparation bed shall be cleaned of all dust and debris. Then prime coat P-602 at a spraying rate of 0.15 to 0.30 gallons per square yard is applied. Allowance of the prime coat to cure without being disturbed for a period of at least 48 hours or longer, as may be necessary to attain penetration into the treated stabilized base course. Furthermore, the P-403 asphalt construction procedures are applied the same as in P-401.

2.10.1.3 Sub-base

The items P-209, crushed aggregate, and P-219, recycled concrete aggregate, are placed on the above subgrade. The materials spread in non-segregated lanes are of such a loose depth that when compacted, the layer must have a specified thickness. The aggregate sub-base course is constructed in layers of uniform thickness of not less than 75 mm but not more than 150 mm of compacted thickness.

2.10.2 Rigid Pavement

2.10.2.1 Surface

A Portland Cement Concrete (PCC) slab is used as the top surface, and its item number is P-501. The slab can be constructed as reinforced or unreinforced, and its standard size depends on structural thickness. These slabs are connected with dowels or tie bars, and longitudinal or transverse joints are provided as per construction guidelines. The free vertical drop of the concrete from one point to another or to the underlying surface shall not exceed 1 m at any point in the concrete conveyance. The finished concrete product must be homogeneous. Without segregation and proper vibration, the finished concrete product is acceptable. A curing agent is applied. Two-lift concreting is common in Europe, but it is uncommon in the United States [11]. Also, the top surface is grooved (P-501-C) and road markings (P-100-14) are applied.

2.10.2.2 Stabilized Base

The rigid pavement P-403 is equivalent to the stabilized flexible pavement. The items P-403, Hot Mix Asphalt (HMA), P-304, Cement Treated Aggregate, and P-306, Lean Concrete, are placed on the subbase. The P-403 follows the same procedure as described in flexible pavement. The P-304 materials are laid in layers, and the compacted thickness is not more than 150 mm. Asphalt emulsion is used as a curing agent on the entire surface at a spraying rate of between 0.15 and 0.30 gallons per square yard. In the P-306, all procedures for lean concreting are done as per the P-501 concreting guideline.

2.10.2.3 Subbase

Item P-209 and P-219, are similar procedures as described in flexible pavement.

2.10.3 Overlay

2.10.3.1 Flexible pavement on Hot Mix Asphalt Overlay

The pavement's entire top surface is milled. This process is done by an asphalt milling machine. The milled surface is cleaned of all dust and debris, and then dried. Afterward, a tack coat is sprayed, and the required HMA thickness is laid on, and then grooved into the overlay surface.

2.10.3.2 Flexible pavement on Portland Cement Concrete unbound Overlay

The pavement's top surface is prepared to clean all dust and debris, and then it is dried. The PCC unbound concrete slab is cast over the entire surface. These slab (longitudinal or transverse) joints are sealed and grooved (saw-cut) on the overlay surface.

2.10.3.3 Rigid Pavement on Portland Cement Concrete unbound Overlay

A percentage of the full-depth damaged slab is replaced and reconstructed. The entire pavement's top surface is cleaned, and a PCC unbounded concrete slab is cast. This slab (longitudinal or transverse) joint is sealed and grooved (saw-cut) on the overlay surface.

2.10.3.4 Rigid Pavement on Hot Mix Asphalt Overlay

The entire pavement's top surface is milled, and all the dust must be cleaned and dried. The next tack coat is sprayed, the required HMA thickness is laid on, and then the overlay surface is grooved.

2.11 Life Cycle Cost

A life cycle cost (LCC) is defined as the sum of all costs incurred during the life span of a project [20]. This term also describes the process and technique of estimating the total cost of the project. It is considered an aid in the budgeting and decision-making process. Dell'lsola acknowledged that LCC is an economic assessment of an item, system, or facility [21].

2.12 Life Cycle Cost Analysis

Life cycle cost analysis (LCCA) is simply defined as the form of economic analysis used to determine the long-term financial efficiency of all the alternative investment options. However, a more detailed definition has been given by the US Federal Highway Administration (2001) as follows: LCCA is an analysis technique that builds on the well-funded principles of economic analysis to evaluate the overall long-term financial efficiency of competing alternative investment options. It does not address equity issues. It addresses initial and discounted future agency, user, and relevant costs over the life of alternative investments. It identifies the best value for investment expenditures [22].

2.13 Life Cycle Cost Analysis Techniques

Economic models are being used by transportation agencies in many countries to compare and select the most economical pavement alternatives. These models (mathematical equations) yield the common basis of economic comparison between the projects and proposals in different formats. Several types of universally accepted economic models or formulas exist for the economic feasibility analysis of pavement projects [23].

i. Net Present Value (NPV) method
ii. Equivalent Uniform Annual Cost (EUAC) method
iii. Benefit over Cost Ratio (BCR) method
iv. Incremental Benefit over Cost Ratio (IBCR) method
v. Rate-of-Return (RR) method
vi. Incremental Rate-of-Return (IRR) method

2.14 The Fundamental Principle of Life Cycle Cost Analysis

The life-cycle cost analysis is regarded as a key decision-making tool for determining pavement type, structure and mix type, construction methods, and maintenance and rehabilitation strategy. In general, it comes after step [24].

Step-1: Initial Strategy and Analysis Decisions

This step includes the fundamental decisions, estimations, and assumptions required to establish the parameters under which life cycle cost analysis is performed. It is linked with alternative pavement design strategies, determining performance periods, activity timing, and analysis periods. It's important to realize that if this parameter changes, the cost-effectiveness of an alternative will also change.

Step-2: Estimate costs

This step is linked to cost estimation. Each alternative cost is split into two parts: agency cost and user cost. The agency's costs include preliminary engineering, contract administration, initial construction supervision, maintenance and rehabilitation, and administrative and salvage value. And the user costs are normal operation, work zone, vehicle operation, user delay, and crash costs.

Step 3: Evaluate Alternatives

This step discusses the relatively new pavement-alternatives economic analysis method. A common computing indicator, such as net present value (NPV), equivalent uniform annual costs (EUAC), and a computer program are chosen.

Step-4: Analyze the Results and Re-evaluate Alternatives

A sensitivity analysis is performed to find out the analyzed results, as well as a probability analysis. This step examines consistency with the most significant costs, factors, and assumptions. The alternative design strategy is re-evaluated on the basis of analytical results to improve the cost-effectiveness of each alternative.

The life cycle cost analyze involves selecting the most cost-effective design strategy and understanding the factors that influence cost effectiveness, not just selecting one alternative over another.

2.15 Life Cycle Cost Analysis Practice

The life-cycle cost analysis of a highway pavement consists of eight steps. The first six steps are carried out for each alternative strategy. The steps are listed below [13].

i. Establish alternative pavement strategies for the analysis period.
ii. Determine pavement performance periods and establish maintenance and rehabilitation activity timing
iii. Estimate agency costs
iv. Estimate user costs
v. Develop expenditure stream diagrams
vi. Compute NPV
vii. Analyze results
viii. Re-evaluate pavement strategies

An extended version of the life cycle cost analysis of airport pavement is suggested. It consists of ten steps, as illustrated in Figure 3.2. The detailed instructions and descriptions for completing these steps are provided elaborately. It is strongly advised that all available, relevant, and reliable data be used. Many life cycle costs are calculated using previous experience-based estimates [25].

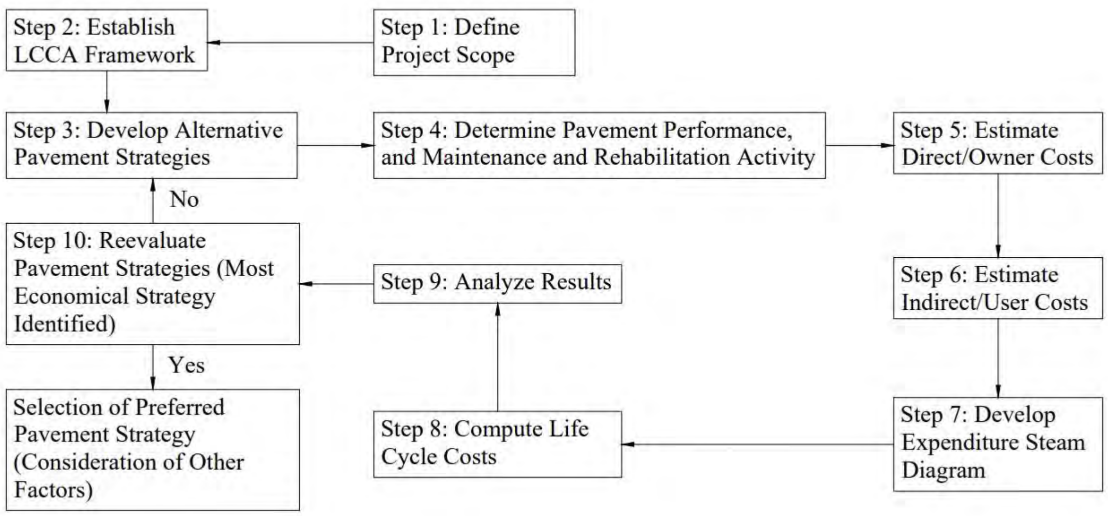

Figure 2.2: Life cycle cost analysis steps.

2.15.1 Step 1: Scope of the Project

It is best practice to conduct separate life cycle cost analyses for projects with a wide range of facilities (apron, taxiway, or runway), special branches, and a specific section that are under construction. There are undoubtedly exceptions to this rule, such as when one section is significantly smaller than another. Given the mobilization and other advantages of using the same material type for both sections, a life cycle cost analysis for the smaller section may not be warranted. The quantities and costs for multi-mile and divided-lane projects are developed for a short representative segment of one mile, and sometimes for the lanes in one direction, rather than for the entire project length and width.

2.15.2 Step-2: Establish Life Cycle Cost Analysis Framework

2.15.2.1 Analysis Period

The standard life cycle cost analysis period for airport pavement is 20 years. According to Gard (2004), airport pavements have significantly outlived their design life, and the FAA-recommended analysis period is too short [26].

2.15.2.2 Economic Analysis Techniques

Once the performance period, activity timing, and costs associated with each alternative are established, the next step is the comparison over the chosen analysis period. This is usually done in one of two ways: net present value or equivalent uniform annual cost. The choice of an appropriate economic analysis indicator depends on the transportation organization.

2.15.2.2.1 Net Present Value Method

The net present value is a calculation of the value of an investment based on a time axis with only the cash flows relevant to the project. A project is defined by a single base year, or present year and cost. Utilizing these base year costs, it is possible to compare the various alternatives. The FAA recommends using the net present value method to evaluate airport pavement design or rehabilitation alternatives. A 20-year analysis period is used. The basic equation for calculating the present value is as follows [9].

$$NPV=C+\sum_{i=1}^{m} M_i \left(\frac{1}{1+r}\right)^{n_i} - S\left(\frac{1}{1+r}\right)^{z} \qquad 2.5$$

Where,

NPV	=	Net present value, $.
C	=	Present cost of initial construction or rehabilitation activity, $.
m	=	Number of future maintenance and rehabilitation activities.
Mi	=	Cost of the ith maintenance or rehabilitation alternative in terms of present costs (i.e., constant/real dollars), $.
r	=	Discount rate.
Ni	=	Total number of years from the present of the ith maintenance or rehabilitation activity.
S	=	Salvage value, $.
z	=	Analysis period length, years.

2.15.2.2.2 Equivalent Uniform Annual Cost Method

An alternative to net present value is the equivalent uniform annual cost. This method of comparing alternatives is determined by converting all project costs to a uniform recurring annual cost over the analysis period. It discounts all projects to a recurring annual cost and then compares these costs to what is a useful indicator when annual budgets are established. In general, net present value is calculated first, and the following equation is used to convert it to an equivalent uniform annual cost [24].

$$EUAC=\frac{NPV}{\left[\frac{\left(1-\frac{1}{(1+i)^n}\right)}{i}\right]} \qquad 2.6$$

Where,

NPV	=	Net present value, $.
i	=	Discount rate
n	=	Analysis period, years.

2.15.2.2.3 Discount Rate

The discount rate is an important and controversial component of the life cycle cost analysis framework because it has a significant impact on the results. It is determined by the interest rate and the inflation rate. The discount rate illustrates the true value of money over time and is used to convert future costs to present-day costs. It is determined using the equation [18].

Life cycle cost analysis should use a reasonable discount rate that reflects historical trends over long periods of time [25]. The most current annual real discount rate based on a long-term (10, 20, or 30 year) basis should be used for deterministic analysis and as the mean value for probabilistic normal distribution. Walls et al. (1998) recommended using a discount rate of 3 to 5 percent [27], and the FAA suggested 4 percent [18].

2.15.2.2.4 Cost Factors

The airport arena has many users, including aircraft crew and passengers, air charter companies, air cargo, the airport owner/operator, and the community of businesses involved in airport operations. This user cost, which is generated as a result of selecting a pavement strategy, is assessed using the following criteria [13].

Normal operating conditions

i. Aircraft operating costs are increased due to added fatigue damage caused by rough pavements. The alternative, with more maintenance and rehabilitation events, could have a longer cumulative period of being in rough condition, resulting in extra upkeep costs.

Construction zone operating conditions

i. The cost of aircraft time delays due to construction, maintenance, and rehabilitation activities with partial or full pavement facilities closures Strategies with longer and more interventions could result in greater lost time and productivity of crew and passengers.

ii. Aircraft operating costs are due to the same reason. Pavement strategies with longer and more interventions could result in increased business costs (fuel, maintenance, crew, upkeep, etc.) for airlines, air cargo, and air charter companies.

iii. Aircraft accident costs are due to the same reason. Pavement alternatives with longer and more interventions yield greater risk for crashes.

iv. Environmental costs for the same reason. Pavement alternatives with longer and more interventions could result in increased air pollution and energy consumption.

It is difficult to estimate the additional costs incurred by various aircraft operators as a result of airfield construction, maintenance, and rehabilitation activities. In terms of reduced daily operating revenues, a better solution for estimating the airport owner's and operator's costs can be found. The American Transportation Association (ATA) estimated that closing runway 18R/36L at Dallas Fort Worth International Airport (DFW) in 1990 would cost $131,000 per day in bad weather and $110,000 per day in good weather. DFW engineers estimated that using concrete block pavers saved $4.3 million in potential delay costs, allowing the runway to be open an additional 2 hours daily for 114 days [28].

2.15.2.3 Statistical Computation Approach

There are two basic approaches to life-cycle cost analysis: deterministic and probabilistic. The deterministic approach is used to select a single value for each input parameter. The group of selected values is then used to compute a single projected life cycle cost.

The input parameters are innate variables in the probabilistic approach. The sampling process is repeated hundreds, or even thousands, of times, generating a large number of estimated life cycle cost values for the pavement strategy. The results are then compared and analyzed in relation to competitive alternatives in order to determine the most relevant and cost-effective strategy. Figure 2.3 depicts a typical pavement strategy in which input sample values are drawn at random from the defined frequency distributions.

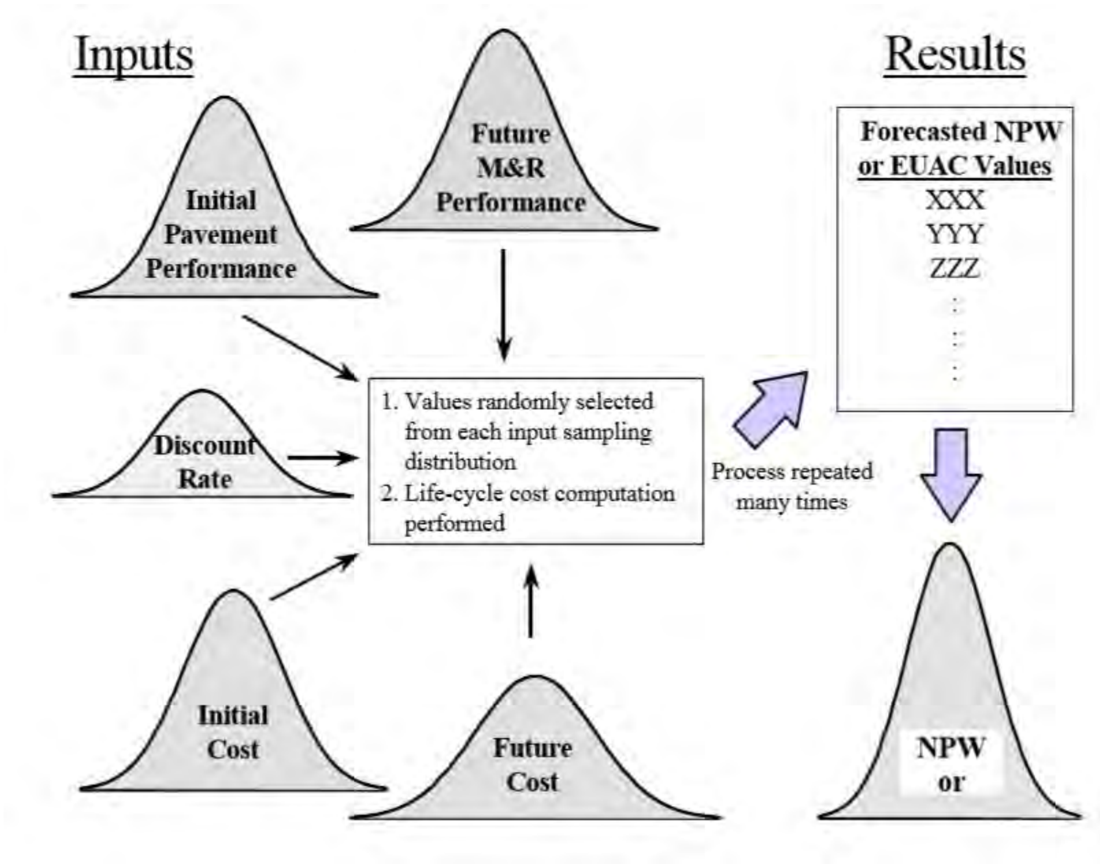

Figure 2.3: An example of a probabilistic life cycle cost analysis process [13].

A probabilistic approach is recommended if reliable historical data exists to model one or more of the input parameters. If such data does not exist, a deterministic approach is used. This method entails sensitivity testing of key input parameters such as discount rates and initial structure service life estimates.

2.15.3 Step-3: Develop Alternative Pavement Strategies

At least two feasible pavement alternatives are identified for evaluation in the life cycle cost analysis of a project. Each alternative is associated with a strategy based on the initial structure (new or rehabilitation) and future maintenance and rehabilitation activities covering the selected analysis period. The traditional approach to establishing maintenance and rehabilitation activities is to use the experiences of the past. Most airports have pavement management systems in place to record and track important pavement information. In general, this information includes the year of original construction, years and types of treatment, structural composition, historical traffic applications, and historical pavement conditions. Allowing for an equation between the current and past maintenance and rehab practices can prove the treatments are acceptable or deviations needed.

2.15.4 Step-4: Determine Pavement Performance and Maintenance and Rehabilitation Activity Timing

The pavement (new, reconstruction, and rehabilitation) weakens under the combined effects of traffic load and environmental conditions. It significantly disrupts pavement serviceability, safety, and ride quality. Each future restoration treatment is anticipated over a picked analysis period. This data is used to establish the sequence and timing of future maintenance and rehabilitation activities. Figure 2.4 depicts a case study of the life cycle model.

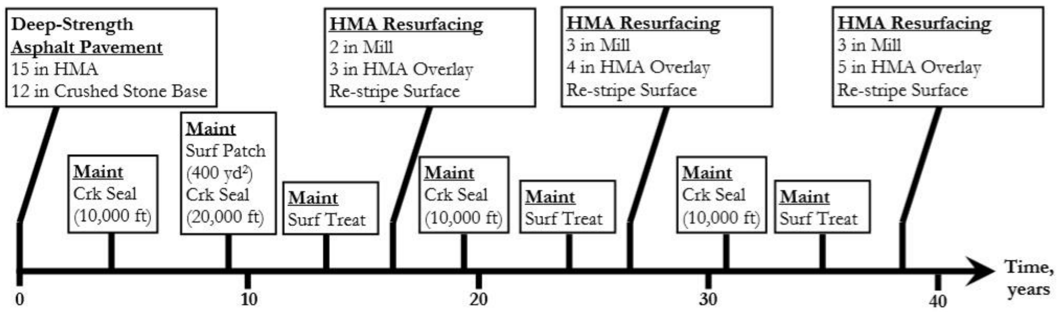

Figure 2.4: An example of a pavement life cycle model [13].

2.15.4.1 Service Lives of Initial Pavement and Future Rehabilitation Treatments

The pavement's initial service life begins when the finishing touches are applied and it is ready for traffic. According to Figure 2.4, the preliminary asphalt pavement structure has a service life of 17 years and requires 10 years for its first resurfacing. The service life of the pavement is the total lifespan of the pavement. It is distinct from the design life and represents a timeframe with a low probability of structural rehabilitation. Pavement service life is assessed in a variety of ways. The expert's common performance prediction models are built using an experienced engineer's opinion and historical performance data. If reliable historical performance data is not available or is restricted, an experience-based assessment is prepared to combine data trends from different areas.

2.15.4.2 Survival Analysis

Most of the time, survival analysis is not always useful for airport pavement because there aren't enough areas in a given airport with an advanced pavement family survival curve. In this case, pavement sections from other airports with comparable conditions are used if available, or the overall performance trend or other types of analysis are used.

2.15.4.3 Timing and Extent of Maintenance and Rehabilitation Treatments

Numerous maintenance interventions are conducted between the construction and rehabilitation of airport pavements. This intervention differs from routine activities such as pothole or spall repairs, foreign object removal, and preventive activities such as crack sealing, joint resealing, surface treatments, and major repairs such as slab replacements, full-depth repairs, and localized skin patching. Routine maintenance is extremely important to maintain high levels of safety. The life cycle cost analysis consists of all sorts of maintenance costs since the types, timings, and extents of maintenance activities are assorted for each pavement alternative. The maintenance cost focuses on the timing and extent of preventive and major forms of maintenance.

2.15.4.4 Performance Trend Analysis

The pavement condition index (PCI) is a numerical index between 0 and 100 that is used to indicate the general condition of a pavement section. Many municipalities use it to measure the performance of their pavement infrastructure and their levels of service. Figure 2.5 illustrates PCI deterioration data for asphalt taxiway pavements located at a large commercial airport.

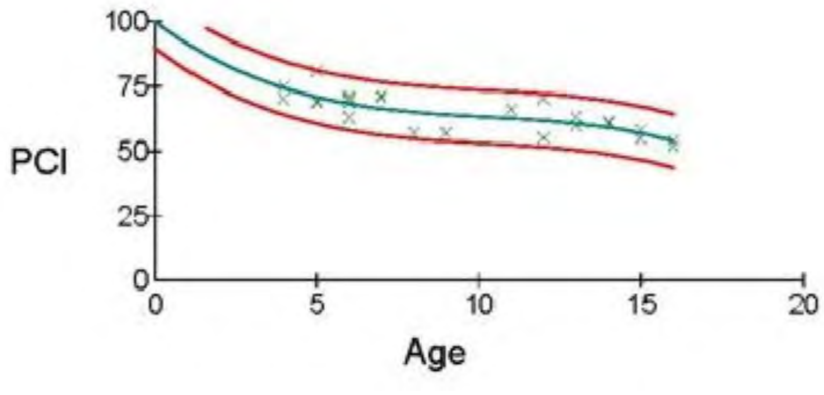

Figure 2.5: An example of pavement performance trend analysis using PCI data [13].

2.15.5 Step-5: Estimate Direct Costs

The cost of pavement construction, maintenance, and rehabilitation is an important element of an alternative pavement strategy. The direct cost involves estimating the unit cost and combining it with estimated pay item quantities to develop the physical cost of pavement activities for use in the life cycle cost analysis. At the end of the pavement analysis period, how much salvage value remains is taken into account. The supplemental costs associated with construction, maintenance, and rehabilitation activities are another component of the direct cost. These costs are classified as administrative, engineering, and traffic control expenses.

2.15.5.1 Physical Costs of Pavement Activities

The most important thing is to collect reliable material unit prices. The life cycle cost analysis makes use of data from historical bidding databases for recent projects. Data is compiled on a regular basis and is available for estimation.

2.15.5.2 Salvage Value

Salvage value is the value of a pavement that remains at the end of an analysis period. This value can be either positive or negative, with positive indicating usable and salvageable material. The negative represents the cost of removing and disposing of the material, which exceeds any positive salvage value. Salvage value is divided into two parts: serviceable life and residual value.

Mitchell (2003) presented a straight-line depreciation method for calculating pavement salvage value. The formulas are as follows [18].

i. Flexible, Salvage value = Last rehabilitation cost / Analysis factor
Note: Analysis factor 1 is considered for 20 years. (2.7)

ii. Rigid, Salvage value = (Initial construction cost / Analysis period, year) x FAA standard design life, 20 year (2.8)

Smith (2010) proposed a modernized and recommended salvage value calculation formula [29]. The formula presented a design life of 20 years. Whereas flexible pavement's expected life was 30 years with an analysis period of 40 years, and rigid pavement's analysis period was 40 years. The formulas are as follows:

i. Flexible, Salvage value = Total cost / 30-year x 10 year (remaining life) x NPV factor at 20 years (mill & overlay Cost) / 15-year x 10 year (remaining life) x NPV factor at 20 year 2.9

ii. Rigid, Salvage value =Total cost / 40-year x 20 year (remaining life) x NPV factor at 20 year 2.10

2.15.5.3 Supplemental Costs

Supplemental costs are only applied to the sequence of activities expected for future maintenance and rehabilitation. If the costs of different alternatives are roughly the same, these costs are ignored and only the physical costs are counted.

i. Administrative costs: contract management and administrative overhead.
ii. Engineering costs: design and construction engineering, construction supervision, and materials testing and analysis.
iii. Ground traffic control costs: traffic control setup and communications.

2.15.6 Step-6: Estimate Indirect Costs

In an airport, the daily revenue deduction is estimated for each event in the life cycle of each pavement alternative (both initial construction and rehabilitation, as well as future maintenance and rehabilitation activities).

2.15.6.1 Type and Duration of Pavement Facility Restrictions

Every airport is unique in terms of airfield pavement system layout and how it manages air and ground traffic operations as well as its construction, maintenance, and rehabilitation practices. So each event in the life cycle of a pavement alternative is examined carefully to identify the most probable construction zone scenario. For each scenario, it is determined whether the daily capacity has been exceeded and, if so, for how long.

2.15.6.2 Reductions in Aircraft Operations, Passengers and Cargo

If the capacity is exceeded, the estimated daily reduction in aircraft operations, passengers, and cargo is recalculated. This estimate reflects how aircraft operators modify their services. If capacity is not expected to exceed capacity but the construction zone is such that airlines and air cargo companies reduce their operational loads due to shortened runways, then estimate the reduction in passengers and landing weights.

2.15.6.3 Loss of Daily Operating Revenue

Commercial airport owners and operators get most of their revenues directly or indirectly from aeronautical activities such as passenger, cargo, fuel taxes and fees collected through the airport improvement program (AIP), passenger facility charges (PFCs), and aircraft take-off or landing fees. The loss of daily revenue calculation for a given construction zone scenario is given below.

i. Multiplying the appropriate fee or tax rates by the daily reductions in aircraft, passengers, and cargo
ii. Summarizing the individual daily revenue losses
iii. Multiplying the overall daily revenue loss by the number of days the construction zone scenario is expected to be in-place.

Table 2.3 shows an example illustration, consider the following runway construction scenario for a major commercial airport:

Table 2.3: An example of airport's loss of daily operating revenue [13].

Item		Description
Initial year	=	0, year
Daily operations	=	1,250 (625 arrival flights and 625 departing flights)
Average number of passengers/flight	=	80
Daily total passengers		(1,250 × 80) = 100,000
Daily passenger enplanements	=	(625 × 80) = 50,000
Daily passenger deplanements	=	(625 × 80) = 50,000
Average aircraft fuel usage	=	320 gal/flight
Daily fuel flowage =	=	(320 × 625) = 200,000 gal.
Average landing fee	=	$750/aircraft
Passenger facility charge	=	$4.50/enplaned passenger

Table 2.3: An example of airport's loss of daily operating revenue [13] (continued).

Item		Description
Passenger facility charge	=	$4.50/enplaned passenger
Fuel flowage fee	=	$0.10/gal
Landing fee daily revenue	=	(625 aircraft x $750/aircraft) = $468,750
Pfc daily revenue	=	(50,000 passenger's x $4.50/enplaned passenger) = $225,000
Fuel flowage daily revenue	=	(200,000 gal x $0.10/gal) = $20,000
Total daily revenue	=	($468,750 + $225,000 + $20,000) = $713,750

2.15.7 Step-7: Develop Expenditure Stream Diagrams

Figure 2.6 shows that the cost is usually described by the up arrow and benefits (salvage value) with a downward arrow. Steam diagrams provide a graphical or tabular presentation of the expenditure in time. It is intended to assist the designer or analyst by showing the magnitude and timing of all expenditures for the period of analysis for each pavement strategy.

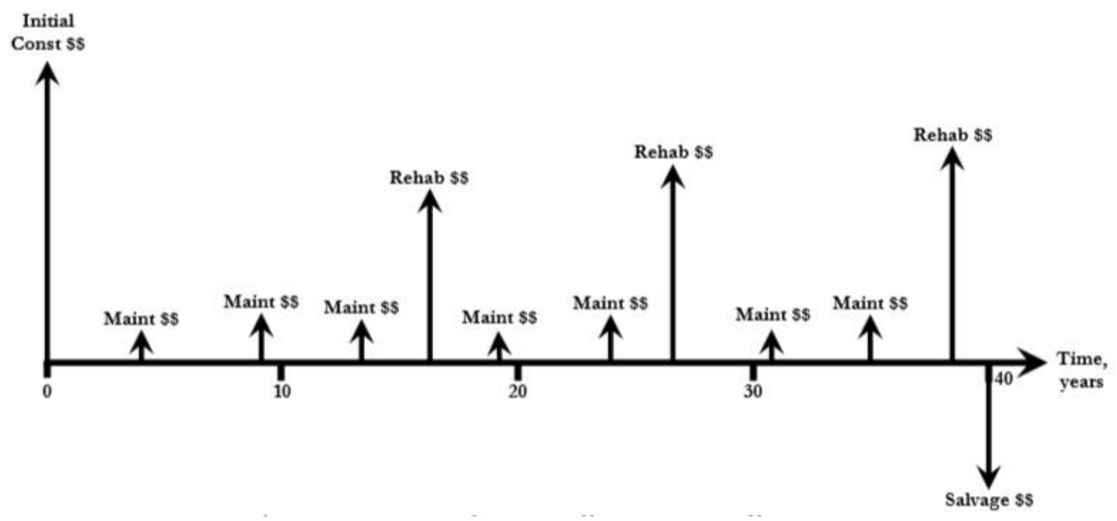

Figure 2.6: An example of expenditure steam diagram [13].

2.15.8 Step-8: Calculate Life Cycle Costs

Every alternative pavement strategy expenditure is accumulated, and it is part of the calculation of the expected life cycle cost. Using a specific discount rate, the deterministic analysis easily converted all future costs expected to occur during the analysis period into net present value. The net present value is determined by adding all initial construction costs and converting future costs. This cost is converted to an equivalent uniform annual cost and presented using a discount rate and analysis period whenever necessary.

Simulation requires a particular computer program. The probabilistic analysis is performed by selecting a random value from each input parameter sampling distribution. These values and the net present value or equivalent uniform annual cost formula compute a single life-cycle cost, and rehashing them repeatedly produces a variety of forecasted costs.

i. A lack of appropriate pre-defined relationships between different input parameters

ii. A lack of fixed limits on input sampling distributions

2.15.9 Step-9: Evaluate and Analyze the Results

The results of the deterministic approach produce a single NPV/EUAC value, and the output results are distinct as well. From a realistic standpoint, if the two alternatives contrast in net present value by 10 percent or less, then it is typically accepted as immaterial and this alternative's present worth is viewed as equal [9]. The deterministic technique calculates the percent contrast in the life-cycle cost of the alternatives. The distinction between the two lowest cost alternatives is more than the minimum requirement of 5 to 10 percent. Afterward, the minimal cost alternative is accepted as the cost-effective one. A basic analysis, three stages are suggested, and the means are given below [13].

2.15.9.1 Trial by Trial Comparison

The most economical pavement alternative is achieved by analyzing the life cycle cost results associated with each iteration—i.e., counting every alternative number of wins and dividing the respective wins by the all-out number of trials acted on in the simulation.

The alternative with the highest probability of being supported gets the most support. By then, extra evaluation is required to decide whether it is the most economical one.

2.15.9.2 Statistical Analysis

The mean and standard deviation of life-cycle cost values calculated for each alternative pavement strategy are used to determine whether there are any differences between the means of each alternative approach. With three or more competing alternatives, an analysis of variance (ANOVA) is performed or a t-test on the two apparently minimal cost alternatives. The alternative strategy with the lowest mean life cycle cost is accepted as the most economical strategy.

2.15.9.3 Risk Assessment

If the statistical analysis is insufficient, a risk assessment is performed. The goal of this assessment is to identify any one-of-a-kind possibility that contradicts the administration's proclivity for risk-taking. This characteristic is seen in the frequency distribution curves' tails. Such distinguishing characteristics must be recognized in order to determine the most cost-effective strategy if the analysis does not reveal a statistically significant difference between the likely meanings of the low-cost alternatives.

2.15.10 Step-10: Re-evaluate the Pavement Strategies

It is carried out after the information resulting from the life cycle cost analysis is evaluated to outline, and any modification of the alternative strategy is required before the ultimate conclusion on which alternative to utilize. This adjustment is made to the authentic structure or rehabilitation treatment, updates to the support of traffic plans, decreases in construction intervals, and adjustments in future maintenance and rehabilitation activities.

2.16 Life Cycle Cost Analysis State of Practice

The pavement's life cycle cost analysis practice is widely used all over the world for pavement cost effectiveness analysis. A short summary of state practice is given below [30].

2.16.1 Canada

Professor Dr. Gordon Sparks conducted a life cycle cost analysis survey in Canada. It is used in nearly 90 percent of pavement designs in the province of Ontario. This analysis method employs both a deterministic and a probabilistic approach. According to the study, it is also widely used in Alberta, Manitoba, Quebec, New Brunswick, and Nova Scotia, among other places.

2.16.2 United States

The majority of states in the United States use life cycle cost analysis for the pavement type selection process. These practice reports are presented by state Departments of Transportation (DOTs). The improvement of this knowledge is shared by the University Transportation Centre for Alabama, University of Texas at Austin, Southwest Region University Transportation Centre, Kentucky Transportation Centre, University of Kentucky, and University of Alabama.

2.16.3 Europe

The economic evaluation of the pavement maintenance life-cycle cost of the project and network level (PAV-ECO) project aims to develop a pavement economic model focused on a life cycle cost analysis. In October 1999, this project was successfully completed. The Danish Road Institute, Anders Nyvig A/S, Laboratorie Central des Ponts et Chaussees, Laboratorie des Voies de Circulation LAVOC-EPFL, Viagroup SA, Transport Research Laboratory, and the University of Cologne all contributed to the project's success.

2.17 Benefits of the Concrete Runway

Airport concrete pavement creates a long-life, low-maintenance runway that is both robust and tough, and it is a cost-effective option in Australia [31]. Concrete has also been selected for the runways at the world's busiest and most important airports, for example, at Shanghai Pudong International and almost every major commercial hub airport in the United States of America, including Atlanta, Los Angeles, Denver, Chicago O'Hare, McCarran, Las Vegas, and New York. Closer to home, Auckland International Airport (AKL) also features a single concrete runway. The benefits of concrete pavement are given below.

Safety

i. Permanent surface texture or grooving to minimize the potential for aircraft skidding or hydroplaning.

ii. light reflectance for excellent runway visibility for approaching aircraft.
iii. Less build-up of superheated air layer above pavement surface.

Economics

i. Construction at a low cost
ii. No periodic resurfacing or surface sealing.
iii. Low maintenance delivers much lower costs across the runway's life.
iv. Less runway downtime for maintenance, increasing runway utilization.

Performance

i. The heavy wheels of slow-moving international airplanes demand a tough concrete pavement that is aviation fuel resistant.
ii. Resistance to degrading agents such as fuel spills or drippings, jet heat, or blast
iii. Rut resistance under channeled traffic or parked aircraft
iv. Load-carrying capacity reserve
v. Designs are available for a range of foundation conditions.
vi. Resistant to the extremes of environmental conditions,

Sustainability

i. Longer design life with low maintenance delivers a lower life cycle cost.
ii. Locally sourced raw materials
iii. Local supply chain that is well-versed in delivering concrete pavements
iv. Resilient concrete construction accommodates extreme weather events.
v. Concrete is recyclable at the end of its design life.

2.18 Conclusion

The literature review discusses the relevant studies concerning airport pavement design standards. It presents the conventional designs as upgraded computer programs as a result of several field and laboratory experiments. There is also discussion of various types of overlay design and construction practices. This also highlights the life cycle cost analysis techniques.

CHAPTER 3

DESIGN AND INITIAL COST FOR FLEXIBLE AND RIGID AIRFIELD PAVEMENTS USING SECONDARY TRAFFIC DATA

3.1 General

This chapter discusses the airport's flexible and rigid pavement designs using FAARFIELD software. It also presents material quantity estimation and initial cost estimation, which lead to achieving the study objective.

3.1.1 Data Collection

The data collection for airport pavement design is shown below the sections.

3.1.2 Air Traffic Data

The aircraft's annual air traffic forecasting statistics were taken from Hazrat Shah Jalal International Airport, Dhaka based on secondary sources. The International Civil Aviation Organization (2010) reported that aircraft's average annual growth rate was 4.4 percent from 1989 to 2009 [33]. So, this study used the aircraft's average annual growth rate of 3 percent. Table 3.1 shows the air traffic data collection.

Table 3.1: List of aircrafts annual departures.

SL No.	Aircraft Model Number	Gross Wt. lbs	Annual Departures	Annual Growth, %	Landing Gear Type
1	A310-200	315,041	3,240	3	2D
2	A310-300	315,041	3,600	3	2D
3	A319-100 std	141,978	720	3	D
4	A320-100	150,796	3,240	3	D
5	A320-200 Twin std	162,922	2,520	3	D
6	A320-200 Twin opt	172,842	1,800	3	D
7	A321-200 std	197,093	1,800	3	D
8	A330-200 std	509,047	1,080	3	2D
9	A330-300 std	509,047	1,440	3	2D

Table 3.1: List of aircrafts annual departures (continued).

SL No.	Aircraft Model Number	Gross Wt. lbs	Annual Departures	Annual Growth, %	Landing Gear Type
10	A340-300 std	608,245	2,160	3	2D
11	A340-300 std Belly	608,245	2,160	3	S
12	A340-500 std	813,947	1,800	3	2D
13	A340-500 std Belly	813,947	1,800	3	S
14	A340-600 std	807,333	1,440	3	2D
15	A340-600 std Belly	807,333	1,440	3	S
16	B737-700	155,000	3,600	3	D
17	B737-800	174,700	4,680	3	D
18	B737-900 ER	188,200	1,440	3	D
19	B777-200 ER	658,000	1,080	3	3D
20	B777-300 ER	777,000	1,080	3	3D
21	B777-300 Baseline	662,000	3,600	3	3D
22	B777 Freighter (Pre)	768,800	1,080	3	3D
23	B787-8	503,500	3,600	3	2D
24	MD83	161,000	3,240	3	D
25	Dash 7	43,799	3,600	3	D
26	DC10-30/40	583,000	3,600	3	2D
27	DC10-30/40 Belly	583,000	3,600	3	S
28	C-130	155,000	3,240	3	2S
29	ERJ-145 ER	45,635	1,440	3	D

3.1.3 Pavement Design Life

The study assumed that flexible and rigid pavement have design lives of 20, 30, and 40 years.

3.1.4 Subgrade Strength

The study assumed flexible and rigid pavement has a constant subgrade strength of 82.74 MPa, or 12,000 Psi.

3.1.5 Data Consideration in Pavement Design

Multiple data sets are required for airport pavement design, such as wind speeds and directions, temperatures, precipitation, frost protection, and so on. These are not taken into account in order to focus on the study's main objectives.

3.1.6 Airport Pavement Dimension

The airport pavement dimension (3500 x 50 yards) is assumed and shown in Figure 3.1. This is used to complete the remaining study.

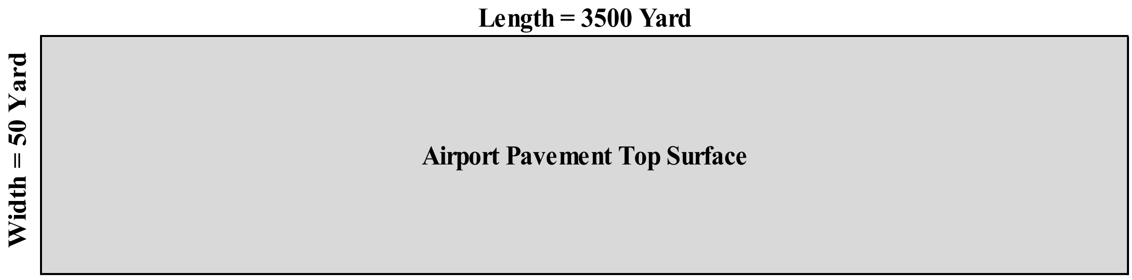

Figure 3.1: Airport pavement layout plan.

3.2 Airport Pavement Design Methodology

The data collection for airport pavement design includes an aircraft's annual air-traffic departure, design life, and subgrade strength. FAARFIELD software is used to design the structural thickness of pavement (both flexible and rigid). Each pavement alternative is designed with its own set of alternative materials. The methodological approaches of the pavement design steps are illustrated in flow chart 3.2.

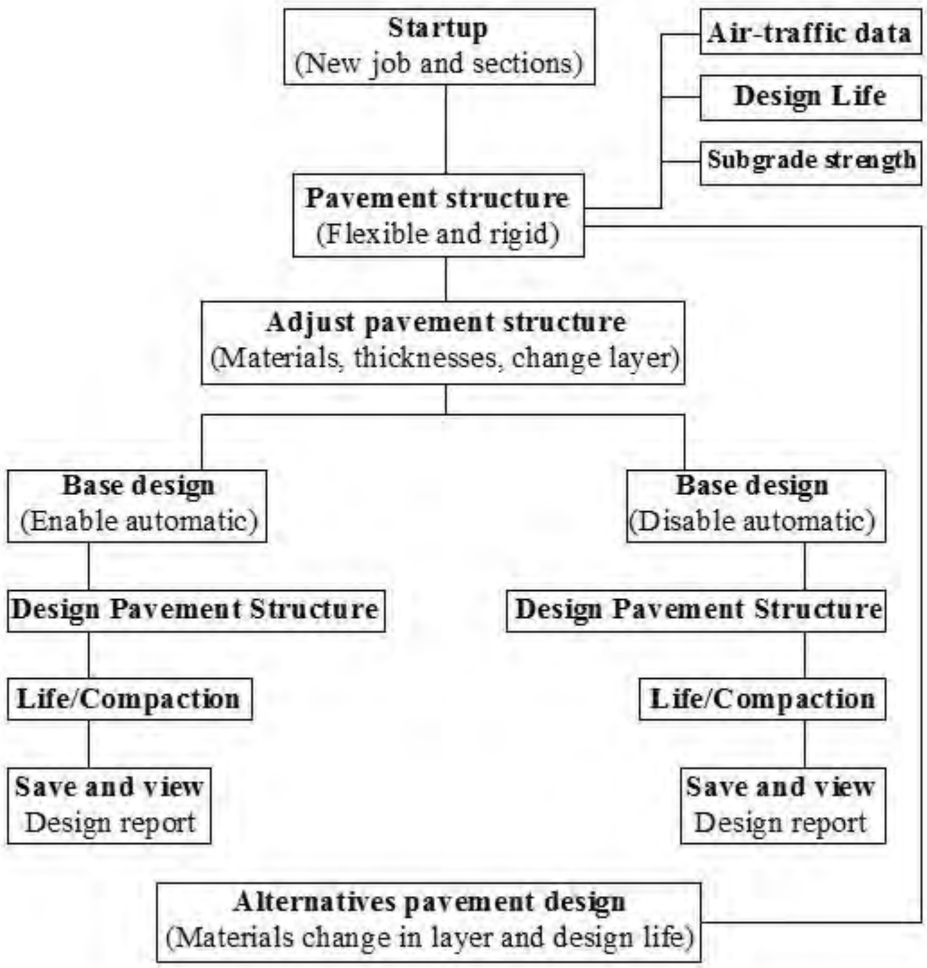

Figure 3.2: FAARFIELD Software's airport pavement design flow chart.

3.3 Airport Pavement Structural Thickness Design

Flexible and rigid pavement designs are discussed in Sections 3.4.1 and 3.4.2. Alternative pavements are designed in the same manner, and structural thickness summaries are included in the appendix (see Appendix A).

3.3.1 Flexible Pavement

The aircraft's annual air-traffic data is taken from Table 3.1. The flexible pavement preliminary design life is chosen for 20 years. The subgrade strength is 82.74 MPa, or 12000 psi. The aircraft's maximum gross takeoff weight is more than 100,000 lbs. This indicates the pavement requires a stabilized base layer with a subbase. The pavement design materials with layers are given below.

Surface	:	P-401/ P-403 HMA Surface
Stabilized base	:	P-401/ P-403 St (flex)
Subbase	:	P-209 Cr Ag

First, the FAARFIELD software is opened. The startup windows are on display, and there is an empty file. To start the design, create a new job file named 041642427. The new flexible pavement is selected in the sample sections, as well as given a code name, F-01-a-20. The code name refers to "F", which is the flexible pavement, "01" is the pavement design serial number, "a" is the minimum structural thickness (recommended by the FAA), and "20" is the pavement design life in a year. Click and go to the structure window. Figure 3.3 shows the flexible pavement design software startup windows.

Next, in the structure window, click on the airplane and enter the airplane window. Clear the old airplane list. Select the airplane group and library list box, and then add one after the other in Table 3.1 of enlisted aircraft. Besides, input each aircraft's annual air-traffic and growth factor and save and float it. Figure 3.4 shows the flexible pavement design software for air-traffic mix windows.

Figure 3.3: FAARFIELD windows for flexible pavement startup.

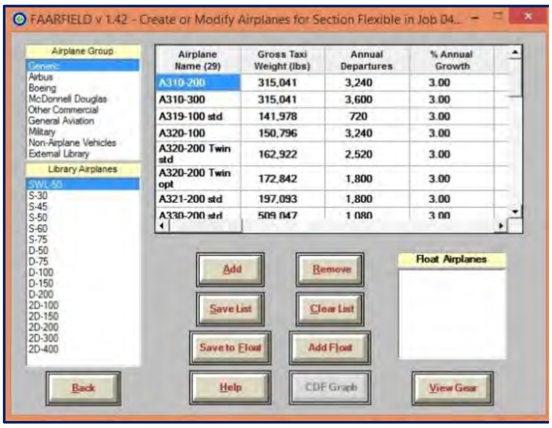

Figure 3.4: FAARFIELD windows for flexible pavement design air traffic mix.

Afterward, modify the structure window, input the design life of 20 years and subgrade strength of 12000 psi. From the structure window, click on each material layer, and then go to the layer type section window and pick the chosen material one after another, saving and returning to the structure window again. Input each layer's minimum thickness according to AC 150/5320-6F, paragraph 314c. Next, save the windows and click on options. In the option windows, check the box labeled "HMA CDF", next "Enable automatic base design", next to units "English" and "Compute compaction requirements." Click OK to return to the structure windows. Now, click on the design structure to run the design.

A moment later, the software automatically notify that the design is completed and finds the minimum flexible pavement structural thickness. Simultaneously, the structure window reports that the subgrade cumulative damage factor (CDF) value is 1. It also reports that the hot mix asphalt HMA CDF is 0.45. The HMA CDF value is less than 1, so the design is acceptable for the HMA fatigue (horizontal strain) design criterion. Figure 3.5 shows the flexible pavement detailed outcome thickness.

Subgrade compaction is required to compute. Click on the life/compaction. Once the life-stop message appears in the clock box, click Save Structure. Next, back to return to the startup window. In the startup window, click "notes" to view design info. Figure 3.6 shows the flexible pavement subgrade compaction.

Finally, the flexible pavement's total thickness is found 32.15 inches, whereas the surface, stabilized base, and subbase thickness are 4.0, 5.0, and 23.15 inches. The detailed reports on pavement design outcome thickness and compaction requirements are given in Table 3.2.

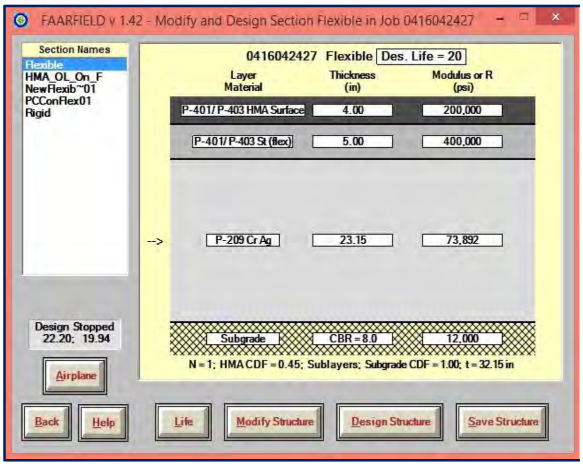

Figure 3.5: FAARFIELD windows for flexible pavement structural thickness.

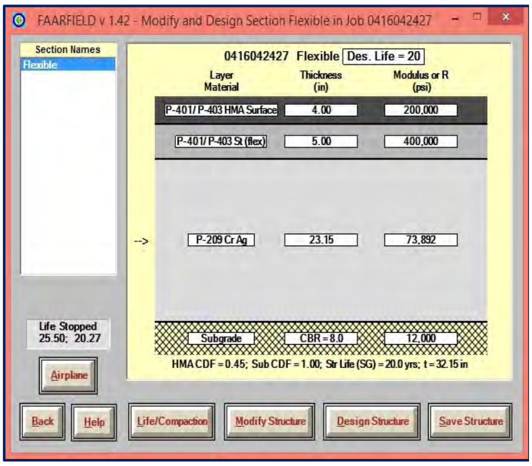

Figure 3.6: FAARFIELD windows for flexible pavement structural life/compaction.

Pavement Structure Information by Layer, Top First

Table 3.2: The flexible pavement (F-01-a-20) structural thickness.

No.	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Surface	4.00	200,000	0.35	0
2	P-401/ P-403 St (flex)	5.00	400,000	0.35	0
3	P-209 Cr Ag	23.15	73,892	0.35	0
4	Subgrade	0.00	12,000	0.35	0

Total thickness to the top of the subgrade = 32.15 inches.

3.3.2 Rigid Pavement

The rigid pavement design uses the same data sets already used in the flexible pavement design. But the pavement materials in the layer are different. In that case, the chosen pavement design materials with layer are given below.

Surface : PCC Surface
Stabilized base : P-401/ P-403 St (flex)
Subbase : P-209 Cr Ag

First, open the job file 0416042427 and create a new rigid pavement section coded by R-01-a-20. The code name refers to "R", which is the rigid pavement, "01" is the pavement design serial number, "a" is the minimum structural thickness (recommended by the FAA), and "20" is the pavement design life in a year. Click and go to the structure window. Figure 3.7 shows the rigid pavement design software startup windows.

Since the aircraft's annual air-traffic departure is the same as in the flexible pavement (F-01-a-20) design, sometimes it can be saved by using the floating airplane list. Therefore, go to the F-01-a-20 design airplane window, click Save to float to copy all the airplanes in the design airplane list. Next, return to the rigid section (R-01-a-20) and click on the airplane window. Clear the old design airplane list, click add float to copy the airplane in the floating list to the design airplane list and save the list. Click on the back button to return to the structure windows. Figure 3.8 shows the rigid pavement design software for air-traffic mix windows.

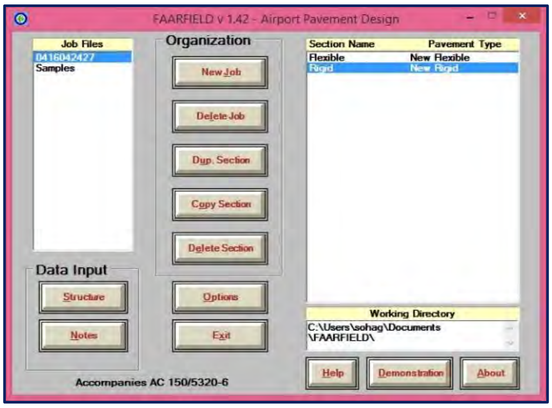

Figure 3.7: FAARFIELD windows for rigid pavement startup.

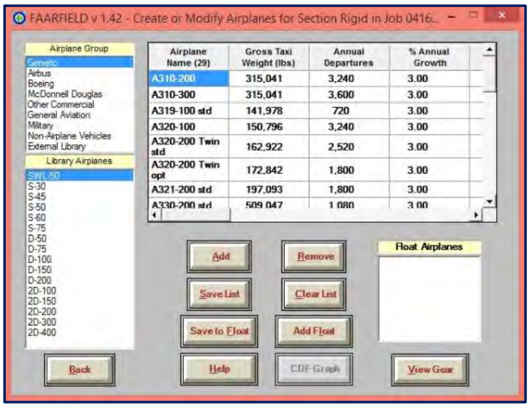

Figure 3.8: FAARFIELD windows for rigid pavement design air traffic mix.

Afterward, modify the structure window, input the design life of 20 years, and subgrade strength of 12000 psi. From the structure window, click on each material layer, and then go to the layer type section window and pick the chosen material one after another, saving and returning to the structure window again. Input each layer's minimum thickness according to AC 150/5320-6F, paragraph 314c. Next, save the windows and click on options. In option windows, check the box labeled "Enable automatic base design", next to units "English" and "Compute compaction requirements." Click OK to return to the structure windows. Now, click on the design structure to run the design.

A moment later, software automatically notifies that the design is complete and obtains the minimum rigid pavement structural thickness. Simultaneously, the structure window reports that the subgrade cumulative damage factor (CDF) value is 1. It also reports that the cumulative damage factor used (CDFU) is 141.32 percent. So the design is acceptable. Figure 3.9 shows the rigid pavement detailed outcome thickness.

Subgrade compaction is required to compute. Click on the life/compaction. Once the life-stop message appears in the clock box, click Save Structure. Next, back to return to the startup window. In the startup window, click "notes" to view design info. Figure 3.10 shows the flexible pavement subgrade compaction.

Finally, the flexible pavement total thickness is obtained at 31.23 inches, whereas the PCC surface, stabilized base, and subbase thickness are 20.23, 5.0, and 6.0 inches. The detailed reports on pavement design outcome thickness and compaction requirements are given in Table 3.3.

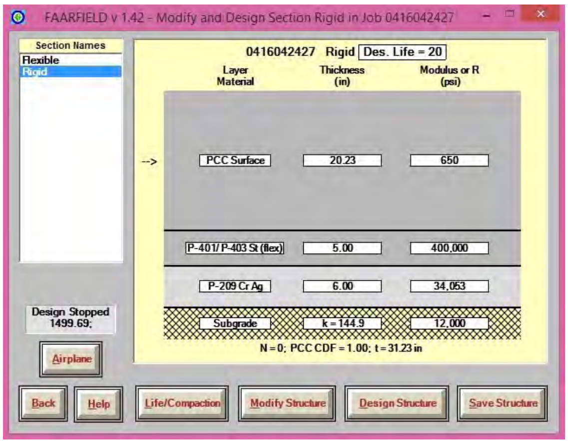

Figure 3.9: FAARFIELD windows for rigid pavement structural thickness.

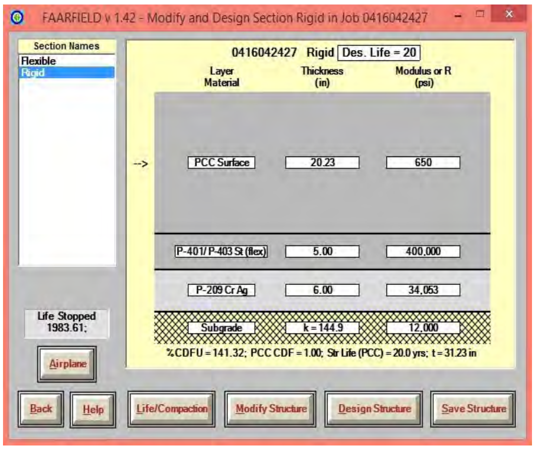

Figure 3.10: FAARFIELD windows for rigid pavement structural life/compaction.

Pavement Structure Information by Layer, Top First

Table 3.3: The rigid pavement (R-01-a-20) structural thickness.

No.	Type	Thickness in	Modulus psi	Poisson's Ratio	Strength R, psi
1	PCC Surface	20.23	4,000,000	0.15	650
2	P-401/ P-403 St (flex)	5.00	400,000	0.35	0
3	P-209 Cr Ag	6.00	34,053	0.35	0
4	Subgrade	0.00	12,000	0.40	0

Total thickness to the top of the subgrade = 31.23 in

3.4 Pavement Cross-section Drawing

The pavement cross sections are drawn and presented following Section 3.5.1 (flexible pavement, F-01-a-20) and Section 3.5.2 (rigid pavement, R-01-a-20). All measurements are taken in the yard, unless otherwise specified.

3.4.1 Flexible Pavement

Figure 3.11 illustrates the cross section of a flexible pavement (F-01-a-20). The pavement is 50 yards wide. The drawing is not scaled, so the measurements are clearly visible. The edges of all sides, offset from the pavement layers, are kept at 12 inches. Bituminous prime coat and tack coat application are also mentioned.

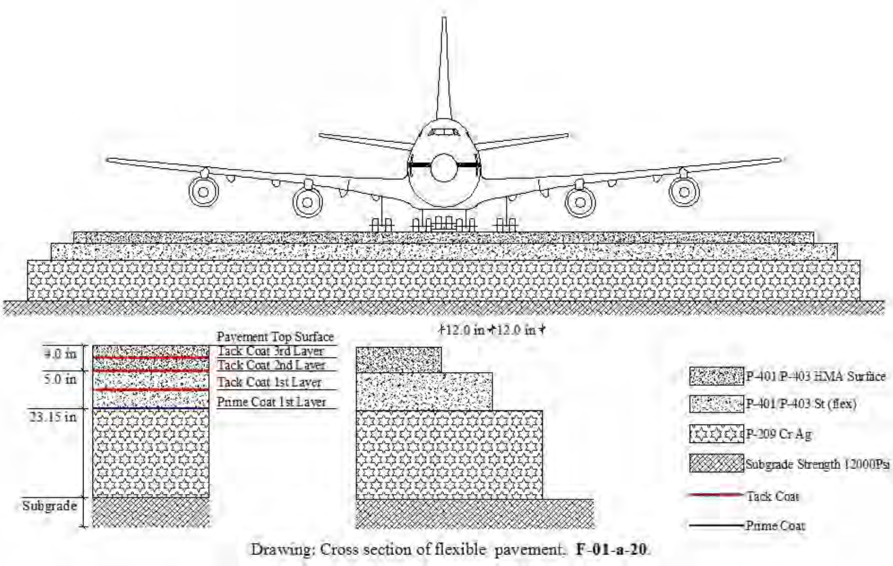

Figure 3.11: Flexible pavement (F-01-a-20) cross sectional drawing.

3.4.2 Rigid Pavement

Figure 3.12 illustrates the cross section of a rigid pavement (R-04-a-20). The pavement is 50 yards wide and the PCC panel size is 5 x 6.67 yards. Panels are connected together by longitudinal and transverse joints. The edges of all sides, offset from the pavement layers, are kept at 12 inches.

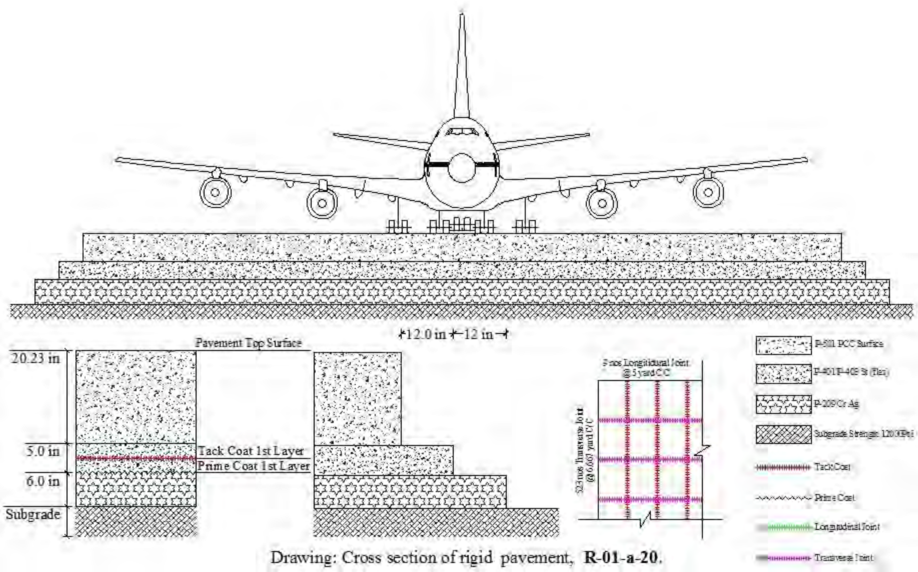

Figure 3.12: Rigid Pavement (R-01-a-20) cross sectional drawing.

3.5 Materials Quantity Estimation

Pavement material quantity estimation includes surface, base, and subbase materials, as well as marking, saw-cut grooving, and construction joints, except subgrade. A calculative example of flexible (F-01-a-20) and rigid (R-01-a-20) pavement material estimation is presented in Sections 3.6.1 and 3.6.2, respectively. The appendix contains all the pavements' estimated material quantities (see Appendix-B).

3.5.1 Flexible Pavement

The material quantity is calculated by multiplying the pavement length, width, and structural thickness. The structural thickness unit is converted from an inch to a yard. Table 3.4 depicts the material quantity estimation for flexible pavement (F-01-a-20).

Table 3.4: Flexible pavement (F-01-a-20) materials quantity estimation.

Pay Item	Item	Unit	Length		Width		Structural Thickness			Layer		Gallon/	Quantity
			Yard		Yard		Inch	Yard				sq. yd.	
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38,093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48,254
P-209-A13	Crushed Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.15	0.644	x		x		115,623

Table 3.4: Flexible pavement (F-01-a-20) materials quantity estimation (continued).

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon/ sq. yd.	Quantity
							Inch	Yard					
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175,000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53,203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52,734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1,575,000

3.5.2 Rigid Pavement

The material quantity is calculated by multiplying the pavement length, width, and structural thickness. The structural thickness unit is converted from an inch to a yard. Table 3.5 depicts the material quantity estimation for rigid pavement (R-01-a-20).

Table 3.5: Rigid pavement (R-01-a-20) materials quantity estimation.

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon/ sq. yd.	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.23	0.562	x		x		98,419
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48,254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29,967

Table 3.5: Rigid pavement (R-01-a-20) materials quantity estimation (continued).

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon/ sq. yd.	Quantity
							Inch	Yard					
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175,000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53,203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17,734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172,950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1,575,000

3.6 Initial Cost Estimation

The initial pavement construction cost is calculated by multiplying the material quantity by the unit price. The pavement total cost ($) is calculated and summarized in $/sq. yd. The estimated material quantity is taken from Appendix-B and the unit price from Appendix-C. All of Pavement's initial cost estimations are shown in the appendix (see Appendix-D). Also, an example of flexible (F-01-a-20) and rigid (R-01-a-20) pavement initial cost estimation is presented in sections 3.7.1 and 3.7.2.

3.6.1 Flexible Pavement

The initial construction cost of flexible pavement (F-01-a-20) is estimated in Table 3.6. The cost of an item is calculated by multiplying the material quantity by the unit price. The total cost is the sum of all item costs divided by the surface area of the pavement. That is the initial cost of the pavement, which is 56.73 $/sq. yd.

Table 3.6: Flexible pavement (F-01-a-20) initial cost estimation.

Pay Item	Item Name	Quantity	Unit	Unit Price, ($)	Extended, ($)
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38,093	tonne	90	3,428,366
P-403-A2	Plant Mix Bituminous Base Course	48,254	tonne	70	3,377,767
P-209-A13	Crushed Aggregate Base Course (24-in depth)	115,623	sq. yd.	20	2,312,467
P-401-B	Saw-Cut Grooving (High Type)	175,000	sq. yd.	1.25	218,750
P-602-A	Bituminous Prime Coat	53,203	gallon	2	106,406
P-603-A	Bituminous Tack Coat	52,734	gallon	2	105,469
P-100-14	Pavement Marking Special	1,575,000	sq. ft.	0.24	378,000
Total			sq. yd.	56.73	9,927,225

3.6.2 Rigid Pavement

The initial construction cost of rigid pavement (R-01-a-20) is estimated in Table 3.7. The cost of an item is calculated by multiplying the material quantity by the unit price. The total cost is the sum of all item costs divided by the surface area of the pavement. That is the initial cost of the pavement, which is 72.42 $/sq. yd.

Table 3.7: Rigid pavement (R-01-a-20) initial cost estimation.

Pay Item	Item Name	Quantity	Unit	Unit Price, ($)	Extended, ($)
P-501-B8	Portland Cement Concrete Pavement (21 inches)	98,419	sq. yd.	81	7,971,935

Table 3.7: Rigid pavement (R-01-a-20) initial cost estimation (continued).

Pay Item	Item Name	Quantity	Unit	Unit Price, ($)	Extended, ($)
P-403-A2	Plant Mix Bituminous Base Course	48,254	tonne	70	3,377,767
P-209-A1	Crushed Aggregate Base Course (6 in)	29,967	sq. yd.	6.5	194,787
P-501-C	Saw-Cut Grooving	175,000	sq. yd.	1.5	262,500
P-602-A	Bituminous Prime Coat	53,203	gallon	2	106,406
P-603-A	Bituminous Tack Coat	17,734	gallon	2	35,469
P-604-A	Joint Seal	172,950	ft.	2	345,900
P-100-14	Pavement Marking Special	1,575,000	sq. ft.	0.24	378,000
Total			sq. yd.	72.42	12,672,764

3.7 Conclusion

The FAARFIELD software is used to design flexible and rigid pavements, as well as alternative pavement designs. The material quantities and initial construction costs of these designs are estimated, which aids in the selection of economic pavement for each design life.

CHAPTER 4

DATA ANALYSIS

4.1 General

This chapter analyzes the multiple flexible and rigid pavement structural thicknesses designed by FAARFIELD software. These designs involve initial construction cost computations that aid in determining the most cost-effective pavement and materials for any design period. The findings are presented in the form of tables, figures, and etc.

4.2 Landing Gear Configuration

The five types of aircraft landing gear configurations with air traffic mix are shown in Figure 4.1. "D" represents Duel Wheel, which has a maximum of 9 aircraft and 40.63 percent of the air-traffic mix of the enlisted aircraft types. The "2D" type is the second highest of the 9 aircraft, which have a 31.77 percent air-traffic mix. The lowest number of aircraft landing gear types is "2S" and the air traffic mix is 4.69 percent. "S" and "3D" are the different types of landing gear that have 4 aircraft, but air traffic mixes are 13.02 percent and 9.90 percent, respectively.

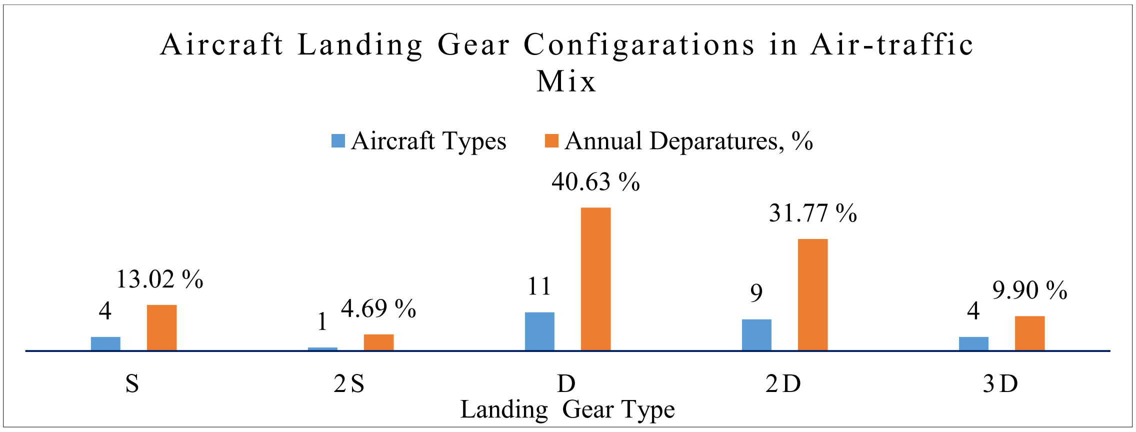

Figure 4.1: Aircraft landing gear configuration.

Note: S = single wheel, 2S = single tandem, D = duel wheel, 2D = duel tandem, and 3D = triple duel tandem.

4.3 Air-traffic Mix

The air traffic mix includes 29 different types of aircraft. In Figure 4.2, the column chart depicts this aircraft's maximum gross take-off weight. The chart shows that an aircraft's maximum gross takeoff weight is greater than 100,000 lbs.

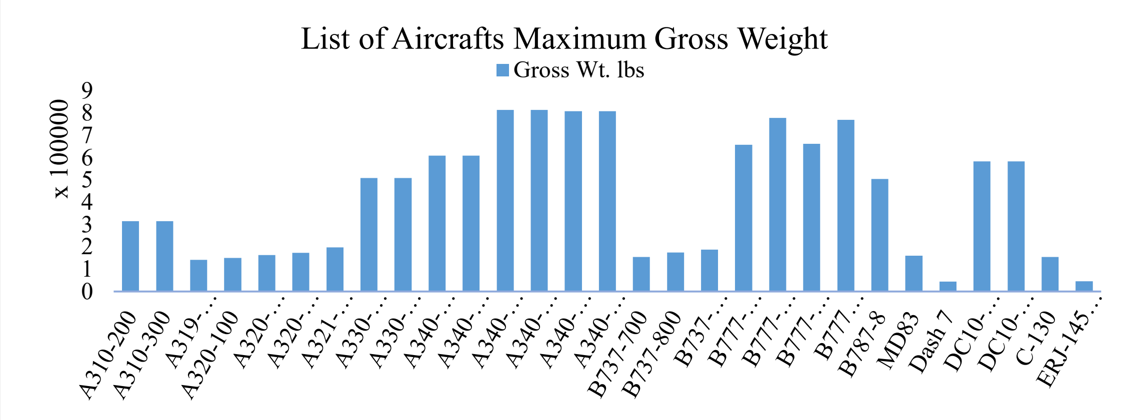

Figure 4.2: List of aircraft maximum gross weights.

4.4 Summary of Airport Pavement Design

The FAARFIELD software is used to design airport flexible and rigid pavement. Pavement design summaries are given in the appendix (see Appendix-A). A detailed discussion of pavement (flexible and rigid) design outcomes and structural thickness is presented in sections (4.4.1 and 4.4.2), respectively.

4.4.1 Flexible Pavement

The flexible pavement (F-01-a-20) is designed for a 20-year life. The automatic base design mode is enabled. The cumulative damage factor (CDF) value of the pavement reached 0.45, which is less than 1 and the total thickness of 32.15 inches. The minimum structural thickness found in the surface, stabilized base, and subbase is 4 inches, 5 inches, and 23.15 inches, respectively. The design meets the pavement design criteria.

F-01-b-20 is the alternative pavement design to F-01-a-20. The automatic base design mode is disabled, and the thickness is kept fixed at 7 inches. The cumulative damage factor (CDF) value of the pavement reached 0.51, which is less than 1 and the total thickness of 31.40 inches. The minimum structural thickness found in the surface, stabilized base, and subbase is 4 inches, 7 inches, and 20.40 inches, respectively. The design meets the pavement design criteria.

Similarly, all the pavement designs satisfy the design criteria. Table 4.1 displays the flexible pavement design summary.

Table 4.1: The structural thickness of flexible pavements.

Design Name	Surface, inch	Stabilized base, inch	Subbase, inch	Total Thickness, inch	HMA CDF	Remarks
F-01-a-20	4.00	5.00	23.15	32.15	0.45	Design Life 20 Years
F-01-b-20	4.00	7.00	20.40	31.40	0.51	
F-02-a-20	4.00	5.00	23.15	32.15	0.45	
F-02-b-20	4.00	7.00	20.40	31.40	0.51	
F-01-a-30	4.00	5.00	23.62	32.62	0.70	Design Life 30 Years
F-01-b-30	4.00	7.00	20.92	31.92	0.78	
F-02-a-30	4.00	5.00	23.62	32.62	0.70	
F-02-b-30	4.00	7.00	20.92	31.92	0.78	
F-01-a-40	4.00	5.00	23.98	32.98	0.99	Design Life 40 Years
F-01-b-40	5.00	5.00	22.90	32.90	0.98	
F-02-a-40	4.00	5.00	23.98	32.98	0.99	
F-02-b-40	5.00	5.00	22.90	32.90	0.98	

4.4.2 Rigid Pavement

The rigid pavement (R-01-a-20) is designed for a 20-year life. The automatic base design mode is enabled. The percentage of cumulative damage factor unit (CDFU) value of the pavement reached 141.32, which is more than 100 and the total thickness of 31.23 inches. The minimum structural thickness found in the concrete surface, stabilized base, and subbase is 20.23 inches, 5 inches, and 6 inches, respectively. The design meets the pavement design criteria. Table 4.2 shows the structural thickness summary of rigid pavements.

R-01-b-20 is the alternative pavement design to R-01-a-20. The automatic base design mode is disabled, and the thickness is kept fixed at 7 inches. The percentage of cumulative damage factor unit (CDFU) value of the pavement reached 149.56, which is more than 100 and the total thickness of 33.09 inches. The minimum structural thickness found in the concrete surface, stabilized base, and subbase is 20.09 inches, 7 inches, and 6 inches, respectively. The design meets the pavement design criteria.

Similarly, all the pavement designs satisfy the design criteria. Table 4.2 displays the rigid pavement design summary.

Table 4.2: The structural thickness of rigid pavements.

Design Name	**Surface, inch**	**Stabilized base, inch**	**Subbase, inch**	**Total Thickness, inch**	**CDFU, %**	**Remarks**
R-01-a-20	20.23	5.00	6.00	31.23	141.32	Design Life 20 Years
R-01-b-20	20.09	7.00	6.00	33.09	149.56	
R-02-a-20	20.23	5.00	6.00	31.23	142.18	
R-02-b-20	20.09	7.00	6.00	33.09	149.56	
R-03-a-20	20.16	5.00	6.00	31.16	150.34	
R-03-b-20	19.98	7.00	6.00	32.98	160.13	
R-04-a-20	20.16	5.00	6.00	31.16	150.32	
R-04-b-20	19.99	7.00	6.00	32.99	157.86	
R-05-a-20	20.22	5.00	6.00	31.22	143.97	
R-05-b-20	20.07	7.00	6.00	33.07	152.26	
R-06-a-20	20.22	5.00	6.00	31.22	143.97	
R-06-b-20	20.07	7.00	6.00	33.07	152.26	
R-01-a-30	20.59	5.00	6.00	31.59	141.23	Design Life 30 Years
R-01-b-30	20.45	7.00	6.00	33.45	149.04	
R-02-a-30	20.59	5.00	6.00	31.59	141.23	
R-02-b-30	20.45	7.00	6.00	33.45	149.04	
R-03-a-30	20.52	5.00	6.00	31.52	149.51	
R-03-b-30	20.34	7.00	6.00	33.34	160.01	
R-04-a-30	20.52	5.00	6.00	31.52	149.51	
R-04-b-30	20.34	7.00	6.00	33.34	160.01	

Table 4.2: The structural thickness of rigid pavements (continued).

Design Name	Surface, inch	Stabilized base, inch	Subbase, inch	Total Thickness, inch	CDFU, %	Remarks
R-05-a-30	20.57	5.00	6.00	31.57	145.14	Design Life 30 Years
R-05-b-30	20.42	7.00	6.00	33.42	154.03	
R-06-a-30	20.57	5.00	6.00	31.57	145.14	
R-06-b-30	20.42	7.00	6.00	33.42	154.03	
R-01-a-40	20.86	5.00	6.00	31.86	140.30	Design Life 40 Years
R-01-b-40	20.72	7.00	6.00	33.72	148.39	
R-02-a-40	20.85	5.00	6.00	31.85	140.30	
R-02-b-40	20.72	7.00	6.00	33.72	148.39	
R-03-a-40	20.78	5.00	6.00	31.78	150.82	
R-03-b-40	20.61	7.00	6.00	33.61	159.64	
R-04-a-40	20.78	5.00	6.00	31.78	150.82	
R-04-b-40	20.61	7.00	6.00	33.61	159.64	
R-05-a-40	20.84	5.00	6.00	31.84	144.21	
R-05-b-40	20.69	7.00	6.00	33.69	153.45	
R-06-a-40	20.84	5.00	6.00	31.84	144.21	
R-06-b-40	20.69	7.00	6.00	33.69	153.45	

4.5 Summary of Initial Cost Estimation

The initial cost of flexible and rigid pavement is estimated at $/sq. yd., as shown in Tables 4.3 and 4.4.

Table 4.3: The initial cost of flexible pavements.

Design Life 20 Years		Design Life 30 Years		Design Life 40 Years	
Design Name	$/sq. yd.	Design Name	$/sq. yd.	Design Name	$/sq. yd.
F-01-a-20	$ 56.73	F-01-a-30	$ 57.00	F-01-a-40	$ 57.20
F-01-b-20	$ 61.77	F-01-b-30	$ 62.03	F-01-b-40	$ 60.99
F-02-a-20	$ 48.31	F-02-a-30	$ 48.41	F-02-a-40	$ 48.48
F-02-b-20	$ 55.23	F-02-b-30	$ 55.33	F-02-b-40	$ 53.20

Table 4.4: The initial cost of rigid pavements.

Design Life 20 Years		Design Life 30 Years		Design Life 40 Years	
Design Name	**$/sq. yd.**	**Design Name**	**$/sq. yd.**	**Design Name**	**$/sq. yd.**
R-01-a-20	$ 72.42	R-01-a-30	$ 73.23	R-01-a-40	$ 73.83
R-01-b-20	$ 80.02	R-01-b-30	$ 80.83	R-01-b-40	$ 81.44
R-02-a-20	$ 71.77	R-02-a-30	$ 72.58	R-02-a-40	$ 73.17
R-02-b-20	$ 79.38	R-02-b-30	$ 80.19	R-02-b-40	$ 80.80
R-03-a-20	$ 54.96	R-03-a-30	$ 55.77	R-03-a-40	$ 56.36
R-03-b-20	$ 55.00	R-03-b-30	$ 57.48	R-03-b-40	$ 58.09
R-04-a-20	$ 54.32	R-04-a-30	$ 55.13	R-04-a-40	$ 55.72
R-04-b-20	$ 54.38	R-04-b-30	$ 56.84	R-04-b-40	$ 57.45
R-05-a-20	$ 56.75	R-05-a-30	$ 57.54	R-05-a-40	$ 58.15
R-05-b-20	$ 59.50	R-05-b-30	$ 60.29	R-05-b-40	$ 60.90
R-06-a-20	$ 56.11	R-06-a-30	$ 56.90	R-06-a-40	$ 57.50
R-06-b-20	$ 58.86	R-06-b-30	$ 59.65	R-06-b-40	$ 60.25

4.6 Pavement's Schematic Scenario

Figure 4.3 depicts a schematic scenario of the total thickness, cumulative damage factor, and initial cost of flexible pavements (20, 30, and 40-year). Figures 4.4, 4.5, and 4.6 depict a schematic scenario of the rigid pavements' total thickness (20, 30, and 40-year), cumulative damage factor unit percentage, and initial cost. This makes it easier to identify economic pavement for each design life.

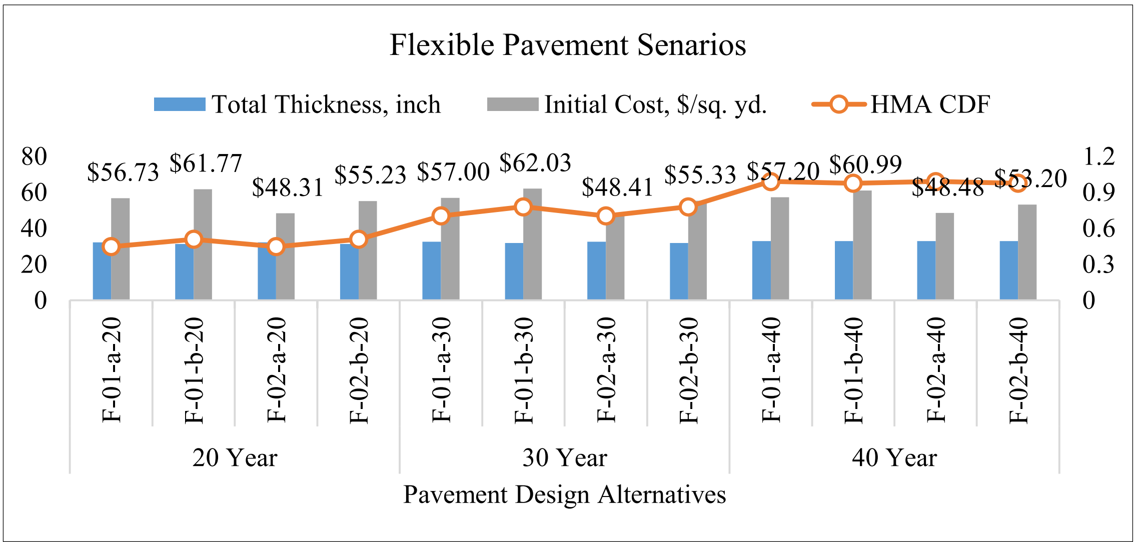

Figure 4.3: Flexible pavements scenario (design life of 20, 30, and 40 years).

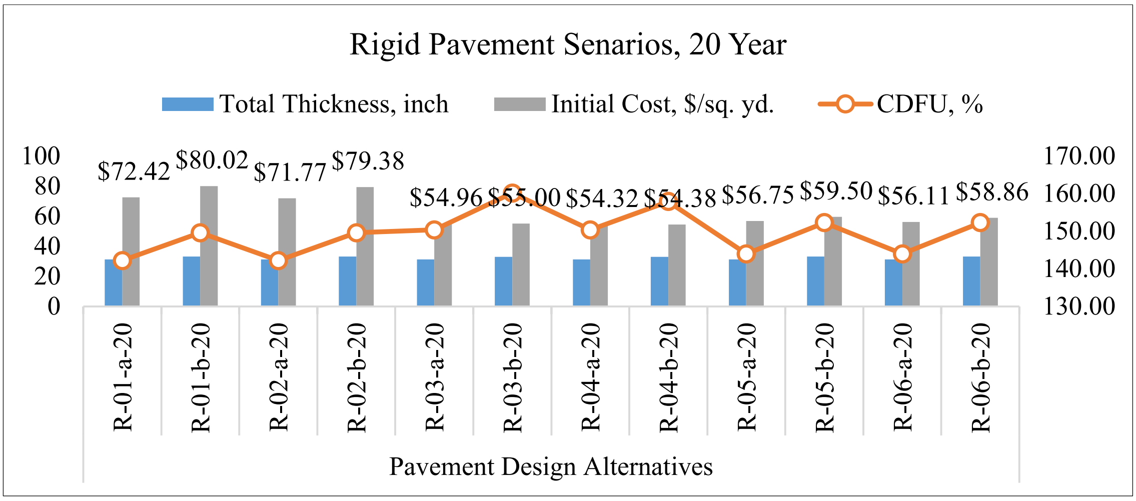

Figure 4.4: Rigid pavements scenario (design life of 20 years).

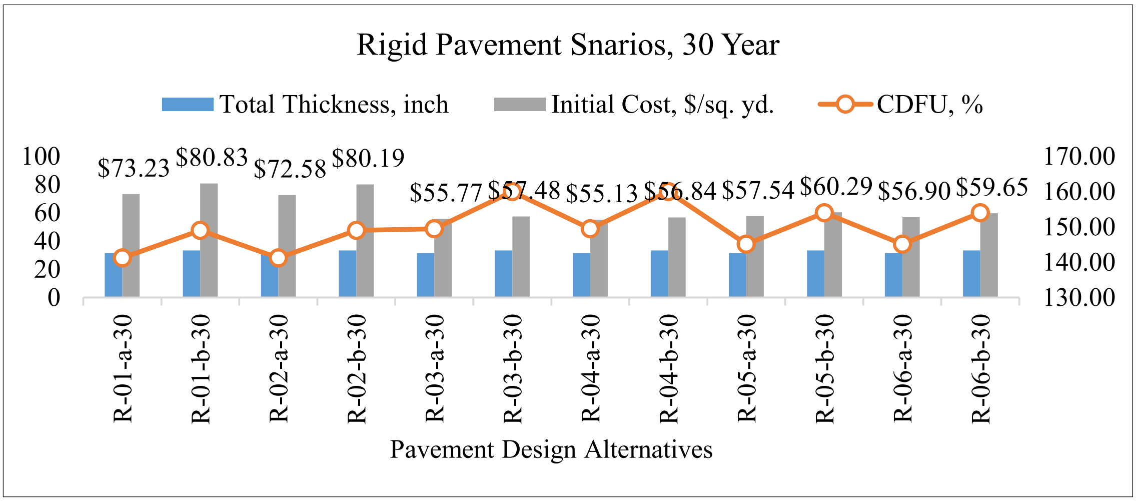

Figure 4.5: Rigid pavements scenario (design life of 30 years).

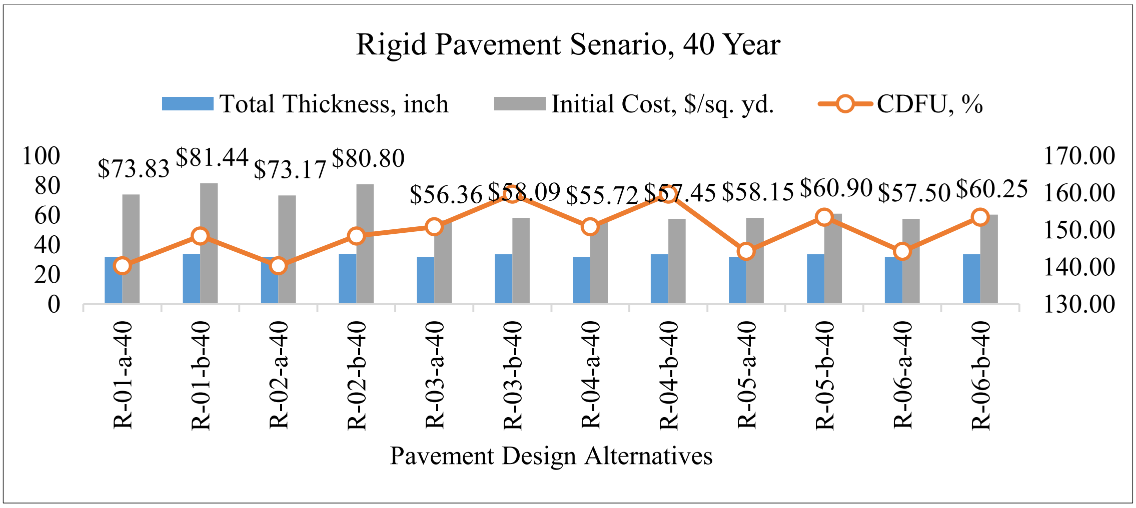

Figure 4.6: Rigid pavements scenario (design life of 40 years).

4.7 Determination of Economic Pavements

4.7.1 Choosing a Pavement Type

The flexible pavement (F-02-a-20) is the most cost-effective pavement for a 20-year design life, with an initial construction cost of 48.31 $/sq. yd. The continuity of the same design materials with different design lives indicates the use of cost-effective materials. For 30 and 40 year’s design lives (F-02-a-30 and F-02-a-40, respectively), the same material costs 48.41 $/sq. yd. and 48.48 $/sq. yd.

Similarly, the rigid pavement (R-04-a-20) is the most cost-effective pavement for a 20-year design life, with an initial construction cost of 54.32 $/sq. yd. The continuity of the same design materials with different design lives indicates the use of cost-effective materials. For 30 and 40 year's design lives (R-04-a-30 and R-04-a-40, respectively), the same material costs 55.13 $/sq. yd. and 55.72 $/sq. yd.

4.7.2 Thickness of the Structure

Table 4.5 and 4.6 shows the selected economical, flexible, and rigid pavement structural thicknesses. Flexible pavements require minimum surface and stabilized base thicknesses of 4 and 5 inches, respectively, with subbase thicknesses of 23.15, 26.62, and 23.98 inches. The cumulative damage factor of hot mix asphalt gradually rises to an acceptable limit. Similarly, rigid pavements require minimum stabilized base and subbase thicknesses of 5 and 6 inches, respectively, with surface thicknesses of 20.16, 20.52, and 20.78 inches. The percentage of cumulative damage factor units indicates the safe design.

Table 4.5: Preliminary selected economic flexible pavement’s structural thicknesses.

Flexible Pavements Structural Thicknesses							
Pavement Layer		**Material Types**		**F-02-a-20**	**F-02-a-30**	**F-02-a-40**
Surface	:	P-401/ P-403 HMA Surface	:	4.00	4.00	4.00
Stabilized base	:	P-401/ P-403 St (flex)	:	5.00	5.00	5.00
Subbase	:	P-219 Recycled Conc. Agg.	:	23.15	23.62	23.98
Subgrade	:	12000 psi or 82.74 MPa	:	12000 psi	12000 psi	12000 psi
CDF	:	HMA CDF ≤ 1	:	0.45	0.70	0.99

Table 4.6: Preliminary selected economic rigid pavement's structural thicknesses.

Rigid Pavements Structural Thicknesses							
Pavement Layer		**Material Types**		**R-04-a-20**	**R-04-a-30**	**R-04-a-40**
Surface	:	PCC Surface	:	20.16	20.52	20.78
Stabilized base	:	P-306 Lean Concrete	:	5.00	5.00	5.00
Subbase	:	P-219 Recycled Conc. Agg.	:	6.00	6.00	6.00
Subgrade	:	12000 psi or 82.74 MPa	:	12000 psi	12000 psi	12000 psi
CDFU, %	:	100	:	150.52	149.51	150.82

The flexible pavement subbase thickness increases at a rate of 0.0, 2.03, and 3.59 percent over the design life of 20, 30, and 40 years, while the rigid pavement surface thickness increases at a rate of 0.0, 1.79, and 3.08 percent.

4.7.3 Design Resources

The study finds the most economical flexible and rigid pavement design materials are shown in Table 4.7. An asphalt surface indicates flexible pavement, and a concrete surface indicates rigid pavement. Flexible pavement has a stabilized base of P-401/P-403 St (flex) is used, while P-306 lean concrete is used in rigid pavement. The P-219 recycled concrete aggregate material is an important finding and it's used in both flexible and rigid pavements.

Table 4.7: Economic flexible and rigid pavement design materials.

Flexible Pavement		Rigid Pavement	
Pavement Layer	**Material Types**	**Pavement Layer**	**Material Types**
Surface	P-401/ P-403 HMA Surface	Surface	PCC Surface
Stabilized base	P-401/ P-403 St (flex)	Stabilized base	P-306 Lean Concrete
Subbase	P-219 Recycled Conc. Agg.	Subbase	P-219 Recycled Conc. Agg.
Subgrade	12,000 psi or 82.74 MPa	Subgrade	12,000 psi or 82.74 MPa

4.7.4 Initial Cost vs. Design Life Comparison

Figure 4.7 shows that the initial construction costs of flexible and rigid pavements increase with the design life. For a 20-year design life, the initial construction cost of flexible pavement is 48.31 $/sq. yd. and for rigid pavement, 54.32 $/sq. yd. The price difference is 6.01 $/sq. yd., which indicates flexible pavement is 12.4 percent cheaper than rigid pavement. Similarly, for the 30 and 40-year design lives, flexible pavement is 13.88 percent and 14.93 percent cheaper than rigid pavement.

The initial cost of flexible pavements, in particular, increases at a rate of 0.0, 0.21, and 0.35 percent over the design life (20 to 20-year, 20 to 30-year, and 20 to 40-year), whereas rigid pavements increase at a rate of 0.0, 1.49, and 2.58 percent.

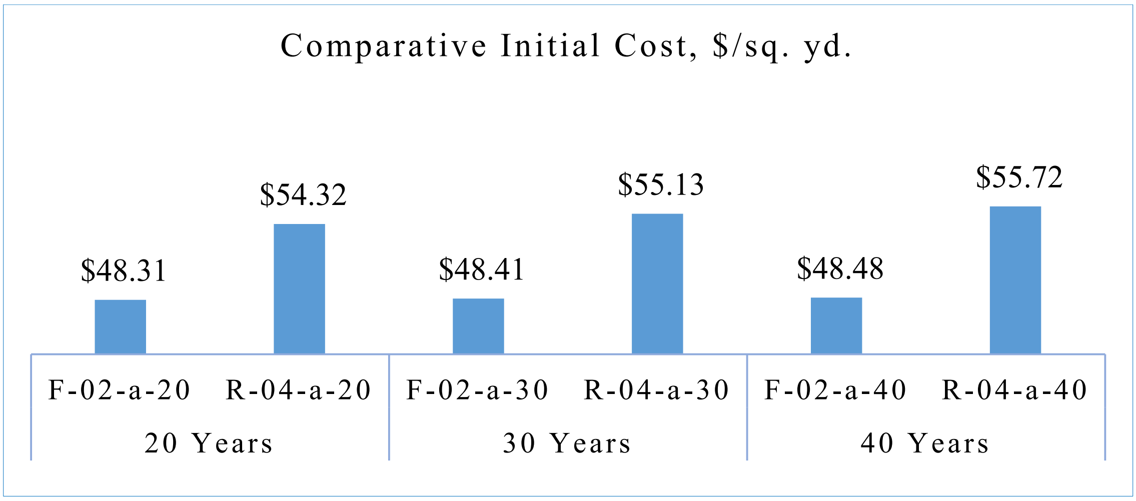

Figure 4.7: The initial cost comparison of the flexible and rigid pavement options.

4.8 Conclusion

The study found that flexible pavements have lower initial construction costs than rigid pavements. The key discovery is the use of recycled concrete aggregate as a subbase design material in both flexible and rigid pavement layers. The structural thickness of the pavement increases with design life.

CHAPTER 5

OVERLAY DESIGNS ON THE INITIAL FLEXIBLE AND RIGID AIRFIELD PAVEMENTS

5.1 General

This chapter describes the airport pavement overlay design. It is the process of laying either Portland cement concrete or hot mix asphalt on top of an existing pavement structure. The concept of a pavement's long-term service life, previously selected economic pavements with different design lives are taken, and a maintenance and rehabilitation schedule plan is established. FAARFIELD software is used to design the overlay designs in accordance with FAA guidelines.

5.2 Overlay Design Software

FAARFIELD 1.42 software is used to overlay designs. The overlay design in the program is based on layered elastic and three-dimensional finite element methods. It designs the overlay thickness required to achieve the desired design life. This is achieved by meeting the limiting stress or strain criterion while keeping the minimum thickness requirements.

5.3 Pavement Identifier Assigned

The names of the referenced designs are replaced for the purposes of the study, and new identification pavement names are assigned, as shown in Table 5.1.

Table 5.1: The new pavement identifier.

Ref. Design	Pavement Type	Overlay Design	Assigned Name	Design Life
F-02-a-20	Flexible	2 HMA Overlay	Alternative 1	20 Year
F-02-a-20	Flexible	1 HMA & 1 PCC	Alternative 2	
R-04-a-20	Rigid	1 PCC Overlay	Alternative 3	
R-04-a-20	Rigid	2 HMA Overlay	Alternative 4	
F-02-a-30	Flexible	2 HMA Overlay	Alternative 1	30 Year
F-02-a-30	Flexible	1 HMA & 1 PCC	Alternative 2	
R-04-a-30	Rigid	1 PCC Overlay	Alternative 3	
R-04-a-30	Rigid	2 HMA Overlay	Alternative 4	

Table 5.1: The new pavement identifier (continued).

Ref. Design	Pavement Type	Overlay Design	Assigned Name	Design Life
F-02-a-40	Flexible	2 HMA Overlay	Alternative 1	40 Year
F-02-a-40	Flexible	1 HMA & 1 PCC	Alternative 2	
R-04-a-40	Rigid	1 PCC Overlay	Alternative 3	
R-04-a-40	Rigid	2 HMA Overlay	Alternative 4	

5.4 Maintenances and Rehabilitations Schedule Plan

Conventionally, pavement maintenance and rehabilitation are linked to the Pavement Condition Index (PCI) report. From the standpoint of pavement long-term analysis (all selected pavements have a service life of 40 years), historical knowledge has been accompanied by expertise from past projects that were advised by the pavement experts. The maintenance and rehabilitation schedules are taken from the North Carolina Department of Transportation (NCDOT), Division of Aviation, United States. The alternative pavement maintenance and rehabilitation schedule is shown in Table 5.2.

Table 5.2: Pavement maintenance and rehabilitation schedule plan [18].

Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
0	Flexible Pavement	Flexible Pavement	Rigid Pavement	Rigid Pavement
7	Maintenance	Maintenance		
10			Maintenance	Maintenance
13	Maintenance	Maintenance		
15	HMA Overlay	HMA Overlay		
19			Maintenance	Maintenance
20			PCC Overlay	HMA Overlay
21	Maintenance	Maintenance		
26				Maintenance
27	Maintenance	Maintenance		
30	HMA Overlay	PCC Overlay	Maintenance	
31				Maintenance
32				HMA overlay

Table 5.2: Pavement maintenance and rehabilitation schedule plan [18] (continued).

Year	Alternative 1	Alternative 2	Alternative 3	Alternative 4
36	Maintenance			
38				Maintenance
39		Maintenance	Maintenance	
40	Pavement life end	Pavement life end	Pavement life end	Pavement life end
	Salvage Value			

5.5 Pavement Overlay Design for 20 Year

The flexible and rigid pavements were designed for a 20-year life span. This pavement's life span ended after 20 years of service. A number of overlays have been performed to increase the service life of this pavement from 20 to 40 years. The overlay schedule plans are taken from Table 5.2. Pavement alternative overlay designs are performed in the sections below in a sequential manner.

5.6 Alternative 1

The flexible pavement (F-02-a-20) is expected to require its first hot mix asphalt overlay after 15 years and its second hot mix asphalt overlay after 30 years. So the first overlay design life is 15 years, and the second is 10 years.

5.6.1 1st Hot Mix Asphalt Overlay

The design life of the existing flexible pavement (F-02-a-20) was 20 years. Table 5.3 depicts the pavement's structural layer types, thickness, and material properties.

Table 5.3: The structural layer properties of flexible pavement (F-02-a-20).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Surface	4	200,000	0.35	0
2	P-401/ P-403 St (flex)	7	400,000	0.35	0
3	P-209 Cr Ag	20.4	67,711	0.35	0
4	Subgrade	0	12,000	0.35	0

First, open the job file "0416042427". Select the pavement type "AC on Flexible" overlay in Job File 0416042427 and create a new section titled "AC Flex OL". Next, open the "Structure" window and enter the airplane traffic information, pavement structural layer information, and subgrade strength modulus of 12,000 psi.

Then, in the structure image, click on "Modify Structure" and then "Add Layer" anywhere within the "P-401/P-403 HMA Surface" layer. A surface layer replica is added to the structure adjacent to the original surface layer. Next, while still in modify mode, click on the layer material box in the new surface layer and select "HMA: All P-401/P-403" from the "Layer Type Selection" box below the heading "P-401/P-403 HMA Overlay". After clicking "OK" to close the layer type selection box, the new surface layer became an overlay. After that, click within the "Design Life" box and enter the "Design Life" 15-year. Later, click "End Modify" to exit the modify mode. Click "Design Structure" to run the design. The design performs until the subgrade CDF reaches 1. This process takes much longer than in the new pavement designs. Table 5.4 depicts the structural thickness of the first HMA overlay is 2 inches.

Table 5.4: The first hot-mix asphalt overlay thickness (FAARFIELD software).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	2	200,000	0.35	0
2	P-401/ P-403 HMA Surface	4	200,000	0.35	0
3	P-401/ P-403 St (flex)	7	400,000	0.35	0
4	P-209 Cr Ag	20.4	67,711	0.35	0
5	Subgrade	0	12,000	0.35	0

The HMA overlay's minimum structural overlay thickness is 3 inches (AC 150/5320-6F, Section 4.5.1). Because a thicker overlay usually performs better. As a result, the overlay thickness is set at 3 inches. The structural thickness of the first HMA overlays is shown in Table 5.5.

Table 5.5: The first hot-mix asphalt overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	3	200,000	0.35	0
2	P-401/ P-403 HMA Surface	4	200,000	0.35	0
3	P-401/ P-403 St (flex)	7	400,000	0.35	0

Table 5.5: The first hot-mix asphalt overlay thickness (continued).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
4	P-209 Cr Ag	20.4	67,711	0.35	0
5	Subgrade	0	12,000	0.35	0

5.6.2 2nd Hot Mix Asphalt Overlay

The second hot mix asphalt overlay on the existing flexible pavement (F-02-a-20) is being undertaken for the remaining 10 years of service life. The second overlay design is exactly the same as the first (Section 5.6.1). The only distinction is in the design life. Enter this information and perform the design. The software determines that the second HMA overlay structural thickness is 2 inches, as shown in Table 5.6.

Table 5.6: The second hot-mix asphalt overlay thickness (FAARFIELD software).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	2	200,000	0.35	0
2	P-401/ P-403 HMA Surface	4	200,000	0.35	0
3	P-401/ P-403 St (flex)	7	400,000	0.35	0
4	P-209 Cr Ag	20.4	67,711	0.35	0
5	Subgrade	0	12,000	0.35	0

The HMA overlay's minimum structural overlay thickness is 3 inches (AC 150/5320-6F, Section 4.5.1). Because a thicker overlay usually performs better. As a result, the overlay thickness is set at 3 inches. The structural thickness of the first HMA overlays is shown in Table 5.7.

Table 5.7: The second hot-mix asphalt overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	3	200,000	0.35	0
2	P-401/ P-403 HMA Surface	4	200,000	0.35	0
3	P-401/ P-403 St (flex)	7	400,000	0.35	0
4	P-209 Cr Ag	20.4	67,711	0.35	0
5	Subgrade	0	12,000	0.35	0

5.7 Alternative 2

The flexible pavement (F-02-a-20) is expected to require its first hot mix asphalt (HMA) overlay after 15 years and its second Portland cement concrete (PCC) overlay after 30 years. So the first overlay design life is 15 years, and the second is 10 years.

5.7.1 1st Hot Mix Asphalt Overlay

The first hot mix asphalt overlay design is exactly the same as the first overlay (Section 5.6.1). The structural thickness of the first HMA overlays are shown in Table 5.8.

Table 5.8: The first hot-mix asphalt overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	3	200,000	0.35	0
2	P-401/ P-403 HMA Surface	4	200,000	0.35	0
3	P-401/ P-403 St (flex)	7	400,000	0.35	0
4	P-209 Cr Ag	20.4	67,711	0.35	0
5	Subgrade	0	12,000	0.35	0

5.7.2 2nd Hot Mix Asphalt Overlay

The second Portland cement concrete overlay on the existing flexible pavement (F-02-a-20) is being undertaken for the remaining 10 years of service life. Table 5.9 depicts the pavement's structural layer types, thickness, and material properties.

Table 5.9: The structural layer properties of flexible pavement (F-02-a-20).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Surface	4	200,000	0.35	0
2	P-401/ P-403 St (flex)	7	400,000	0.35	0
3	P-209 Cr Ag	20.4	67,711	0.35	0
4	Subgrade	0	12,000	0.35	0

First, open the job file "0416042427". Select the pavement type "PCC on Flexible" overlay in Job File 0416042427 and create a new section titled "PCC Flex OL". Next, open the "Structure" window and enter the airplane traffic information, pavement structural layer information, and subgrade strength modulus of 12,000 psi.

Then, in the structure image, click on "Modify Structure" and then "Add Layer" anywhere within the "P-401/P-403 HMA Surface" layer. A surface layer replica is added to the structure adjacent to the original surface layer. Next, while still in modify mode, click on the layer material box in the new surface layer and select "PCC: All P-501" from the "Layer Type Selection" box below the heading "Overlay on flexible". After clicking "OK" to close the layer type selection box, the new surface layer became an overlay. After that, click within the "Design Life" box and enter the "Design Life" 10-year. Later, click "End Modify" to exit the modify mode. Click "Design Structure" to run the design. This process takes much longer than in the new pavement designs. Table 5.10 depicts the structural thickness of the first PCC overlay is 18.23 inches.

Table 5.10: The second Portland cement concrete overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	PCC Overlay on Flex.	18.23	4,000,000	0.15	650
2	P-401/ P-403 HMA Surface	4	200,000	0.35	0
3	P-401/ P-403 St (flex)	7	400,000	0.35	0
4	P-209 Cr Ag	20.4	67,711	0.35	0
5	Subgrade	0	12,000	0.35	0

5.8 Alternative 3

The rigid pavement (R-04-a-20) is expected to require its Portland cement concrete (PCC) overlay after 20 years. So the overlay design life is 20 years.

5.8.1 Portland Cement Concrete Overlay

The design life of the existing rigid pavement (R-04-a-20) was 20 years. Table 5.11 depicts the pavement's structural layer types, thickness, and material properties.

Table 5.11: The structural layer properties of rigid pavement (R-04-a-20).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	PCC Surface	20.16	4,000,000	0.15	650
2	P-306 Lean Concrete	5	700,000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34,053	0.35	0
4	Subgrade	0	12,000	0.4	0

First, open the job file "0416042427". Select the pavement type "PCC on Rigid" overlay in Job File 0416042427 and create a new section titled "PCC Rigid OL". Next, open the "Structure" window and enter the airplane traffic information, pavement structural layer information, and subgrade strength modulus of 12,000 psi.

Then, in the structure image, click on "Modify Structure" and then "Add Layer" anywhere within the "PCC Surface" layer. A surface layer replica is added to the structure adjacent to the original surface layer. Next, while still in modify mode, click on the layer material box in the new surface layer and select "PCC: All P-501" from the "Layer Type Selection" box. After clicking "OK" to close the layer type selection box, the new surface layer became an overlay. To the right of the design life box, two additional data entry boxes, structural condition index (SCI) and percent cumulative damage factor used (CDFU), appear. By default, the new PCC overlay contains a concrete strength of 650 psi. There is no need to adjust the concrete strength in this case. Change the value of the "SCI" box to 80. The percent of CDFU noticed is set to 100 by default. Because the value is greater than 100, there is no need to modify it. After that, click within the "Design Life" box and enter the "Design Life" 20-year. Later, click "End Modify" to exit the modify mode. Click "Design Structure" to run the design. This process takes much longer than in the new pavement designs. Table 5.12 depicts the structural thickness of the first PCC overlay is 6.45 inches.

Table 5.12: The Portland cement concrete overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	PCC Overlay Unbond	6.45	4,000,000	0.15	650
2	PCC Surface	20.16	4,000,000	0.15	650
3	P-306 Lean Concrete	5	700,000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34,053	0.35	0
5	Subgrade	0	12,000	0.4	0

5.9 Alternative 4

The rigid pavement (R-04-a-20) is expected to require its first hot mix asphalt overlay after 20 years and its second hot mix asphalt overlay after 32 years. So the first overlay design life is 12 years, and the second is 8 years.

5.9.1 1st Hot Mix Asphalt Overlay

The design life of the existing rigid pavement (R-04-a-20) was 20 years. Table 5.13 depicts the pavement's structural layer types, thickness, and material properties.

Table 5.13: The structural layer properties of rigid pavement (R-04-a-20).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	PCC Surface	20.16	4,000,000	0.15	650
2	P-306 Lean Concrete	5	700,000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34,053	0.35	0
4	Subgrade	0	12,000	0.4	0

First, open the job file "0416042427". Select the pavement type "AC on Rigid" overlay in Job File 0416042427 and create a new section titled "AC Rigid OL". Next, open the "Structure" window and enter the airplane traffic information, pavement structural layer information, and subgrade strength modulus of 12,000 psi.

Then, in the structure image, click on "Modify Structure" and then "Add Layer" anywhere within the "P-401/ P-403 HMA Surface" layer. A surface layer replica is added to the structure adjacent to the original surface layer. Next, while still in modify mode, click on the layer material box in the new surface layer and select "P-401/ P-403 HMA Surface" from the "Layer Type Selection" box below the heading "P-401/ P-403 HMA Overlay". After clicking "OK" to close the layer type selection box, the new surface layer became an overlay. To the right of the design life box, two additional data entry boxes, structural condition index (SCI) and percent cumulative damage factor used (CDFU), appear. By default, the new PCC overlay contains a concrete strength of 650 psi. There is no need to adjust the concrete strength in this case. Change the value of the "SCI" box to 80. The percent of CDFU noticed is set to 100 by default. Because the value is greater than 100, there is no need to modify it. After that, click within the "Design Life" box and enter the "Design Life" 12-year. Later, click "End Modify" to exit the modify mode. Click "Design Structure" to run the design. This process takes much longer than in the new pavement designs. Table 5.14 depicts the structural thickness of the first HMA overlay is 2 inches.

Table 5.14: The first hot-mix asphalt overlay thickness (FAARFIELD software).

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	2	4,000,000	0.15	650
2	PCC Surface	20.16	4,000,000	0.15	650
3	P-306 Lean Concrete	5	700,000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34,053	0.35	0
5	Subgrade	0	12,000	0.4	0

The HMA overlay's minimum structural overlay thickness is 3 inches (AC 150/5320-6F, Section 4.5.1). Because a thicker overlay usually performs better. As a result, the overlay thickness is set at 3 inches. The structural thickness of the first HMA overlays is shown in Table 5.15.

Table 5.15: The first hot-mix asphalt overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	3	4,000,000	0.15	650
2	PCC Surface	20.16	4,000,000	0.15	650
3	P-306 Lean Concrete	5	700,000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34,053	0.35	0
5	Subgrade	0	12,000	0.4	0

5.9.2 2nd Hot Mix Asphalt Overlay

The second hot mix asphalt overlay on the rigid flexible pavement (R-04-a-20) is being undertaken for the remaining 8 years of service life. The second overlay design is exactly the same as the first (Section 5.9.1). The only distinction is in the design life. Enter this information and perform the design. The software determines that the second HMA overlay structural thickness is 3 inches, as shown in Table 5.16.

Table 5.16: The second hot-mix asphalt overlay thickness.

No	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R, psi
1	P-401/ P-403 HMA Overlay	3	4,000,000	0.15	650
2	PCC Surface	20.16	4,000,000	0.15	650
3	P-306 Lean Concrete	5	700,000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34,053	0.35	0
5	Subgrade	0	12,000	0.4	0

5.10 Overlay Design Summary

Table 5.17 summarizes existing overlay design thicknesses for flexible pavement (F-02-a-20, F-02-a-30, and F-02-a-40) and rigid pavement (R-02-a-20, R-04-a-30, and R-04-a-40).

Table 5.17: The FAARFIELD software overlay design summary.

Ref. Design: F-02-a-20					
Alternative 1			Alternative 2		
Year	Overlay	Inch	Year	Overlay	Inch
15	1st HMA	2	15	1st HMA	2
30	2nd HMA	2	30	1st PCC	18.23
Ref. Design: F-02-a-30					
Alternative 1			Alternative 2		
Year	Overlay	Inch	Year	Overlay	Inch
15	1st HMA	2	15	1st HMA	2
30	2nd HMA	2	30	1st PCC	18.17
Ref. Design: F-02-a-40					
Alternative 1			Alternative 2		
Year	Overlay	Inch	Year	Overlay	Inch
15	1st HMA	2	15	1st HMA	2
30	2nd HMA	2	30	1st PCC	18.13
Ref. Design: R-04-a-20					
Alternative 3			Alternative 4		
Year	Overlay	Inch	Year	Overlay	Inch
20	1st PCC	6.45	20	1st HMA	2
			32	2nd HMA	2
Ref. Design: R-04-a-30					
Alternative 3			Alternative 4		
Year	Overlay	Inch	Year	Overlay	Inch
20	1st PCC	5	20	1st HMA	2
			32	2nd HMA	2
Ref. Design: R-04-a-40					
Alternative 3			Alternative 4		
Year	Overlay	Inch	Year	Overlay	Inch
20	1st PCC	5	20	1st HMA	2
			32	2nd HMA	2

5.11 Conclusion

Overlays for both flexible and rigid pavements are designed using the FAARFIELD software. Flexible pavement on hot-mix asphalt overlay (minimum thickness) and Portland cement concrete overlay (thick thickness) are required, according to the design. Rigid pavement on Portland cement concrete unbond overlay (minimum thickness) and hot-mix asphalt overlay (thin thickness) as needed.

CHAPTER 6

LIFE CYCLE COST ANALYSIS

6.1 General

This chapter discusses the airport pavement life cycle cost analysis techniques. It illustrates the long-term analysis process with various pavement alternatives. The analysis is carried out using the net present value method and AirCost software. Only major maintenance and rehabilitation activities are permitted. The same parameters are used to achieve the analysis goal.

6.2 Pavement Performance

The life cycle cost analysis period of an airport pavement is suggested to be the same as the design life (i.e., 20 years). Furthermore, the airfield asphalt pavement technology program recommends a longer analysis period, such as

i. For new construction, the lifespan is 40 years.
ii. 30 years for rehabilitation/overlays.
iii. Only about half of the airports surveyed used a life cycle cost analysis period of 20 years.

An analysis period is a time period in which the initial and future costs associated with various pavement strategies are assessed. The pavement performance curve is shown in Figure 6.1.

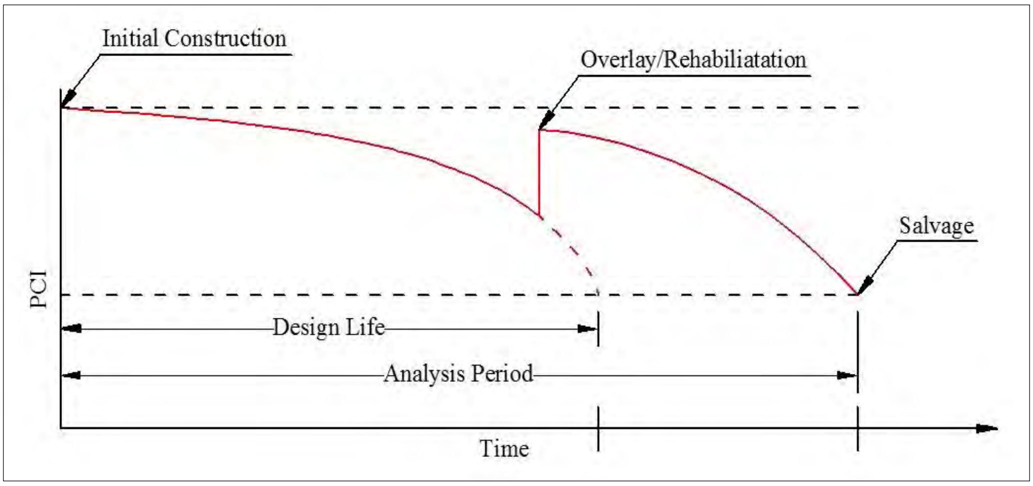

Figure 6.1: Pavement performance curve.

6.3 Life Cycle Cost Analysis Plan

The life cycle cost analysis of the pavement is done in two ways.

i. Net present value method
ii. AirCost LCCA software

6.4 Net Present Value Method Analysis

The pavement life cycle cost analysis timeframe is 40 years. The pavement overlay thickness and maintenance and rehabilitation schedule plan are taken (see Appendix-E and Chapter 5, Table 5.1). Only the pavement's material cost is considered in the analysis. Other costs, such as user costs, direct and indirect costs, administrative costs, engineering costs, and traffic maintenance costs, are not included. This section (6.4.2) shows how to conduct a 40-year life cycle cost analysis (the preliminary design life was 20 years). Similarly, other pavement (the preliminary design life was 30 and 40 years) life cycle cost analyses are performed in a similar manner (see Appendix-F).

6.4.1 Parameters

The discount rate is one of the most important factors to consider during the life cycle cost analysis of a pavement. Airport pavement discounts range from 2 percent to 5 percent (AAPTP 2011). Table 6.1 lists the analysis parameters for the net present value technique.

Table 6.1: Life cycle cost analysis parameters.

SL	Item	Parameters
1	Analysis base, year	2017
2	Initial construction, year	2018
3	Analysis period, year	40
4	Discount rate, %	4%
5	Salvage value	Straight line depreciation

6.4.2 Design Life 20 Years and Life Cycle Cost Analysis 40 Years

Alternative 1 is the alternative flexible pavement (F-02-a-20) of Alternative 2, whereas Alternative 3 is the alternative rigid pavement (R-04-a-20) of Alternative 4. These pavements' life cycle cost analyses are computed and provided in Tables 6.2, 6.3, 6.4, and 6.5.

Table 6.2: Alternative 1: life cycle cost analysis.

LIFE - CYCLE COST ANALYSIS
FLEXIBLE PAVEMENT
Analysis Name: Alternative 1

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
		Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-20)	1	sq. yd.	$ 8454416	$ 8454416	1.0000	$ 8454416
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.3083	$ 1005897
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
36	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2437	$ 63963
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 16291964		$ 11899202
						Salvage Value	$ -1631262		$ -339774
						Grand Total	$		$ 11559428

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 66.05

Table 6.3: Alternative 2: life cycle cost analysis.

LIFE - CYCLE COST ANALYSIS

FLEXIBLE PAVEMENT

Analysis Name: Alternative 2

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 1 HMA & 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-20)	1	sq. yd.	$ 8454416	$ 8454416	1.0000	$ 8454416
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
		P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500		
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
15	1st Rehabilitation	P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000	0.5553	$ 1811564
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
		P-830-A1	Unbonded PCC Overlay 18.23"	175000	sq. yd.	$ 58.34	$ 10208800		
30	2nd Rehabilitation	P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900	0.3083	$ 3335145
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
39	Maintenance	P-604-A	Joint Seal Replacement	172950	sq. yd.	$ 2	$ 345900	0.2166	$ 74929
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 23930040		$ 14239416
						Salvage Value	$ -5408600		$ -1126552
						Grand Total	$		$ 13112864

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$	74.93

Table 6.4: Alternative 3: life cycle cost analysis.

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 3

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-20)	1	sq. yd.	$ 9506175	$ 9506175	1.000	$ 9506175
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.676	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.475	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622588	0.456	$ 2210277
		P-830-A2	Unbonded PCC Overlay 6.45"	175000	sq. yd.	$ 20.64	$ 3612000		
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
30	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.308	$ 85318
39	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.217	$ 22479
40			Pavement Life End			$ 0	$ 0	0.208	$ 0
						Sub Total	$ 15110143		$ 12060444
						Salvage Value	$ -4753087		$ -990016
						Grand Total	$		$ 11070428

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 63.26

Table 6.5: Alternative 4: life cycle cost analysis.

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 4

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-20)	1	sq. yd.	$ 9506175	$ 9506175	1.0000	$ 9506175
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.6756	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.4746	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622563	0.4564	$ 1573434
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
26	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3607	$ 94681
31	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2965	$ 77821
32	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 1.5	$ 262500	0.2851	$ 880123
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
38	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2253	$ 59137
40			Pavement life end			$	$ 0	0.2083	$ 0
						Sub Total	$ 17209276		$ 12427567
						Salvage Value	$ -4753087		$ -990016
						Grand Total	$		$ 11437551

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$ 65.36

6.5 Net Present Value Analysis Result

6.5.1 Design Life 20 Years and Life Cycle Cost Analysis 40 Years

The summary of outcome results is presented in Table 6.6.

Table 6.6: The outcome of the life cycle cost analysis (preliminary design life of 20 years, and life cycle cost analysis of 40 years).

Cost item	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Initial cost	$ 8,454,416	$ 8,454,416	$ 9,506,175	$ 9,506,175
Total investment	$16,291,964	$18,894,999	$15,110,143	$17,209,276
Net present value	$11,559,428	$12,084,838	$11,070,428	$11,437,551
Salvage value	$ 1,631,262	$ 2,891,079	$ 4,753,087	$ 4,753,087

The initial cost of rigid pavement is 12.44 percent higher than flexible pavement. Alternative 1 is the most cost-effective flexible pavement option. The total investment cost is estimated as initial cost of 51.89 percent and 48.1 percent for maintenance and rehabilitation costs over its entire life span. At the end of the service life, the salvage value remains at 9.98 percent. Alternative 3 is the most cost-effective option in terms of rigid pavement. The total investment cost is estimated by 62.9 percent of the initial cost and 37.09 percent for maintenance and rehabilitation over its entire life time. At the end of the service life, the salvage value is still 31.46 percent. Moreover, alternative 1 is 7.82 percent more expensive to invest in comparison with alternative 3. Alternative 3 is 4.4 percent less expensive than alternative 1 according to the life cycle cost analysis. As a result, alt-3 is the most cost-effective of the pavement alternatives.

6.5.2 Design Life 30 Years and Life Cycle Cost Analysis 40 Years

The summary of outcome results is presented in Table 6.7.

Table 6.7: The outcome of the life cycle cost analysis (preliminary design life of 30 years, and life cycle cost analysis of 40 years).

Cost item	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Initial cost	8,471,437	8,471,437	9,648,054	9,648,054
Total investment	16,308,985	18,878,019	15,000,022	17,351,155

Table 6.7: The outcome of the life cycle cost analysis (preliminary design life of 30 years, and life cycle cost analysis of 40 years) continued.

Cost item	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Net present value	11,576,449	12,094,917	11,082,522	11,564,654
Salvage value	1,631,262	2,874,079	4,824,027	4,824,027

The initial cost of rigid pavement is 13.88 percent higher than flexible pavement. Alternative 1 is the most cost-effective flexible pavement option. The total investment cost is estimated as initial cost of 51.94 percent and 48.06 percent for maintenance and rehabilitation costs over its entire life span. At the end of the service life, the salvage value remains at 10 percent. Alternative 3 is the most cost-effective option in terms of rigid pavement. The total investment cost is estimated by 64.32 percent of the initial cost and 35.68 percent for maintenance and rehabilitation over its entire life time. At the end of the service life, the salvage value is still 32.16 percent. Moreover, alternative 1 is 8.73 percent more expensive to invest in comparison with alternative 3. Alternative 3 is 4.45 percent less expensive than alternative 1 according to the life cycle cost analysis. As a result, alt-3 is the most cost-effective of the pavement alternatives.

6.5.3 Design Life 40 Years and Life Cycle Cost Analysis 40 Years

The summary of outcome results is presented in Table 6.8.

Table 6.8: The outcome of the life cycle cost analysis (preliminary design life of 40 years, and life cycle cost analysis of 40 years).

Cost item	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Initial cost	8,484,472	8,484,472	9,750,519	9,750,519
Total investment	16,322,020	18,868,449	15,102,487	17,453,620
Net present value	11,589,484	12,103,337	11,174,315	11,656,448
Salvage value	1,631,262	2,862,777	4,875,260	4,875,260

The initial cost of rigid pavement is 14.90 percent higher than flexible pavement. Alternative 1 is the most cost-effective flexible pavement option. The total investment cost is estimated as initial cost of 51.98 percent and 48.02 percent for maintenance and rehabilitation costs over its entire life span. At the end of the service life, the salvage value remains at 9.99 percent. Alternative 3 is the most cost-effective option in terms of rigid pavement. The total investment cost is estimated by 64.56 percent of the initial cost and 35.44 percent for maintenance and rehabilitation over its entire life time. At the end of the service life, the salvage value is still 32.28 percent. Moreover, alternative 1 is 8.08 percent more expensive to invest in comparison with alternative 3. Alternative 3 is 3.73 percent less expensive than alternative 1 according to the life cycle cost analysis. As a result, alt-3 is the most cost-effective of the pavement alternatives.

6.6 AirCost Software Result

The basic life cycle cost analysis data set are given in Table 6.9.

Table 6.9: The life cycle cost analysis data set for AirCost software.

Item	Description
Data Input	The AirCost LCCA software uses historical data to provide a deterministic and normal probabilistic life cycle cost analysis while accounting for the uncertainty and variability of the input data. To achieve a life cycle cost analysis result, it is critical to have relevant data for simulation.
Analysis Period	The pavement life cycle cost analysis has a 40-year analysis period.
Parameters	Historical data is taken from (AAPTP 2011), while others are assumed.
Construction Timeframe	The timing (day) of new pavement construction, maintenance, and rehabilitation is determined by previous project experience and the engineering judgments of pavement experts. The construction timeframe depends on the type of pavement. The AirCost LCCA software uses a construction timeframe (see Chapter 5, Section 5.3, Table 5.2).
Airport Daily Revenue	The study assumes that the airport's daily revenue is $150,000. This is not an exact value.

Revenue Growth Rate	The study assumes that the airport's revenue growth rate is 4 percent.
Daily Revenue Reduction	AirCost software assumes a 5 percent daily revenue reduction. If the assumption of daily revenue is $150,000, then the loss for one night of work is $7,500. This calculated value represents the total loss of work activities related to the closing of the runway. The runway remains closed only for 4 or 5 hours throughout the night when there is no traffic.

6.7 Deterministic Output

The software's simulation for the analysis of deterministic approach output is generated separately for net present value (NPV) and equivalent uniform annual cost (EUAC). This method provides a single value for comparison with other alternatives. In the calculations, the study used a discount rate of 4 percent, compound growth of daily revenue of 4 percent, and a daily reduction of 5 percent for daily revenue.

6.7.1 Agency Costs

The agency cost is calculated using the NPV and EUAC values shown in Figures 6.2 and 6.3.

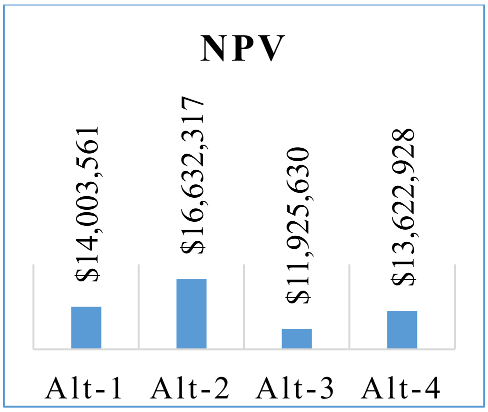

Figure 6.2: The NPVs agency cost.

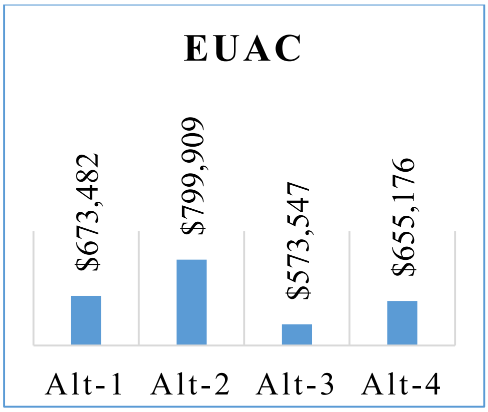

Figure 6.3: The EUACs agency cost.

According to the NPV and EUAC values, alternative 3 is the most cost-effective pavement alternative option.

6.7.2 User Costs

The user cost is calculated using the NPV and EUAC values shown in Figures 6.4 and 6.5.

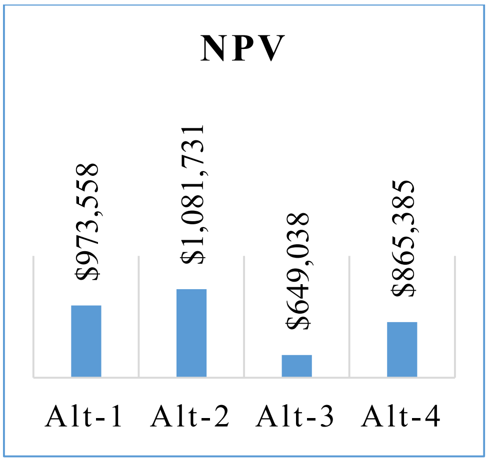

Figure 6.4: The NPVs user cost.

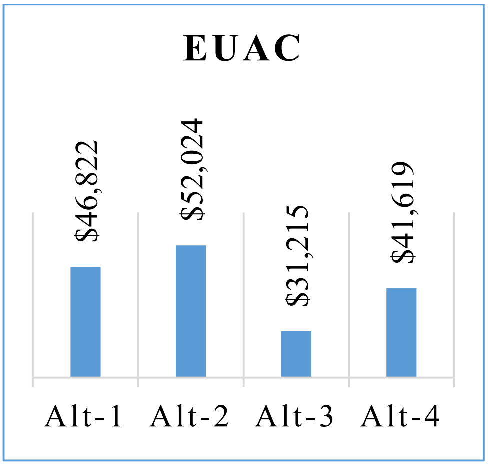

Figure 6.5: The EUACs user cost.

According to the NPV and EUAC values, alternative 3 is the most cost-effective pavement alternative option.

6.7.3 Total Costs

The total cost is calculated by adding the agency cost and the user cost. It is calculated using the NPV and EUAC values shown in Figures 6.6 and 6.7.

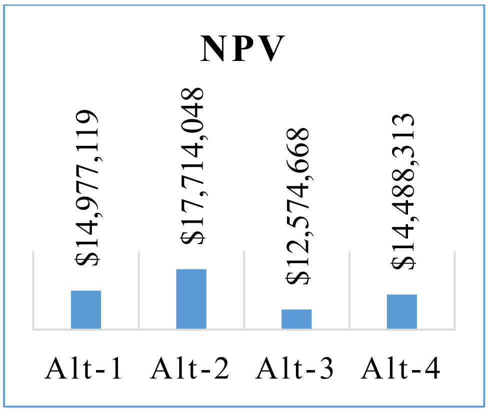

Figure 6.6: The NPVs total cost.

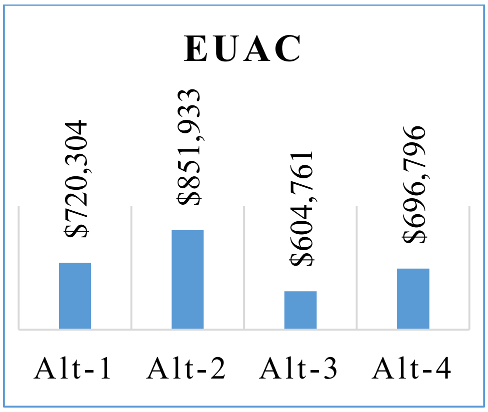

Figure 6.7: The EUACs total cost.

According to the NPV and EUAC values, alternative 3 is the most cost-effective pavement alternative option. Alternative 1 is the most cost-effective flexible pavement option.

6.8 Normal Probabilistic Output

The software's simulation for the analysis of normal probabilistic approach output is generated separately for net present value (NPV) and equivalent uniform annual cost (EUAC). This method provides a range of minimum and maximum values for comparison with other alternatives presented in a bell curve with a mean and standard deviation. In the calculations, the study used a discount rate of 4 percent with a standard deviation of 0.5 percent, compound daily revenue growth of 4 percent, and a daily revenue reduction of 5 percent.

6.8.1 Agency Costs

The agency cost is calculated using the NPV and EUAC values shown in Tables 6.10 and 6.11. The tables display the distribution's mean, standard deviation, and minimum and maximum values. Furthermore, the chosen statistics percentiles are 5 percent, 50 percent, 75 percent, and 95 percent.

Table 6.10: The NPVs agency cost.

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Mean	$ 14,123,000	$ 16,884,000	$ 11,991,000	$ 13,756,000
Standard Deviation	$ 1,430,000	$ 2,371,000	$ 1,717,000	$ 1,929,000
Minimum	$ 9,728,000	$ 11,231,000	$ 5,858,000	$ 8,037,000
Maximum	$ 18,949,000	$ 28,255,000	$ 17,096,000	$ 21,115,000
Percentile 1 (5%)	$ 11,785,000	$ 13,356,000	$ 9,182,000	$ 10,551,000
Percentile 2 (50%)	$ 14,122,000	$ 16,675,000	$ 11,989,000	$ 13,751,000
Percentile 3 (75%)	$ 15,079,000	$ 18,245,000	$ 13,145,000	$ 15,063,000
Percentile 4 (95%)	$ 16,561,000	$ 21,079,000	$ 14,813,000	$ 16,879,000

Table 6.11: The EUACs agency cost.

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Mean	$ 677,000	$ 813,000	$ 575,000	$ 660,000
Standard Deviation	$ 64,000	$ 102,000	$ 83,000	$ 92,000
Minimum	$ 513,000	$ 543,000	$ 330,000	$ 361,000
Maximum	$ 912,000	$ 1,299,000	$ 852,000	$ 964,000
Percentile 1 (5%)	$ 580,000	$ 664,000	$ 439,000	$ 508,000
Percentile 2 (50%)	$ 674,000	$ 805,000	$ 574,000	$ 662,000

Table 6.11: The EUACs agency cost (continued).

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Percentile 3 (75%)	$ 717,000	$ 882,000	$ 635,000	$ 721,000
Percentile 4 (95%)	$ 794,000	$ 987,000	$ 709,000	$ 805,000

The most cost-effective pavement alternative option, based on the NPV and EUAC values, is alternative 3 (rigid). Alternative 1 is the most cost-effective flexible pavement option. The bell curve in Figures 6.8 and 6.9 graphically depicts the dissimilarity of alternative costs.

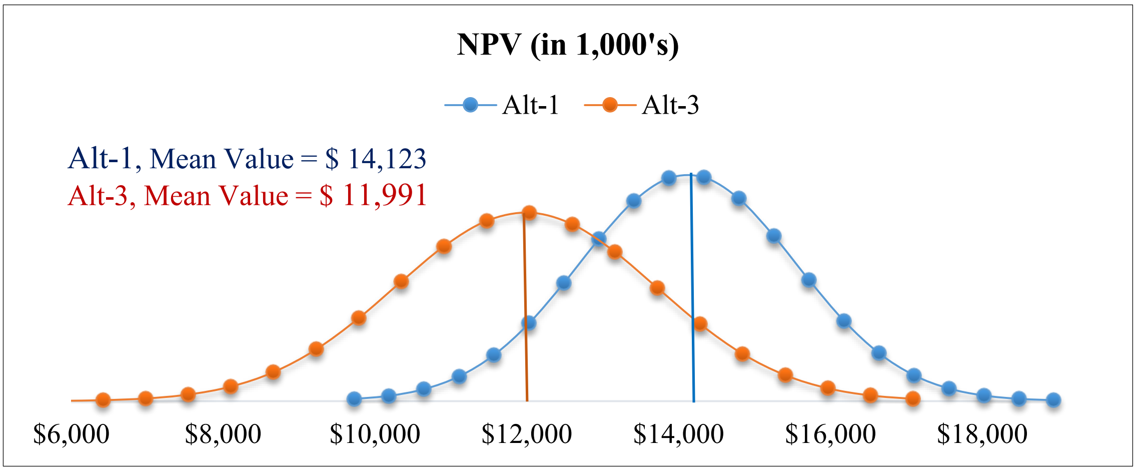

Figure 6.8: The NPVs bell curve of agency cost.

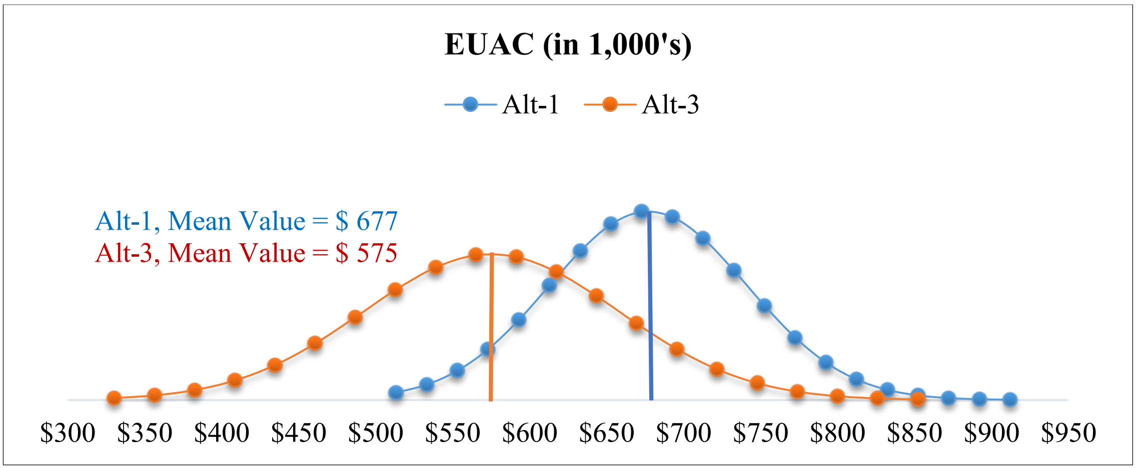

Figure 6.9: The EUACs bell curve of agency cost.

Figures 6.8 and 6.9 depict the findings of the NPV and EUAC values, respectively, in a simple visual representation using only the mean value of the alternative agency cost. The cost variation between the mean values of these two choices is $213,000 (NPV) and

$102,000 (EUAC). As a result, alternative 3 (rigid) is the most cost-effective pavement alternative option.

6.8.2 User Costs

The user cost is calculated using the NPV and EUAC values shown in Tables 6.12 and 6.13. The tables display the distribution's mean, standard deviation, and minimum and maximum values. Furthermore, the chosen statistics percentiles are 5 percent, 50 percent, 75 percent, and 95 percent.

Table 6.12: The NPVs user cost.

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Mean	$ 1,027,000	$ 1,180,000	$ 745,000	$ 915,000
Standard Deviation	$ 85,000	$ 143,000	$ 120,000	$ 77,000
Minimum	$ 819,000	$ 910,000	$ 583,000	$ 733,000
Maximum	$ 1,410,000	$ 1,745,000	$ 1,085,000	$ 1,159,000
Percentile 1 (5%)	$ 905,000	$ 995,000	$ 617,000	$ 803,000
Percentile 2 (50%)	$ 1,018,000	$ 1,155,000	$ 677,000	$ 907,000
Percentile 3 (75%)	$ 1,084,000	$ 1,277,000	$ 858,000	$ 968,000
Percentile 4 (95%)	$ 1,178,000	$ 1,438,000	$ 954,000	$ 1,053,000

Table 6.13: The EUACs user cost.

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Mean	$ 49,000	$ 57,000	$ 36,000	$ 44,000
Standard Deviation	$ 3,000	$ 5,000	$ 5,000	$ 3,000
Minimum	$ 42,000	$ 50,000	$ 28,000	$ 39,000
Maximum	$ 58,000	$ 75,000	$ 42,000	$ 52,000
Percentile 1 (5%)	$ 46,000	$ 52,000	$ 30,000	$ 41,000
Percentile 2 (50%)	$ 48,000	$ 52,000	$ 32,000	$ 42,000
Percentile 3 (75%)	$ 52,000	$ 62,000	$ 42,000	$ 47,000
Percentile 4 (95%)	$ 53,000	$ 63,000	$ 42,000	$ 47,000

The most cost-effective pavement alternative option, based on the NPV and EUAC values, is alternative 3 (rigid). Alternative 1 is the most cost-effective flexible pavement option. The bell curve in figures 6.10 and 6.11 graphically depicts the dissimilarity of alternative user costs.

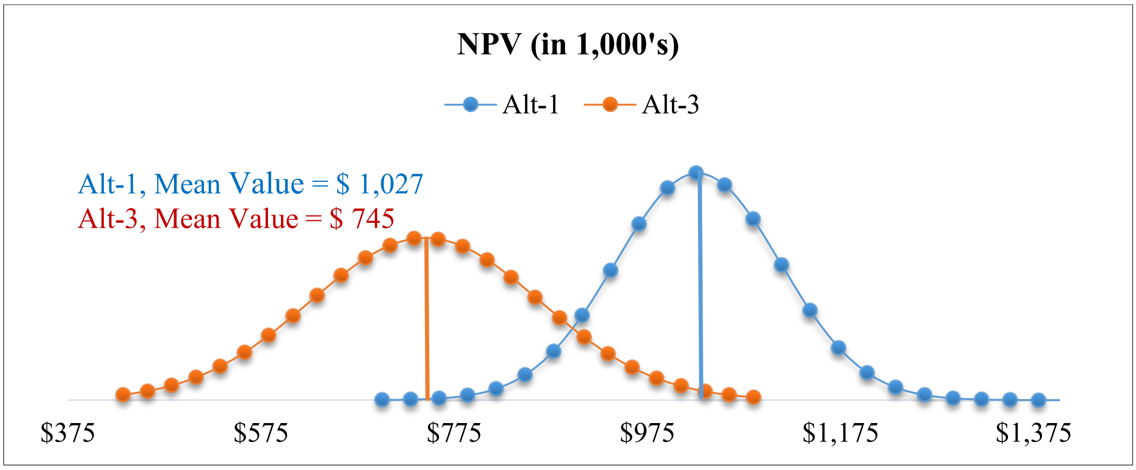

Figure 6.10: The NPVs bell curve of user cost.

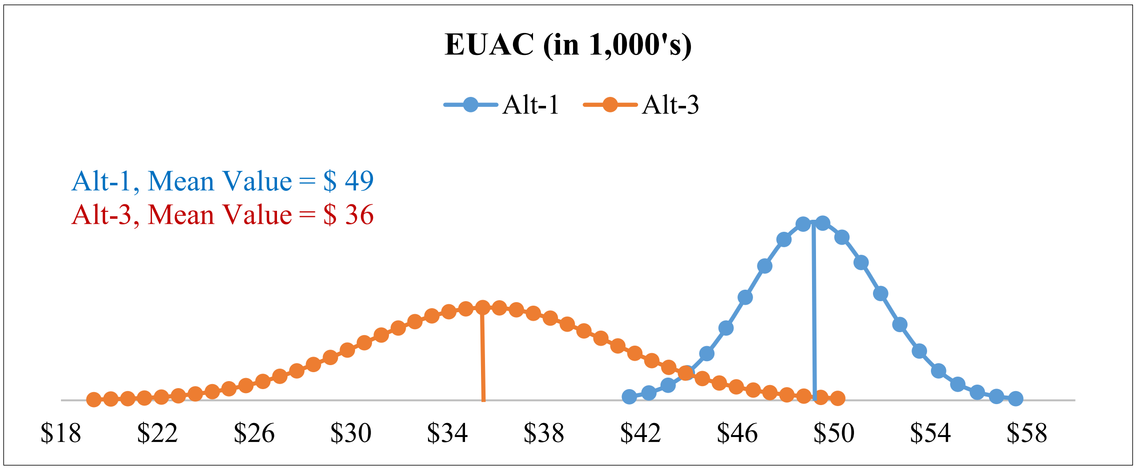

Figure 6.11: The EUACs bell curve of user cost.

Figures 6.10 and 6.11 depict the findings of the NPV and EUAC values, respectively, in a simple visual representation using only the mean value of the alternative user cost. The cost variation between the mean values of these two choices is $282,000 (NPV) and $13,000 (EUAC). As a result, alternative 3 (rigid) is the most cost-effective pavement alternative option.

6.8.3 Total Costs

The total cost is calculated by adding the agency cost and the user cost. It is calculated using the NPV and EUAC values shown in Tables 6.14 and 6.15. The tables display the distribution's mean, standard deviation, and minimum and maximum values. Furthermore, the chosen statistics percentiles are 5 percent, 50 percent, 75 percent, and 95 percent.

Table 6.14: The NPVs total cost.

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Mean	$ 15,151,000	$ 18,064,000	$ 12,736,000	$ 14,672,000
Standard Deviation	$ 1,480,000	$ 2,474,000	$ 1,752,000	$ 1,959,000
Minimum	$ 10,547,000	$ 12,179,000	$ 6,442,000	$ 8,950,000
Maximum	$ 20,092,000	$ 29,831,000	$ 18,022,000	$ 22,153,000
Percentile 1 (5%)	$ 12,791,000	$ 14,418,000	$ 9,826,000	$ 11,427,000
Percentile 2 (50%)	$ 15,130,000	$ 17,862,000	$ 12,726,000	$ 14,653,000
Percentile 3 (75%)	$ 16,122,000	$ 19,527,000	$ 13,925,000	$ 15,996,000
Percentile 4 (95%)	$ 17,675,000	$ 22,441,000	$ 15,674,000	$ 17,900,000

Table 6.15: The EUACs total cost.

Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Mean	$ 726,000	$ 869,000	$ 611,000	$ 704,000
Standard Deviation	$ 65,000	$ 106,000	$ 84,000	$ 93,000
Minimum	$ 560,000	$ 595,000	$ 361,000	$ 402,000
Maximum	$ 965,000	$ 1,371,000	$ 894,000	$ 1,012,000
Percentile 1 (5%)	$ 625,000	$ 716,000	$ 472,000	$ 552,000
Percentile 2 (50%)	$ 724,000	$ 860,000	$ 610,000	$ 706,000
Percentile 3 (75%)	$ 766,000	$ 941,000	$ 670,000	$ 765,000
Percentile 4 (95%)	$ 845,000	$ 1,049,000	$ 748,000	$ 851,000

The most cost-effective pavement alternative option, based on the NPV and EUAC values, is alternative 3 (rigid). Alternative 1 is the most cost-effective flexible pavement option. The bell curve in figures 6.12 and 6.13 graphically depicts the dissimilarity of alternative user costs.

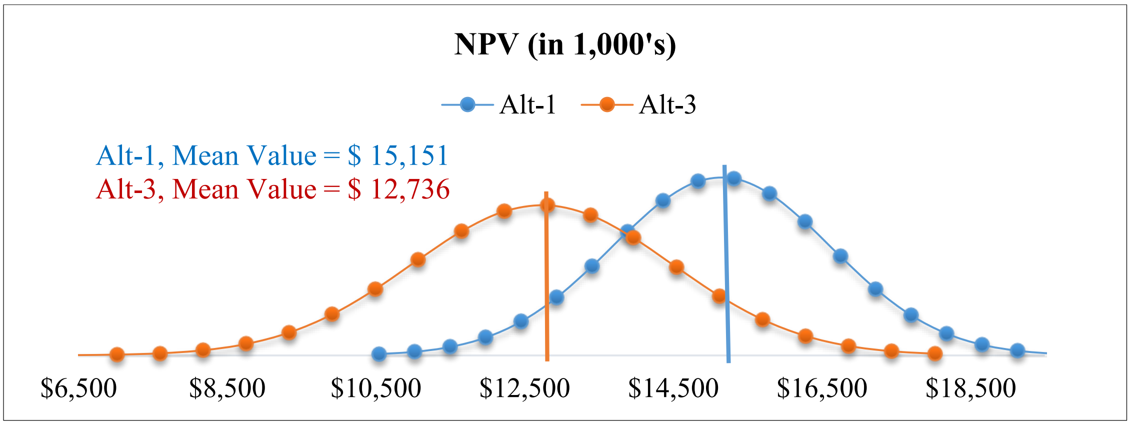

Figure 6.12: The NPVs bell curve of total cost.

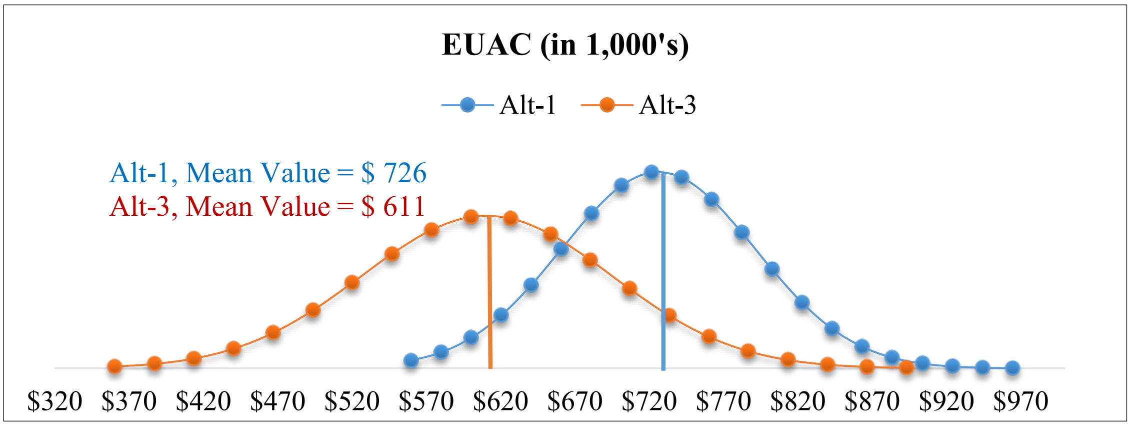

Figure 6.13: The EUACs bell curve of total cost.

Figures 6.12 and 6.13 depict the findings of the NPV and EUAC values, respectively, in a simple visual representation using only the mean value of the alternative total cost. The cost variation between the mean values of these two choices is $241,5000 (NPV) and $115,000 (EUAC). As a result, alternative 3 (rigid) is the most cost-effective pavement alternative option.

6.9 Deterministic Result Analysis

6.9.1 Design Life 20 Years and Life Cycle Cost Analysis 40 Years

The total cost of economic flexible pavement (alternative 1) is $14,977,119, which includes 93.5 percent agency and 6.5 percent user costs. Similarly, the total cost of economic rigid pavement (alternative 3) is $12,574,668. (94.84 percent agency costs and 5.16 percent user costs). Alternative 1 is 19.11 percent more expensive than alternative 3. It indicates that alternative 3 is the most cost-effective of the pavement alternatives.

6.9.2 Design Life 30 Years and Life Cycle Cost Analysis 40 Years

The total cost of economic flexible pavement (alternative 1) is $1,500,576, which includes 93.51 percent agency and 6.49 percent user costs. Similarly, the total cost of economic rigid pavement (alternative 3) is $12,583,105. (94.84 percent agency costs and 5.16 percent user costs). Alternative 1 is 19.23 percent more expensive than alternative 3. It indicates that alternative 3 is the most cost-effective of the pavement alternatives.

6.9.3 Design Life 40 Years and Life Cycle Cost Analysis 40 Years

The total cost of economic flexible pavement (alternative 1) is $15,022,070, which includes 93.52 percent agency and 6.48 percent user costs. Similarly, the total cost of economic rigid pavement (alternative 3) is $12,681,629. (94.88 percent agency costs and 5.12 percent user costs). Alternative 1 is 18.46 percent more expensive than alternative 3. It indicates that alternative 3 is the most cost-effective of the pavement alternatives.

6.10 Normal Probabilistic Result Analysis

6.10.1 Design Life 20 Years and Life Cycle Cost Analysis 40 Years

The total cost of economic flexible pavement (alternative 1) is $15,151,000, which includes 93.222 percent agency and 6.778 percent user costs. Similarly, the total cost of economic rigid pavement (alternative 3) is $11,991,000. (94.151 percent agency costs and 5.849 percent user costs). Alternative 1 is 18.96 percent more expensive than alternative 3. It indicates that alternative 3 is the most cost-effective of the pavement alternatives.

6.10.2 Design Life 30 Years and Life Cycle Cost Analysis 40 Years

The total cost of economic flexible pavement (alternative 1) is $15,176,000, which includes 93.223 percent agency and 6.767 percent user costs. Similarly, the total cost of economic rigid pavement (alternative 3) is $12,741,000. (94.153 percent agency costs and 5.847 percent user costs). Alternative 1 is 19.11 percent more expensive than alternative 3. It indicates that alternative 3 is the most cost-effective of the pavement alternatives.

6.10.3 Design Life 40 Years and Life Cycle Cost Analysis 40 Years

The total cost of economic flexible pavement (alternative 1) is $15,196,000, which includes 93.242 percent agency and 6.758 percent user costs. Similarly, the total cost of economic rigid pavement (alternative 3) is $12,840,000. (94.198 percent agency costs and 5.802 percent user costs). Alternative 1 is 18.34 percent more expensive than alternative 3. It indicates that alternative 3 is the most cost-effective of the pavement alternatives.

6.11 Summary of Life Cycle Cost Analysis in Dollars Per Square Yard

The life cycle cost of the pavements is summarized in Table 6.16 in $/sq. yd.

Table 6.16: Life cycle cost analysis values in $/sq. yd.

SL No.	Pavement Alternatives	Design Life, Year	Analysis Period, Year	Life Cycle Cost Analysis, $/sq. yd.	
				Net Present Value	AirCost Software
1	Alternative 1	20	40	66.05	85.58
2	Alternative 2	20	40	74.93	101.22
3	Alternative 3	20	40	63.26	71.86
4	Alternative 4	20	40	65.36	82.79
5	Alternative 1	30	40	66.15	85.73
6	Alternative 2	30	40	74.99	99.93
7	Alternative 3	30	40	63.33	71.9
8	Alternative 4	30	40	66.08	83.93
9	Alternative 1	40	40	66.23	85.84
10	Alternative 2	40	40	75.04	101.37
11	Alternative 3	40	40	63.85	72.47
12	Alternative 4	40	40	66.61	84.75

6.12 Conclusion

The pavement's life-cycle cost is calculated using a single discount rate. The Net Present Value method determines only the pavement material costs. AirCost software analyzes initial construction costs, supplemental costs, and maintenance and rehabilitation costs, etc.

CHAPTER 7

COST-EFFECTIVENESS ANALYSIS

7.1 General

This chapter summarizes the life cycle cost analysis results of pavement alternatives. It is carried out using the Net Present Value (NPV) method and the AirCost software analysis. The economic pavement is chosen based on the pavement's life cycle cost. A sensitivity analysis is also performed on the chosen pavement. It aids in determining the most cost-effective pavement option.

7.2 Life-Cycle Cost Analysis Outcome

The pavement life cycle cost is computed in Chapter 6, and the results are presented in the appendix (see Appendix-F and Appendix-G).

7.2.1 Net Present Value Result Analysis

The average life cycle cost of the pavement is 67.66 $ per square yard. It is compared to the alternative pavement life cycle costs. The serial number 3 (alternative 3) rigid pavement with a Portland cement concrete unbond overlay has the lowest life cycle cost. Alternative 3 is the least cost-effective pavement, followed by the serial numbers 3, 7, and 11. These alternatives have the best chance of success with the least amount of risk. In terms of flexible pavement life cycle cost, serial number 1 (alternative 1) with a two-hot mix asphalt overlay has the lowest life cycle cost. The cheapest pavement is Alternative 1, followed by Serial Numbers 1, 5, and 9. These alternatives have the best chance of success with the least amount of risk. Serial numbers 1, 4, 5, 7, 8, 9, 11, and 12 have life cycle costs that are within 10 percent of the average life cycle cost. Also, serial numbers 2, 6, and 10 are the most expensive, costing more than 10 percent of the average life cycle costs. So, the study found serial number 3 (alternative 3) is the most cost-effective pavement design alternative. Table 7.1 shows the life cycle cost ranking of the 12th number of pavement alternatives.

Table 7.1: Summary of the life cycle cost analysis (using the net present value method).

Serial Number	Pavement Alternatives	Design Life, Year	LCCA Analysis Period, Year	Initial Cost, $/sq. yd.	Net Present Value, $/sq. yd.	Mean LCC, $/sq. yd.	Initial Cost Ranking	Net Present Value Ranking	Deviation From The Mean, $/Sq. yd.	Construction Time, Days	Cost Variation, %	Simplified Risk Ratio, %	Chance For Success, %	Remarks
1	Alt-1	20	40	48.31	66.05	67.66	1	5	-2.37	90	97.63	73.14	5	Within 10%
2	Alt-2	20	40	48.31	74.93		1	10	10.75	105	110.75	64.47	10	Exceeds 10%
3	Alt-3	20	40	54.32	63.26		4	1	-6.50	90	93.50	85.87	1	Most Promising Within 10%
4	Alt-4	20	40	54.32	65.36		4	4	-3.39	90	96.61	83.11	4	Within 10%
5	Alt-1	30	40	48.41	66.15		2	7	-2.23	90	97.77	73.18	7	Within 10%
6	Alt-2	30	40	48.41	74.99		2	11	10.84	105	110.84	64.56	11	Exceeds 10%
7	Alt-3	30	40	55.13	63.33		5	2	-6.40	90	93.60	87.05	2	Within 10%
8	Alt-4	30	40	55.13	66.08		5	6	-2.33	90	97.67	83.43	6	Within 10%
9	Alt-1	40	40	48.48	66.23		3	8	-2.11	90	97.89	73.20	8	Within 10%
10	Alt-2	40	40	48.48	75.04		3	12	10.91	105	110.91	64.61	12	Exceeds 10%
11	Alt-3	40	40	55.72	63.85		6	3	-5.63	90	94.37	87.27	3	Within 10%
12	Alt-4	40	40	55.72	66.61		6	9	-1.55	90	98.45	83.65	9	Within 10%

7.2.2 AirCost Software

The average life cycle cost of the pavement is 85.61 $ per square yard. It is compared to the alternative pavement life cycle costs. The serial number 3 (alternative 3) rigid pavement with a Portland cement concrete unbond overlay has the lowest life cycle cost. Alternative 3 is the least cost-effective pavement, followed by the serial numbers 3, 7, and 11. These alternatives have the best chance of success with the least amount of risk. In terms of flexible pavement life cycle cost, serial number 1 (alternative 1) with a two-hot mix asphalt overlay has the lowest life cycle cost. The cheapest pavement is alternative 1, followed by serial numbers 1, 5, and 9. These alternatives have the best chance of success with the least amount of risk. Serial numbers 1, 4, 5, 8, 9, and 12 have life cycle costs that are within 10 percent of the average life cycle cost. Additionally, serial numbers 7 and 11 is also cheapest pavement as compare to serial number 3. The serial numbers 2, 6, and 10 are the most expensive, costing more than 10 percent of the average life cycle costs. So, the study found serial number 3 (alternative 3) is the most cost-effective pavement design alternative. Table 7.2 shows the life cycle cost ranking of the 12th number of pavement alternatives.

Table 7.2: Summary of the life cycle cost analysis (using the AirCost software).

Serial Number	Pavement Alternatives	Design Life, Year	LCCA Analysis Period, Year	Initial Cost, $/sq. yd.	Net Present Value $/sq. yd.	Mean LCC, $/sq. yd.	Initial Cost Ranking	Net Present Value Ranking	Deviation from the Mean, $/sq. yd.	Construction Time, Days	Cost Variation, %	Simplified Risk Ratio, %	Chance for Success, %	Remarks
1	Alt-1	20	40	48.31	85.58	85.61	1	7	-0.04	90	99.96	56.45	7	Within 10%
2	Alt-2	20	40	48.31	101.2		1	11	18.23	105	118.23	47.73	11	Exceeds 10%

Table 7.2: Summary of the life cycle cost analysis (using the AirCost software) continued.

Serial Number	Pavement Alternatives	Design Life, Year	LCCA Analysis Period, Year	Initial Cost, $/sq. yd.	Net Present Value $/sq. yd.	Mean LCC, $/sq. yd.	Initial Cost Ranking	Net Present Value Ranking	Deviation from the Mean, $/sq. yd.	Construction Time, Days	Cost Variation, %	Simplified Risk Ratio, %	Chance for Success, %	Remarks
3	Alt-3	20	40	54.32	71.86	85.61	4	1	-16.07	90	83.93	75.59	1	Most Promising Less 10%
4	Alt-4	20	40	54.32	82.79		4	4	-3.30	90	96.70	65.61	4	Within 10%
5	Alt-1	30	40	48.41	85.73		2	8	0.14	90	100.14	56.47	8	Within 10%
6	Alt-2	30	40	48.41	99.93		2	10	16.72	105	116.72	48.44	10	Exceeds 10%
7	Alt-3	30	40	55.13	71.9		5	2	-16.02	90	83.98	76.68	2	Less 10%
8	Alt-4	30	40	55.13	83.93		5	5	-1.97	90	98.03	65.69	5	Within 10%
9	Alt-1	40	40	48.48	85.84		3	9	0.26	90	100.26	56.48	9	Within 10%
10	Alt-2	40	40	48.48	101.4		3	12	18.40	105	118.40	47.82	12	Exceeds 10%
11	Alt-3	40	40	55.72	72.47		6	3	-15.35	90	84.65	76.89	3	Less 10%
12	Alt-4	40	40	55.72	84.75		6	6	-1.01	90	98.99	65.75	6	Within 10%

7.3 Trial-by-Trial Comparison of Probability

The pavement strategy with the highest overall probability is chosen as the preferred strategy. More research is needed to determine whether it is the most cost-effective option.

Tables 7.3, 7.4, and 7.5 present the deterministic (NPV) results for four alternative strategies with design lives of 20, 30, and 40 years, respectively, and 700 trials in columns 2–5. Columns 6–11 indicate whether a specific strategy has a lower cost than one or all other alternatives for a given trial, with values of 0 or 1—0 indicating that the cost is not lower, and 1 indicating that the cost is lower.

Table 7.3: Trial-by-trial process for tallying life cycle cost results (design life 20 years).

Iteration No.	Net Present Value				Condition						Lowest life-cycle cost			
	Alt-1	Alt-2	Alt-3	Alt-4	Alt-1<Alt-2	Alt-1<Alt-3	Alt-1<Alt-4	Alt-2<Alt-3	Alt-2<Alt-4	Alt-3<Alt-4	Alt-1	Alt-2	Alt-3	Alt-4
1	14,863,748	14,096,480	10,816,142	14,591,954	0	0	0	0	1	1	0	0	1	0
2	16,105,040	24,678,281	14,361,014	15,610,478	1	0	0	0	0	1	0	0	1	0
3	12,108,422	16,612,633	11,833,837	15,065,703	1	0	1	0	0	1	0	0	1	0

Table 7.3: Trial-by-trial process for tallying life cycle cost results (design life 20 years) continued.

Iteration No.	Net Present Value				Condition						Lowest life-cycle cost			
	Alt-1	**Alt-2**	**Alt-3**	**Alt-4**	**Alt-1<Alt-2**	**Alt-1<Alt-3**	**Alt-1<Alt-4**	**Alt-2<Alt-3**	**Alt-2<Alt-4**	**Alt-3<Alt-4**	**Alt-1**	**Alt-2**	**Alt-3**	**Alt-4**
700	17,292,266	18,797,912	119,57,256	16,986,116	1	0	0	0	0	1	0	0	1	0
Total					604	103	304	18	97	553	73	9	499	119

Table 7.4: Trial-by-trial process for tallying life cycle cost results (design life 30 years).

Iteration No.	Net Present Value				Condition						Lowest life-cycle cost			
	Alt-1	**Alt-2**	**Alt-3**	**Alt-4**	**Alt-1<Alt-2**	**Alt-1<Alt-3**	**Alt-1<Alt-4**	**Alt-2<Alt-3**	**Alt-2<Alt-4**	**Alt-3<Alt-4**	**Alt-1**	**Alt-2**	**Alt-3**	**Alt-4**
1	14,888,508	14,024,899	10,818,157	14,791,183	0	0	0	0	1	1	0	0	1	0
2	16,132,756	24,213,354	14,342,790	15,827,995	1	0	0	0	0	1	0	0	1	0
3	12,126,898	16,426,099	11,841,994	15,267,488	1	0	1	0	0	1	0	0	1	0
700	17,315,259	18,523,091	11,938,765	17,208,189	1	0	0	0	0	1	0	0	1	0

Table 7.4: Trial-by-trial process for tallying life cycle cost results (design life 30 years) continued.

Iteration No.	Net Present Value				Condition						Lowest life-cycle cost			
	Alt-1	Alt-2	Alt-3	Alt-4	Alt-1<Alt-2	Alt-1<Alt-3	Alt-1<Alt-4	Alt-2<Alt-3	Alt-2<Alt-4	Alt-3<Alt-4	Alt-1	Alt-2	Alt-3	Alt-4
Total					586	103	326	22	125	570	76	11	509	104

Table 7.5: Trial-by-trial process for tallying life cycle cost results (design life 40 years).

Iteration No.	Net Present Value				Condition					Lowest life-cycle cost				
	Alt-1	Alt-2	Alt-3	Alt-4	Alt-1<Alt-2	Alt-1<Alt-3	Alt-1<Alt-4	Alt-2<Alt-3	Alt-2<Alt-4	Alt-3<Alt-4	Alt-1	Alt-2	Alt-3	Alt-4
1	14,907,468	14,136,058	10,900,292	14,935,032	0	0	1	0	1	1	0	0	1	0
2	16,153,980	24,685,730	14,450,686	15,985,049	1	0	0	0	0	1	0	0	1	0
3	12,141,045	16,641,084	11,930,115	15,413,183	1	0	1	0	0	1	0	0	1	0
700	17,332,867	18,826,146	12,023,622	17,368,533	1	0	1	0	0	1	0	0	1	0
Total					603	112	343	22	122	572	80	11	507	102

The results of all trials are tallied at the bottom of the tables, and it is clear that alternative 3 has the lowest life cycle cost in 499, 509, and 507 of the 700 total trials. Tables 7.6, 7.7, and 7.8 summarize these results in terms of a probability matrix.

Table 7.6: Life cycle cost probability matrix for trial-by-trial comparison (design life 20 years).

Pavement Strategy Alternative	Probability of Life Cycle Cost of:				Probability of Life Cycle Cost (LCC), %
	Alt-1 < LCC	Alt-2 < LCC	Alt-3 < LCC	Alt-4 < LCC	
Alt-1	X	96	597	396	10.43
Alt-2	604	X	682	603	1.29
Alt-3	103	18	X	147	71.29
Alt-4	304	97	553	X	17.00

Table 7.7: Life cycle cost probability matrix for trial-by-trial comparison (design life 30 years).

Pavement Strategy Alternative	Probability of Life Cycle Cost of:				Probability of Life Cycle Cost of:
	Alt-1 < LCC	Alt-2 < LCC	Alt-3 < LCC	Alt-4 < LCC	
Alt-1	X	114	597	374	10.86
Alt-2	586	X	678	575	1.57
Alt-3	103	22	X	130	72.71
Alt-4	326	125	570	X	14.86

Table 7.8: Life cycle cost probability matrix for trial-by-trial comparison (design life 40 years).

Pavement Strategy Alternative	Probability of Life Cycle Cost of:				Probability of Life Cycle Cost of:
	Alt-1 < LCC	Alt-2 < LCC	Alt-3 < LCC	Alt-4 < LCC	
Alt-1	X	97	588	357	11.43
Alt-2	603	X	678	578	1.57
Alt-3	112	22	X	128	72.43
Alt-4	343	122	572	X	14.57

Alternative 3 has the lowest life cycle cost of the four alternatives, with probabilities of 71.29, 72.71, and 72.43 percent, respectively.

7.4 Economic Pavement Selection

Table 7.9 depicts the cost scenarios for the economic flexible (alternative 1) and rigid (alternative 3) pavement alternatives.

Table 7.9: The economic flexible and rigid pavements life-cycle cost scenarios.

LCCA Serial Number	Referenced Design Name	Design Life, Year	Pavement Alternatives	Initial Cost		LCCA Analysis Period, Year	Total Cost Investment		Net Present Value (NPV) Method		AirCost LCCA Software	
				$/sq. yd.	Alt-3 > Alt-1, %		$/sq. yd.	Alt-1 > Alt-3, %	$/sq. yd.	Alt-1 > Alt-3, %	$/sq. yd.	Alt-1 > Alt-3, %
1	F-02-a-20	20	Alt-1	48.31	12.44	40	93.09	7.82	66.05	4.41	85.58	19.09
3	R-04-a-20		Alt-3	54.32		40	86.34		63.26		71.86	
5	F-02-a-30	30	Alt-1	48.41	13.88	40	93.19	8.73	66.15	4.45	85.73	19.24
7	R-04-a-30		Alt-3	55.13		40	85.71		63.33		71.9	
9	F-02-a-40	40	Alt-1	48.48	14.93	40	93.26	8.08	66.23	3.73	85.84	18.45
11	R-04-a-40		Alt-3	55.72		40	86.29		63.85		72.47	

This table provides a clear comparison between alternatives 1 and 3 in terms of initial cost, investment cost, and life cycle cost. It is clear that alternative 1 (flexible pavement) has the lowest initial cost but a higher investment cost and life-cycle cost. Similarly, alternative 3 (rigid pavement) exhibits the inverse trend.

The initial cost difference between alternatives 1 and 3 is gradually increased over the design life of 20, 30, and 40 years, respectively. Instead of a 40-year investment cost analysis, it is discovered that the minimum value is reached for a design life of 20 years, and the highest value is reached for a design life of 30, but this value decreases for a design life of 40 years. The minimum value of the life-cycle cost (NPV and AirCost) begins at 20 years, rises to the maximum value at 30 years, and falls to the minimum value at 40 years lower than 20 years.

7.5 Economical Pavement Projected Cost Scenario

This study identifies the most cost-effective rigid pavement (alternative 3, R-04-a-20) and its alternative flexible pavement (alternative 1, F-02-a-20). Overall, this study finds that rigid pavement has a higher initial cost but lower future maintenance and rehabilitation costs, whereas flexible pavement has a lower initial cost but higher future maintenance and rehabilitation costs. Furthermore, rigid pavement has a higher salvage value than flexible pavement. Finally, the study determines that alternative 1 is the most promising alternative to alternative 3 for any analysis period. The cost projections are shown below the sections.

7.5.1 Flexible Pavement

The flexible pavement (F-02-a-20, alternative 1) was designed to last 20 years, but maintenance and rehabilitation activities were carried out to extend its service life to 40 years. A total investment of $16,291,964 is required over the lifespan of this pavement. The rehabilitation costs for 15 and 30 years remain the same, as shown in the Figure 7.1. At the age of 40, the salvage value is still 10.1 percent.

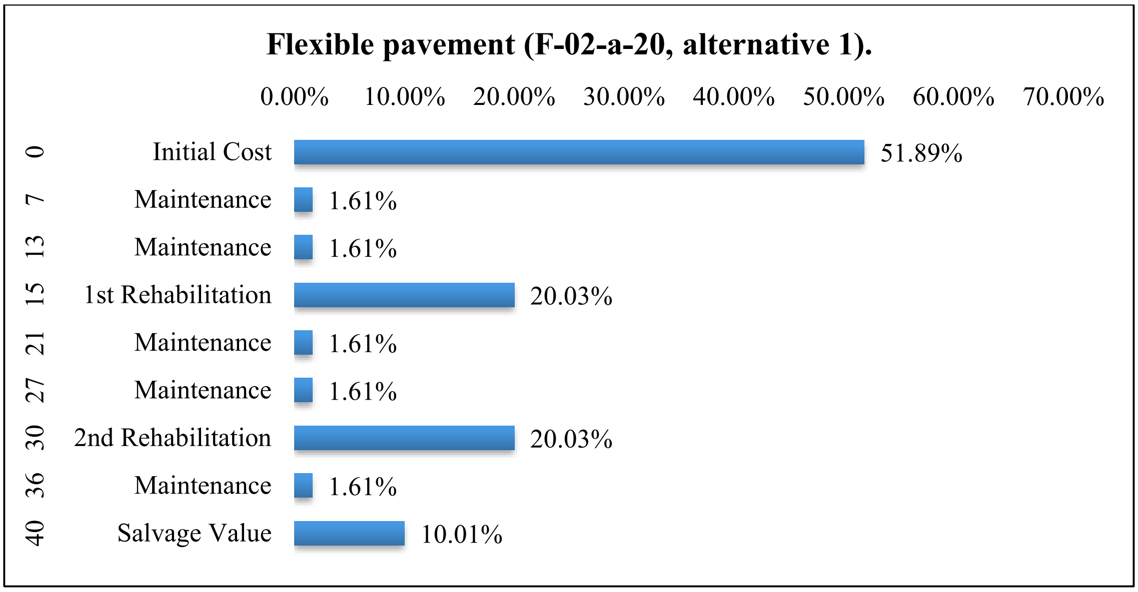

Figure 7.1: Flexible pavement's entire life cycle investment cost (F-02-a-20, alternative 1).

7.5.2 Rigid Pavement

The rigid pavement (R-04-a-20, alternative 3) was designed to last 20 years, but maintenance and rehabilitation activities were carried out to extend its service life to 40 years. A total investment of $15,110,143 is required over the lifespan of this pavement. As shown in Figure 7.2, a one-time rehabilitation cost of 32.05 percent is required at the age of 20. A significant amount of salvage value, 31.46 percent, remains at the age of 40 years.

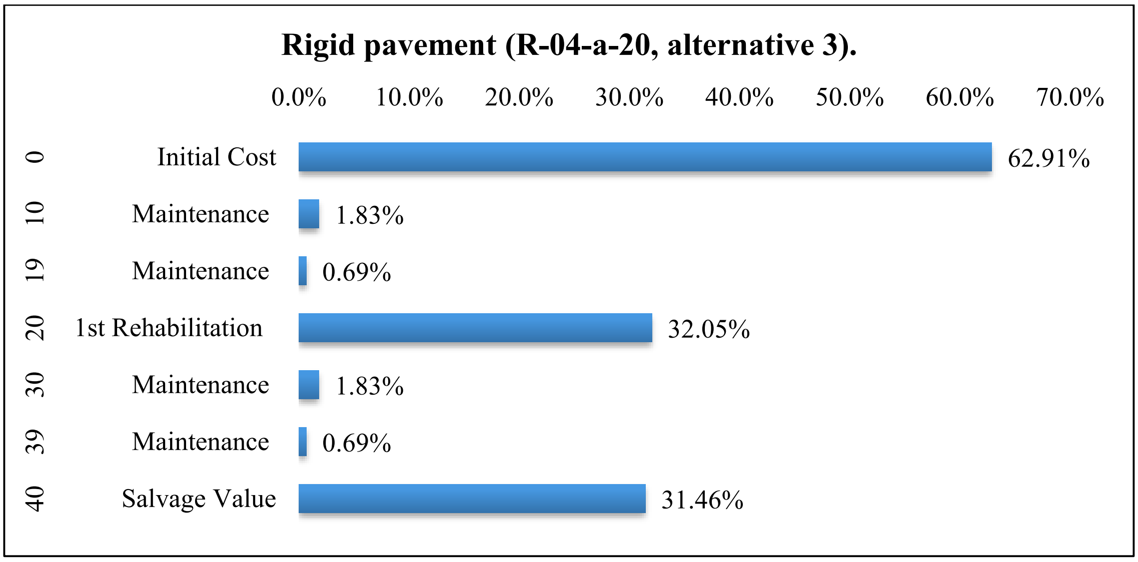

Figure 7.2: Rigid pavement's entire life cycle investment cost (R-04-a-20, alternative 3).

7.6 Sensitivity Analysis

The life cycle cost analysis (40 years) of the study revealed that rigid pavement (alternative 3) is the most cost-effective pavement option throughout all the design life (20, 30, and 40 years). The AirCost software is used to perform a deterministic sensitivity analysis, as shown in Table 7.10 and Figure 7.3 (see Appendix-G). The following discount rates are used in the analysis: 3, 3.5, 4, 4.5, and 5 percent.

Table 7.10: Alternative 3's deterministic life-cycle cost sensitivity analysis.

Pavement	**Reference Design**	**Design Life, Year**	**LCCA Analysis Period, Year**	**Cost Item**	**Discount Rate, %**				
					3	**3.5**	**4**	**4.5**	**5**
Alternative 3	R-04-a-20, Alt-3	20	40	Agency Cost	$ 12,641,174	$ 12,266,058	$ 11,925,630	$ 11,616,100	$ 11,334,124
	R-04-a-30, Alt-3	30	40		$ 12,622,138	$ 12,261,520	$ 11,934,066	$ 11,636,149	$ 11,364,567
	R-04-a-40, Alt-3	40	40		$ 12,721,619	$ 12,360,520	$ 12,032,590	$ 11,734,202	$ 11,462,153
	R-04-a-20, Alt-3	20	40	User Cost	$ 701,906	$ 674,170	$ 649,038	$ 626,239	$ 605,531
	R-04-a-30, Alt-3	30	40		$ 701,906	$ 674,170	$ 649,038	$ 626,239	$ 605,531
	R-04-a-40, Alt-3	40	40		$ 701,906	$ 674,170	$ 649,038	$ 626,239	$ 605,531
	R-04-a-20, Alt-3	20	40	Total Cost	$ 13,343,081	$ 12,940,228	$ 12,574,668	$ 12,242,339	$ 11,939,655
	R-04-a-30, Alt-3	30	40		$ 13,324,045	$ 12,935,690	$ 12,583,105	$ 12,262,388	$ 11,970,098
	R-04-a-40, Alt-3	40	40		$ 13,423,525	$ 13,034,690	$ 12,681,629	$ 12,360,441	$ 12,067,684

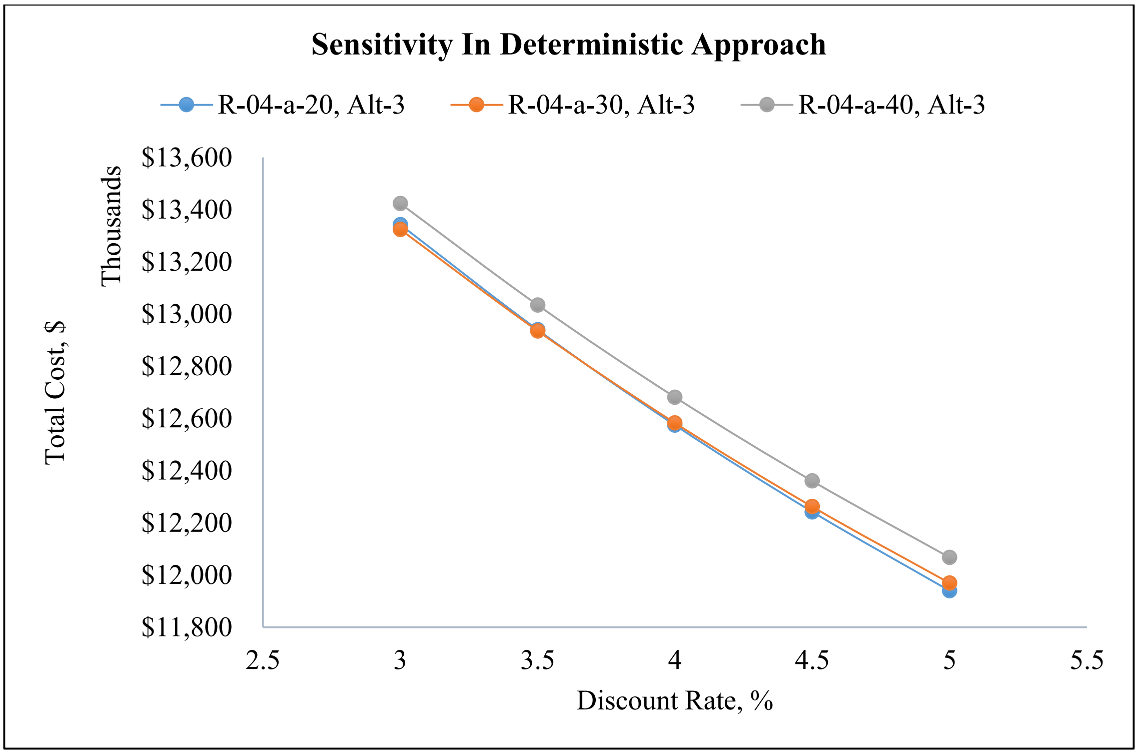

Figure 7.3: Total cost summary of alternative 3 sensitivity analysis (deterministic).

The figure shows that as the discount rate rises, the total cost decreases. Total costs for the design life of 20 and 30 years are overlapped at a discount rate of 3.5 to 4 percent.

7.7 Conclusion

Flexible pavement has higher investment costs, maintenance and rehabilitation costs, and life-cycle costs than rigid pavement. The sensitivity analysis of rigid pavement reveals that the life cycle cost decreases as the discount rate increases. Life cycle cost analysis is an analysis of the total cost of a pavement over its entire life span.

CHAPTER 8

CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

The objective of this study is to design multiple airport pavements with different types of materials used in the layers, and to analyze the respective pavement life-cycle costs. The findings are as follows:

FAARFIELD software was used to design multiple flexible and rigid pavement structural thicknesses, and all of the pavements fulfill the FAA's minimum design criteria. During the design stage of flexible and rigid pavement, it was discovered that all values of subbase structural thickness of P-219 recycled concrete aggregate and P-209 crushed aggregate remained constant.

The economic pavements were chosen based on their initial cost. Flexible pavement costs 12.4 percent, 13.88 percent, and 14.93 percent more than rigid pavement (design life of 20, 30, and 40 years, respectively). This cost is compared to a design life of 20–30 years and 20–40 years, with an increasing cost rate of 0.21 percent and 0.35 percent for flexible pavement, and 1.49 percent and 2.58 percent for rigid pavement, respectively. One of the most important findings was the low-cost pavement design materials. The layer materials for flexible pavement (P-401, P-403, and P-219) and rigid pavement (P-501, P-306, and P-219) are cost-effective for any design life.

The subbase material P-219 recycled concrete aggregate was used for both flexible and rigid pavements is another major finding. As surface and stabilized base remain constant, then the subbase thickness is compared with the design life of 20–30 years and 20–40 years, with an increasing thickness rate of 2.03 percent and 3.59 percent for flexible pavement and 1.79 percent and 3.08 percent for rigid pavement surfaces, when the stabilized base and subbase remain constant.

Overlay design was conducted for pavement long-term (40 year) analysis. As per study results, flexible pavements on hot-mix asphalt and Portland cement concrete overlay thickness are required minimum and thick. The rigid pavement on hot-mix asphalt and Portland cement concrete unbond overlay thickness is required minimum and thin.

According to the life cycle cost analysis, the rigid pavement (R-04-a-20, Alt-alternative 3) is the most cost-effective. This pavement has a higher initial cost but has the lowest maintenance and rehabilitation costs over its life span, as well as a significant amount of salvage value retained at the end of its life. It has the highest chance of success and the lowest risk.

Flexible pavement (F-02-a-20, alternative 1) is a cost-effective alternative to rigid pavement. The life cycle cost analysis revealed that it is 4.41 percent (NPV) and 19.09 percent (AirCost) more expensive than rigid pavement. It has the lowest initial cost but higher maintenance and rehabilitation costs over its life span, with only a small amount of salvage value remaining at the end. Trial by trial analysis reveals the rigid pavements (alternative 3) have high chances of success in the life cycle cost analysis. According to the sensitivity analysis of rigid pavement (alternative 3), the life cycle cost decreases as the discount rate increases.

8.2 Recommendations of the Study

Life cycle cost analysis is an important technique for determining the most cost-effective solution for airport new pavement construction or renovation. This will allow decision makers to make quick decisions when selecting a pavement type, defining structure and mix types, construction methods, timing, and maintenance and rehabilitation strategy. It is applicable not only to airport pavement but also to other transportation-related sectors. The study recommendations are given below.

i. The cost of construction has a significant impact on the type of pavement selection. For example, if the initial stage budget is limited and subsequent years' allocating funds will increase, then flexible pavement (F-02-a-20, alternative 1) with two hot-mix asphalt overlays can be chosen as a cost-effective pavement option. It has a lower initial cost but a higher maintenance and rehabilitation cost.

ii. Or else, if the initial construction budget is available and future years' allocating funds are available. The rigid pavement (R-04-a-20, alternative 3) with a single Portland cement concrete unbond overlay is now the most cost-effective option. Because it has a high initial cost but the lowest maintenance and rehabilitation cost.

iii. The P-219, Recycled concrete aggregate, is a waste construction material that can be used as a subbase material in new pavement construction to save landfill space and reduce the demand for virgin material and preserve the environment, and save landfill space. Also, it is less expensive than virgin materials.

iv. For the new pavement design in Bangladesh, a long-term design life (40 years) has been recommended. The rigid pavement scenario (R-04-a-40, alternative 3) and flexible pavement scenario (F-02-a-40, alternative 1) are considered the more sophisticated safe design modes. When compared to the design life of 20 years to 40 years with increasing cost rate, the life cycle cost of Net Present Value is 0.27 percent and 0.93 percent for alternative 1 and alternative 3, respectively. Similarly, in AirCost software, this rate rises to 0.30 percent, then 0.85 percent.

v. If the authorities do not want to use P-219 Recycle concrete aggregate, P-209 Crash aggregate can be substituted. Then the structural thickness and future maintenance and rehabilitation costs will remain the same, with the exception of a slight increase in the initial construction cost of the subbase.

vi. Finally, based on the study results, the decision has been taken to select rigid pavement (R-04-a-20, alternative 3) as the most economically cost-effective pavement.

8.3 Recommendations for Future Research

This research offers a comprehensive framework for airport pavement design as well as a life cycle cost analysis. It will help researchers and aviation authorities, particularly Civil Aviation Authority of Bangladesh, with future research and decision-making. There is a good chance that this research will be conducted on a large scale.

REFERENCES

[1] A Guide to Airfield Pavement Design and Evaluation (2011). Ministry of Defense, United Kingdom.

[2] Ahsan, H. M., Eleous, M., Hasan, M. E., Rahman, M. S., & Ahmed, F. (2014). Increasing Air Traffic Demand and Relevant Issues in Bangladesh. 2nd International Conference on Civil Engineering for Sustainable Development (ICCESD-2014), KUET. Khulna, Bangladesh.

[3] Airport Pavements – Benefits of Concrete Runways (2018). Cement Concrete & Aggregates Australia, Australia. [Retrieved from https://www.ccaa.com.au/imis_prod/documents/CCAA_Market_Info_Sheet_Concrete_Runway.pdf?hkey=df05767d-f831-4e33-95d4-682703418932]

[4] Alam, J. B., & Karim, D. M. (1998). Air Travel Demand Model for Domestic Air Transportation in Bangladesh. Journal of Civil Engineering, 26(1), 1-13.

[5] Civil Aviation Authority of Bangladesh (2019). All Airports. [Retrieved March 17, 2020, from http://caab.gov.bd/airportsf.html]

[6] Bangladesh - Air transport, passengers carried (2019). [Retrieved April 5, 2020, from IndexMundi : https://www.indexmundi.com/facts/bangladesh/indicator/IS.AIR.PSGR]

[7] BD achieves robust air traffic growth, facilities up-gradation now a must (2019). Bangladesh Monitor, Electronic Media. Dhaka, Bangladesh. [Retrieved April 3, 2020, from BD achieves robust air traffic growth, facilities up-gradation now a must: https://www.bangladeshmonitor.com/front_page/90/BD-achieves-robust-air-traffic-growth,-facilities-up-gradation-now-a-must]

[8] Brill, D. R., Kawa, I., & Gordon, H. F. (2004). Development of FAARFIELD airport pavement design software. Transportation Systems 2004 Workshop.

[9] Ceylan, H., Gopalakrishnan, K., & Kim, S. (2016). Innovative and sustainable airfield pavement engineering solutions. Institute for Transportation at Iowa State University. [Retrieved May 4, 2020, from International Airport Review: https://www.internationalairportreview.com/article/23208/innovative-sustainable-airfield-pavement-engineering-solutions/]

[10] Esfandani, M. T., Mansourian, A., & Babaei, A. (2013). Investigation of Runway Pavement Design Software and Determination of Optimization Software. Journal of Basic and Applied Scientific Research, 3(4), 143-150.

[11] Extended Airport Pavement Life (2011). Federal Aviation Administration, Website. [Retrieved April 3, 2020, from Federal Aviation Administration (FAA):https://www.airporttech.tc.faa.gov/Airport-Pavement/Extended-Airport-Pavement-Life]

[12] FAARFIELD 1.42 Software (2017). [Retrieved January 12, 2018, from Federal Aviation Administration: https://www.airporttech.tc.faa.gov/Products/Airport-Pavement-Software-Programs/Airport-Software-Detail/ArtMID/3708/ArticleID/4/FAARFIELD-142]

[13] Federal Aviation Administration (2014). Standards for Specifying Construction of Airports, Advisory Circular: 150/5370-10G. U.S. Department of Transportation, Washington DC.

[14] Federal Aviation Administration (2016). Airport Pavement Design and Evaluation, Advisory circular: 150/5320-6F. U.S. Department of Transportation, Washington DC.

[15] Flexible Pavement Design for Airfields (1993). Departments of the Navy, Army, and Air-Force. Washington, DC.

[16] Gransberg, D. D. (2005). Life Cycle Evaluation Criteria for Design-Build Highway Pavement Projects. PhD Thesis, University of Colorado.

[17] Gransberg, D. D. (2010). Life Cycle Costing for Engineers, Boca Rotan: CRC Press. In Construction Management and Economics (pp. 1113-1114).

[18] Kirk, Stephen J. & Dell'Isola, Alphonse J. (1985). Life Cycle Costing for Design Professionals. McGraw-Hill.

[19] Airfield Asphalt Pavement Technology Program (2011). Life Cycle Cost Analysis for Airport Pavements, Final Report 06-06. Auburn, Alabama.

[20] McNerney, M. T., & Harrison, R. (1995). Full-Cost Approach to Airport Pavement Management. McGraw-Hill, First Edition, 121–130.

[21] Mitchell, G. L. (2003). Life Cycle Cost Analysis, Warren Field Airport Runway 5-23 Rehabilitation. American Concrete Pavement Association, Southeast Chapter. Washington, DC.

[22] Guide for Mechanistic-Empirical Design of New and Rehabilitated Pavement Structure (2004). National Cooperative Highway Research Program, NCHRP Project 1-37A, Washington, DC.

[23] OMB Circular A-94 (2009). Discount Rate for Cost-effectiveness, Lease Purchase, and Related Analysis, Appendix C. Washington, DC. [Retrieved 4 25, 2020]

[24] Operational Life of Airport Pavements (2004). Federal Aviation Administration, Website. [Retrieved January 4, 2020, from : https://www.airporttech.tc.faa.gov/Products/Airport-Safety-Papers-Publications/Airport-Safety-Detail/ArtMID/3682/ArticleID/130/Operational-Life-of-Airport-Pavements]

[25] Pavement Interactive (2020). Pavement Types, Online. [Retrieved April 12, 2020, from https://pavementinteractive.org/reference-desk/pavement-types-and-history/pavement-types/]

[26] Pavement Interactive (2007). Life-Cycle Cost Analysis. Online [Retrieved April 23, 2020, from https://pavementinteractive.org/reference-desk/pavement-management/analysis/life-cycle-cost-analysis/]

[27] Rahman, M. M., Das, A., Barua, S., & Khan, M. N. (2015). An Evaluation of Life Cycle Cost Analysis of Airport Pavement. International Journal of Engineering Research & Technology, 4(8).

[28] Rangaraju, R. P., Amirkhan, S., & Guven, Z. (2008). Life Cycle Cost Analysis for Pavement Type Selection. Department of Civil Engineering, Clemson University. Washington, DC.

[29] Sharif, M. O. (2013). Life Cycle Costing Analysis using the Mechanistic-Empirical Pavement Design Guide for Flexible Pavements. MASc Thesis, Department of Civil Engineering, Ryerson University. Toronto, Canada.

[30] Smith, T. (2010). Life Cycle Cost Analysis / Assessment of Airfield Pavements. Building a Sustainable Tomorrow. SWIFT Conference.

[31] Walls, J., & Smith, M. (1998). Life Cycle Cost Analysis in Pavement Design: In Search of Better Investment Decisions. U.S. Federal Highway Administration. Washington, DC.

[32] White, D. G. (2017). Airport Pavement Essentials. Australian Airports Association, Australia.

[33] International Civil Aviation Organization (2010). Aircrafts Annual Growth Rate in Asian Sub-Regional.

APPENDIX-A

AIRPORT PAVEMENT DESIGN STRUCTURAL THICKNESS

Name: F-01-a-20
The structure is New Flexible. Asphalt CDF = 0.4472.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 10.53.00.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	23.15	73892	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.15 in

Name: F-01-b-20
The structure is New Flexible. Asphalt CDF = 0.5097.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 11.12.29.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-209 Cr Ag	20.4	67711	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 31.40 in

Name: F-02-a-20
The structure is New Flexible. Asphalt CDF = 0.4473.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 11.24.06.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	23.15	73890	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.15 in

Name: F-02-b-20
The structure is New Flexible. Asphalt CDF = 0.5097.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 11.27.12.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	23.15	73890	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 31.40 in

Name: F-01-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.7034.
Design Life = 30 years.
A design for this section was completed on 04-27-19 at 20.36.57.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	23.62	74871	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.62 in

Name: F-01-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.7795.
Design Life = 30 years.
A design for this section was completed on 04-27-19 at 20.42.58.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-209 Cr Ag	20.92	68949	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 31.92 in

Name: F-02-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.7034.
Design Life = 30 years.
A design for this section was completed on 04-27-19 at 21.01.35.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	23.62	74871	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.62 in

Name: F-02-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.7795.

Design Life = 30 years.
A design for this section was completed on 04-27-19 at 21.09.54.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-219 Recycled Conc. Agg.	20.92	68949	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 31.92 in

Name: F-01-a-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.9900.
Design Life = 40 years.
A design for this section was completed on 04-27-19 at 20.39.31.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	23.98	75591	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.98 in

Name: F-01-b-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.9757.
Design Life = 40 years.
A design for this section was completed on 04-27-19 at 21.21.37.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	5	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	22.9	73361	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.90 in

Name: F-02-a-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.9900.
Design Life = 40 years.
A design for this section was completed on 04-27-19 at 21.03.44.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	4	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	23.98	75591	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.98 in

Name: F-02-b-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Flexible. Asphalt CDF = 0.9757.
Design Life = 40 years.
A design for this section was completed on 04-27-19 at 21.20.02.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Surface	5	200000	0.35	0
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	22.9	73361	0.35	0
4	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 32.90 in

Name: R-01-a-20

The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 19.04.37.

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.23	4000000	0.15	650
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.23 in

Name: R-01-b-20

The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 19.25.06.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.09	4000000	0.15	650
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.09 in

Name: R-02-a-20

The structure is New Rigid.
Design Life = 20 years.

A design for this section was completed on 04-22-19 at 19.56.46.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.23	4000000	0.15	650
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.23 in

Name: R-02-b-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 20.20.16.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.09	4000000	0.15	650
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.09 in

Name: R-03-a-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 20.39.17.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.16	4000000	0.15	650
2	P-306 Lean Concrete	5	700000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.16 in

Name: R-03-b-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-22-19 at 21.12.00.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	19.98	4000000	0.15	650
2	P-306 Lean Concrete	7	700000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 32.98 in

Name: R-04-a-20
The structure is New Rigid.

Design Life = 20 years.
A design for this section was completed on 04-25-19 at 20.07.54.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.16	4000000	0.15	650
2	P-306 Lean Concrete	5	700000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.16 in

Name: R-04-b-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-25-19 at 22.56.26.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	19.99	4000000	0.15	650
2	P-306 Lean Concrete	7	700000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 32.99 in

Name: R-05-a-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-25-19 at 20.31.47.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.22	4000000	0.15	650
2	P-304 CTB	5	500000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.22 in

Name: R-05-b-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-25-19 at 21.26.08.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.07	4000000	0.15	650
2	P-304 CTB	7	500000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.07 in

Name: R-06-a-20

The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-25-19 at 22.30.21.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.22	4000000	0.15	650
2	P-304 CTB	5	500000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.22 in

Name: R-06-b-20
The structure is New Rigid.
Design Life = 20 years.
A design for this section was completed on 04-25-19 at 21.51.45.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.07	4000000	0.15	650
2	P-304 CTB	7	500000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.07 in

Name: R-01-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 04-29-19 at 19.26.19.

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.59	4000000	0.15	650
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.59 in

Name: R-01-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 04-29-19 at 20.05.38.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.45	4000000	0.15	650
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.45 in

Name: R-02-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 04-29-19 at 20.54.36.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.59	4000000	0.15	650
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.59 in

Name: R-02-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 04-29-19 at 21.12.37.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.45	4000000	0.15	650
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.45 in

Name: R-03-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 04-29-19 at 21.48.36.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.52	4000000	0.15	650
2	P-306 Lean Concrete	5	700000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.52 in

Name: R-03-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 04-29-19 at 22.20.11.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.34	4000000	0.15	650
2	P-306 Lean Concrete	7	700000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.34 in

Name: R-04-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 05-01-19 at 15.55.56.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.52	4000000	0.15	650
2	P-306 Lean Concrete	5	700000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.52 in

Name: R-04-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 05-01-19 at 16.21.16.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.34	4000000	0.15	650
2	P-306 Lean Concrete	7	700000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.34 in

Name: R-05-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.

Design Life = 30 years.
A design for this section was completed on 05-01-19 at 16.45.40.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.57	4000000	0.15	650
2	P-304 CTB	5	500000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.57 in

Name: R-05-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 05-01-19 at 17.10.12.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.42	4000000	0.15	650
2	P-304 CTB	7	500000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.42 in

Name: R-06-a-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 05-01-19 at 17.34.51.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.57	4000000	0.15	650
2	P-304 CTB	5	500000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.57 in

Name: R-06-b-30
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 30 years.
A design for this section was completed on 05-01-19 at 17.59.54.

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.42	4000000	0.15	650
2	P-304 CTB	7	500000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.42 in

Name: R-01-a-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 18.26.03.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.86	4000000	0.15	650
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.86 in

Name: R-01-b-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 18.49.32.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.72	4000000	0.15	650
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.72 in

Name: R-02-a-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 19.46.45.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.85	4000000	0.15	650
2	P-401/ P-403 St (flex)	5	400000	0.35	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.85 in

Name: R-02-b-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 19.14.22.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.72	4000000	0.15	650
2	P-401/ P-403 St (flex)	7	400000	0.35	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.72 in

Name: R-03-a-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 20.11.57.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.78	4000000	0.15	650
2	P-306 Lean Concrete	5	700000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.78 in

Name: R-03-b-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 20.34.20.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.61	4000000	0.15	650
2	P-306 Lean Concrete	7	700000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.61 in

Name: R-04-a-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 21.24.29.

Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.78	4000000	0.15	650
2	P-306 Lean Concrete	5	700000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.78 in

Name: R-04-b-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 21.49.21.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.61	4000000	0.15	650
2	P-306 Lean Concrete	7	700000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.61 in

Name: R-05-a-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 22.15.15.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.84	4000000	0.15	650
2	P-304 CTB	5	500000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.84 in

Name: R-05-b-40

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 22.40.19.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.69	4000000	0.15	650
2	P-304 CTB	7	500000	0.2	0
3	P-209 Cr Ag	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.69 in

Name: R-06-a-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 23.05.08.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.84	4000000	0.15	650
2	P-304 CTB	5	500000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 31.84 in

Name: R-06-b-40
The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is New Rigid.
Design Life = 40 years.
A design for this section was completed on 05-01-19 at 23.30.26.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Surface	20.69	4000000	0.15	650
2	P-304 CTB	7	500000	0.2	0
3	P-219 Recycled Conc. Agg.	6	34053	0.35	0
4	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.69 in

FAARFIELD Software Flexible Pavement Design, HMA CDF ≤ 1

Design Life	Design Name		CDF	Design Life	Design Name		CDF	Design Life	Design Name		CDF
Design Life 20 Years	F-01-a-20	=	0.45	Design Life 30 Years	F-01-a-30	=	0.70	Design Life 40 Years	F-01-a-40	=	0.99
	F-01-b-20	=	0.51		F-01-b-30	=	0.78		F-01-b-40	=	0.98
	F-02-a-20	=	0.45		F-02-a-30	=	0.70		F-02-a-40	=	0.99
	F-02-b-20	=	0.51		F-02-b-30	=	0.78		F-02-b-40	=	0.98

FAARFIELD Software Rigid Pavement Design, CDFU%

Design Life	Design Name		CDFU, %	Design Life	Design Name		CDFU, %	Design Life	Design Name		CDFU, %
Design Life 20 Years	R-01-a-20	=	142.18	Design Life 30 Years	R-01-a-30	=	141.23	Design Life 40 Years	R-01-a-40	=	140.30
	R-01-b-20	=	149.56		R-01-b-30	=	149.04		R-01-b-40	=	148.39
	R-02-a-20	=	142.18		R-02-a-30	=	141.23		R-02-a-40	=	140.30
	R-02-b-20	=	149.56		R-02-b-30	=	149.04		R-02-b-40	=	148.39
	R-03-a-20	=	150.34		R-03-a-30	=	149.51		R-03-a-40	=	150.82
	R-03-b-20	=	160.13		R-03-b-30	=	160.01		R-03-b-40	=	159.64
	R-04-a-20	=	150.32		R-04-a-30	=	149.51		R-04-a-40	=	150.82
	R-04-b-20	=	157.86		R-04-b-30	=	160.01		R-04-b-40	=	159.64
	R-05-a-20	=	143.97		R-05-a-30	=	145.14		R-05-a-40	=	144.21
	R-05-b-20	=	152.26		R-05-b-30	=	154.03		R-05-b-40	=	153.45
	R-06-a-20	=	143.97		R-06-a-30	=	145.14		R-06-a-40	=	144.21
	R-06-b-20	=	152.26		R-06-b-30	=	154.03		R-06-b-40	=	153.45

APPENDIX-B

MATERIALS QUANTITY ESTIMATION

Name : F-01-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A13	Crushed Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.15	0.644	x		x		115623
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-01-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A10	Crushed Aggregate Base Course (21-in depth)	sq. yd.	3501.312	x	51.312	x	20.4	0.567	x		x		101888
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	4	x	0.10	70469
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-02-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.15	0.644	x		x		115623
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3501.312	x	51.312	x			x	1	x	0.30	53898
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-02-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A10	Recycled Concrete Aggregate Base Course (21-in depth)	sq. yd.	3501.312	x	51.312	x	20.4	0.567	x		x		101888
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3501.312	x	51.312	x			x	1	x	0.30	53898
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	4	x	0.10	70469
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-01-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A13	Crushed Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.62	0.657	x		x		117971
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-01-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A10	Crushed Aggregate Base Course (21-in depth)	sq. yd.	3501.312	x	51.312	x	20.92	0.582	x		x		104486
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	4	x	0.10	70469
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-02-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.62	0.657	x		x		117971
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3501.312	x	51.312	x			x	1	x	0.30	53898
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-02-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A10	Recycled Concrete Aggregate Base Course (21-in depth)	sq. yd.	3501.312	x	51.312	x	20.92	0.582	x		x		104486
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3501.312	x	51.312	x			x	1	x	0.30	53898
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	4	x	0.10	70469
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-01-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A13	Crushed Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.98	0.667	x		x		119769
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-01-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	5	0.139	x		x		47616
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A12	Crushed Aggregate Base Course (23-in depth)	sq. yd.	3501.312	x	51.312	x	22.9	0.637	x		x		114375
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-02-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	4	0.111	x		x		38093
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	sq. yd.	3501.312	x	51.312	x	23.98	0.667	x		x		119769
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3501.312	x	51.312	x			x	1	x	0.30	53898
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : F-02-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	3500.000	x	50.000	x	5	0.139	x		x		47616
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A12	Recycled Concrete Aggregate Base Course (23-in depth)	sq. yd.	3501.312	x	51.312	x	22.9	0.637	x		x		114375
P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3501.312	x	51.312	x			x	1	x	0.30	53898
P-603-A	Bituminous Tack Coat	gallon	3500.000	x	50.000	x			x	3	x	0.10	52734
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-01-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.23	0.562	x		x		98419
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name: R-01-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.09	0.559	x		x		97738
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	2	x	0.10	35469
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-02-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.23	0.562	x		x		98419
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-02-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.09	0.559	x		x		97738
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	2	x	0.10	35469
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-03-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.16	0.560	x		x		98078
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-03-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B7	Portland Cement Concrete Pavement (20 in)	sq. yd.	3500.000	x	50.000	x	19.98	0.555	x		x		97203
P-306-A2	Econocrete Base Course (8 in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		34511
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-04-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.16	0.560	x		x		98078
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-04-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B7	Portland Cement Concrete Pavement (20 in)	sq. yd.	3500.000	x	50.000	x	19.99	0.556	x		x		97251
P-306-A2	Econocrete Base Course (8 in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		34511
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-05-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.22	0.562	x		x		98370
P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-05-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.07	0.558	x		x		97641
P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-06-a-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.22	0.562	x		x		98370
P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-06-b-20

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.07	0.558	x		x		97641
P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-01-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.59	0.572	x		x		100170
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-01-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.45	0.569	x		x		99489
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	2	x	0.10	35469
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-02-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.59	0.572	x		x		100170
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-02-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.45	0.569	x		x		99489
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	2	x	0.10	35469
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-03-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.52	0.570	x		x		99830
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-03-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.34	0.565	x		x		98954
P-306-A2	Econocrete Base Course (8 in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		34511
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-04-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.52	0.570	x		x		99830
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-04-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.34	0.565	x		x		98954
P-306-A2	Econocrete Base Course (8 in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		34511
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-05-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.57	0.572	x		x		100073
P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-05-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.42	0.568	x		x		99343
P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-06-a-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.57	0.572	x		x		100073
P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-06-b-30

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.42	0.568	x		x		99343
P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-01-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.86	0.580	x		x		101484
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-01-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.72	0.576	x		x		100803
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	2	x	0.10	35469
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-02-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness			Layer		Gallon	Quantity
							Inch	Yard					
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.85	0.580	x		x		101435
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	1	x	0.10	17734
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-02-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.72	0.576	x		x		100803
P-403-A2	Plant Mix Bituminous Base Course	tonne	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-603-A	Bituminous Tack Coat	gallon	3500.660	x	50.660	x			x	2	x	0.10	35469
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-03-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.78	0.578	x		x		101095
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-03-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.61	0.573	x		x		100268
P-306-A2	Econocrete Base Course (8 in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		34511
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-04-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.78	0.578	x		x		101095
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-04-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.78	0.578	x		x		101095
P-306-A1	Econocrete Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		24651
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-05-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.84	0.579	x		x		101387
P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		48254
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-05-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.69	0.575	x		x		100657
P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		67555
P-209-A1	Crushed Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-06-a-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.84	0.579	x		x		101387
P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	3500.660	x	50.660	x	5	0.139	x		x		48254
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

Name : R-06-b-40

Pay Item	Item	Unit	Length Yard		Width Yard		Structural Thickness Inch	Structural Thickness Yard		Layer		Gallon	Quantity
P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	3500.000	x	50.000	x	20.69	0.575	x		x		100657
P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	3500.660	x	50.660	x	7	0.195	x		x		67555
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	sq. yd.	3501.312	x	51.312	x	6	0.167	x		x		29967
P-501-C	Saw-Cut Grooving	sq. yd.	3500.000	x	50.000	x			x		x		175000
P-602-A	Bituminous Prime Coat	gallon	3500.660	x	50.660	x			x	1	x	0.30	53203
P-604-A	Joint Seal	ft.	3500.000	x	50.000	x			x		x		172950
P-100-14	Pavement Marking Special	sq. ft.	3500.000	x	50.000	x			x		x		1575000

APPENDIX-C

MATERIALS UNIT PRICE

SL No	Pay Item	Item	Unit	Unit Price	Remarks
1	P-501-B1	Portland Cement Concrete Pavement (10 in)	sq. yd.	$ 48.00	AirCost Library
2	P-501-B2	Portland Cement Concrete Pavement (12 in)	sq. yd.	$ 54.00	
3	P-501-B3	Portland Cement Concrete Pavement (14 in)	sq. yd.	$ 60.00	
4	P-501-B4	Portland Cement Concrete Pavement (16 in)	sq. yd.	$ 66.00	
5	P-501-B5	Portland Cement Concrete Pavement (18 in)	sq. yd.	$ 72.00	
6	P-501-B6	Portland Cement Concrete Pavement (19 in)	sq. yd.	$ 75.00	Price Adjusted
7	P-501-B7	Portland Cement Concrete Pavement (20 in)	sq. yd.	$ 78.00	
8	P-501-B8	Portland Cement Concrete Pavement (21 in)	sq. yd.	$ 81.00	
9	P-501-B9	Portland Cement Concrete Pavement (22 in)	sq. yd.	$ 84.00	
10	P-501-B6	Portland Cement Concrete Pavement (23 in)	sq. yd.	$ 87.00	
11	P-501-B7	Portland Cement Concrete Pavement (24 in)	sq. yd.	$ 90.00	
12	P-209-B	Crushed Aggregate Base Course	cu. yd.	$ 25.00	AirCost Library
13	P-209-A1	Crushed Aggregate Base Course (6-in depth)	sq. yd.	$ 6.50	
14	P-209-A2	Crushed Aggregate Base Course (8-in depth)	sq. yd.	$ 8.00	
15	P-209-A3	Crushed Aggregate Base Course (10-in depth)	sq. yd.	$ 9.50	
16	P-209-A4	Crushed Aggregate Base Course (12-in depth)	sq. yd.	$ 11.00	
17	P-209-A5	Crushed Aggregate Base Course (14-in depth)	sq. yd.	$ 12.50	Price Adjusted
18	P-209-A6	Crushed Aggregate Base Course (16-in depth)	sq. yd.	$ 14.00	
19	P-209-A7	Crushed Aggregate Base Course (18-in depth)	sq. yd.	$ 15.50	
20	P-209-A8	Crushed Aggregate Base Course (19-in depth)	sq. yd.	$ 16.25	
21	P-209-A9	Crushed Aggregate Base Course (20-in depth)	sq. yd.	$ 17.00	
22	P-209-A10	Crushed Aggregate Base Course (21-in depth)	sq. yd.	$ 17.75	
23	P-209-A11	Crushed Aggregate Base Course (22-in depth)	sq. yd.	$ 18.50	
24	P-209-A12	Crushed Aggregate Base Course (23-in depth)	sq. yd.	$ 19.25	
25	P-209-A13	Crushed Aggregate Base Course (24-in depth)	sq. yd.	$ 20.00	

SL No	Pay Item	Item	Unit	Unit Price	Remarks
26	P-209-B	Crushed Aggregate Base Course	cu. yd.	$ 25.00	AirCost Library
27	P-219-A1	Recycled Concrete Aggregate Base Course	tonne	$ 6.00	
28	P-219-A1	Recycled Concrete Aggregate Base Course (6-in depth)	sq. yd.	$ 2.75	
29	P-219-A2	Recycled Concrete Aggregate Base Course (8-in depth)	sq. yd.	$ 3.25	
30	P-219-A3	Recycled Concrete Aggregate Base Course (10-in depth)	sq. yd.	$ 3.75	
31	P-219-A4	Recycled Concrete Aggregate Base Course (12-in depth)	sq. yd.	$ 4.25	
32	P-219-A5	Recycled Concrete Aggregate Base Course (14-in depth)	sq. yd.	$ 4.75	Price Adjusted
33	P-219-A6	Recycled Concrete Aggregate Base Course (16-in depth)	sq. yd.	$ 5.25	
34	P-219-A7	Recycled Concrete Aggregate Base Course (18-in depth)	sq. yd.	$ 5.75	
35	P-219-A8	Recycled Concrete Aggregate Base Course (19-in depth)	sq. yd.	$ 6.00	
36	P-219-A9	Recycled Concrete Aggregate Base Course (20-in depth)	sq. yd.	$ 6.25	
37	P-219-A10	Recycled Concrete Aggregate Base Course (21-in depth)	sq. yd.	$ 6.50	
38	P-219-A11	Recycled Concrete Aggregate Base Course (22-in depth)	sq. yd.	$ 6.75	
39	P-219-A12	Recycled Concrete Aggregate Base Course (23-in depth)	sq. yd.	$ 7.00	
40	P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	sq. yd.	$ 7.25	
41	P-401-A1	Plant Mix Bituminous Surface Course (High Type)	tonne	$ 90.00	AirCost Library
42	P-401-B	Saw-Cut Grooving (High Type)	sq. yd.	$ 1.25	
43	P-602-A	Bituminous Prime Coat (gallon)	gallon	$ 2.00	
44	P-603-A	Bituminous Tack Coat (gallon)	gallon	$ 2.00	
45	P-403-A2	Plant Mix Bituminous Base Course	tonne	$ 70.00	
46	P-501-C	Saw-Cut Grooving	sq. yd.	$ 1.50	
47	P-304-A1	Cement-Treated Base Course (6-in)	sq. yd.	$ 14.00	
48	P-304-A2	Cement-Treated Base Course (8-in)	sq. yd.	$ 18.00	
49	P-306-A1	Econocrete Base Course (6-in)	sq. yd.	$ 20.00	
50	P-306-A2	Econocrete Base Course (8-in)	sq. yd.	$ 25.00	
51	P-604-A	Compression Joint Seals of Concrete Pavements (ft)	ft.	$ 2.00	

SL No	Pay Item	Item	Unit	Unit Price	Remarks
52	P-100-14	Pavement Marking Special	sq. ft.	$ 0.24	AirCost Library
53	P-609-C1	Patching and Crack Sealing	sq. yd.	$ 1.50	
54	P-101-5.1f	Cold Milling 0 to 2 in	sq. yd.	$ 2.50	
55	P-626-6.5	Unbonded PCC Overlay 5"	sq. yd.	$ 16.00	
56	P-626-6.4	Crack Seal	ft.	$ 0.75	
57	P-626-6.7	PCC Pavement (17 in)	sq. yd.	$ 60.00	
58	P-626-6.6	Full Depth Slab Replacement	sq. yd.	$ 71.15	Price Adjusted
59	P-830-A2	Unbonded PCC Overlay 6.45"	sq. yd.	$ 20.64	
60	P-830-A2	Unbonded PCC Overlay 18.17"	sq. yd.	$ 58.14	
61	P-830-A3	Unbonded PCC Overlay 6.0"	sq. yd.	$ 19.20	
62	P-830-A4	Unbonded PCC Overlay 18.13"	sq. yd.	$ 58.02	
63	P-830-A1	Unbonded PCC Overlay 18.23"	sq. yd.	$ 58.34	

APPENDIX-D

PAVEMENTS INITIAL COST ESTIMATION

Name : F-01-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-209-A13	Crushed Aggregate Base Course (24-in depth)	115623	sq. yd.	$ 20	$ 2312467
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105469
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	56.73	$ 9927225

Name : F-01-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-209-A10	Crushed Aggregate Base Course (21-in depth)	101888	sq. yd.	$ 17.75	$ 1808519
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	70469	gallon	$ 2	$ 140937
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 61.77	$ 10809852

Name : F-02-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	115623	sq. yd.	$ 7.25	$ 838269
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53898	gallon	$ 2	$ 107796
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105469
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 48.31	$ 8454416

Name : F-02-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-219-A10	Recycled Concrete Aggregate Base Course (21-in depth)	101888	sq. yd.	$ 6.5	$ 662275
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53898	gallon	$ 2	$ 107796
P-603-A	Bituminous Tack Coat	70469	gallon	$ 2	$ 140937
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 55.23	$ 9664997

Name : F-01-a-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-209-A13	Crushed Aggregate Base Course (24-in depth)	117971	sq. yd.	$ 20	$ 2359420
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105469
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 57.00	$ 9974178

Name : F-01-b-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-209-A10	Crushed Aggregate Base Course (21-in depth)	104486	sq. yd.	$ 17.75	$ 1854627
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	70469	gallon	$ 2	$ 140937
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 62.03	$ 10855960

Name : F-02-a-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	117971	sq. yd.	$ 7.25	$ 855290
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53898	gallon	$ 2	$ 107796
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105469
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 48.41	$ 8471437

Name : F-02-b-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-219-A10	Recycled Concrete Aggregate Base Course (21-in depth)	104486	sq. yd.	$ 6.5	$ 679159
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53898	gallon	$ 2	$ 107796
P-603-A	Bituminous Tack Coat	70469	gallon	$ 2	$ 140937
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 55.33	$ 9681882

Name : F-01-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-209-A13	Crushed Aggregate Base Course (24-in depth)	119769	sq. yd.	$ 20	$ 2395380
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105469
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	57.20	$ 10010138

Name : F-01-b-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	47616	tonne	$ 90	$ 4285440
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377780
P-209-A12	Crushed Aggregate Base Course (23-in depth)	114375	sq. yd.	$ 19.25	$ 2201719
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105468
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 60.99	$ 10673563

Name : F-02-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	38093	tonne	$ 90	$ 3428366
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-219-A13	Recycled Concrete Aggregate Base Course (24-in depth)	119769	sq. yd.	$ 7.25	$ 868325
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53898	gallon	$ 2	$ 107796
P-603-A	Bituminous Tack Coat	52734	gallon	$ 2	$ 105469
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 48.48	$ 8484472

Name : F-02-b-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-401-A1	Plant Mix Bituminous Surface Course (High Type)	47616	tonne	$ 90	$ 4285440
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377780
P-219-A12	Recycled Concrete Aggregate Base Course (23-in depth)	114375	sq. yd.	$ 7	$ 800625
P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750
P-602-A	Bituminous Prime Coat	53898	gallon	$ 2	$ 107796
P-603-A	Bituminous Tack Coat	70469	gallon	$ 2	$ 140937
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 53.20	$ 9309328

Name: R-01-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98419	sq. yd.	$ 81	$ 7971935
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	17734	gallon	$ 2	$ 35469
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 72.42	$ 12672764

Name : R-01-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	97738	sq. yd.	$ 81	$ 7916766
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	35469	gallon	$ 2	$ 70937
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 80.02	$ 14004170

Name : R-02-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98419	sq. yd.	$ 81	$ 7971935
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	17734	gallon	$ 2	$ 35469
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 71.77	$ 12560387

Name : R-02-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	97738	sq. yd.	$ 81	$ 7916766
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	35469	gallon	$ 2	$ 70937
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 79.38	$ 13891793

Name : R-03-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98078	sq. yd.	$ 81	$ 7944350
P-306-A1	Econocrete Base Course (6-in)	24651	sq. yd.	$ 20	$ 493015
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 54.96	$ 9618552

Name : R-03-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B7	Portland Cement Concrete Pavement (20 in)	97203	sq. yd.	$ 78	$ 7581811
P-306-A2	Econocrete Base Course (8 in)	34511	sq. yd.	$ 25	$ 862776
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 55.00	$ 9625773

Name : R-04-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98078	sq. yd.	$ 81	$ 7944350
P-306-A1	Econocrete Base Course (6-in)	24651	sq. yd.	$ 20	$ 493015
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 54.32	$ 9506175

Name : R-04-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B7	Portland Cement Concrete Pavement (20 in)	97251	sq. yd.	$ 78	$ 7585605
P-306-A2	Econocrete Base Course (8 in)	34511	sq. yd.	$ 25	$ 862776
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 54.38	$ 9517191

Name : R-05-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98370	sq. yd.	$ 81	$ 7967994
P-304-A1	Cement-Treated Base Course (6-in)	48254	sq. yd.	$ 14	$ 675553
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 56.75	$ 9931140

Name : R-05-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	97641	sq. yd.	$ 81	$ 7908885
P-304-A2	Cement-Treated Base Course (8-in)	67555	sq. yd.	$ 18	$ 1215996
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 59.50	$ 10412473

Name : R-06-a-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98370	sq. yd.	$ 81	$ 7967994
P-304-A1	Cement-Treated Base Course (6-in)	48254	sq. yd.	$ 14	$ 675553
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 56.11	$ 9818764

Name : R-06-b-20

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	97641	sq. yd.	$ 81	$ 7908885
P-304-A2	Cement-Treated Base Course (8-in)	67555	sq. yd.	$ 18	$ 1215996
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 58.86	$ 10300097

Name : R-01-a-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100170	sq. yd.	$ 81	$ 8113770
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	17734	gallon	$ 2	$ 35469
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 73.23	$ 12814599

Name : R-01-b-30

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	99489	sq. yd.	$	81	$	8058609
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$	70	$	4728874
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$	6.5	$	194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-602-A	Bituminous Prime Coat	53203	gallon	$	2	$	106406
P-603-A	Bituminous Tack Coat	35469	gallon	$	2	$	70937
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	80.83	$	14146013

Name : R-02-a-30

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	100170	sq. yd.	$	81	$	8113770
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$	70	$	3377767
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$	2.75	$	82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-602-A	Bituminous Prime Coat	53203	gallon	$	2	$	106406
P-603-A	Bituminous Tack Coat	17734	gallon	$	2	$	35469
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	72.58	$	12702222

Name : R-02-b-30

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	99489	sq. yd.	$	81	$	8058609
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$	70	$	4728874
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$	2.75	$	82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-602-A	Bituminous Prime Coat	53203	gallon	$	2	$	106406
P-603-A	Bituminous Tack Coat	35469	gallon	$	2	$	70937
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	80.19	$	14033636

Name : R-03-a-30

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	99830	sq. yd.	$	81	$	8086230
P-306-A1	Econocrete Base Course (6-in)	24651	sq. yd.	$	20	$	493015
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$	6.5	$	194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	55.77	$	9760431

Name : R-03-b-30

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	98954	sq. yd.	$	81	$	8015274
P-306-A2	Econocrete Base Course (8 in)	34511	sq. yd.	$	25	$	862776
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$	6.5	$	194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	57.48	$	10059236

Name : R-04-a-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	99830	sq. yd.	$ 81	$ 8086230
P-306-A1	Econocrete Base Course (6-in)	24651	sq. yd.	$ 20	$ 493015
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 55.13	$ 9648054

Name : R-04-b-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	98954	sq. yd.	$ 81	$ 8015274
P-306-A2	Econocrete Base Course (8 in)	34511	sq. yd.	$ 25	$ 862776
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 56.84	$ 9946860

Name : R-05-a-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100073	sq. yd.	$ 81	$ 8105913
P-304-A1	Cement-Treated Base Course (6-in)	48254	sq. yd.	$ 14	$ 675553
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 57.54	$ 10069059

Name : R-05-b-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	99343	sq. yd.	$ 81	$ 8046783
P-304-A2	Cement-Treated Base Course (8-in)	67555	sq. yd.	$ 18	$ 1215996
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 60.29	$ 10550372

Name : R-06-a-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100073	sq. yd.	$ 81	$ 8105913
P-304-A1	Cement-Treated Base Course (6-in)	48254	sq. yd.	$ 14	$ 675553
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 56.90	$ 9956682

Name : R-06-b-30

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	99343	sq. yd.	$ 81	$ 8046783
P-304-A2	Cement-Treated Base Course (8-in)	67555	sq. yd.	$ 18	$ 1215996
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 59.65	$ 10437995

Name : R-01-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	101484	sq. yd.	$ 81	$ 8220204
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	17734	gallon	$ 2	$ 35469
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 73.83	$ 12921033

Name : R-01-b-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100803	sq. yd.	$ 81	$ 8165043
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	35469	gallon	$ 2	$ 70937
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 81.44	$ 14252447

Name : R-02-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	101435	sq. yd.	$ 81	$ 8216235
P-403-A2	Plant Mix Bituminous Base Course	48254	tonne	$ 70	$ 3377767
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	17734	gallon	$ 2	$ 35469
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 73.17	$ 12804687

Name : R-02-b-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100803	sq. yd.	$ 81	$ 8165043
P-403-A2	Plant Mix Bituminous Base Course	67555	tonne	$ 70	$ 4728874
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-603-A	Bituminous Tack Coat	35469	gallon	$ 2	$ 70937
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 80.80	$ 14140070

Name : R-03-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	101095	sq. yd.	$ 81	$ 8188695
P-306-A1	Econocrete Base Course (6-in)	24651	sq. yd.	$ 20	$ 493015
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 56.36	$ 9862896

Name : R-03-b-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100268	sq. yd.	$ 81	$ 8121708
P-306-A2	Econocrete Base Course (8 in)	34511	sq. yd.	$ 25	$ 862776
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 58.09	$ 10165670

Name : R-04-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	101095	sq. yd.	$ 81	$ 8188695
P-306-A1	Econocrete Base Course (6-in)	24651	sq. yd.	$ 20	$ 493015
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 55.72	$ 9750519

Name : R-04-b-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	100268	sq. yd.	$ 81	$ 8121708
P-306-A2	Econocrete Base Course (8 in)	34511	sq. yd.	$ 25	$ 862776
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$ 2.75	$ 82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 57.45	$ 10053294

Name : R-05-a-40

Pay Item	Item	Quantity	Unit	Unit Price	Extended
P-501-B8	Portland Cement Concrete Pavement (21 in)	101387	sq. yd.	$ 81	$ 8212347
P-304-A1	Cement-Treated Base Course (6-in)	48254	sq. yd.	$ 14	$ 675553
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$ 6.5	$ 194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500
P-602-A	Bituminous Prime Coat	53203	gallon	$ 2	$ 106406
P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$ 0.24	$ 378000
	Total		sq. yd.	$ 58.15	$ 10175493

Name : R-05-b-40

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	100657	sq. yd.	$	81	$	8153217
P-304-A2	Cement-Treated Base Course (8-in)	67555	sq. yd.	$	18	$	1215996
P-209-A1	Crushed Aggregate Base Course (6 in)	29967	sq. yd.	$	6.5	$	194787
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-602-A	Bituminous Prime Coat	53203	gallon	$	2	$	106406
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	60.90	$	10656806

Name : R-06-a-40

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	101387	sq. yd.	$	81	$	8212347
P-304-A1	Cement-Treated Base Course (6-in)	48254	sq. yd.	$	14	$	675553
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$	2.75	$	82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-602-A	Bituminous Prime Coat	53203	gallon	$	2	$	106406
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	57.50	$	10063116

Name : R-06-b-40

Pay Item	Item	Quantity	Unit	Unit Price		Extended	
P-501-B8	Portland Cement Concrete Pavement (21 in)	100657	sq. yd.	$	81	$	8153217
P-304-A2	Cement-Treated Base Course (8-in)	67555	sq. yd.	$	18	$	1215996
P-219-A1	Recycled Concrete Aggregate Base Course (6 in)	29967	sq. yd.	$	2.75	$	82410
P-501-C	Saw-Cut Grooving	175000	sq. yd.	$	1.5	$	262500
P-602-A	Bituminous Prime Coat	53203	gallon	$	2	$	106406
P-604-A	Joint Seal	172950	ft.	$	2	$	345900
P-100-14	Pavement Marking Special	1575000	sq. ft.	$	0.24	$	378000
	Total		sq. yd.	$	60.25	$	10544429

APPENDIX-E

OVERLAY DESIGN THICKNESS

Referenced Design: F-02-a-20, Alternative 1

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 15 years.
A design for this section was completed on 06/26/19 at 19:33:49.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.15	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.15 in

- **2nd HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 10 years.
A design for this section was completed on 06/26/19 at 19:36:22.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.15	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.15 in

Referenced Design: F-02-a-20, Alternative 2

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 15 years.
A design for this section was completed on 06/26/19 at 19:33:49.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.15	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.15 in

- **1st PCC Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is PCC Overlay on Flexible.
Design Life = 10 years.
A design for this section was completed on 06-03-19 at 17.41.23.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Overlay on Flex.	18.23	400000	0.15	650
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.15	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 50.38 in

Referenced Design: R-04-a-20, Alternative 3

- **1st PCC Overlay Design**

The structure is Unbonded PCC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 20 years.
A design for this section was completed on 06/15/19 at 20:54:58.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Overlay Unbond	6.45	4000000	0.15	650
2	PCC Surface	20.16	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 37.61 in

Referenced Design: R-04-a-20, Alternative 4

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 12 years.
A design for this section was completed on 06/26/19 at 20:45:38.

Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	PCC Surface	20.16	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.16 in

- **2nd HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 8 years.
A design for this section was completed on 06-12-19 at 19.44.17.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	PCC Surface	20.16	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.16 in

Referenced Design: F-02-a-30, Alternative 1

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 15 years.
A design for this section was completed on 06/26/19 at 19:08:47.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.62	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.62 in

- **2nd HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.

The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 10 years.
A design for this section was completed on 06/26/19 at 19:12:38.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.62	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.62 in

Referenced Design: F-02-a-30, Alternative 2

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 15 years.
A design for this section was completed on 06/26/19 at 19:15:55.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.62	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.62 in

- **1st PCC Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is PCC Overlay on Flexible.
Design Life = 10 years.
A design for this section was completed on 06/23/19 at 00:11:11.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Overlay on Flex.	18.17	400000	0.15	650
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.62	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 50.79 in

Referenced Design: R-04-a-30, Alternative 3

- **1st PCC Overlay Design**

The structure is Unbonded PCC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 20 years.
A design for this section was completed on 06-30-19 at 11:56:54.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Overlay Unbond	5	4000000	0.15	650
2	PCC Surface	20.52	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 36.52 in

Referenced Design: R-04-a-30, Alternative 4

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 12 years.
A design for this section was completed on 06/26/19 at 21:50:07.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	PCC Surface	20.52	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.52 in

- **2nd HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 8 years.
A design for this section was completed on 06/26/19 at 22:47:58.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	PCC Surface	20.52	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.52 in

Referenced Design: F-02-a-40, Alternative 1

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 15 years.
A design for this section was completed on 06/26/19 at 19:43:41.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.98	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.98 in

- **2nd HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.
Design Life = 10 years.
A design for this section was completed on 06/26/19 at 19:41:13.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.98	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.98 in

Referenced Design: F-02-a-40, Alternative 2

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Flexible. Asphalt CDF was not computed.

Design Life = 15 years.
A design for this section was completed on 06/26/19 at 19:43:41.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.98	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 34.98 in

- **1st PCC Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is PCC Overlay on Flexible.
Design Life = 10 years.
A design for this section was completed on 06/22/19 at 23:03:32.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Overlay on Flex.	18.13	400000	0.15	650
2	P-401/ P-403 HMA Surface	4	200000	0.35	0
3	P-401/ P-403 St (flex)	5	400000	0.35	0
4	P-219 Recycled Conc. Agg.	23.98	73890	0.35	0
5	Subgrade	0	12000	0.35	0

Total thickness to the top of the subgrade = 51.11 in

Referenced Design: R-04-a-40, Alternative 3

- **1st PCC Overlay Design**

The structure is Unbonded PCC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 20 years.
A design for this section was completed on 06-30-19 at 11:42:04.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	PCC Overlay Unbond	5	4000000	0.15	650
2	PCC Surface	20.78	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 36.78 in

Referenced Design: R-04-a-40, Alternative 4

- **1st HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 12 years.
A design for this section was completed on 06/26/19 at 23:47:33.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	PCC Surface	20.78	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.78 in

- **2nd HMA Overlay Design**

The section does not have a design life of 20 years. This constitutes a deviation from standards and requires FAA approval.
The structure is AC Overlay on Rigid.
SCI of the existing pavement = 80.
Design Life = 8 years.
A design for this section was completed on 06/27/19 at 00:43:11.
Minimum layer thicknesses were reached.
Pavement Structure Information by Layer, Top First

No.	Type	Thickness, in	Modulus, psi	Poisson's Ratio	Strength R,psi
1	P-401/ P-403 HMA Overlay	2	200000	0.35	0
2	PCC Surface	20.78	4000000	0.15	650
3	P-306 Lean Concrete	5	700000	0.2	0
4	P-219 Recycled Conc. Agg.	6	34053	0.35	0
5	Subgrade	0	12000	0.4	0

Total thickness to the top of the subgrade = 33.78 in

APPENDIX-F

NET PRESENT VALUE (NPV) ANALYSIS

LIFE - CYCLE COST ANALYSIS
FLEXIBLE PAVEMENT
Analysis Name: Alternative 1

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
		Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-20)	1	sq. yd.	$ 8454416	$ 8454416	1.0000	$ 8454416
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.3083	$ 1005897
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
36	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2437	$ 63963
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 16291964		$ 11899202
						Salvage Value	$ -1631262		$ -339774
						Grand Total	$		$ 11559428

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 66.05

LIFE - CYCLE COST ANALYSIS
FLEXIBLE PAVEMENT
Analysis Name: Alternative 2

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 1 HMA & 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-20)	1	sq. yd.	$ 8454416	$ 8454416	1.0000	$ 8454416
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-830-A1	Unbonded PCC Overlay 18.23"	175000	sq. yd.	$ 58.34	$ 10208800	0.3083	$ 3335145
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
39	Maintenance	P-604-A	Joint Seal Replacement	172950	sq. yd.	$ 2	$ 345900	0.2166	$ 74929
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 23930040		$ 14239416
						Salvage Value	$ -5408600		$ -1126552
						Grand Total	$		$ 13112864

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 74.93

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 3

Pavement Length	: 3500 yd.		Design Life :	20 year
Pavement Width	: 50 yd.		Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.		Discount Rate :	4%
No of Overlay & Types	: 1 PCC Overlay		Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.		Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-20)	1	sq. yd.	$ 9506175	$ 9506175	1.000	$ 9506175
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.676	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.475	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622588	0.456	$ 2210277
		P-830-A2	Unbonded PCC Overlay 6.45"	175000	sq. yd.	$ 20.64	$ 3612000		
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
30	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.308	$ 85318
39	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.217	$ 22479
40			Pavement Life End			$ 0	$ 0	0.208	$ 0
						Sub Total	$ 15110143		$ 12060444
						Salvage Value	$ -4753087		$ -990016
						Grand Total	$		$ 11070428

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 63.26

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 4

Pavement Length	: 3500 yd.	Design Life :	20 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-20)	1	sq. yd.	$ 9506175	$ 9506175	1.0000	$ 9506175
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.6756	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.4746	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622563	0.4564	$ 1573434
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
26	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3607	$ 94681
31	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2965	$ 77821
32	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 1.5	$ 262500	0.2851	$ 880123
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
38	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2253	$ 59137
40			Pavement life end			$	$ 0	0.2083	$ 0
						Sub Total	$ 17209276		$ 12427567
						Salvage Value	$ -4753087		$ -990016
						Grand Total	$		$ 11437551

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 65.36

LIFE - CYCLE COST ANALYSIS

FLEXIBLE PAVEMENT

Analysis Name: Alternative 1

Pavement Length	: 3500 yd.	Design Life :	30 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
		Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-30)	1	sq. yd.	$ 8471437	$ 8471437	1.0000	$ 8471437
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.3083	$ 1005897
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
36	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2437	$ 63963
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 16308985		$ 11916223
						Salvage Value	$ -1631262		$ -339774
						Grand Total	$		$ 11576449

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$ 66.15

LIFE - CYCLE COST ANALYSIS

FLEXIBLE PAVEMENT

Analysis Name: Alternative 2

Pavement Length	: 3500 yd.	Design Life :	30 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 1 HMA & 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-30)	1	sq. yd.	$ 8471437	$ 8471437	1.0000	$ 8471437
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-830-A2	Unbonded PCC Overlay 18.17"	175000	sq. yd.	$ 58.14	$ 10175200	0.3083	$ 3324785
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
39	Maintenance	P-604-A	Joint Seal Replacement	172950	sq. yd.	$ 2	$ 345900	0.2166	$ 74929
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 23913461		$ 14246077
						Salvage Value	$ -5391800		$ -1123053
						Grand Total	$		$ 13123025

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 74.99

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 3

Pavement Length	: 3500 yd.	Design Life :	30 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-30)	1	sq. yd.	$ 9648054	$ 9648054	1.000	$ 9648054
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.676	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.475	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622588	0.456	$ 2095267
		P-830-A3	Unbonded PCC Overlay 6.0"	175000	sq. yd.	$ 19.2	$ 3360000		
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
30	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.308	$ 85318
39	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.217	$ 22479
40			Pavement Life End			$ 0	$ 0	0.208	$ 0
						Sub Total	$ 15000022		$ 12087314
						Salvage Value	$ -4824027		$ -1004792
						Grand Total	$		$ 11082522

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$	63.33

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 4

Pavement Length	: 3500 yd.	Design Life :	30 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-30)	1	sq. yd.	$ 9648054	$ 9648054	1.0000	$ 9648054
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.6756	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.4746	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622563	0.4564	$ 1573434
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
26	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3607	$ 94681
31	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2965	$ 77821
32	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 1.5	$ 262500	0.2851	$ 880123
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
38	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2253	$ 59137
40			Pavement life end			$	$ 0	0.2083	$ 0
						Sub Total	$ 17351155		$ 12569446
						Salvage Value	$ -4824027		$ -1004792
						Grand Total	$		$ 11564654

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard : $ 66.08

LIFE - CYCLE COST ANALYSIS
FLEXIBLE PAVEMENT
Analysis Name: Alternative 1

Pavement Length	: 3500 yd.	Design Life :	40 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
		Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-40)	1	sq. yd.	$ 8484472	$ 8484472	1.0000	$ 8484472
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.3083	$ 1005897
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
36	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2437	$ 63963
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 16322020		$ 11929258
						Salvage Value	$ -1631262		$ -339774
						Grand Total	$		$ 11589484

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$ 66.23

LIFE - CYCLE COST ANALYSIS

FLEXIBLE PAVEMENT

Analysis Name: Alternative 2

Pavement Length	**:** 3500 yd.	Design Life :	40 year
Pavement Width	**:** 50 yd.	Analysis Period :	40 year
Total Pavement Area	**:** 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	**:** 1 HMA & 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	**:** (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial cost		Design reference (F-02-a-40)	1	sq. yd.	$ 8484472	$ 8484472	1.0000	$ 8484472
7	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.7599	$ 199478
13	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.6006	$ 157651
15	1st Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 2.5	$ 437500	0.5553	$ 1811564
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
21	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.4388	$ 115194
27	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3468	$ 91039
30	2nd Rehabilitation	P-830-A4	Unbonded PCC Overlay 18.13"	175000	sq. yd.	$ 58.02	$ 10152800	0.3083	$ 3317879
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
39	Maintenance	P-604-A	Joint Seal Replacement	172950	sq. yd.	$ 2	$ 345900	0.2166	$ 74929
40			Pavement life end			$ 0	$ 0	0.2083	$ 0
						Sub Total	$ 23904096		$ 14252206
						Salvage Value	$ -5380600		$ -1120720
						Grand Total	$		$ 13131486

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$	75.04

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 3

Pavement Length	: 3500 yd.	Design Life :	40 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 1 PCC Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-40)	1	sq. yd.	$ 9750519	$ 9750519	1.000	$ 9750519
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.676	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.475	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622588	0.456	$ 2095267
		P-830-A2	Unbonded PCC Overlay 6.0"	175000	sq. yd.	$ 19.2	$ 3360000		
		P-604-A	Joint Seal	172950	ft.	$ 2	$ 345900		
		P-501-C	Saw-Cut Grooving	175000	sq. yd.	$ 1.5	$ 262500		
30	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.308	$ 85318
39	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.217	$ 22479
40			Pavement Life End			$ 0	$ 0	0.208	$ 0
						Sub Total	$ 15102487		$ 12189779
						Salvage Value	$ -4875260		$ -1015463
						Grand Total	$		$ 11174315

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$ 63.85

LIFE - CYCLE COST ANALYSIS

RIGID PAVEMENT

Analysis Name: Alternative 4

Pavement Length	: 3500 yd.	Design Life :	40 year
Pavement Width	: 50 yd.	Analysis Period :	40 year
Total Pavement Area	: 175000 sq. yd.	Discount Rate :	4%
No of Overlay & Types	: 2 HMA Overlay	Analysis Base Year :	2017
PCC Panel Size	: (5 x 6.667) yd.	Initial Construction Year :	2018

Year	Activity	Pay Item	Item Name	Quantity	Unit	Unit Price	Extended	NPV Factor, 4%	Net Present Value
0	Initial Cost		Design reference (R-04-a-40)	1	sq. yd.	$ 9750519	$ 9750519	1.0000	$ 9750519
10	Maintenance	P-604-A	Joint Seal Replacement	138360	ft.	$ 2	$ 276720	0.6756	$ 186942
19	Maintenance	P-626-6.4	Crack Seal	138360	ft.	$ 0.75	$ 103770	0.4746	$ 49254
20	1st Rehabilitation	P-626-6.6	Full Depth Slab Replacement, 5 %	8750	sq. yd.	$ 71.15	$ 622563	0.4564	$ 1573434
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
26	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.3607	$ 94681
31	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2965	$ 77821
32	2nd Rehabilitation	P-101-5.1f	Cold Milling 0 to 2 in	175000	sq. yd.	$ 1.5	$ 262500	0.2851	$ 880123
		P-401-A1	Plant Mix Bituminous Surface Course 3"	28570	tonne	$ 90	$ 2571274		
		P-603-A	Bituminous Tack Coat (gallon)	17500	gallon	$ 2	$ 35000		
		P-401-B	Saw-Cut Grooving (High Type)	175000	sq. yd.	$ 1.25	$ 218750		
38	Maintenance	P-609-C1	Patching and Crack Sealing	175000	sq. yd.	$ 1.5	$ 262500	0.2253	$ 59137
40			Pavement life end			$	$ 0	0.2083	$ 0
						Sub Total	$ 17453620		$ 12671911
						Salvage Value	$ -4875260		$ -1015463
						Grand Total	$		$ 11656448

Note: 4% discount rate used in net present value factor calculation. Salvage value is based on straight-line depreciation of the expected life of the last rehabilitation item.

Net present value per square yard :	$ 66.61

APPENDIX-G

AIRCOST SOFTWARE ANALYSIS

Analysis Base Year : 2017
Analysis Period, Years : 40
Discount Rate, % : 4.000%

Deterministic Output

Net Present Value (NPV)

Design Life : **20 Years**
Referenced Design : F-02-a-20 [Alt-1 & Alt-2]
Referenced Design : R-04-a-20 [Alt-3 & Alt-4]

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs - NPV	:	$ 14,003,561	$ 16,632,317	$ 11,925,630	$ 13,622,928
Salvage Value - NPV	:	$ -	$ -	$ -	$ -
Subtotal	:	$ 14,003,561	$ 16,632,317	$ 11,925,630	$ 13,622,928
User Costs - NPV	:	$ 973,558	$ 1,081,731	$ 649,038	$ 865,385
TOTAL	:	$ 14,977,119	$ 17,714,048	$ 12,574,668	$ 14,488,313

Design Life : **30 Years**
Referenced Design : F-02-a-30 [Alt-1 & Alt-2]
Referenced Design : R-04-a-30 [Alt-3 & Alt-4]

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs - NPV	:	$ 14,029,018	$ 16,405,530	$ 11,934,066	$ 13,821,658
Salvage Value - NPV	:	$ -	$ -	$ -	$ -
Subtotal	:	$ 14,029,018	$ 16,405,530	$ 11,934,066	$ 13,821,658
User Costs - NPV	:	$ 973,558	$ 1,081,731	$ 649,038	$ 865,385
TOTAL	:	$ 15,002,576	$ 17,487,260	$ 12,583,105	$ 14,687,043

Design Life : **40 Years**
Referenced Design : F-02-a-40 [Alt-1 & Alt-2]
Referenced Design : R-04-a-40 [Alt-3 & Alt-4]

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs - NPV	:	$ 14,048,512	$ 16,658,049	$ 12,032,590	$ 13,965,147
Salvage Value - NPV	:	$ -	$ -	$ -	$ -
Subtotal	:	$ 14,048,512	$ 16,658,049	$ 12,032,590	$ 13,965,147
User Costs - NPV	:	$ 973,558	$ 1,081,731	$ 649,038	$ 865,385
TOTAL	:	$ 15,022,070	$ 17,739,780	$ 12,681,629	$ 14,830,532

Analysis Base Year : 2017
Analysis Period, Years : 40
Discount Rate, % : 4.000%

Deterministic Output

Equivalent Uniform Annual Costs (EUAC)

Design Life : **20 Years**
Referenced Design : F-02-a-20 [Alt-1 & Alt-2]
Referenced Design : R-04-a-20 [Alt-3 & Alt-4]

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs - EUAC	:	$ 673,482	$ 799,909	$ 573,547	$ 655,176
Salvage Value - EUAC	:	$ -	$ -	$ -	$ -
Subtotal	:	$ 673,482	$ 799,909	$ 573,547	$ 655,176
User Costs - EUAC	:	$ 46,822	$ 52,024	$ 31,215	$ 41,619
TOTAL	:	$ 720,304	$ 851,933	$ 604,761	$ 696,796

Design Life : **30 Years**
Referenced Design : F-02-a-30 [Alt-1 & Alt-2]
Referenced Design : R-04-a-30 [Alt-3 & Alt-4]

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs - EUAC	:	$ 674,706	$ 789,001	$ 573,953	$ 664,734
Salvage Value - EUAC	:	$ -	$ -	$ -	$ -
Subtotal	:	$ 674,706	$ 789,001	$ 573,953	$ 664,734
User Costs - EUAC	:	$ 46,822	$ 52,024	$ 31,215	$ 41,619
TOTAL	:	$ 721,528	$ 841,026	$ 605,167	$ 706,353

Design Life : **40 Years**
Referenced Design : F-02-a-40 [Alt-1 & Alt-2]
Referenced Design : R-04-a-40 [Alt-3 & Alt-4]

		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs - EUAC	:	$ 675,644	$ 801,146	$ 578,691	$ 671,635
Salvage Value - EUAC	:	$ -	$ -	$ -	$ -
Subtotal	:	$ 675,644	$ 801,146	$ 578,691	$ 671,635
User Costs - EUAC	:	$ 46,822	$ 52,024	$ 31,215	$ 41,619
TOTAL	:	$ 722,466	$ 853,170	$ 609,906	$ 713,254

Analysis Base Year : 2017
Analysis Period, Years : 40
Discount Rate, % : 4.000%

Normal Probabilistic Output

Total Net Present Value (in $ 1,000's)

Design Life : **20 Years**
Referenced Design : F-02-a-20 [Alt-1 & Alt-2]
Referenced Design : R-04-a-20 [Alt-3 & Alt-4]

	Statistic		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs	Mean	:	$ 14,123	$ 16,884	$ 11,991	$ 13,756
	Standard Deviation	:	$ 1,430	$ 2,371	$ 1,717	$ 1,929
	Minimum	:	$ 9,728	$ 11,231	$ 5,858	$ 8,037
	Maximum	:	$ 18,949	$ 28,255	$ 17,096	$ 21,115
	Percentile 1 (5%)	:	$ 11,785	$ 13,356	$ 9,182	$ 10,551
	Percentile 2 (50%)	:	$ 14,122	$ 16,675	$ 11,989	$ 13,751
	Percentile 3 (75%)	:	$ 15,079	$ 18,245	$ 13,145	$ 15,063
	Percentile 4 (95%)	:	$ 16,561	$ 21,079	$ 14,813	$ 16,879
User Costs	Mean	:	$ 1,027	$ 1,180	$ 745	$ 915
	Standard Deviation	:	$ 85	$ 143	$ 120	$ 77
	Minimum	:	$ 819	$ 910	$ 583	$ 733
	Maximum	:	$ 1,410	$ 1,745	$ 1,085	$ 1,159
	Percentile 1 (5%)	:	$ 905	$ 995	$ 617	$ 803
	Percentile 2 (50%)	:	$ 1,018	$ 1,155	$ 677	$ 907
	Percentile 3 (75%)	:	$ 1,084	$ 1,277	$ 858	$ 968
	Percentile 4 (95%)	:	$ 1,178	$ 1,438	$ 954	$ 1,053
Total Costs	Mean	:	$ 15,151	$ 18,064	$ 12,736	$ 14,672
	Standard Deviation	:	$ 1,480	$ 2,474	$ 1,752	$ 1,959
	Minimum	:	$ 10,547	$ 12,179	$ 6,442	$ 8,950
	Maximum	:	$ 20,092	$ 29,831	$ 18,022	$ 22,153
	Percentile 1 (5%)	:	$ 12,791	$ 14,418	$ 9,826	$ 11,427
	Percentile 2 (50%)	:	$ 15,130	$ 17,862	$ 12,726	$ 14,653
	Percentile 3 (75%)	:	$ 16,122	$ 19,527	$ 13,925	$ 15,996
	Percentile 4 (95%)	:	$ 17,675	$ 22,441	$ 15,674	$ 17,900

Analysis Base Year : 2017
Analysis Period, Years : 40
Discount Rate, % : 4.000%

Normal Probabilistic Output

Total Equivalent Uniform Annual Costs (in 1,000's)

Design Life : **20 Years**
Referenced Design : F-02-a-20 [Alt-1 & Alt-2]
Referenced Design : R-04-a-20 [Alt-3 & Alt-4]

	Statistic		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs	Mean	:	$ 677	$ 813	$ 575	$ 660
	Standard Deviation	:	$ 64	$ 102	$ 83	$ 92
	Minimum	:	$ 513	$ 543	$ 330	$ 361
	Maximum	:	$ 912	$ 1,299	$ 852	$ 964
	Percentile 1 (5%)	:	$ 580	$ 664	$ 439	$ 508
	Percentile 2 (50%)	:	$ 674	$ 805	$ 574	$ 662
	Percentile 3 (75%)	:	$ 717	$ 882	$ 635	$ 721
	Percentile 4 (95%)	:	$ 794	$ 987	$ 709	$ 805
User Costs	Mean	:	$ 49	$ 57	$ 36	$ 44
	Standard Deviation	:	$ 3	$ 5	$ 5	$ 3
	Minimum	:	$ 42	$ 50	$ 28	$ 39
	Maximum	:	$ 58	$ 75	$ 42	$ 52
	Percentile 1 (5%)	:	$ 46	$ 52	$ 30	$ 41
	Percentile 2 (50%)	:	$ 48	$ 52	$ 32	$ 42
	Percentile 3 (75%)	:	$ 52	$ 62	$ 42	$ 47
	Percentile 4 (95%)	:	$ 53	$ 63	$ 42	$ 47
Total Costs	Mean	:	$ 726	$ 869	$ 611	$ 704
	Standard Deviation	:	$ 65	$ 106	$ 84	$ 93
	Minimum	:	$ 560	$ 595	$ 361	$ 402
	Maximum	:	$ 965	$ 1,371	$ 894	$ 1,012
	Percentile 1 (5%)	:	$ 625	$ 716	$ 472	$ 552
	Percentile 2 (50%)	:	$ 724	$ 860	$ 610	$ 706
	Percentile 3 (75%)	:	$ 766	$ 941	$ 670	$ 765
	Percentile 4 (95%)	:	$ 845	$ 1,049	$ 748	$ 851

Design Life : **30 Years**
Referenced Design : F-02-a-30 [Alt-1 & Alt-2]
Referenced Design : R-04-a-30 [Alt-3 & Alt-4]

	Statistic		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs	Mean	:	$ 14,149	$ 16,638	$ 11,996	$ 13,955
	Standard Deviation	:	$ 1,431	$ 2,267	$ 1,729	$ 1,961
	Minimum	:	$ 9,745	$ 11,121	$ 5,843	$ 8,133
	Maximum	:	$ 18,973	$ 27,249	$ 17,101	$ 21,449
	Percentile 1 (5%)	:	$ 11,811	$ 13,252	$ 9,179	$ 10,698
	Percentile 2 (50%)	:	$ 14,147	$ 16,434	$ 11,990	$ 13,955
	Percentile 3 (75%)	:	$ 15,108	$ 17,956	$ 13,144	$ 15,279
	Percentile 4 (95%)	:	$ 16,583	$ 20,647	$ 14,864	$ 17,130
User Costs	Mean	:	$ 1,027	$ 1,180	$ 745	$ 915
	Standard Deviation	:	$ 85	$ 143	$ 120	$ 77
	Minimum	:	$ 819	$ 910	$ 583	$ 733
	Maximum	:	$ 1,410	$ 1,745	$ 1,085	$ 1,159
	Percentile 1 (5%)	:	$ 905	$ 995	$ 617	$ 803
	Percentile 2 (50%)	:	$ 1,018	$ 1,155	$ 677	$ 907
	Percentile 3 (75%)	:	$ 1,084	$ 1,277	$ 858	$ 968
	Percentile 4 (95%)	:	$ 1,178	$ 1,438	$ 954	$ 1,053
Total Costs	Mean	:	$ 15,176	$ 17,818	$ 12,741	$ 14,870
	Standard Deviation	:	$ 1,481	$ 2,369	$ 1,763	$ 1,991
	Minimum	:	$ 10,564	$ 12,069	$ 6,426	$ 9,047
	Maximum	:	$ 20,116	$ 28,825	$ 18,000	$ 22,487
	Percentile 1 (5%)	:	$ 12,812	$ 14,286	$ 9,866	$ 11,562
	Percentile 2 (50%)	:	$ 15,157	$ 17,631	$ 12,722	$ 14,853
	Percentile 3 (75%)	:	$ 16,153	$ 19,218	$ 13,912	$ 16,216
	Percentile 4 (95%)	:	$ 17,709	$ 21,997	$ 15,670	$ 18,146

Design Life : **30 Years**
Referenced Design : F-02-a-30 [Alt-1 & Alt-2]
Referenced Design : R-04-a-30 [Alt-3 & Alt-4]

	Statistic		Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs	Mean	:	$ 678	$ 801	$ 575	$ 670
	Standard Deviation	:	$ 64	$ 98	$ 84	$ 93
	Minimum	:	$ 514	$ 541	$ 329	$ 365
	Maximum	:	$ 913	$ 1,252	$ 853	$ 979
	Percentile 1 (5%)	:	$ 580	$ 658	$ 437	$ 515
	Percentile 2 (50%)	:	$ 675	$ 792	$ 574	$ 672
	Percentile 3 (75%)	:	$ 718	$ 868	$ 635	$ 732
	Percentile 4 (95%)	:	$ 795	$ 967	$ 711	$ 817
User Costs	Mean	:	$ 49	$ 57	$ 36	$ 44
	Standard Deviation	:	$ 3	$ 5	$ 5	$ 3
	Minimum	:	$ 42	$ 50	$ 28	$ 39
	Maximum	:	$ 58	$ 75	$ 42	$ 52
	Percentile 1 (5%)	:	$ 46	$ 52	$ 30	$ 41
	Percentile 2 (50%)	:	$ 48	$ 52	$ 32	$ 42
	Percentile 3 (75%)	:	$ 52	$ 62	$ 42	$ 47
	Percentile 4 (95%)	:	$ 53	$ 63	$ 42	$ 47
Total Costs	Mean	:	$ 727	$ 858	$ 611	$ 713
	Standard Deviation	:	$ 65	$ 101	$ 85	$ 94
	Minimum	:	$ 561	$ 594	$ 359	$ 406
	Maximum	:	$ 966	$ 1,325	$ 895	$ 1,027
	Percentile 1 (5%)	:	$ 626	$ 710	$ 470	$ 559
	Percentile 2 (50%)	:	$ 725	$ 850	$ 610	$ 715
	Percentile 3 (75%)	:	$ 767	$ 927	$ 670	$ 776
	Percentile 4 (95%)	:	$ 846	$ 1,029	$ 750	$ 863

Design Life : **40 Years**
Referenced Design : F-02-a-40 [Alt-1 & Alt-2]
Referenced Design : R-04-a-40 [Alt-3 & Alt-4]

	Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs	Mean	$ 14,169	$ 16,908	$ 12,095	$ 14,098
	Standard Deviation	$ 1,432	$ 2,365	$ 1,748	$ 1,984
	Minimum	$ 9,758	$ 11,259	$ 5,878	$ 8,203
	Maximum	$ 18,990	$ 28,230	$ 17,251	$ 21,690
	Percentile 1 (5%)	$ 11,831	$ 13,386	$ 9,255	$ 10,804
	Percentile 2 (50%)	$ 14,169	$ 16,710	$ 12,088	$ 14,097
	Percentile 3 (75%)	$ 15,130	$ 18,265	$ 13,258	$ 15,435
	Percentile 4 (95%)	$ 16,599	$ 21,082	$ 14,998	$ 17,310
User Costs	Mean	$ 1,027	$ 1,180	$ 745	$ 915
	Standard Deviation	$ 85	$ 143	$ 120	$ 77
	Minimum	$ 819	$ 910	$ 583	$ 733
	Maximum	$ 1,410	$ 1,745	$ 1,085	$ 1,159
	Percentile 1 (5%)	$ 905	$ 995	$ 617	$ 803
	Percentile 2 (50%)	$ 1,018	$ 1,155	$ 677	$ 907
	Percentile 3 (75%)	$ 1,084	$ 1,277	$ 858	$ 968
	Percentile 4 (95%)	$ 1,178	$ 1,438	$ 954	$ 1,053
Total Costs	Mean	$ 15,196	$ 18,089	$ 12,840	$ 15,014
	Standard Deviation	$ 1,482	$ 2,468	$ 1,781	$ 2,014
	Minimum	$ 10,577	$ 12,207	$ 6,462	$ 9,116
	Maximum	$ 20,133	$ 29,806	$ 18,143	$ 22,728
	Percentile 1 (5%)	$ 12,829	$ 14,450	$ 9,935	$ 11,662
	Percentile 2 (50%)	$ 15,178	$ 17,887	$ 12,823	$ 14,998
	Percentile 3 (75%)	$ 16,176	$ 19,546	$ 14,016	$ 16,377
	Percentile 4 (95%)	$ 17,736	$ 22,443	$ 15,777	$ 18,314

Design Life : **40 Years**
Referenced Design : F-02-a-40 [Alt-1 & Alt-2]
Referenced Design : R-04-a-40 [Alt-3 & Alt-4]

	Statistic	Alternative 1	Alternative 2	Alternative 3	Alternative 4
Agency Costs	Mean	$ 679	$ 814	$ 580	$ 676
	Standard Deviation	$ 64	$ 102	$ 85	$ 94
	Minimum	$ 515	$ 544	$ 331	$ 368
	Maximum	$ 914	$ 1,297	$ 861	$ 989
	Percentile 1 (5%)	$ 581	$ 665	$ 440	$ 521
	Percentile 2 (50%)	$ 676	$ 806	$ 579	$ 678
	Percentile 3 (75%)	$ 719	$ 883	$ 641	$ 739
	Percentile 4 (95%)	$ 796	$ 988	$ 717	$ 826
User Costs	Mean	$ 49	$ 57	$ 36	$ 44
	Standard Deviation	$ 3	$ 5	$ 5	$ 3
	Minimum	$ 42	$ 50	$ 28	$ 39
	Maximum	$ 58	$ 75	$ 42	$ 52
	Percentile 1 (5%)	$ 46	$ 52	$ 30	$ 41
	Percentile 2 (50%)	$ 48	$ 52	$ 32	$ 42
	Percentile 3 (75%)	$ 52	$ 62	$ 42	$ 47
	Percentile 4 (95%)	$ 53	$ 63	$ 42	$ 47
Total Costs	Mean	$ 728	$ 871	$ 616	$ 720
	Standard Deviation	$ 65	$ 105	$ 86	$ 95
	Minimum	$ 561	$ 597	$ 361	$ 409
	Maximum	$ 967	$ 1,370	$ 902	$ 1,037
	Percentile 1 (5%)	$ 627	$ 718	$ 474	$ 563
	Percentile 2 (50%)	$ 726	$ 861	$ 615	$ 722
	Percentile 3 (75%)	$ 768	$ 942	$ 675	$ 784
	Percentile 4 (95%)	$ 847	$ 1,050	$ 756	$ 871

APPENDIX-H

SENSITIVITY ANALYSIS

Introduction

The sensitivity analyses are used to quantify the effects of input variables on computer models and programs. In the analysis AirCost LCCA software was used to analyze sensitivity. Below the table analysis variables are given below.

In the sensitivity analysis requires varying one input variable at a time, while the rest of the variables involved in the program are left constant at an average/medium value. An average value is defined as one that will generally be used in practice under normal design conditions. A "high" value is one, either high or low, which will produce a high life-cycle cost. Conversely, a "low" value is the high or low value of a variable that will produce a low life-cycle cost.

Referenced Design

According to the pavement life-cycle cost analysis the most cost effective pavement alternatives were carried out for sensitivity analysis and references are given below.

Pavement Alternatives	Design Life, Year	Analysis Period, Year
Alternative 3	20	40
Alternative 3	30	40
Alternative 3	40	40

Analysis Parameters

For the deterministic analysis of AirCost LCCA software's input variables are given below.

Sensitivity Analysis LCCA Parameters		
Analysis Base, Year	:	2017
Initial Construction, Year	:	2018
Initial Design Life, Year	:	20, 30 and 40 Years
Analysis Period, Year	:	40
Salvage Value	:	Prorated Life
Supplemental Costs		
Administrative	:	5%
Engineering	:	5%
Main. Of Traffic	:	5%
Indirect/User Costs (Include)		
Total Airport Daily Revenue, $	:	150000
Project Revenue Growth Rate, %	:	4%
Analysis Variables		
Discount Rate		***Deterministic Analysis***
Mean	:	**3%, 3.5%, 4.0%, 4.5% and 5.0%**
Service Life	:	Deterministic
Pay Item Unit Costs	:	Deterministic

Procedure

The analysis program as the same as general life-cycle costing analysis. Only the difference was utilized multiple discount rate with following analysis which already presented in Appendix-G.

Deterministic Output Results

Pavement Alternative	:	Alternative 3
Design Life, Year	:	20
Analysis Period, Year	:	40
Analysis Base, Year	:	2017

Discount Rate, %		3.0%	3.5%	4.0%	4.5%	5.0%
Agency Costs - NPV	:	$12,641,174	$12,266,058	$11,925,630	$11,616,100	$11,334,124
Salvage Value - NPV	:	$ -	$ -	$ -	$ -	$ -
Subtotal	:	$12,641,174	$12,266,058	$11,925,630	$11,616,100	$11,334,124
User Costs - NPV	:	$ 701,906	$ 674,170	$ 649,038	$ 626,239	$ 605,531
TOTAL	:	$13,343,081	$12,940,228	$12,574,668	$12,242,339	$11,939,655

Pavement Alternative	:	Alternative 3
Design Life, Year	:	30
Analysis Period, Year	:	40
Analysis Base, Year	:	2017

Discount Rate, %		3.0%	3.5%	4.0%	4.5%	5.0%
Agency Costs - NPV	:	$12,622,138	$12,261,520	$11,934,066	$11,636,149	$11,364,567
Salvage Value - NPV	:	$ -	$ -	$ -	$ -	$ -
Subtotal	:	$12,622,138	$12,261,520	$11,934,066	$11,636,149	$11,364,567
User Costs - NPV	:	$ 701,906	$ 674,170	$ 649,038	$ 626,239	$ 605,531
TOTAL	:	$13,324,045	$12,935,690	$12,583,105	$12,262,388	$11,970,098

Pavement Alternative	:	Alternative 3
Design Life, Year	:	40
Analysis Period, Year	:	40
Analysis Base, Year	:	2017

Discount Rate, %		3.0%	3.5%	4.0%	4.5%	5.0%
Agency Costs - NPV	:	$12,721,619	$12,360,520	$12,032,590	$11,734,202	$11,462,153
Salvage Value - NPV	:	$ -	$ -	$ -	$ -	$ -
Subtotal	:	$12,721,619	$12,360,520	$12,032,590	$11,734,202	$11,462,153
User Costs - NPV	:	$ 701,906	$ 674,170	$ 649,038	$ 626,239	$ 605,531
TOTAL	:	$13,423,525	$13,034,690	$12,681,629	$12,360,441	$12,067,684