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7. Author(s) Ampol Karoonsoontawong Zhanmin Zhang Randy B. Machemehl		6. Performing Organization Code 8. Performing Organization Report No. 0-4186-2
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16. Abstract

Research Project 0-4186 entitled, "Cradle-to-Grave Monitoring of Pavements and Pavement Management Information System (PMIS) Functionality Enhancement Planning," is intended to develop strategic plans for integrating the pavement-related databases at the Texas Department of Transportation (TxDOT) and enhancing the decision support functions in the PMIS. To integrate pavement-related data, a new information system is proposed. This report presents a comprehensive cost-effectiveness analysis as a part of the feasibility study for developing the proposed information system.

The concept of information system integration is outlined first, followed by a brief review of the current pavement-related databases and a discussion of the conceptual framework for the proposed information system. Then, potential methods for conducting cost-benefit analysis are reviewed. Using the findings from the review, a framework for cost-effectiveness analysis is established with an eight-step process. Using the eight-step process, the cost-effectiveness analysis for the proposed information system is conducted. Sensitivity analyses are also performed to examine the relative impact of the selected input parameters on the output of the cost-effectiveness analysis. Based on the analysis results from the capital budgeting models, it is evident that the investment on developing a new information system to support the pavement engineering and management activities at TxDOT is fully justified.

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Cost-Effectiveness Analysis of Enhancing the Pavement-Related Information Systems at the Texas Department of Transportation

Ampol Karoonsoontawong
Zhanmin Zhang
Randy B. Machemehl

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Research Project 0-4186
Cradle-to-Grave Pavement Monitoring of Pavements and Pavement Management Information System (PMIS) Functionality Enhancement Planning

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Zhanmin Zhang, Ph.D.
Research Supervisor

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1. Introduction

Highway pavements in Texas are an important asset maintained by the Texas Department of Transportation (TxDOT). To keep the pavements in good condition, TxDOT operates an annual maintenance and rehabilitation (M&R) program of approximately $900 million. Appropriate efforts to make the M&R program more effective cannot be overemphasized. For example, a ten percent increase in the effectiveness of the M&R program would yield a savings of $90 million.

The current Texas Pavement Management Information System (PMIS) can be enhanced in two areas: one is the integration of all pavement-related databases; the other is the improvement to the PMIS functions. To provide a mechanism for integrating the pavement-related databases, a new information system based on the concept of a data warehouse is proposed. As part of the feasibility study for developing the new information system, this report documents the research work on justifying the benefits of the proposed information system against the costs by employing capital budgeting models.

1.1 Background

Presently, the Texas PMIS uses only pavement evaluation data and estimated traffic loading along with mainly estimated performance curves to assess pavement condition, conduct needs analysis, and predict the remaining life at network level. This is adequate for apportioning funding to various programs and districts at a statewide level, as the first stage (Stage I) of the PMIS was intended to do.

The second stage (Stage II) of the PMIS was intended to capture pavement layer data, work history, and maintenance cost in order to develop more accurate and specific performance curves. This would in turn yield the ability to conduct accurately pavement condition assessment, needs analysis, and the remaining life prediction at project level. In essence, Stage II of the PMIS was envisioned to serve the pavement management needs of TxDOT districts. It would also better serve the statewide network applications by providing answers to frequently asked questions, such as, which design procedures, construction methodologies, or materials provide better pavement performance in various regions of the state, or whether districts are provided adequate funds to apply the best pavement management practices. Stage II was envisioned and planned during the development of the first stage of the PMIS. However, the completion of Stage II was never materialized, with an important reason being the high cost associated with the development and maintenance of the system.

Currently, two factors make it feasible to develop Stage II of the PMIS. The first is that information technology (IT) has developed to a degree where the cost for information management has been significantly reduced. The districts are currently capturing different kinds of information during the life cycle of a project, including planning, design, construction, in-service evaluation, and maintenance and rehabilitation, as part of their daily business practice. Furthermore, more data are captured in an automated fashion. IT will allow TxDOT to make the PMIS much more user-friendly and robust, so districts can easily extract the kind of information in the format they need.

The second factor is the imperative need for the retention of corporate knowledge. Districts have always depended on personnel with years of experience or corporate knowledge in making pavement management decisions. These experienced personnel have become more rare over the last 10 years because of the changed nature of the U.S. economy. As a result, very expensive decisions have to be made with less and less corporate knowledge and inadequate quality information. Stage II of the PMIS, with the intention to use more accurate performance curves and more complete historical information, would help retain more of the corporate knowledge to support a better process for decision making.

In addition to the PMIS, pavement engineering and pavement forensic analyses also require information about a pavement from cradle to grave. This can include: 1) assumptions and data used in the design of the pavement; 2) how and when the pavement was actually constructed including any anomalies that occurred in construction; 3) what and when maintenance treatments were applied throughout the life of the pavement including cost data for these maintenance treatments; and 4) the performance and accurate traffic data of the pavement throughout the life of the pavement.

The research team for Project 0-4186, entitled "Cradle-to-Grave Monitoring of Pavements and Pavement Management Information System (PMIS) Functionality Enhancement Planning," intends to develop comprehensive plans to guide the cradle-to-grave monitoring of pavements so that adequate and accurate data can be made available to enhance the PMIS and other activities related to the better engineering and management of pavements in Texas.

As shown in Figure 1.1, the research project can be divided into two parts: the integration of pavement-related databases and the enhancement to the PMIS functions. The first part encompasses all the pavement-related databases: Pavement Management Information System (PMIS), Maintenance Management Information System (MMIS), Texas Reference Marker Database (TRM), Road Life (RL), and SiteManager. Specifically, research needs to be carried out to determine what information in these various databases is important to pavement management, and how and when to capture all this information in a relational database. Furthermore, it has to be determined if there is any required information that is not being captured in an existing database; if there is, what would be the best approach to capture this information with the least impact on the current operations of TxDOT personnel.

The second part of the research project aims at the potential enhancements to the PMIS, taking advantage of the additional information and a more user-friendly operating environment. The information gathered in the second part would help determine if the current PMIS can be modified, a new PMIS developed, or a replacement selected from off-the-shelf software. The two parts also complement each other. The needs for PMIS enhancement help define the data integration needs; at the same time, the improved pavement data can provide additional means for the PMIS enhancement.

This research project will yield the strategic plans for the new information system to integrate pavement-related data and to provide the needed information for the PMIS. As an initial step in proposing the new information system to TxDOT, a cost-effectiveness analysis will be conducted to justify the investment on the research.

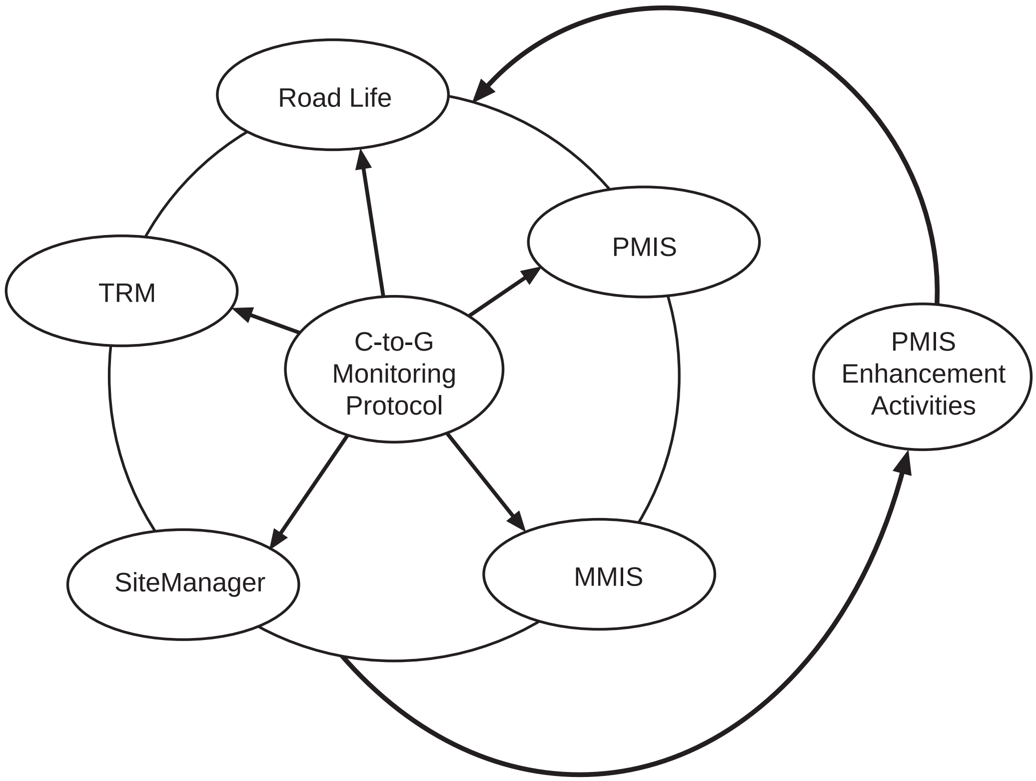

Figure 1.1 Scope of the Project

1.2 Purpose of Report

The proposed information system for enhancing the pavement-related databases will be a large and expensive IT project. The operational development of the proposed system will ultimately need the approval of both TxDOT's Information Resource Council (IRC) and potentially the Texas Department of Information Resources (DIR). One of the key issues for securing the support of IRC and DIR is a comprehensive cost-effectiveness analysis report. This report is intended to facilitate the cost-effectiveness analysis of the proposed information system through evaluating the costs and the benefits with five capital budgeting models.

1.3 Report Organization

This report is composed of seven chapters. Chapter 1 explains the background and scope of the research project, the purpose of the report, and the organization of the report.

Chapter 2 discusses data integration and its impact on costs and benefits of the information system. It also discusses three possible approaches for integrating information systems: database design for the integration, data warehouse, and Enterprise Resource Planning (ERP) system. Additionally, Chapter 2 emphasizes the importance and existence of information politics within an organization.

Chapter 3 briefly describes five existing pavement-related databases at TxDOT: 1) Pavement Management Information System (PMIS), 2) Road Life (RL), 3) Maintenance Management Information System (MMIS), 4) Texas Reference Marker Database (TRM), and 5) SiteManager. Then, it illustrates the proposed information system for integrating these databases and enhancing the decision support functions in the PMIS.

Chapter 4 summarizes the results of the literature review regarding costs and benefits of information systems, the concept of present value, potential methodologies for justifying investments in information systems, and the process of cost-benefit analysis.

Based on the information reviewed in Chapter 4, the framework for the cost-effectiveness analysis is described in Chapter 5. The framework includes eight steps: document assumptions, establish alternatives, select an analysis period, select a discount factor and a discount rate, determine costs, determine benefits, evaluate costs and benefits, and conduct sensitivity analysis.

Chapter 6 provides the results of the cost-effectiveness analysis, using the framework presented in Chapter 5. The results of the sensitivity analyses are also presented.

Chapter 7 summarizes the research process and results, and gives recommendations for further research.

2. Concept of Information Systems Integration

Any enhancement to the pavement-related information systems at the Texas Department of Transportation (TxDOT) would require the integration of those information systems. Literature regarding information systems integration is summarized in this chapter. The chapter begins with the discussion of data integration, followed by the impact of data integration on the costs and benefits of information systems, and then information systems integration. Additionally, the issue of information politics is discussed as another important point of the integration.

2.1 Data Integration

An integrated information system can yield the desired environment of data integration. With data integration, the data in different databases are logically compatible, and the data items have the same meaning across time and users [Martin 86]. In general, data integration means the standardization of data definitions, field and record definitions, structures, and rules for updating data values [Heimbigner et al. 85]. An integrated information system has three properties [Brittain 92]. First of all, it provides any authorized user in the organization with the capability to access all data or information necessary to support the business process and the fulfillment of organizational goals and objectives. Next, it is available at any location within the organization. Finally, it presents information or data in a suitable form and quality to enable the user to work at maximum efficiency in achieving the organizational goals and objectives [Brittain 92].

To understand the importance of data integration, two examples are illustrated in Table 2.1, where Divisions A and B are put in an integrated and a nonintegrated environment. Assume there is an inquiry regarding pavement roughness evaluation from the administration. Divisions A and B in the integrated environment that use the same measure (i.e., Present Serviceability Index (PSI)) will give consistent information, while Divisions A and B in the non-integrated environment using different measures (i.e., PSI for Division A and International Roughness Index (IRI) for Division B) will not give compatible information. A situation like this occurs because the nonintegrated environment does not have standardized data definitions. As another example, there is a request for the total length of new construction roads in the past fiscal year. In the integrated environment, both divisions will provide the same information. However, in the nonintegrated environment, Division B will give a higher number than Division A possibly because Division B has gathered data for the length of new construction roads in addition to that of rehabilitated roads. Such inconsistency in information is caused by the lack of data integration.

Table 2.1 Two Examples of Data Integration [Goodhue et al. 92]

	INTEGRATED ENVIRONMENT		NON-INTEGRATED ENVIRONMENT	
	DIVISION A	DIVISION B	DIVISION A	DIVISION B
1) Pavement roughness measure	PSI	PSI	PSI	IRI
2) Total length of new construction roads	33,450	33,450	33,450	50,450

2.2 Impact of Data Integration on the Costs and Benefits of Information Systems

Goodhue et al. [92] pointed out three important organizational factors that can make a difference in net benefits with the same increased level of data integration. Those three factors include the interdependence of subunits, the need for locally unique or flexible action by subunits, and the difficulty of designing and implementing systems with integrated data as shown in Figure 2.1. Therefore, there is a possibility that a partial data integration of an organization's data could be more cost-effective than a complete integration.

In other words, an organization should decide which level of data integration is suitable by analyzing the impact of such integration on the costs and benefits through the three factors. If an organization consists of different subunits that largely do not have to share data and information, then integrating these different units' databases will not yield significant benefits. Under such circumstances, it is wise to decrease the degree of data integration, given that the other two factors are the same [Goodhue et al. 92].

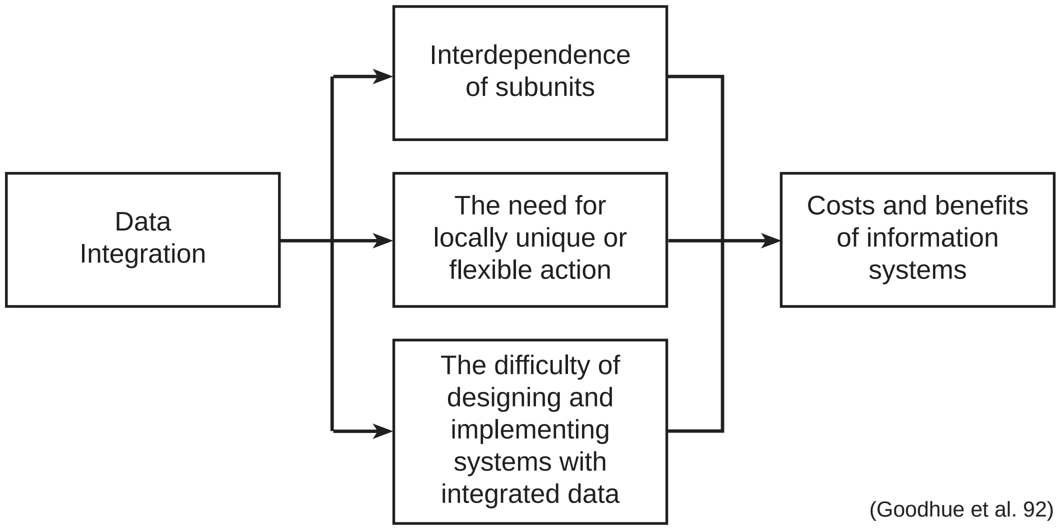

Figure 2.1 The Impact of Data Integration on the Costs and Benefits of Information Systems [Goodhue et al. 92]

If an organization's subunits have more locally unique tasks, they certainly do not have to share data and information. The integration of their databases would yield unnecessary high costs. Under such a situation, if that organization still chooses to have data integration, the difficulty of changing the data models will occur because the approval from all subunits has to be obtained before making any changes to the data models. Therefore, given that the other two factors are the same, as the difference among subunits increases, the level of data integration should decrease [Goodhue et al. 92].

If an organization's subunits need diverse information and have different database platforms, it will be difficult to integrate these databases according to the consensus of the subunits. Therefore, the degree of data integration should decrease, as there are many heterogeneous subunits involved, provided that the other two factors are the same [Goodhue et al. 92].

The impact of the three factors on the costs and benefits of information systems is summarized in five propositions, as follows [Goodhue et al. 92]:

Proposition 1: All other things being equal, as the interdependence between subunits increases, the benefits of data integration will increase, and the amount of data integration in rational organizations should also increase.

Proposition 2a: All other things being equal, as the differentiation between subunits increases, data integration will impose more and more compromise costs on local units; therefore, the amount of data integration in rational firms should decrease.

Proposition 2b: All other things being equal, firms with increased data integration will experience greater bureaucratic delay in getting approval for changes affecting the data models used by individual subunits.

Proposition 3a: All other things being equal, as the number and heterogeneity of subunit information needs increase, the difficulty of arriving at acceptable design compromises increases, and the cost of the resulting design will increase exponentially. Thus, rational firms will integrate less extensively when there are many heterogeneous subunits involved.

Proposition 3b: As organizations face greater instability in their environments and their information requirements, the importance of proposition 3a will increase. In turbulent environments, firms with many heterogeneous subunits will be even less likely to integrate extensively, and firms with homogeneous subunits will be more likely to integrate extensively [Goodhue et al. 92]."

The degree of data integration is a function of the three factors: the interdependence of subunits, the need for locally unique or flexible action, and the difficulty of designing and implementing systems with integrated data. The combination of these three factors influences the costs and benefits of information systems. When an organization decides on the degree of data integration, many approaches for information systems integration can be used. The following section discusses three possible approaches for integrating information systems.

2.3 Information Systems Integration

Currently, many organizations are faced with the disintegration of their existing information systems. Developed on different platforms, these existing information systems are unable to efficiently communicate among related databases, in addition to the problems of inconsistent and redundant data. As such, the information systems do not seem to efficiently support organizational processes. The process of information systems integration aims to transform an existing system into a more efficient system that is more supportive of organizational processes so the organization can be more efficient and more competitive [Sanders 95]. In the past, integrating various information systems was difficult because of such limitations as high cost of technology and the lack of tools for guiding and modeling organizations. At the present time, information technology is more cost-effective and there are many tools for guiding and modeling organizations. The typical strategies for information systems integration include "new hardware and software platforms, the restructuring of applications programs, the development of new telecommunications networks, and complete system rewrites" [Sanders 95]. Apparently, three possible approaches for systems integration have been suggested: 1) use database design to restructure the existing systems, 2) use data warehouse as a new integrated system in addition to the existing systems, and 3) replace the existing systems by an off-the-shelf software package (i.e., an Enterprise Resource Planning (ERP) system).

2.3.1 Use of Database Design for the Integration

Normally, a disintegrated information system faces problems called data anomalies. Data anomalies consist of update, deletion and insertion anomalies [Sanders 95]. An update anomaly occurs when an attribute has to be changed, but the changed attribute of those records has to be updated accordingly because it exists in several records. A deletion anomaly occurs when the removal of a record results in a loss of important information about an entity. An insert anomaly occurs when a new attribute needs to be added, but there is not an appropriate place in existing tables.

To understand data anomalies, an example of an update anomaly is shown as follows. There are only two tables in a relational database of a highway department in a country. The tables contain information about different highways in the country, so the records of the tables are different highway routes, and columns are different attributes of the routes. The first table contains location, construction, cross section, maintenance, and rehabilitation data, whereas the second table contains location, traffic, and visual distress data. If a highway has realignment, the location data will have to be updated. If only one of the two tables is updated, the other table will still contain the wrong location data. This is an update anomaly.

In terms of database design, Sanders [95] describes the process of systems integration as a two-phase iterative cycle. The first phase is identifying and formalizing data requirements with a conceptual data model by using a graphical language called data modeling to represent data. The second phase is the implementation of the conceptual data model in the appropriate hardware and software configuration [Sanders 95]. To integrate the existing databases that are not integrated, the conceptual data models can indicate which parts of the systems should be restructured in order to achieve the integration.

The primary tool in conceptual data modeling is the entity relationship (ER) diagram, which is discussed in the literature by Chen [76] and Sanders [95]. The strict use of ER diagrams certainly prevents the occurrence of data anomalies, but does not guarantee a good data organization, which consists of three properties: tightness, simplicity, and efficiency of processing. Therefore, it needs trade-offs by relaxing some parts of ER diagrams. This surely leads to some occurrences of data anomalies, but provides a better data organization.

There is another approach for database designs: normalization. It is a bottom-up strategy when compared with the ER diagrams, which are a top-down strategy [Sanders 95]. The normalization begins with identifying the attributes and then assigning them to the relational tables, while the ER diagrams start with identifying entities or relational tables then assigning attributes to them. In practice, skilled database designers design and re-engineer databases using both ER diagrams and normalization [Sanders 95].

2.3.2 Data Warehouse

The integration of information systems can also be achieved by imposing the architectural environment on the existing system. The architectural environment is composed of four levels: operational, data warehouse, departmental, and individual, as shown in Figure 2.2 [Inmon 96a]. The operational level contains current data, is application-oriented, and has high possibility of access. The data warehouse level is subject-oriented. It contains integrated data derived from the operational level and primitive data that is not updated. In addition, it has some elements of time associated with each record. The departmental level contains derived data from the data warehouse; it partitions data into different departments such as accounting, engineering, marketing, and manufacturing. The individual level is normally in a personal computer or workstation. It contains temporary and ad hoc data, and can perform heuristic analysis.

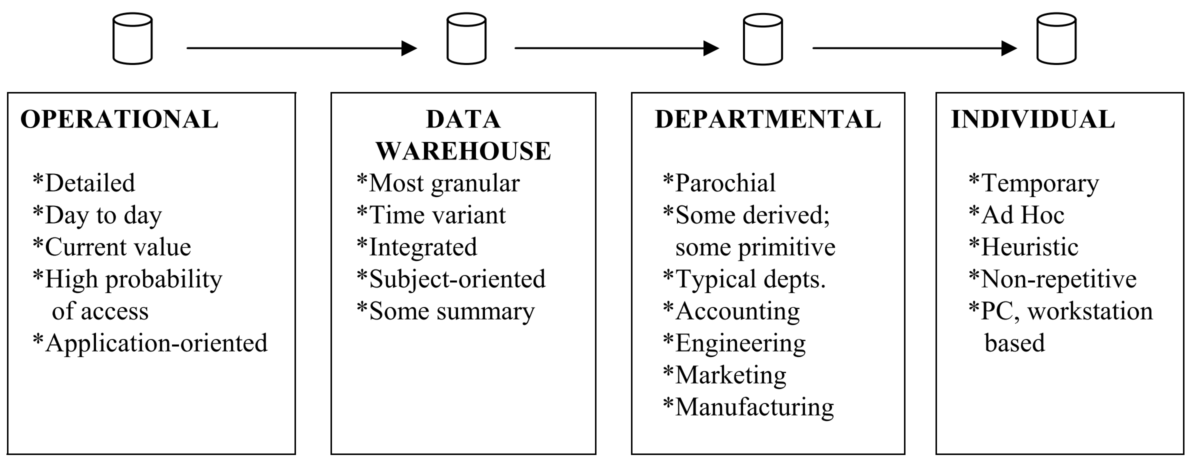

Figure 2.2 The Architectural Environment [Inmon 96a]

Furthermore, the data warehouse level of the architectural environment provides the foundation for effective data mining [Inmon 96b]. Data mining can be done even if there is no data warehouse, but with clean, integrated, and complete data offered by a data warehouse, data mining could have a high possibility of success. Inmon [96b] indicated that four kinds of data offered by a data warehouse would enhance the data mining process: integrated data, detailed and summarized data, historical data, and metadata. First, with integrated data, data miners can concentrate on data mining as opposed to devoting a lot of time to cleansing and integrating data. Second, the data warehouse contains both detailed and summarized data. Data miners do not have to perform analysis to get the particular summarized data because those data are already stored in the data warehouse. If data miners need to examine the detailed data to reveal the hidden information, the data warehouse can provide such data. Third, trends and long-term patterns of behavior are hidden in historical data that are also stored in the data warehouse. Finally, data miners can use metadata that describe the context of data. Data miners would not be able to comprehend the content of data without the context of data [Inmon 96b].

2.3.3 Enterprise Resource Planning (ERP) System

Enterprise resource planning systems are pre-written software available off-the-shelf with sufficient flexibility to match most needs; they are designed to solve the fragmentation of information in large business organizations [Willcocks et al. 00 and Davenport 98]. The products of ERP systems include software systems such as SAP, ORACLE, Baan, JD Edward, and Peoplesoft.

There are pros and cons for adopting ERP systems. According to Davenport [98], an ERP system has three advantages and five disadvantages as shown in Table 2.2.

Table 2.2 Advantages and Disadvantages of ERP Systems [Davenport 98]

Advantage	Disadvantage
• streamline the data flow of an organization • provide management with direct access to real-time operating information • provide a generic solution as the best procedure	• needs huge storage • have training overhead costs • lead to a large-scale business process of reengineering • impact an organization and culture • need high implementation efforts

Interestingly, Scheer et al. [00] indicate that the ratio between ERP implementation efforts and software purchases is approximately 5 to 1. This high ratio would prompt an organization to be much more careful when considering moving its system toward an ERP system.

2.4 Information Politics

Organizations have expected information technology to encourage information flow and eliminate hierarchy, but the opposite results have taken place; this is because information becomes the key organizational currency [Davenport et al. 92]. Information is too valuable for most managers to just give away. To achieve information-based organizations, the power of politics needs to be controlled by allowing the stakeholders to negotiate the use and definition of information [Davenport et al. 92]. In the following section, the definitions of different information politics models are given, assessed in different dimensions. Finally, some suggestions for moving an organization toward effective political models are discussed.

2.4.1 Information Politics Models

To learn about politics behind information, the five politics models – technocratic utopianism, anarchy, feudalism, monarchy, and federalism – are defined as shown in Table 2.3. An organization that sets the information management policy primarily based on technologies will belong to the technocratic utopianism model. If it does not have any information management policy, and anyone can manage one's information arbitrarily, then it will belong to the anarchy model. If it has different information management policies on various units of the organization and those policies are not consistent and not coordinated, then it will belong to the feudalism model. If its leaders set up the mandatory information management policy and every unit of the organization strictly follows the policy, then it will belong to the monarchy model. If it allows the managers from different units to negotiate about the information management policy to reach a consensus, it will belong to the federalism model.

2.4.2 Assessment of Information Politics Models

Davenport et al. [92] assessed the five models in four different dimensions: commonality of vocabulary, access to information, quality of information, and efficiency of information management as shown in Table 2.4. Each of the models is rated with a score ranging from 1 to 5 for each of the dimensions, where 5 is the highest and 1 is the lowest. The total score indicates that federalism is the best model and monarchy the second best, while the other three models are less effective.

Table 2.3 Models of Information Politics [Davenport et al. 92]

Technocratic Utopianism	A heavily technical approach to information management stressing categorization and modeling of an organization's full information assets, with heavy reliance on emerging technologies.
Anarchy	The absence of any overall information management policy, leaving individuals to obtain and manage their own information.
Feudalism	The management of information by individual business units or functions, which define their own information needs and report only limited information to the overall corporation.
Monarchy	The definition of information categories and reporting structures by the firm's leaders, who may or may not share the information willingly after collecting it.
Federalism	An approach to information management based on consensus and negotiation on the organization's key information elements and reporting structures.

Table 2.4 Ranking Alternative Models of Information Politics [Davenport et al. 92]

	Federalism	Monarchy	Technocratic Utopianism	Anarchy	Feudalism
Commonality Of Vocabulary	5	5	3	1	1
Access to Information	5	2	3	4	1
Quality of Information	3	2	1	2	2
Efficiency of Information Management	3	5	3	1	3
Total	16	14	10	8	7
Key: 5 = high 3 = moderate 1 = low					

2.4.3 Suggestions for Moving Organizations Toward Effective Models

To move an organization to the effective models, Davenport et al. [92] propose five steps: 1) select an information state, 2) match information politics to the organizational culture, 3) practice technological realism, 4) elect the right information politicians, and 5) avoid building information empires. First, an organization must identify the current models in use, which model currently dominates, which is the most desirable model, and how to select it. Then, the organization has to adjust its culture to match the desired model before the process actually takes place. The desired culture has to be supportive of automated information management and free information exchange. Subsequently, focused and less ambitious information management objectives should be set up because they are more likely to succeed given the great volume of information in the organization. Focused information should be in units that managers can understand and use for negotiation. Desirable technology platforms should be as common as possible. Furthermore, the organization should appoint a leader as an information politician who has the capability of persuading others of the importance of information management and the correctness of the chosen political model. Finally, the organization should introduce the concept of information stewardship; that is, the responsibility for ensuring data quality with ownership by the organization at large [Davenport et al. 92].

3. Current Pavement-Related Databases at TxDOT and the Conceptual Framework for the Proposed New Information System

This chapter briefly describes the existing pavement-related databases at the Texas Department of Transportation. Then, the proposed conceptual information system architecture that integrates pavement-related databases and provides required data for the decision support functions in PMIS is illustrated.

3.1 Current Pavement-Related Information Systems at TxDOT

There are five pavement-related databases that are closely related to the engineering and management of pavements: Pavement Management Information System (PMIS), Road Life database (RL), Maintenance Management Information System (MMIS), Texas Reference Marker database (TRM), and SiteManager. The information about the databases and the data elements contained within the databases was obtained from Victorine [98]. This review gives the background and the pavement-related data categories of the databases, in addition to their responsible division, control section size, data updating party, data collection party, frequency of data updating, degree of population, etc. Critical information regarding these five databases is summarized in Table 3.1.

3.1.1 Pavement Management Information System (PMIS)

The Pavement Management Information System is an automated system that TxDOT uses for "storing, retrieving, analyzing, and reporting information to help with pavement-related decision making process" [TxDOT 94]. It is an analysis tool to support pavement management, the process of "providing, evaluating, and maintaining pavements in a serviceable condition according to the most cost effective strategy" [TxDOT 94]. PMIS supports a wide range of activities including planning, highway design, in-service evaluations, maintenance, rehabilitation, research, and extensive detailed reporting to a variety of decision makers.

The PMIS database has been in use since its inception on May 7, 1993, to satisfy the requirement of the Federal Highway Administration for all states to use pavement management systems. However, PMIS is just the embodiment of what was originally the Pavement Evaluation System (PES). The PES was created in 1982 in order to provide data about the present condition of the Texas highway system, monitor the changes in the condition of highways, and acquire the needed funds to improve the highway system [Victorine 98]. Therefore, the current PMIS carries data collected from 1983 to the present [Victorine 98].

Table 3.1 Critical Information of Five Pavement-Related Databases [after Victorine 98]

	PMIS	**RL**	**MMIS**	**TRM**	**SiteManager**
Responsible Division	Construction Division (CST)	Construction Division (CST)	Construction Division (CST)	Transportation Planning And Programming Division (TPP)	Construction Division (CST)
Control Section Size	0.5 mile	Homogeneous Sections	Distance Between TRMs	Continuous	Not Applicable
Data Updating Party	District PMIS Coordinator	Ad-Lib	Maintenance Crew Chief	District TRM Coordinator /TPP	Varies
Data Collection Party	District Level	Ad-Lib	District Level	District Level/ TPP	Varies
Frequency of Data Updating	Annually/ Bi-Annually	Ad-Lib	As Needed	As Needed	Varies
Degree of Data Population	Complete	Sparse	Complete	Complete	Under Pilot
Imports from	TRM, RL, MMIS	TRM	Not Applicable	Traffic Database	Unknown
Exports to	Not Applicable	PMIS	PMIS	PMIS, RL	Unknown
Data stored in	Mainframe	Mainframe	Mainframe	Mainframe	Relational Database

As shown in Table 3.1, the Construction Division is responsible for PMIS. A PMIS control section is generally 0.5-mile long. PMIS data are collected at the district level. District PMIS coordinators update data either annually or bi-annually. The degree of data population is complete. Some of the data items are imported from other databases such as TRM, RL, and MMIS. The PMIS does not export data to other databases. The PMIS contains nine pavement-related data categories:

- location data
- pavement type and characteristics
- visual distress data
- other nonvisual distress data
- condition scores
- maintenance data
- climatic data
- traffic data
- cross-section data

Details on the data elements such as exact function, format, etc., are available in the data dictionary of the PMIS database.

PMIS data are stored on the TxDOT mainframe computer in two ADABAS-type files. The data may be accessed remotely through two kinds of software: Customer Information and Control System (CICS) and Remote Operating Systems Conversational On-Line Environment (ROSCOE). Therefore, theoretically the PMIS data are accessible from any properly connected personal computer. "CICS provides a direct access environment with easy to use menus for accessing" [TxDOT 94]. With CICS, preliminary database manipulations and inquiries can be performed directly. "ROSCOE provides a batch job environment for reviewing jobs submitted from the PMIS/CICS environment" [TxDOT 94]. More complex functions are handled by submitting batch jobs from the menus.

3.1.2 Road Life (RL)

The Road Life database was designed to support four functional areas: 1) performance of pavements, 2) rehabilitation design, 3) life-cycle costs, and 4) preventive maintenance [Victorine 98]. It was created to offer an immediate solution for the data collection needs of TxDOT. Completed in June 1996, RL was originally designed as a prototype database. RL has been used on a voluntary basis by only some of the districts.

As shown in Table 3.1, the Construction Division maintains RL. The length of the RL control section depends on the homogeneity of the section. Because the use of RL is voluntary, the parties responsible for data collection and updating as well as the frequency of data updating, vary among districts. The degree of data population is low. Some data items are exported to the PMIS while others are imported from the TRM. RL data are stored on the TxDOT mainframe computer, and can be accessed through CICS and ROSCOE from a properly connected personal computer. RL has three pavement-related data categories:

- location
- pavement type and characteristics
- cross-section data

Details on the data elements such as exact function, format, etc., are available in the data dictionary of the RL database.

3.1.3 Maintenance Management Information System (MMIS)

The Maintenance Management Information System keeps track of all maintenance activities performed on highways that fall under the jurisdiction of TxDOT [Victorine 98]. Full data collection for MMIS began on September 1, 1989.

As shown in Table 3.1, the Construction Division maintains MMIS. The length of the MMIS control section is the distance between reference markers. A maintenance crew chief is responsible for updating data as needed. The data collection party is at the district level. The degree of data population is complete. Some data are exported to the PMIS. No data are imported from other databases. MMIS data are stored on the TxDOT mainframe computer in four files: audit, master, transaction, and FIMS-ENC41. MMIS data can be accessed remotely through CICS and ROSCOE. There are two pavement-related data categories in RL:

- location data
- maintenance data such as date work performed, amount spent, type of work, etc.

Details on the data elements such as the exact function, format, etc., are available in the data dictionary of the MMIS database.

3.1.4 Texas Reference Marker Database (TRM)

The Texas Reference Marker database, taking its name from the roadway identification system used to organize TRM data, is designed to be a control-location-based inventory of current roadway conditions within the TxDOT road network [Victorine 98]. The TRM system produces a statewide location system for the on-system routes in the state of Texas, based on the physical markers located in the field. The Texas Reference Marker system was developed primarily because the prior control section-based system used by TxDOT was inadequate for statewide reporting. The TRM database was born as a component of the Road Inventory Network (RI) that uses the control-section-based identification system. The TRM database was implemented on May 1, 1995. However, it stores data on the on-system roads, while the RI stores both on-system and off-system data.

As shown in Table 3.1, the Transportation Planning and Programming Division (TPP) maintains the TRM database. The TRM control section size is continuous. TxDOT districts and TPP are responsible for collecting TRM data, which are updated as needed by district TRM coordinators and TPP staff. The degree of data population is complete. Some of the TRM data are exported to PMIS and RL. The TRM database imports traffic data from the traffic database. TRM data are stored on the TxDOT mainframe computer in nine files: transaction, administration, feature, geometric, link, master, pavement, tracking, and traffic. TRM data can be accessed remotely through CICS. There are four pavement-related data categories in the TRM database:

- location
- pavement type and characteristics
- traffic
- cross section

Details on the data elements such as the exact function, format, etc. are available in the data dictionary of the TRM database.

3.1.5 SiteManager

SiteManager officially started in October 1995 with the award of the contract for its creation to MCI Systemhouse. As it was envisioned, SiteManager is a comprehensive, state-of-the-art, a jointly developed construction management system sponsored by the American Association of State Highway and Transportation Officials (AASHTO), 18 state departments of transportation, one Canadian province, and the

Federal Highway Administration (FHWA). It is intended to automate five major functional areas: 1) daily work reports and project records, 2) materials management, 3) contractor payments and progress monitoring, 4) civil rights requirements and 5) administrative support [Victorine 98].

As shown in Table 3.1, the responsible division for SiteManager is the Construction Division (CST).

SiteManager does not have control sections like other pavement-related databases. SiteManager data are stored in a relational database. It should be noted that the other information from Table 3.1, such as the parties responsible for data collection and updating, the frequency of data updating, the degree of data population, etc., are outdated. SiteManager is capable of running on Microsoft Windows 95, Microsoft Windows for Workgroups, Microsoft Windows NT, and IBM's OS/2 platform [AASHTO 98]. SiteManager works in a client-server, local, or wide-area network environment. There are 24 pavement-related data categories in SiteManager:

- location
- material gradations
- Hveem mix description
- Marshall mix description
- SuperPave mix description
- bituminous materials
- Portland cement concrete (PCC) description
- PCC materials
- aggregate mix description
- aggregate mix compressive strength
- pavement structural design data
- specifications
- material descriptions
- mix designs
- Hveem mix properties
- Marshall mix properties
- SuperPave mix properties
- bituminous gradations
- PCC properties
- PCC gradations
- aggregate mix materials
- aggregate mix gradation
- aggregate blend data
- material test results

Details on the data are available in AASHTO [98].

After reviewing the existing pavement-related databases, the following section discusses the proposed information system, which would integrate pavement-related data and provide needed data to the PMIS.

3.2 Proposed Conceptual Information System

As shown in Figure 3.1, the proposed information system is a new relational database functioning as a data warehouse in an architectural environment discussed in Section 2.3.2. The five existing pavement-related databases will not be changed. The proposed database will communicate with the existing databases through a middleware. A middleware is a utility software that interfaces systems built with incompatible technologies, and serves as a consistent bridge between two or more technologies [Whitten et al. 98]. The data in the existing databases will be selected, extracted, cleansed, integrated, and then stored into the proposed database. Subsequently, the decision support functions in the PMIS could receive more accurate and more current data from the proposed database. The communications between the proposed database and the decision support functions also can be made possible through the middleware. The other pavement-related areas, such as forensic studies and administrative legislative inquiries, can benefit from the proposed database as well.

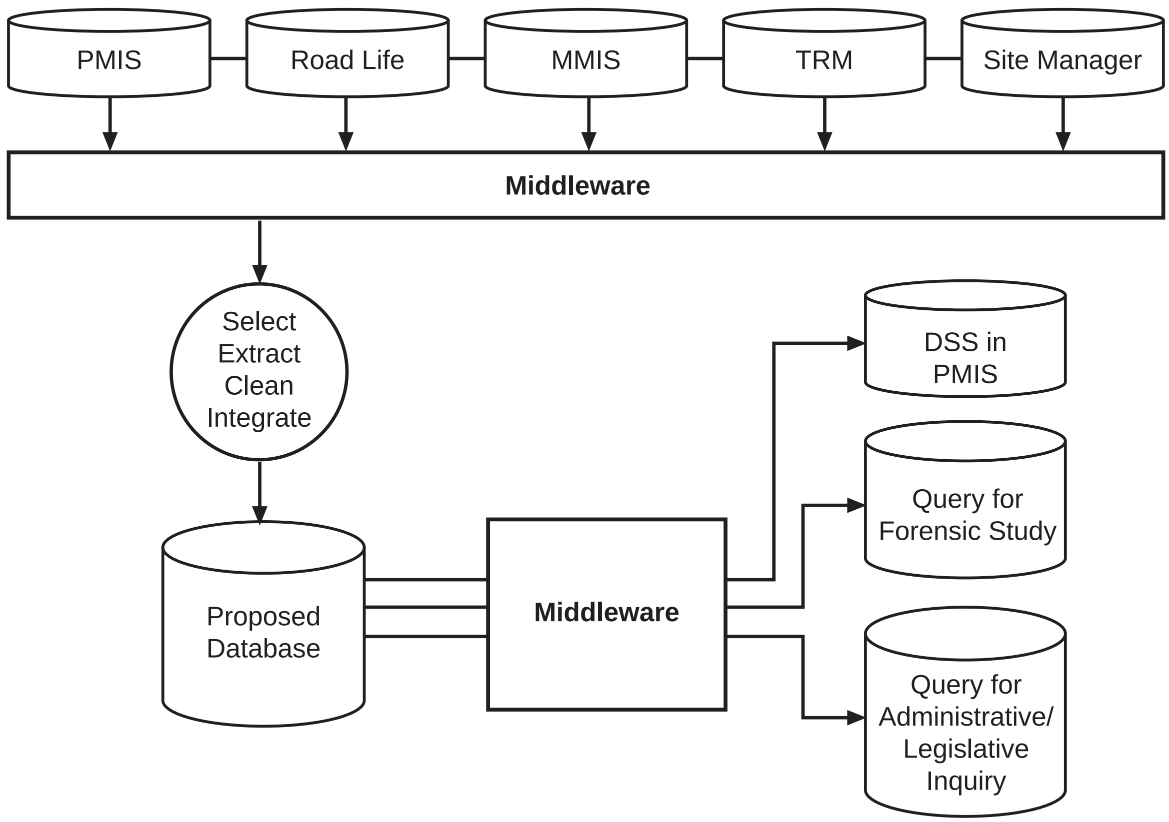

Figure 3.1 Proposed Conceptual Information System Architecture

4. Literature Review of Cost-Benefit Analysis

This chapter summarizes various methods and efforts regarding cost-benefit analysis, starting with the discussion of costs and benefits of information systems. In order to calculate costs and benefits incurred in different time frames, the concept of present value is discussed. Also, different methodologies for justifying information system investments are provided and discussed.

4.1 Costs of Information Systems

All costs for the life cycle of information systems, including planning, design, development, implementation, operation, and maintenance, have to be included. There are five factors that must be considered: 1) activities and resources, 2) cost categories, 3) personnel burdened costs, 4) depreciation, and 5) social subsystem costs.

4.1.1 Activities and Resources

Tasks associated with each stage of the system life cycle should be identified in order for the required resources or cost elements to be determined [NIH 99a]. Table 4.1 shows an example of a system life-cycle cost matrix. There are eight activities over this system life cycle: project initiation, information technology resources acquisition, system design, development, operation, maintenance, evaluation, and management. Within each activity, different tasks and corresponding cost elements are identified. These activities can be either implemented within an organization or outsourced to a contractor.

4.1.2 Cost Categories

Costs should be identified so they can be related to the budget and accounting processes [NIH 99a]. There are nine cost categories [OMBA11 99]. The first is equipment costs, which can be divided into two subcategories: capital purchases and other equipment purchases/leases. The second is software costs with two subcategories: capital purchases and other software purchases/leases. Categories 3, 4, 5, and 6 are services, support services, supplies, and personnel, respectively. Category 7 is costs that are not included in any of the cost categories, divided into two subcategories: capital purchases and other purchases. The last two categories are intra-governmental payments and intra-governmental collections.

Table 4.1   System Life-Cycle Cost Matrix Example [NIH 99a]

Activity	Task	Cost Elements
Project Initiation	Problem Definition	*Analysts, Managers, **Processors, Customers
	Work Process Evaluation	Analysts, Managers, Processors, Customers
	Processing Requirements Definition	Analysts, Managers, Processors, Customers
	Security Planning	Analysts, Managers, Processors, Customers
	Develop IT Performance Measures	Analysts, Managers, Processors, Customers
	Prepare Cost Benefit Analysis	Analysts, Managers, Processors, Customers
IT Resources Acquisition	Develop Statement of Work	Analysts, Managers, Processors, Customers
	Award Contract	Project Manager, Analysts, Contracting Personnel
	Monitor Contract	Project Manager, Contracting and Finance Personnel
System Design	Develop System Design	Analysts, Managers, Processors
	Approve System Design	Analysts, Managers, Processors
System Development	Develop and Test Programs and Procedures	Analysts, Managers, Processors, Programmers, Computers, Software
	Develop Transition Plan	Analysts, Managers, Processors
	Implement New System & Procedures	Analysts, Managers, Processors, Programmers, Computers, Software
System Operation	Operate New System	Computers, Software
System Maintenance	Correct Errors & Make Changes to the System	Analysts, Managers, Processors, Programmers, Computers, Software
System Evaluation	Evaluate System Performance Compared to Expectations	Analysts, Managers, Processors, Customers
System Management	Oversee System	Project Manager, Managers

*Analysts will usually be Management Analysts and/or Computer Systems Analysts.
**Processors are the people in the organization performing the work process that is being automated.

4.1.3 Personnel Burdened Costs

Personnel burdened costs are the summation of direct labor costs, fringe benefits, and overhead. Direct labor costs can be determined by prevailing wage rates and salaries[1]. The annual fringe benefits can be determined with the product of the fringe benefits factor and the appropriate basic pay. Fringe benefit factors are estimated according to the Federal

[1] Prevailing wage rates and salaries can be found in Office of Management and Budget (OMB) Circular A-76, Supplemental Handbook, Part II-Preparing the Cost Comparison Estimates.

Accounting Standards for Liabilities-Exposure. The total fringe benefit factor[2] for full or part-time permanent federal civilian employees is 32.45 percent. The annual overhead costs are determined by multiplying the overhead rate to the summation of the annual salary and the annual fringe benefits. The overhead rate of 12 percent[3] is normally used.

4.1.4 Depreciation

Depreciation is defined as "lowering the estimated value (referred to as book value) of a capital asset (usually only those items valued at $5,000 or more)" [NIH 99a]. It can be determined by the difference of the original costs of information systems and the residual or salvage value at the end of its useful life[4]. However, Laudon et al. [98] suggest that the salvage value of an information system should be zero. Therefore, the depreciation of an information system would be equal to the initial investment.

4.1.5 Social Subsystem Costs

Information Technology decision makers frequently consider social subsystem costs as training costs, which include the training vendor, materials, and other purchases from external sources [Ryan et al. 00]. However, a few organizations also consider the "on the clock" time lost by the employees while attending training courses [Ryan et al. 00]. An organization should consider two additional social subsystem costs: management of changes and recognition of an on-the-job learning curve. The consideration of the management of changes encompasses planning, overseeing, and communicating information to the end users on IT-induced change [Ahituv et al. 94]. An on-the-job learning curve characterizes the time period in which the employees learn and become proficient in using an information technology [Robertson et al. 93]. It should be evaluated as the amount of time required for an employee to get acquainted with using the new system after the training is completed [Ryan et al. 00].

4.2 Benefits of Information Systems

Benefits of information systems can be defined as "the services, capabilities, and qualities of each alternative system, and can be viewed as the return from an investment" [NIH 99a]. It can be classified into two categories: tangible and intangible [Emery 71]. Tangible benefits can be quantified and assigned a monetary value, whereas intangible benefits cannot be immediately quantified but may lead to quantifiable gains in the long run [Laudon et al. 98].

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[2] The current fringe benefit factors can be found in OMB Circular A-76, Supplemental Handbook, Part II-Preparing the Cost Comparison Estimates, Chapter 2-Developing the Cost of Government Performance, B. Personnel-Line 1, 6f. Fringe Benefits.
[3] The overhead rate of 12% is specified in OMB Circular A-76, Supplemental Handbook, Part II-Preparing the Cost Comparison Estimates, Chapter 2-Developing the Cost of Government Performance, E. Overhead-Line 4.
[4] The useful life and disposal values for computer resources are provided in OMB Circular A-76, Appendix 3, Useful Life and Disposal Values. However, most of the values are from 13 to 15 years, which is not realistic [NIH 99a].

Intangible benefits, such as customer goodwill, are especially hard to translate into monetary value [Emery 71]. Difficulty in expressing a benefit in monetary terms does not imply that the benefit cannot be quantified. Intangible benefits can be assigned a monetary value if sufficient effort is devoted to the task and the methodology is justified. Therefore, the difference between a tangible and an intangible benefit lies in the level of difficulty for estimating monetary value [Emery 71].

For the purpose of quantification, benefits of information systems could be organized into three types: efficiency benefit, effectiveness benefit, and intangible benefit. One can easily quantify efficiency benefits from personnel cost savings. Effectiveness benefits are difficult to quantify because specific tasks affected by the new information system need to be identified in order to make reasonable estimates. Intangible benefits are those that cannot be assigned a dollar value.

4.2.1 Efficiency Benefits

Efficiency benefits occur when the tasks are automated by the new systems in a way in which the system has little change in the quality of the output but operates at a lower cost [Gillespie 94 and Emery 71]. They are the reduction in variable costs for running the application, and the greater part of these costs is usually personnel costs [Gillespie 94]. Also referred to as tangible cost reductions, the efficiency benefits are made possible for the new system to aim at clear-cut cost reductions in information processing [Emery 71].

As an example, the development of the new information system, Health Research Management Evaluation System (HRMES), at the National Institutes of Health (NIH) was intended to provide health research managers with an administrative information system that allowed them to generate reports showing the status of the organization, and evaluate the effectiveness of the managers [NIH 99b]. HRMES would automate previously manual tasks. It was estimated that 75 percent of the time for each person in the organization would be available for other duties, since approximately 25 percent of a person's time would still be required for data entry. The cost avoidance factor of 75 percent can be used to determine the efficiency benefits. The annual efficiency benefits are the product of the cost avoidance factor of 0.75 and the annual personnel burdened costs, which are the summation of the annual salary, fringe benefits, and overhead.

In another example illustrated by Hall et al. [00], the efficiency benefits of implementing the Geographic Information System (GIS) at the Illinois Department of Transportation (IDOT) have resulted from three parts: estimated personnel savings by a fully implemented GIS project; the GIS-enabled replacement of existing map preparation functions by IDOT personnel; and savings in travel, supplies and other miscellaneous costs.

4.2.2 Effectiveness Benefits

Effectiveness benefits occur when the new information system enhances the quality of the output, or produces an output that was not previously available [Gillespie 94]. The effectiveness benefits could be such factors as faster and better decisions made by managers, which are difficult to assign a dollar value. They could simply be listed in the cost-benefit analyses as intangible benefits, such as:

- improved decision making
- unprecedented analysis of information
- more timely information
- more information
- improved asset utilization
- improved resource control
- improved organizational planning
- increased management capabilities
- higher client satisfaction
- increased service to the public [Laudon et al. 98 and TN 99]

As discussed in Gillespie [94], the U.S. Geological Survey (USGS) has developed a simple and practical method to estimate effectiveness benefits. As a remarkable example of using the USGS technique, the GIS implementation at Illinois Department of Transportation (IDOT) was estimated to yield effectiveness benefits from two specific areas: 1) accident analysis and remediation, and 2) annual and multiyear network-level rehabilitation program development, as shown in Hall [99]. The case study of IDOT provides insight into how to quantify the effectiveness benefits.

The effectiveness benefits determined in this report are solely based on the work done by Hall [99]. Therefore, it is very worthwhile to briefly summarize the relevant information from his work, i.e., the effectiveness benefits from the annual and multi-year network-level rehabilitation program development.

4.2.2.1 Effectiveness Benefits Example [Hall 99]

For program development, the available budget for improving the roadway network is fixed; therefore, the value of better decisions would be the ability to better prioritize projects in terms of user serviceability and structural life [Hall 99]. Theoretically, the more effective use of the available budget would result from selecting a project over another based on better information. GIS would perform as a tool for integrating different databases so that previously disparate information can be accessed. This would enable better decisions in selecting projects for the annual and multi-year programs as the effectiveness benefits from GIS. To be specific, two effectiveness benefits were addressed: (1) user benefits from a reduction in traveling on rough interstate highway (IH) pavement and (2) IH pavement life extension [Hall 99].

One can better understand how the quantification of the two effectiveness benefits function by looking at IDOT's pavement management program.. Previously, the IDOT interstate program development used the "Ranking" method that approximated a worse-first case based on Condition Rating Survey (CRS) values. If CRS is below 6.4, the project will generally be considered for inclusion in the multi-year program. If it is below 6.0, the project will be included in the annual program. However, the desired method for pavement network rehabilitation management was "Incremental Benefit/Cost (IBC)". The difficulty of implementing the IBC method in the past was the lack of information for developing scenarios in the rehabilitation selection process. With the GIS, the previously missing information would be gathered, enabling IDOT personnel to make more sophisticated project selection decisions.

The methodology to quantify user benefits from a reduction in traveling on rough interstate highway pavement is described as follows. From a study at IDOT, the IBC and the Ranking methods were examined to determine what the user benefits would be when applied to a pavement project. The outcome for each of these methods were assessed at $386 and $287 million, respectively. So, if IDOT completely changes from the Ranking to the IBC method by using GIS technology, the user benefits will increase 34 percent or (386-287)/287*100 = 34%.

Another study at IDOT indicated that traveling on pavement with CRS>=6.0 would cost 27 cents/mile, while traveling on pavement with CRS between 5.0 and 6.0 would cost 31 cents/mile. The difference in user costs is user benefits resulting from the GIS implementation, i.e. $0.04 per mile or ($0.31-$0.27 = $0.04 /mile).

From the Fiscal Year 1999 annual program, the IH resurfacing projects of 122 miles were addressed. Hall [99] estimated a conservative 10 percent improvement in the timing and selection of projects based on discussions with program development staff and management. The average Vehicle Miles of Travel (VMT) per mile on the interstate system was 12.7 million in 1997. The estimated annual effectiveness benefits resulting from increased user benefits from enhanced program development with GIS capabilities were estimated as follows:

$$EBUB = \frac{E1}{100} \times \frac{E2}{100} \times UB \times M \times V \quad = \text{ \$2,027,140} \tag{4.0a}$$

Where:

EBUB = Annual effectiveness benefits from user benefits in dollars per year

E1 = Estimated improvement in the timing and selection of projects (10%)

E2 = Estimated percentage of effectiveness increase of completely changing from Ranking to IBC method (34%)

UB = User benefits from traveling on smooth pavement instead of rough pavement (= $UC_{CRS<6.0}$ -$UC_{CRS>6.0}$ = $0.31 - $0.27 = $0.04 / mile)

M = The number of miles of interstate resurfacing projects in annual program (122 miles)

V = Average VMT per mile on the Interstate System in IL (12.7 million VMT/mile).

Next, the methodology to quantify effectiveness benefits from IH pavement life extension is described as follows. From a study at IDOT, the IBC and the Ranking methods can yield a total added life value of 4.7 and 3.4 years per mile, respectively. Therefore, changing from the Ranking to IBC method would increase the total added life by (4.7-3.4) = 1.3 years per mile. The GIS implementation would provide a means of integrating additional information on which to base more effective rehabilitation strategies, which in turn would result in a longer expected life to the network. Hall [99] estimates a conservative 0.1 year life extension. For the Fiscal Year 1999, the IDOT annual program included 122 miles of IH resurfacing projects. Typically, an IH resurfacing project has an average cost of $400,000 per centerline mile. The annual effectiveness benefits from the IH pavement life extension were calculated as follows:

$$EBPL = E \times C \times M \quad = \text{ \$4,800,000} \qquad (4.0b)$$

Where:

EBPL	=	Annual effectiveness benefits from IH pavement life extension
E	=	Estimated years of pavement life extension due to the impact of GIS implementation
C	=	Average IH resurfacing project costs ($400,000 per centerline mile)
M	=	The number of miles of IH resurfacing projects in annual program (120 miles)

4.2.3 Intangible Benefits

Intangible benefits of the new information system are those that cannot be assigned a monetary value [Emery 71]. They include better corporate image, attainment of legal requirements, implementation of government policies, provision of privacy and confidentiality, better security, more compatibility with the existing facilities, and more reliability [Laudon et al. 98; TN 99; and NIH 99a]. In a cost-benefit analysis, some of the effectiveness benefits may not be quantified because the quantifiable effectiveness benefits of a few focused and important areas are sufficient to justify the costs. Therefore, those effectiveness benefits that are not included for quantification should be listed simply as intangible benefits.

4.3 Concept of Present Value

Present value is the value in current dollars of a payment or stream of payments incurred in the past or the future. Normally, the cost of an investment takes place at Year 0, and the cash inflows occur in the following years [Laudon et al. 98]. Those cash outflows and inflows have different time frames, so therein exists the time value of money. To compare money made with different time frames, present worth factors and present value factors are introduced as shown below [Hall 99].

Present worth factor $= (1+I)^N$ (Eq. 4.1)

Where:

I = discount rate; and

N = the number of years from the given year in the past to the present year.

Present value factor $= \frac{1}{(1+I)^N}$ (Eq. 4.2)

Where:

I = discount rate; and

N = the number of years from the present year to the given year in the future.

The result of an amount of money incurred in the past multiplied by its present worth factor is its present value, whereas a payment in the future is multiplied by its present value factor to arrive at its present value.

The formulas of present worth factor and present value factor are based on an assumption that the payments occur as lump sums at the end of the year. Appendix B of the OMB Circular A-94 suggests two additional formulas using midyear and beginning-of-year factors. When the payments occur in a steady stream, applying midyear factors is more appropriate. If the payments occur at the beginning of the year, beginning-of-year factors should be applied. Midyear factors and beginning-of-year factors can be calculated with Equations 4.1 and 4.2 by replacing $(1+I)^n$ with $(1+I)^{(n-0.5)}$ and $(1+I)^{(n-1)}$, respectively.

For the cost-effectiveness analysis, the discount rates are the real interest rates, which are included in Appendix C of the OMB Circular A-94 under the title "Real Discount Rates." Appendix C of the circular is updated annually. The current (February 2002) real interest rates are 2.1, 2.8, 3.0, 3.1, and 3.9 percent for the analysis period of 3, 5, 7, 10, and 30 years, respectively. The linear interpolation can be used to determine the real interest rate for different analysis periods.

4.4 Methodologies for Justifying Information System Investments

Once the costs and benefits of the information systems are determined, two possible methodologies can be used to justify the benefits against the costs: capital budgeting models and a portfolio approach. In addition, nonfinancial and strategic considerations can also be employed for the purpose of justifying information system investments.

4.4.1 Capital Budgeting Models

Capital budgeting models are used to measure the value of investing in long-term capital investment projects, including information systems investments [Laudon et al. 98].

Capital budgeting is the process of analyzing and selecting various alternatives for capital expenditures. It normally concerns itself with manufacturing equipment and other long-term investments such as electrical generating facilities and telephone networks. The expected lives of these investments could be from 1 year to 25 years. Information systems are similar to traditional capital investment projects in that they produce upfront investment costs and are expected to produce cash benefits over a term greater than a year. However, information systems investments have a shorter life than other capital investment projects, because the rate of technological change is very high. Laudon et al. [98] indicated that most large-scale information systems would require significant investment to be redesigned or rebuilt after 5 years.

To employ capital budgeting models, the cash flow of the capital project has to be established [Laudon et al. 98]. When an organization purchases capital equipment, the immediate cash outflow takes place. In the following years, benefits of the investment occur as cash inflow to balance the initial investment and additional cost outflow. With the cash flow of different investment alternatives, comparison of the alternatives can be made with six methods: 1) payback method, 2) accounting rate of return on investment (ROI), 3) cost-benefit ratio, 4) net present value, 5) profitability index, and 6) internal rate of return (IRR) [Laudon et al. 98].

4.4.1.1 Payback Method

The payback method is "a measure of time required to pay back the initial investment of a project" [Laudon et al. 98]. The payback period can be determined with the following equation:

$$\text{Payback period} = \frac{\text{Initial Investment}}{\text{Annual Net Cash Inflow}} \qquad \text{(Eq. 4.3)}$$

This equation is applicable to a project that has a constant value of annual net cash inflow. In practice, the payback period can be determined as follows. From the cash flow matrix, the payback period is the number of years from the beginning of the project to the year that the cumulative net cash inflow becomes greater than or equal to zero.

The payback method is a simple, initial screening method that is especially good for high-risk projects in which the useful life is difficult to determine [Laudon et al. 98]. However, it ignores some important factors, such as amount of cash flow after payback period, the disposal value that is equal to zero for computer systems, and the profitability of the investment [Laudon et al. 98]. It should be noted that the time value of money can be incorporated into this method.

4.4.1.2 Cost-Benefit Ratio

The cost-benefit ratio is a simple method to express the returns from a capital expenditure [Laudon et al. 98]. The cost-benefit ratio can be determined with the following formula.

$$\text{Cost-benefit ratio} = \frac{\text{Total benefits}}{\text{Total costs}} \qquad \text{(Eq. 4.4)}$$

The formula can include the time value of money by substituting benefits and costs with their present values:

$$\text{Cost-benefit ratio} = \frac{\text{Total discounted benefits}}{\text{Total discounted costs}} \qquad \text{(Eq. 4.5)}$$

4.4.1.3 Accounting Rate of Return on Investment (ROI)

The accounting rate of return on investment is calculated by "adjusting cash inflows produced by the investment for depreciation" [Laudon et al. 98]. The formula is shown as follows:

$$\text{ROI} = \frac{\text{Net benefit}}{\text{Total initial investment}} \times 100\% \qquad \text{(Eq. 4.6)}$$

$$\text{Net benefit} = \frac{\text{Total benefits - Total costs - Depreciation}}{\text{Useful life}}$$

Where:

Depreciation = Total initial investment – Disposal value = Total initial investment

However, another study proposes a simpler way to determine ROI by excluding depreciation. The calculation is as follows [NIH 99b]:

$$\begin{aligned}\text{ROI} &= \frac{\text{Total benefits - Total costs}}{\text{Total costs}} \times 100\% \qquad \text{(Eq. 4.7)}\\ &= \text{Cost-benefit ratio} - 1\end{aligned}$$

The values of ROI determined by different approaches are significantly different; however, both approaches are used in practice. Therefore, when considering a value of ROI, one should examine how the value is determined. The author prefers the first method that concerns the depreciation costs of the systems over the second approach that does not give a different meaning from the cost-benefit ratio.

When concerned about the time value of money and depreciation, the accounting rate of return on investment, derived from Equations 4.6 and 4.7, can be determined with the following:

$$ROI = \frac{(\text{Total discounted benefits - Total discounted costs - Depreciation})}{\text{Total discounted costs}} \times 100\%$$

(Eq. 4.8)

Where:

Depreciation = Discounted initial investment.

Laudon et al. [98] suggested that in the long run, the desired ROI must equal or exceed the cost of capital in the marketplace; otherwise, a firm would not be able to borrow money from anyone. The cost of capital (the prime rate) stays around 8 to 10 percent. The returns on invested capital in corporate bonds are about 10 percent. The criterion for the returns of internal projects in many firms is 25 percent [Laudon et al. 98].

4.4.1.4 Net Present Value (NPV)

The net present value is "the amount of money an investment is worth, taking into account its cost, earnings, and the time value of money" [Laudon et al. 98]. It can be determined with the following formula:

$$\text{NPV} = \text{Total discounted benefits} - \text{Total discounted costs} \qquad \text{(Eq. 4.9)}$$

The disadvantages of NPV are that it provides neither a measure of profitability nor a way to rank different possible alternatives [Laudon et al. 98].

4.4.1.5 Profitability Index

The profitability index is calculated by dividing the total discounted net by the initial cost of the investment. It can be a simple way to rank different possible investments:

$$\text{Profitability index} = \frac{\text{Total Discounted Net}}{\text{Initial Investment}} \qquad \text{(Eq. 4.10)}$$

4.4.1.6 Internal Rate of Return (IRR)

The internal rate of return is defined as "the rate of return or profit that an investment is expected to earn" [Laudon et al. 98]. The IRR is the discount rate that will equate the present value of the project's future cash flow to the initial cost of the project.

4.4.2 Portfolio Approach

For the effectiveness benefits of an information system, it is difficult to predict exactly when and how much the system will be of benefit [Gremillion 85]. There are inherent risks in the development of an information system because of the uncertainty regarding its payoff. However, the high risk of an information system investment could yield a high return. The portfolio approach shifts the focus from a single information system development project to a group of projects. It is similar to the management of research and development (R&D) organizations in which the success is reached when some benefits are produced every year, and greater payoffs are produced at irregular intervals. The portfolio should include only the investments that are likely to yield the highest return. However, no one should expect that every investment will be a good one. The organization should expect a reasonable overall payoff on the initial investment [Gremillion 85].

4.4.3 Nonfinancial and Strategic Considerations

Selecting and evaluating new information system investments should involve nonfinancial and strategic considerations. There are two methods that can be used to examine nonfinancial and strategic considerations: portfolio analysis and a scoring model [Laudon et al. 98].

4.4.3.1 Portfolio Analysis

The portfolio of potential investments should be established in an organization [Laudon et al. 98]. It includes two aspects of different investments: project risk and potential benefits, as shown in Figure 4.1. Each aspect is simply categorized as high or low. When strategic analyses have determined the overall direction of systems development, a portfolio analysis can help decision makers select alternatives. First, the projects that belong to the group of high benefits and low risk should be identified and developed. Second, the projects with high benefits and high risk should be cautiously examined. Next, the low-benefit, high-risk projects should definitely be avoided. The low-benefit, low-risk projects should be reexamined so that they can be rebuilt and replaced with more desirable projects yielding higher benefits.

The general risks of an IT project are identified as: 1) benefits may not be achieved, 2) costs of implementation may exceed budgets, 3) implementation time frames may be exceeded, 4) technical performance is less than expected, and 5) the system is incompatible with existing software or hardware [Laudon et al. 98]. Normally, there are three factors that increase the risks of a project: project size, organizational experience, and project task complexity [Ein-Dor et al. 78; McFarlan 81; and Laudon 89].

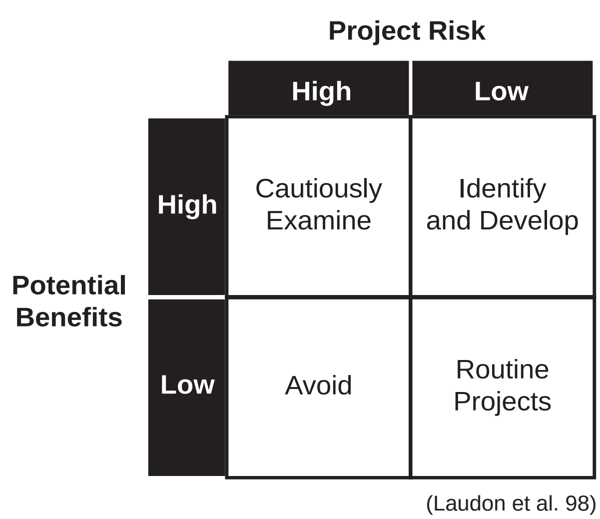

Figure 4.1 A System Portfolio [Laudon et al. 98]

4.4.3.2 Scoring Model

Scoring model is a method for "deciding among alternative systems based on a system of ratings for selected objectives" [Laudon et al. 98]. This method allows decision-makers to rate alternatives by a single score based on the degree to which each alternative meets selected objectives [Matlin 89; Buss 83]. The objectives or criteria are usually the result of extensive discussions among decision makers; for different criteria, the weights can be derived from the discussion as well. The key is not the score but the agreement on the criteria used to judge alternatives [Ginzberg 79; Nolan 82]. Also, the scoring model helps decision makers reach a consensus regarding the rank of alternatives [Laudon et al. 98].

4.5 Process of Cost-Benefit Analysis (CBA)

According to OMB Circular A-94 Guidelines and Discount Rates for Benefit-Cost Analysis of Federal Programs, the cost-benefit analysis (CBA) or economic analysis can be categorized into two types: benefit-cost analysis (BCA) and cost-effectiveness analysis (CEA). A benefit-cost analysis is a systematic, quantitative method of assessing the life-cycle costs and benefits of competing alternative approaches and identifying the best alternative [NIH 99a]. A cost-effectiveness analysis is "a simplified BCA which can be done when either the benefits or the costs are the same for all alternatives" [NIH 99a]. The best alternative is selected as the one with the highest benefit when the costs are the same for all alternatives; or the best alternative is chosen as the one with the lowest cost when the benefits are the same for all alternatives. The analysis process can be divided into 11 steps: 1) determine/define project objectives, 2) document current process, 3) estimate future requirements, 4) collect cost data, 5) establish at least three alternatives, 6) document CBA assumptions, 7) estimate costs, 8) estimate benefits, 9) discount costs and benefits, 10) evaluate alternatives, and 11) perform sensitivity analysis [NIH 99a].

Step 1. The CBA document should include the project objectives and other related background information so that a reviewer who is not intimately familiar with the organization and its work process can understand the project well.

Step 2. The current process should be documented because it is the baseline for almost all decisions regarding new alternatives. The key components are customer services, system capabilities, system architecture, and system costs.

Step 3. The future customer requirements should be estimated, because they determine the system capabilities and architecture, which in turn affect the costs and benefits of the new system. The key factors include the determination of life-cycle time and the estimation of life-cycle demands. To determine how far into the future to plan, the time period for the analysis should cover the system life cycle composed of 6 stages: feasibility study, design, development, implementation, operation, and maintenance. The system life cycle ends when the system is terminated or replaced by a system with significant changes in such aspects as processing, operational capabilities, resource requirements, and system outputs. Generally, large and complex systems should have a minimum life cycle of 5 years and a maximum life cycle of 10 or 12 years [NIH 99a]. To estimate life-cycle demands, the best measures of the demand should be determined; then, the demands can be determined from methods such as extrapolation based on demands in the past.

Step 4. Cost data should be collected for estimating the costs and benefits of each alternative from six possible sources: historical organization data, current system costs, market research, publications, analyst judgment, and special studies.

Step 5. At least three alternatives should be established. One of them may not have to be a "no change" alternative if it is unacceptable, and the supporting reasons have to be documented. Alternatives can be established by considering whether the development, operation, and maintenance are with in-house personnel or through contractors [NIH 99a].

Step 6. It is critical to document all assumptions made in the analysis. The assumptions should be justified based on prior experiences or real data. If some alternatives are infeasible and eliminated in the early stage of the analysis based on assumptions, those assumptions need to be clearly justified.

Step 7. Annual costs, incurred during the system life cycle or the analysis period, should be estimated.

Step 8. Annual benefits incurred during the analysis period should be estimated.

Step 9. Discounted costs and benefits should be calculated by applying appropriate discount factors and discount rates provided in OMB Circular A-94 [OMBA94 02].

Step 10. The capital budgeting models should be used to evaluate alternatives. This step should also identify the best alternative.

Step 11. Sensitivity analysis of the input parameters should be performed with three steps: 1) identify input parameters, 2) repeat the analysis, and 3) evaluate the results. The assumptions documented in Step 6 should indicate the input parameters that should be tested for sensitivity. For a selected input parameter, when its minimum and maximum values are determined, the analysis is repeated with the minimum or maximum value as the new parameter. Next, the results from the sensitivity analysis could be evaluated against the following guidelines:

- A parameter is not considered to be sensitive if it requires a decrease of 50 percent or an increase of 100 percent to cause a change in the selected alternative.
- A parameter is considered to be sensitive if a change between 10 percent and 50 percent causes a change in the selected alternative.
- A parameter is considered to be very sensitive if a change of 10 percent or less causes a change in the selected alternative [NIH 99a].

In summary, this chapter documents the results of the literature review regarding cost-benefit analysis, including the costs and benefits of information systems, the concept of present value, the possible methodologies for justifying information system investments, and the process of cost-benefit analysis. Based on the review results, the framework of the cost-effectiveness analysis for the proposed information system at TxDOT is presented in Chapter 5.

5. Framework of the Cost-Effectiveness Analysis

Selected methods or components of a method from various literature, together with appropriate adjustments, contribute to the construction of the framework to be discussed in this chapter. The cost-effectiveness analysis for the proposed information system at the Texas Department of Transportation (TxDOT) assumes the same amount of benefits but different costs for the alternatives considered. The cost-effectiveness analysis can be divided into eight steps: 1) document assumptions, 2) establish alternatives, 3) select an analysis period, 4) select a discount factor and a discount rate, 5) determine costs, 6) determine benefits, 7) evaluate costs and benefits, and 8) conduct sensitivity analysis.

5.1 Document Assumptions

An important part of the analysis is to document all assumptions employed to determine necessary estimates and to conduct the analysis. Those assumptions are critical and debatable, so they should be justified based on actual data or prior experiences [NIH 99a]. For example, if some alternatives are not feasible because of certain assumptions, those assumptions need to be documented. As another example, the time from system operation to system upgrading may be assigned for 3 years; such an assumption is based on the rapid increases in capacity and speed, and decreases in cost for personal computers over the past 15 years [NIH 99a].

5.2 Establish Alternatives

At least three alternatives should be established, and one of them should be "doing nothing" [NIH 99a]. However, Office of Management and Budget (OMB) Circular A-94 indicates that benefits and costs of different alternatives should be based on the incremental amount of costs and benefits. That is, sunk costs and realized benefits should be ignored. Therefore, the alternative of "doing nothing" is not acceptable, because it is presented as the base for other alternatives producing incremental costs and benefits. An alternative is composed of different activities such as feasibility study, pilot study, system design, system development, and system operation. An alternative can also mean the proposal of a new information system, such as replacing all mainframes with relational databases or developing a new data warehouse. On the other hand, the execution of system development can be either outsourcing or in-house, resulting in two different alternatives, given that all other things are equal.

5.3 Select an Analysis Period

The analysis period for a cost-benefit analysis should encompass the useful life of proposed information systems ranging between f5 years and t12 years [Laudon et al. 98]. For example, if the feasibility study, the pilot study, the development, and the selected useful life of the new system take 3, 2, 1, and 5 years, respectively, then the analysis period for the cost-benefit analysis will cover 11 years.

5.4 Select a Discount Factor and a Discount Rate

An appropriate discount factor and discount rate should be selected. The discount factor could be applied at the beginning of the year, midyear, or year-end, depending on the stream of payments as discussed in Section 4.3. The current discount rate of the cost-effectiveness analysis should be taken from Appendix C of the U.S. Office of Management and Budget (OMB) Circular A-94, where the discount rate is updated annually.

5.5 Determine Costs

Typically, costs can be determined from different activities of the established alternatives. These activities are ordered over the analysis period. For each year of the analysis period, costs can be determined as annual costs. Personnel burdened costs, total activity costs, and the life-cycle costs should be considered respectively.

5.5.1 Annual Personnel Burdened Costs

The annual personnel burdened cost can be calculated as discussed in Section 4.1.3. Hourly personnel burdened costs are calculated by dividing the annual personnel burdened costs by 2,087[5]. Table 5.1 can be used to gather needed data. For each year in the analysis period, related personnel, their hourly rates, and the number of hours in a month devoted to the project should be identified.

Table 5.1 Annual Personnel Burdened Costs Determination Matrix [NIH 99b]

		Number of hours in a month devoted to the project													
		Month													
Personnel	Hourly Rate ($)	1	2	3	4	5	6	7	8	9	10	11	12	Total Hours	Total cost
Total															

5.5.2 Annual Total Activity Costs

Annual total activity costs over the analysis period can be determined by using Table 5.2. Table 5.2 includes nine cost categories: equipment, software, services, support services, supplies, personnel, other purchases, intragovernmental payments, and intragovernmental collections. The personnel costs category is taken from the annual personnel burdened costs in Section 5.5.1.

[5] The number of hours employees are paid annually, 2,087, is specified in OMB Circular A-76, Supplemental Handbook, Part II-Preparing the Cost Comparison Estimates, Chapter 2-Developing the Cost of Government Performance, B. Personnel-Line 1, 6d-Annual Salary/Wages.

5.5.3 Life-Cycle Costs

After determining annual total activity costs over the analysis period, the life-cycle cost matrix of the alternative can be established, as shown in Table 5.3.

For this cost-effectiveness analysis, the annual costs incurred by responsible organizations are estimated over the analysis period; therefore, only Table 5.3 is used, while Tables 5.1 and 5.2 are neglected.

Table 5.2 Annual Total Activity Costs Determination Matrix [NIH 99b]

Cost Category	Description	Cost
1.Equipment		
A.Capital Purchases		
B.Other Equipment		
Purchases/Leases		
2.Software		
A.Capital Purchases		
B.Other software		
Purchases/Leases		
3.Services		
4.Support services		
5.Supplies		
6.Personnel		
7.Other		
A.Capital Purchases		
B.Other Purchases		
8.Intra-government payments		
9.Intra-government collections		
Total costs		

Table 5.3 Life-Cycle Cost Matrix

Year	Activity 1	Activity 2	Activity 3	Activity 4	Activity 5	Total
1						
2						
3						
4						
5						
6						
7						
8						
9						
Total						

5.6 Determine Benefits

Benefits of information systems are composed of three categories: efficiency, effectiveness, and intangible. The benefits can be determined with the following procedures.

5.6.1 Personnel Cost Savings

The proposed information system is expected to facilitate work performed by related personnel on the Pavement Management Information System (PMIS), forensic studies, and administrative/legislative inquiries. Assume previously manual work of these three jobs will be automated by the proposed information system; the saved time from the personnel can be devoted to other jobs. The saved time of related personnel can be used to determine the fraction of their personnel burdened cost represented as efficiency benefits. The procedures for determining such cost savings are shown in Table 5.4. First, the affected positions and the number of each position in the three jobs are identified. Then, the annual salaries of those personnel are determined. If the hourly rate of a full-time employee is given, it can be converted to annual salary by multiplying the hourly rate by 2,087. Annual fringe benefit, annual overhead, and annual personnel burdened cost can be calculated as shown in Table 5.4. The fringe benefit rate of 32.42 percent and the overhead rate of 12 percent are used, as discussed in Section 4.1.3. Then, the estimated fractions of personnel time devoted to the three jobs are identified. Next, the estimated fractions of saved time by using the proposed information system for each position in the three jobs are determined. After that, the personnel cost savings for a position in the three jobs is the product of the estimated fraction of time saved from using the proposed information system, the estimated fraction of time devoted to the job, the number of employees, and the annual personnel burdened cost. Finally, the summation of personnel cost savings across the three jobs is the total personnel cost savings representing the efficiency benefits.

5.6.2 Effectiveness Benefits

The proposed information system would integrate needed data for the decision support functions in the PMIS, so that it can improve its capability in prioritizing the annual maintenance and rehabilitation (M&R) projects. With better-prioritized projects, the annual M&R budget would be used more effectively by selecting one project over another based on better information. The two focused areas of effectiveness benefits are pavement life extension and highway user benefits.

Table 5.4 Annual Personnel Cost Savings Determination Matrix

	PMIS	Forensic Studies	Administrative/ Legislative Inquiries
Annual salary, AS ($)			
Annual fringe benefit ($), AF=AS*FBR			
Annual overhead ($), AO=(AS+AF)*OR			
Annual personnel burdened cost ($), BC=(AS+AF+AO)			
Number of employees, N			
Estimated fraction of time devoted to the job (%), E1			
Estimated fraction of time saved from using the proposed information system (%), E2			
Personnel cost savings ($), BC*N*E1/100*E2/100			
Total annual personnel cost savings ($)			

5.6.2.1 Annual Pavement Life Extension Benefits

The proposed information system would integrate various kinds of needed data and provide them to the decision support functions in the PMIS. The improved data would help the decision support functions to generate more effective maintenance and rehabilitation programs. The improved M&R programs would in turn extend the service life of the pavements in Texas. Because the proposed information system extends pavement life in the network, the saved funds portray the annual pavement life extension benefits. To quantify the annual pavement life extension benefits, three data elements are required for all highway categories in an annual M&R program: 1) the number of miles of maintenance or rehabilitation projects in the annual M&R program (centerline miles), 2) the average maintenance or rehabilitation project cost ($/centerline mile), and 3) the estimated years of pavement life extension resulting from the proposed information system (years). Table 5.5 is used for the calculation of the annual pavement life extension benefits. For each highway category, the annual pavement life extension benefits can be determined by multiplying the estimated years of pavement life extension by the annual maintenance or rehabilitation project cost. The total annual pavement life extension benefits are the summation of the annual pavement life extension benefits across all highway categories.

Table 5.5 Annual Pavement Life Extension Benefit Determination Matrix

Highway Category	# of miles of maintenance or rehabilitation projects in annual program (centerline mile), M	Average maintenance or rehabilitation project cost ($/centerline mile), C	Annual maintenance or rehabilitation project cost ($/year), M*C	Estimated years of pavement life extension resulting from the proposed information system, E	Annual pavement life extension benefits ($/year), AEPLB=E*(M*C)
1					
2					
3					
4					
5					
				Total	

For simplicity, it can be assumed that all highway categories in the annual M&R program will have the same years of pavement life extension resulting from the proposed information system. Then, the calculation in Table 5.5 can be reduced to use only two factors: 1) annual M&R budget in Texas ($/year), and 2) estimated years of pavement life extension resulting from the proposed information system (years). The calculation can be done as follows:

$$APLEB = C \times E \quad \text{(Eq. 5.1)}$$

Where:

APLEB = Annual pavement life extension benefits

C = Annual M&R budget in Texas ($/year)

E = Estimated years of pavement life extension resulting from the proposed information system

5.6.2.2 Annual Highway User Benefits

The more effective annual M&R program resulting from the proposed information system would yield the incremental highway user benefits when people are traveling on a smooth pavement instead of a less smooth pavement. The smooth pavement is defined by a Ride Score of 4.5, whereas the less smooth pavement has a Ride Score of 3.0. The Ride Score used in the TxDOT PMIS is equivalent to the Serviceability Index (SI) [Stampley et al. 95]. The annual highway user benefits from the proposed information system are the product of the four factors as follows:

$$AHUB = E \times V \times UB \times M \quad \text{(Eq. 5.2)}$$

Where:

AHUB	=	Annual highway user benefits
E	=	Estimated percentage of the annual highway user benefits resulting from the proposed information system (%)
V	=	Average Vehicle-Miles of Travel (VMT) per centerline mile on the Texas highway system (VMT/centerline mile)
UB	=	User benefits from traveling on smooth pavement with a Ride Score of 4.5 instead of less smooth pavement with a Ride Score of 3.0 ($/VMT)
M	=	The centerline miles of the maintenance and rehabilitation projects in the annual M&R program

5.6.3 Intangible Benefits

Intangible benefits from the proposed information system should be listed. They also include quantifiable effectiveness benefits that are not quantified for one reason or another. These lists will be considered from the perspective of financial impact.

5.7 Evaluate Costs and Benefits

After all annual costs and annual benefits over the analysis period are determined, the cash flow of the proposed information system can be established. Because there is not an off-the-shelf model to justify an information technology (IT) investment project, five capital budgeting models are used for this project: payback period, cost-benefit ratio, accounting rate of return on investment (ROI), net present value (NPV), and internal rate of return (IRR). If the results from all the models are positive, then the investment would be strongly justified; otherwise, an appropriate model would have to be selected as the model for justification.

5.8 Conduct Sensitivity Analysis

The sensitivity analysis of selected input parameters shows how much their changes would affect the results of the capital budgeting models. The assumptions documented in Section 5.1 should help identify the input parameters that should be tested for sensitivity. For a selected input parameter, its upper or lower limit values in the direction of worse case will be estimated. The analysis will be repeated with the input values ranging from the parameter's original value to its limit value, given all other parameters are the same. The results will be documented. After the sensitivity analyses, the worst case can be established using the upper or lower limits of the selected input parameters.

In summary, this chapter outlines the framework of the cost-effectiveness analysis. As an application of the eight-step process, Chapter 6 documents the results of the cost-effectiveness analysis for the proposed information system at TxDOT.

6. Cost-Effectiveness Analysis and Discussion of Analysis Results

This chapter provides the detailed process of conducting a cost-effectiveness analysis, using the framework presented in Chapter 5. Some of the data used in the analysis were obtained directly from the Texas Department of Transportation (TxDOT) or TxDOT publications. Certain parameter values were estimated based on similar studies conducted by other state departments of transportation or government agencies.

6.1 Document Assumptions

The following is a list of assumptions used for the analysis:

- The present time is the beginning of Year 2002.
- The system operation will take place in Year 2007.
- The costs and benefits incur evenly throughout each year of the analysis period, so the midyear discount factors are used.
- The Information Resource (IR) staff salaries are $250,000.
- The contracted vendor costs are $2,000,000, $815,000, and $800,000 in Years 2004, 2005, and 2006, respectively.
- The computer hardware and software costs are $95,000 in Year 2005.
- The costs for the system operation and maintenance are estimated at $220,000 per year.
- All maintenance and rehabilitation programs will yield the same amount of pavement life extension from the proposed information system.
- The estimated pavement life extension resulting from the proposed information system is 0.01 years.
- The annual pavement life extension benefits will take place one year after the system is under operation (i.e., Years 2008, 2009 and 2010).
- Highway user benefits are the difference between the user cost for smooth pavements with a Ride Score of 4.5 and that for less smooth pavements with a Ride Score of 3.0.
- Highway user benefits determined by Zaniewski et al. [81] are conservative when compared with those that have incorporated inflation and changes in motor vehicle technology.
- The number of miles covered by the annual maintenance and rehabilitation (M&R) projects is reasonably estimated at 10 percent of the highways maintained by TxDOT.

- The estimated annual highway user benefits resulting from the proposed information system are 10 percent of the total highway user benefits resulting from the M&R program without the proposed information system.
- The annual highway user benefits will take place one year after the system is under operation (i.e., Years 2008, 2009 and 2010).

With all assumptions used in the analysis well documented, the next step is to establish alternatives for the integration of pavement-related databases and provision of needed data to the decision support functions in the PMIS.

6.2 Establish Alternatives

As discussed in Section 5.2, "doing nothing" is used as the base upon which the established alternatives will produce incremental costs and benefits. After all the constraints are realistically considered, only one alternative is selected for detailed cost-effectiveness analysis. The activities for the selected alternative are described in Table 6.1.

Table 6.1 Activities of the Established Alternative

Activity	Responsible Organization	Duration	From	To
System development	Information Resource (IR) Staffs	3 years	2004	2006
System development	Contracted Vendor	3 years	2004	2006
System operation and maintenance	TxDOT	4 years	2007	2010

It is noted that the system design is excluded because it is done by research. For typical information technology (IT) projects at TxDOT, the usual duration of the system operation and maintenance for cost-effectiveness analyses is 4 years. With the agreement among the research team and TxDOT staffs, the proposed information system is a relational database functioning as a data warehouse, as discussed in Section 3.2.

6.3 Select an Appropriate Analysis Period

It is assumed that the present time is the beginning of Year 2002. The analysis period encompasses the system development and the system operation and maintenance (i.e., Year 2002 to Year 2010). Therefore, the appropriate analysis period of the alternative is nine years.

The next step is to select an appropriate discount factor and a discount rate used to convert the future money stream to the present dollar values.

6.4 Select a Discount Factor and a Discount Rate

It is assumed that the costs and benefits take place fairly evenly throughout each year of the analysis period, so midyear discount factors are used. Midyear discount factors can be calculated from the following formula:

$$\text{Present value factor} = \frac{1}{(1+I)^{(N-0.5)}} \qquad \text{(Eq. 6.1)}$$

Where:

I = discount rate

N = the number of years from the present year to the given year in the future

For the cost-effectiveness analysis, the discount rate for the analysis period of 9 years is 3.1 percent.[6] Table 6.2 shows the midyear present worth factors and present value factors over the analysis period of 9 years from Year 2002 to Year 2010, given that the present time is the beginning of Year 2002.

Table 6.2 Midyear Factors with Discount Rate of 3.1%

Year	N	Mid-Year Present Value Factor
2002 (Present)	1	0.9849
2003	2	0.9552
2004	3	0.9265
2005	4	0.8987
2006	5	0.8716
2007	6	0.8454
2008	7	0.8200
2009	8	0.7954
2010	9	0.7714

6.5 Determine Costs

Costs can be determined from all the related activities of the alternative. The total costs of the research conducted by the Center for Transportation Research (CTR) and the Texas Transportation Institute (TTI) from Year 2001 to Year 2005 are not included. The Information Resource (IR) staff salaries are estimated at $250,000. For Year 2004, the contracted vendor costs of $2,000,000 are broken down as the consultant contract services of $1,655,000 and the nonconsultant contract services of $345,000. For Year 2005, the contracted vendor costs of $815,000 are composed of three parts: the consultant contract services of $455,000, the nonconsultant contract services of $345,000, and the software maintenance costs of $15,000. For Year 2006, the consultant contract services costs of $455,000 and the nonconsultant contract services costs of $345,000 give the contracted vendor costs of $800,000. The computer hardware and software costs of $20,000 and $75,000, respectively, are incurred in Year 2005. The total costs for TxDOT to operate

[6] The discount rate of 3.1% is determined from Appendix C of the OMB Circular A-94 (Revised February 2002).

and maintain the system are estimated at $220,000 per year, taking into consideration the operation and maintenance costs used by the National Institutes of Health (NIH) [NIH 99b]. These costs are summarized in Table 6.3.

Table 6.3 Life-Cycle Costs of the Proposed Information System

Year	IR Staff Salaries	Contracted Vendor	Computer Hardware and Software	TxDOT Staff	Total
2002	-	-	-	-	-
2003	-	-	-	-	-
2004	$250,000	$2,000,000	-	-	$2,250,000
2005	$250,000	$815,000	$95,000	-	$1,160,000
2006	$250,000	$800,000	-	-	$1,050,000
2007	-		-	$220,000	$220,000
2008	-	-	-	$220,000	$220,000
2009	-	-	-	$220,000	$220,000
2010	-	-	-	$220,000	$220,000

6.6 Determine Benefits

Two categories of benefits are identified: effectiveness and intangible. The first category is tangible. It is noted that efficiency benefits represented by annual personnel cost savings in three areas – Pavement Management Information System (PMIS), forensic studies, and administrative/legislative inquiries – are not considered. The two focused effectiveness benefits are the annual pavement life extension benefits and the annual highway user benefits. The intangible benefits are also identified.

6.6.1 Annual Pavement Life Extension Benefits

It is assumed that all highway categories in the annual maintenance and rehabilitation program will receive the same amount of pavement life extension from the proposed information system. Normally, the annual maintenance and rehabilitation budget at TxDOT is about $900 million. The pavement life extension from the proposed information system is very conservatively estimated at 0.01 years. The number 0.01 comes from 10 percent of the number estimated by Hall [99], as Hall estimated a 0.1 year life extension due to the impact of GIS implementation at the Illinois Department of Transportation. The annual pavement life extension benefits are the product of the annual M&R budget and the estimated years of pavement life extension from the proposed information system, resulting in $9 million. Another assumption is that the annual pavement life extension benefits would take place one year after the system is under operation (i.e., from Year 2008 to Year 2010).

6.6.2 Annual Highway User Benefits

For the analysis, the percentage of the annual highway user benefits resulting from the proposed information system is estimated at 10 percent of the total highway user benefits resulting from the M&R program without the proposed information system. The number of miles covered under the annual M&R projects is also needed to estimate the user benefits. For the analysis, it is reasonably estimated at 10 percent of 78,000 centerline miles of highway pavements maintained by TxDOT, giving 7,800 centerline miles. The following two sections determine the other two required data for the quantification of the annual highway user benefits.

6.6.2.1 User Benefits from Traveling on Smooth Pavement (Ride Score=4.5) Instead of Less Smooth Pavement (Ride Score=3.0)

Zaniewski et al. [81] conducted a study to determine vehicle-operating costs (VOC) (which include the consumption of fuel and oil, tire wear, vehicle maintenance and repair, and use-related depreciation) as a function of vehicle and roadway characteristics. Table 6.4 shows the vehicle operating costs of automobiles and trucks when traveling at speeds of 55, 60, 65, and 70 miles per hour on pavement with the Serviceability Index (SI) of 4.5 and 3.0. There are three categories of automobiles: small, medium, and large autos; and five categories of trucks: pickup, two-axle single unit (2A SU), three-axle single unit (3A SU), four-axle semi's (2-S2), and five-axle semi's (3-S2). The vehicle operating costs in Table 6.4 are in dollars per 1,000 miles. The difference between VOC for pavement with the SI of 4.5 and the SI of 3.0 is used as the user benefits.

Table 6.4 Vehicle Operating Costs on the Highway Grade of 0% [after Zaniewski et al. 81]

	Speed = 55 mph ($/1,000 miles)			Speed = 60 mph ($/1,000 miles)		
	SI =4.5	SI=3.0	Diff.	SI=4.5	SI=3.0	Diff.
Automobiles:						
small auto	105	116	11	109	120	11
medium auto	137	149	12	145	157	12
large auto	147	161	14	154	168	14
Trucks:						
Pickup	150	166	16	156	173	17
2A SU	327	342	15	344	360	16
3A SU	405	438	33	415	450	35
2-S2	351	386	35	362	398	36
3-S2	431	467	36	459	497	38

Table 6.4 (Continued) Vehicle Operating Costs on the Highway Grade of 0% [after Zaniewski et al. 81]

	Speed = 65 mph ($/1,000 miles)			Speed = 70 mph ($/1,000 miles)		
	SI=4.5	SI=3.0	Diff.	SI=4.5	SI=3.0	Diff.
Automobiles:						
small auto	114	126	12	120	133	13
medium auto	153	166	13	162	176	14
large auto	163	178	15	172	189	17
Trucks:						
Pickup	175	193	18	194	213	19
2A SU	360	377	17	376	395	19
3A SU	434	470	36	448	487	39
2-S2	377	417	40	394	437	43
3-S2	511	552	41	555	599	44

Table 6.5 gives the user benefits for automobiles and trucks at four different speeds of 55, 60, 65, and 70 mph, along with the average user benefits across the four speeds for automobiles and trucks. However, the vehicle operating costs in Zaniewski et al. [81] may have changed because of inflation and changes in motor vehicle technology. Taking into consideration such changes, the user benefits derived from Zaniewski's study may be conservative.

Table 6.5 User Benefits on the Highway Grade of 0% [after Zaniewski et al. 81]

User benefit on the highway grade of 0% from traveling on smooth pavement with a Ride Score of 4.5 instead of less smooth pavement with a Ride Score of 3.0 = Difference of VOC (cents/mile)					
	55 mph	60 mph	65 mph	70 mph	Average
Automobiles:					
small auto	1.1	1.1	1.2	1.3	1.2
medium auto	1.2	1.2	1.3	1.4	1.3
large auto	1.4	1.4	1.5	1.7	1.5
Average User Benefits for Automobiles	1.3				
Trucks:					
Pickup	1.6	1.7	1.8	1.9	1.8
2A SU	1.5	1.6	1.7	1.9	1.7
3A SU	3.3	3.5	3.6	3.9	3.6
2-S2	3.5	3.6	4.0	4.3	3.9
3-S2	3.6	3.8	4.1	4.4	4.0
Average User Benefits for Trucks	3.0				

To determine the average user benefits of automobiles and trucks, the vehicle miles traveled (VMT) values of automobiles and trucks on the Texas highway system are used as the weighting factors. Table 6.6 shows that the VMT of automobiles on the Texas highway system is 139,657.53x10,[6] and that of trucks and buses is 66,365.47x10.[6] The percentage of the VMT for automobiles and trucks is 67.79 and 32.21, respectively. The weighted user benefits are estimated as:

$$0.6779 \times 1.3 + 0.3221 \times 3.0 = 1.848 \text{ cents/mile.}$$

6.6.2.2 Average VMT per Centerline Mile on the Texas Highway System

The annual VMT on the Texas highway system and the centerline mile of the Texas highway system, as shown in Table 6.7, are extracted from 1989-2000 Highway Statistics. Figure 6.1 shows the relationship between the annual VMT per centerline mile and time, where the annual VMT per centerline mile increases with the increase of time. To be conservative, the annual VMT per centerline mile for Year 2000 is selected to determine the annual highway user benefits from Years 2001 to 2009.

Table 6.6 Annual VMT by Vehicle Type on the Texas Highway System in Year 1998[7]

	Annual Vehicle-Miles of Travel (millions)	
	Automobile	Trucks and Buses
Rural functional class		
1 Interstate	8,430.71	6,754.29
2 Other principal arterial	10,364.71	7,670.29
3 Minor arterial	6,895.11	5,239.89
4 Major collector	8,505.58	7,434.42
5 Minor collector	1,535.94	1,114.06
6 Local	2,378.88	1,736.12
Urban functional class		
1 Interstate	22,708.90	8,818.10
2 Other freeways & expressways	15,601.40	5,095.60
3 Other principal arterial	22,626.35	8,258.65
4 Minor arterial	15,429.64	6,685.36
5 Collector	7,373.64	3,937.36
6 Local	17,806.67	3,621.33
Total	139,657.53	66,365.47

[7] Estimates supplied by Center for Transportation Research, based on unpublished data provided by Texas Department of Transportation and on Table VM-4 in Highway Statistics, 1998.

Table 6.7 Annual VMT and Centerline Miles of the Texas Highway System [after USDOT 90 – USDOT 01]

Year	Annual VMT on the Texas Highway System	Centerline Miles of the Texas Highway System	VMT/Centerline Mile
1989	159,512,000,000	305,692	521,806
1990	162,232,000,000	305,951	530,255
1991	158,756,000,000	293,509	540,890
1992	163,329,000,000	293,317	556,834
1993	167,611,000,000	294,142	569,830
1994	178,348,000,000	294,491	605,614
1995	181,096,000,000	296,186	611,427
1996	185,386,000,000	296,259	625,757
1997	198,700,000,000	296,651	669,811
1998	206,023,000,000	296,581	694,660
1999	210,874,000,000	300,507	701,727
2000	220,064,000,000	301,035	731,025

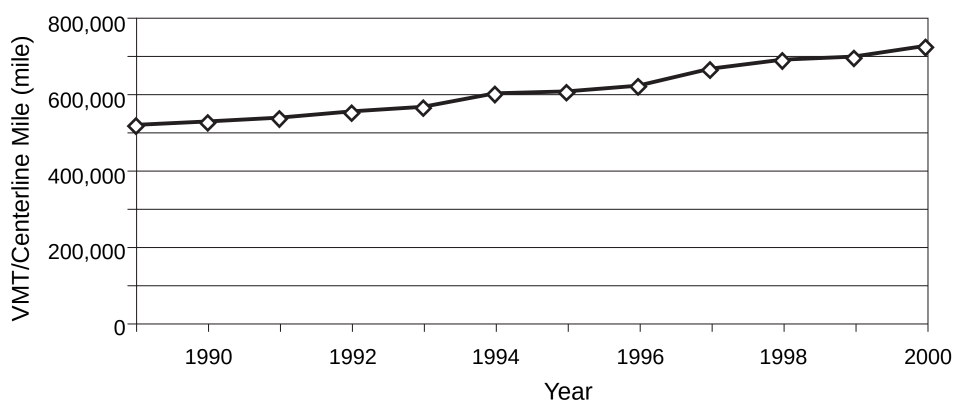

Figure 6.1 Relationship Between the Annual VMT/Centerline Mile and Time

The annual highway user benefits of $10,537,287 (use $10,500,000) are the product of the four parameters: 1) the estimated percentage of the annual highway user benefits resulting from the proposed information system (10 percent), 2) the total miles of the annual M&R projects (7,800 centerline miles), 3) the average user benefits (1.848 cents per mile), and 4) the average VMT per centerline mile on the Texas highway system (731,025). The annual highway user benefits are assumed to take place one year after the system is under operation (i.e., from Year 2008 to Year 2010).

The benefits of the proposed information system over the analysis period of 9 years are summarized in Table 6.8.

Table 6.8 Benefits of the Proposed Information System

Year	Annual Pavement Life Extension Benefits	Annual Highway User Benefits	Total
2002	-	-	-
2003	-	-	-
2004	-	-	-
2005	-	-	-
2006	-	-	-
2007	-	-	-
2008	$9,000,000	$10,500,000	$19,500,000
2009	$9,000,000	$10,500,000	$19,500,000
2010	$9,000,000	$10,500,000	$19,500,000

6.6.3 Intangible Benefits

The following is a list of the potential intangible benefits of the proposed information system:

- Improved decision making due to integrated and complete information
- Improved asset utilization
- More accurate and complete data for future pavement research endeavors
- Unprecedented analysis of information
- Easy access to information
- More current and higher quality information
- Reduced redundant data sources
- Quicker response to internal and external inquiries
- Reduced errors
- Increased job satisfaction
- Increased organizational learning
- Increased service to the public
- Higher highway user satisfaction

6.7 Evaluate Costs and Benefits Using the Five Capital Budgeting Models

After all the costs and benefits of the proposed information system are determined, the cash flow can be established as shown in Table 6.9. The present time is the beginning of Year 2002. The discount factors, annual costs, and annual benefits are taken from Tables 6.2, 6.3, and 6.8, respectively.

Table 6.9 Cash Flow of the Proposed Information System

Year	Annual Costs, $ (AC)	Annual Benefits, $ (AB)	Discount Factor (DF)	Discounted Costs, $ (DC= AC*DF)	Discounted Benefits, $ (DB= AB*DF)	Discounted Net, $ (DB-DC)	Cumulative Discounted Net, $
2002	0	0	0.9849	0	0	0	0
2003	0	0	0.9552	0	0	0	0
2004	2,250,000	0	0.9265	2,084,663	0	(2,084,663)	(2,084,663)
2005	1,160,000	0	0.8987	1,042,444	0	(1,042,444)	(3,127,107)
2006	1,050,000	0	0.8716	915,220	0	(915,220)	(4,042,326)
2007	220,000	0	0.8454	185,994	0	(185,994)	(4,228,321)
2008	220,000	19,500,000	0.8200	180,402	15,990,178	15,809,776	11,581,455
2009	220,000	19,500,000	0.7954	174,978	15,509,387	15,334,409	26,915,864
2010	220,000	19,500,000	0.7714	169,716	15,043,052	14,873,336	41,789,199
Total	3,781,543	58,500,000		4,753,417	46,542,616	41,789,199	

The results of the five capital budgeting models are discussed in the following sections.

1) Payback Period

As discussed in Section 4.4.1.1, the payback period is the number of years from the beginning of the analysis period to the year that has the cumulative discounted net greater than or equal to zero. From the information in Table 6.9, it can be seen that the payback period is 7 years. In other words, the payback time is Year 2008.

2) Cost-Benefit Ratio

The cost-benefit ratio can be determined by dividing the total discounted benefits ($46,542,616) by the total discounted costs ($4,753,417), giving 9.79.

3) Accounting Rate of Return on Investment (ROI)

From Equation 4.8, the return on investment (ROI) can be determined as follows:

$$\text{Depreciation} = \text{Discounted initial investment} = \sum_{n=2002}^{2006} (DC)_n = \$4{,}042{,}327 \qquad \text{(Eq. 6.2)}$$

$$ROI = \frac{(\text{Total discounted benefits - Total discounted costs - Depreciation})}{\text{Total discounted costs}} \times 100\%$$

$$= \frac{(46{,}542{,}616 - 4{,}753{,}417 - 4{,}042{,}327)}{4{,}753{,}417} \times 100\%$$

$$= 794\%$$

4) Net Present Value (NPV)

The net present value can be determined by subtracting the total discounted annual costs ($4,753,417) from the total discounted annual benefits ($46,542,616), giving $41,789,199.

5) Internal Rate of Return (IRR)

The internal rate of return is the interest rate, which satisfies the following equation:

Initial cost of the project = Present value of project's future cash flows (Eq. 6.3)

$$\sum_{n=2002}^{2006}(DC)_n = \frac{(AB-AC)_{2007}}{(1+IRR)^{5.5}} + \frac{(AB-AC)_{2008}}{(1+IRR)^{6.5}} + \frac{(AB-AC)_{2009}}{(1+IRR)^{7.5}} + \frac{(AB-AC)_{2010}}{(1+IRR)^{8.5}}$$

$$4{,}042{,}327 = \frac{-220{,}000}{(1+IRR)^{5.5}} + \frac{19{,}280{,}000}{(1+IRR)^{6.5}} + \frac{19{,}280{,}000}{(1+IRR)^{7.5}} + \frac{19{,}280{,}000}{(1+IRR)^{8.5}}$$

IRR = 43.26%

6) Summary of the Results

The analysis results are summarized as follows:

- Payback period = 7 years
- Cost-benefit ratio = 9.79
- Accounting rate of return on investment (ROI) = 794%
- Net present value = $41,789,199;
- Internal rate of return = 43.26%
- Total discounted costs = $4,753,417
- Total discounted benefits = $46,542,616

The total discounted benefits can be broken down into two portions: the discounted pavement life extension benefits of $21,481,207 (46.15 percent of the total discounted benefits), and the discounted highway user benefits of $25,061,409 (53.85 percent of the total discounted benefits). These two portions of the total discounted benefits are illustrated in Figure 6.2.

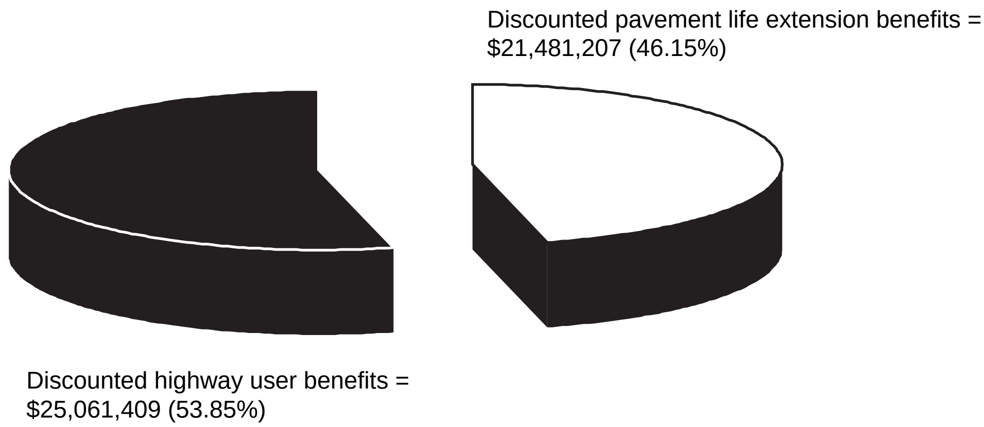

Figure 6.2 Two Portions of the Total Discounted Benefits

6.8 Conduct Sensitivity Analysis

Based on the assumptions described in Section 6.1, there are eight input parameters that should be considered for sensitivity analysis. The eight parameters are listed as follows:

- E1 = The estimated years of pavement life extension resulting from the proposed information system
- E2 = The estimated percentage of the annual highway user benefits resulting from the proposed information system
- C1 = The number times the IR staff salaries of the base case
- C2 = The number times the contracted vendor costs of the base case
- C3 = The number times the computer hardware and software costs of the base case
- C4 = The number times the annual operation and maintenance costs of the base case
- I = Discount rate
- Y = The time between the year when the system is put into operation (Year 2007) and the year when the effectiveness benefits take place

6.8.1 Sensitivity Analysis of Input Parameter E1

To analyze the impact of E1, the value of E1 is gradually decreased from 0.01 years to 0.00125 years, given that all other input parameters remain the same. Table 6.10 shows the results of the analysis. As it can be seen, the total discounted pavement life extension benefits are affected by the changes of E1. The payback periods remain 7 years for all the values of E1. The ROI, NPV, cost-benefit ratio, and IRR are changed with the change of E1. Figure 6.3 illustrates the increase of cost-benefit ratios with the increase of E1. Even if the value of E1 is decreased to 0.00125 years, the cost-benefit ratio still remains high at 5.84.

A similar process was applied to the other seven input parameters. The results are presented in Table A.1 through Table A.7 of Appendix A.

Table 6.10 Results of the Sensitivity Analysis of Input Parameter E1

	E1=0.01 years	E1=0.005 years	E1=0.0025 years	E1=0.00125 years
Total discounted pavement life extension benefits, $	21,481,207	10,740,604	5,370,302	2,685,151
Total discounted highway user benefits, $	25,061,409	25,061,409	25,061,409	25,061,409
Total discounted benefits, $	46,542,616	35,802,012	30,431,711	27,746,560
Total discounted costs, $	4,753,417	4,753,417	4,753,417	4,753,417
Payback period, years	7	7	7	7
ROI, %	794	568	455	399
NPV, $	41,789,199	31,048,595	25,678,294	22,993,143
Cost-benefit ratio	9.79	7.53	6.40	5.84
IRR, %	43.26	38.09	34.97	33.23

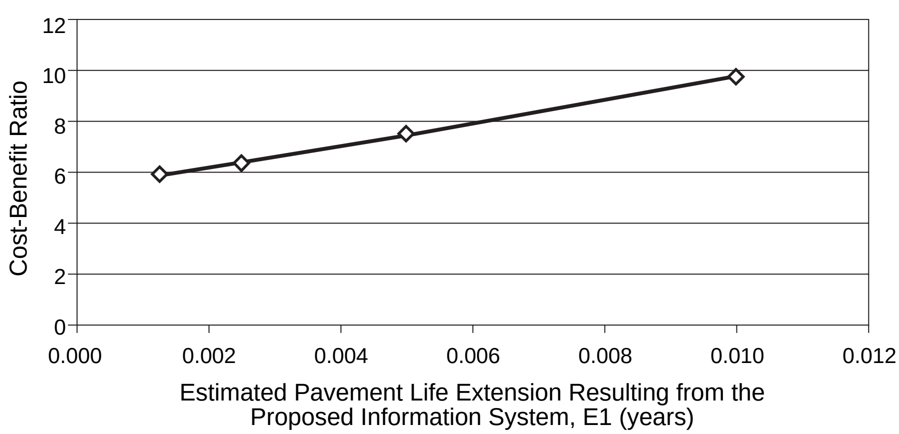

Figure 6.3 Relationship Between Cost-Benefit Ratio and Input Parameter E1

6.8.2 Worst Case

From the results of the sensitivity analyses in Sections 6.8.1, a worst case where several input parameters are set to their worst possible values can be established. The parameters in the worst case are set to the worst values from the results of the sensitivity analyses except the parameters E1 and I. The parameter E1 must be set at 0.01 as opposed to 0.00125, 0.0025, or 0.005; otherwise, the cost-benefit ratio of the worst case will be less than one. The eight input parameters of the worst case are summarized as follows:

- E1 = 0.01 years
- E2 = 1.25 %
- C1 = 2
- C2 = 2
- C3 = 2
- C4 = 2
- I = 8%
- Y = 1 years

Given that the eight input parameters above and all other parameters are the same, the results of the worst case analysis are shown in Table 6.11, where the results of the base case and the worst case are presented side by side. As it can be seen from Table 6.11, the total discounted benefits for the worst case are higher than the total discounted costs. The payback period is 1-year later when compared to the base case. The ROI and the IRR are much lower than those for the base case, but remain at healthy rates.

As shown in Section 4.4.1.3, the criterion of ROI for internal projects in many firms is 25 percent. This means that even the worst-case analysis indicates that the project is a good investment. Moreover, the IRR of 21.12 percent is much higher than the general interest rate. The total discounted benefits are 2.18 times as much as the total discounted costs.

Table 6.11 Results of the Base Case and the Worst Case

	Base Case	Worst Case
Total discounted pavement life extension benefits, $	21,481,207	15,189,470
Total discounted highway user benefits, $	25,061,409	2,215,131
Total discounted benefits, $	46,542,616	17,404,601
Total discounted costs, $	4,753,417	8,000,596
Payback period, years	7	8
Cost-benefit ratio	9.79	2.18
ROI, %	794	30
NPV, $	41,789,199	9,404,005
IRR, %	43.26	21.12

6.9 Discussion of the Analysis Results

Among the eight input parameters, the most sensitive parameter is Y. If Y is greater than three, then the total discounted benefits will be less than the total discounted costs. The Y value of three entails that the pavement life extension benefits and the highway user benefits will occur in Year 2010. This would be true when the proposed information system can enhance the decision support functions in PMIS to produce a more effective M&R program for Year 2010. The second most sensitive parameters are E1 and E2. The rest of the input parameters are less sensitive when compared to Y, E1, and E2.

The input parameters used in the base case are conservatively estimated. However, the input parameters may possibly be worse than the conservative estimates. Even though the worst case in Section 6.8.2 is constructed by using the values of the input parameters on the worst side, it still yields good results. The input parameters used in the worst case could be set up as the upper or the lower limits of the parameters, as shown in Table 6.12.

E1 of the worst case is the same as the base case because the value of 0.01 years are very conservatively estimated. The lower limits for E2 is 1.25 percent. The upper limits of C1, C2, C3 and C4 are two. The upper limit of the discount rate is 8 percent. Since Y is the most sensitive input parameter to achieve good results, the value of Y for the worst case must be the same as the base case when using values on the worse side for the other input parameters.

Table 6.12 Lower Limits and Upper Limits of the Eight Input Parameters

	Lower Limit	Upper Limit	Base Case
The estimated number of years of pavement life extension caused by the proposed information system, E1	0.01 years (3.65 days)	N/A	0.01 years (3.65 days)
The estimated percentage of the annual highway user benefits caused by the proposed information system, E2	1.25%	N/A	10%
The number of times the IR staff salaries of the base case, C1	N/A	2	1
The number of times the contracted vendor costs of the base case, C2	N/A	2	1
The number of times the computer hardware and software costs of the base case, C3	N/A	2	1
The number of times the annual operation and maintenance costs of the base case, C4	N/A	2	1
Discount rate, I	N/A	8%	3.1%
The number of years from the beginning of the system operation (Year 2007) to the year that the effectiveness benefits take place, Y	N/A	1	1

As long as the real values of the eight input parameters do not exceed their limits, the results from the capital budgeting models would still justify the investment, given that all other input parameters are the same. However, if the real values of the input parameters are in fact beyond the limits, revisions to the cash flow and the five capital budgeting models would be needed.

7. Summary, Conclusions, and Recommendations

The following three sections present the summary, conclusions, and recommendations of the report.

7.1 Summary

Research Project 0-4186, entitled "Cradle-to-Grave Monitoring of Pavements and Pavement Management Information System (PMIS) Functionality Enhancement Planning," is intended to develop strategic plans for integrating the pavement-related databases and enhancing the decision support functions in the PMIS. To integrate pavement-related data, a new information system is proposed. This report presents a comprehensive cost-effectiveness analysis as a part of the feasibility study for developing the proposed information system.

The report began by outlining the concept of information system integration, followed by a brief review of the current pavement-related databases and a discussion of the conceptual framework for the proposed information system. Subsequently, potential methods for conducting cost-benefit analysis were reviewed. Based on the review results, a framework for cost-effectiveness analysis was established with an eight-step process. Using the eight-step process, the cost-effectiveness analysis for the proposed information system was conducted. Sensitivity analyses were also performed to examine the relative impact of the selected input parameters on the output of the cost-effectiveness analysis. Based on the economic models used for the analysis, it is evident that the investment on developing a new information system to support the pavement engineering and management activities at the Texas Department of Transportation (TxDOT) is fully justified.

7.2 Conclusions

Based on the research findings, the following conclusions can be drawn:

1. The proposed information system will be a relational database functioning as a data warehouse to integrate pavement-related data and provide needed information to the decision support functions in PMIS, forensic studies, and administrative/legislative inquiries.

2. The quantifiable costs and benefits of the proposed information system are summarized as follows:

- The total discounted cost is $4,753,417.
- The total discounted benefit is $46,542,616. The benefit is broken down into two categories: the total discounted pavement life extension benefits of $21,481,207 (46.15%) and the total discounted highway user benefits of $25,061,409 (53.85%).

3. The intangible benefits, or the benefits that are not quantified, are identified as follows:

- Improved decision making due to integrated and complete information
- Improved asset utilization
- More accurate and complete data for future pavement research endeavors
- Unprecedented analysis of information
- Easy access to information
- More current and higher-quality information
- Reduced redundant data sources
- Quicker response to internal and external inquiries
- Reduced errors
- Increased job satisfaction
- Increased organizational learning
- Increased service to the public
- Higher highway user satisfaction

4. Using the calculated costs and benefits, the analysis results from the five capital budgeting models are:

- The payback period is 7 years
- The cost-benefit ratio is 9.79
- The accounting rate of return on investment (ROI) is 794%
- The net present value (NPV) is $41,789,199
- The internal rate of return (IRR) is 43.26%

5. Among the selected eight input parameters, the most sensitive input is Input Parameter Y (the time between the year when the system is put into operation and the year when the effectiveness benefits take place). The second most sensitive input parameter is E1 (the estimated pavement life extension resulting from the proposed information system) and E2 (the estimated percentage of the annual highway user benefits resulting from the proposed information system). The other input parameters are much less sensitive when compared to these three input parameters.

6. Based on the results of the sensitivity analyses, the upper and lower limits of the eight inputs were established such that the limits of the eight input

parameters represent the worst case but still yield good results. Based on the analysis results from the worst case, as long as the values of the eight input parameters vary within their limits, the project is always justified because of the positive results of the capital budgeting models, given that all other inputs remain the same.

7.3 Recommendations

The following are three recommendations for the future research:

1. It is recommended that a post cost-effectiveness analysis be conducted after the completion of the information technology (IT) project so that the real value of the eight input parameters can be estimated and used to validate this analysis.
2. The quantifiable effectiveness benefits, which were identified as intangible benefits, should be quantified so that the decision makers can be more convincing with benefits expressed in dollar amounts rather than verbal descriptions.
3. Input parameters with uncertainty should be determined in terms of probability distributions so that the results of the cost-effectiveness analysis can be presented with a degree of reliability.

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Appendix A.

Results of Sensitivity Analyses of Seven Input Parameters

Sensitivity Analysis of Input Parameter E2

Given that all other input parameters remain the same, the value of E2 is decreased gradually from 10 percent to 1.25 percent. Table A.1 shows the results of the analysis. The results show that the total discounted costs are not affected by the changes of E2, neither are the total discounted pavement life extension benefits. The total discounted highway user benefits are affected by the changes of E2. The payback periods remain the same 7 years across the range of E2. The ROI, NPV, cost-benefit ratio, and IRR are significantly changed with the change of E2. Figure A.1 illustrates the increase of cost-benefit ratios with the increase of E2. It is interesting to note that even if the value of E2 is decreased to 1.25 years, the cost-benefit ratio stays high at 5.18.

Sensitivity Analysis of Input C1

To analyze the impact of C1, the value of C1 is gradually increased from one to two, given that all other input parameters remain the same. Table A.2 shows the results of the analysis. Table A.2 shows that the total discounted benefits are not affected by the changes of C1. The total discounted costs are affected by the changes of C1. The payback periods remain the same 7 years across the range of C1. The ROI, NPV, cost-benefit ratio, and IRR are not significantly changed with the variation of C1. Figure A.2 illustrates the decrease of cost-benefit ratios with the increase of C1. Even if the value of C1 is increased to two, the cost-benefit ratio still remains high at 8.58.

Table A.1 Results of the Sensitivity Analysis of Input Parameter E2

	E2=10%	E2=5%	E2=2.5%	E2=1.25%
Total discounted pavement life extension benefits, $	21,481,207	21,481,207	21,481,207	21,481,207
Total discounted highway user benefits, $	25,061,409	12,530,704	6,265,352	3,132,676
Total discounted benefits, $	46,542,616	34,011,912	27,746,560	24,613,884
Total discounted costs, $	4,753,417	4,753,417	4,753,417	4,753,417
Payback period, years	7	7	7	7
ROI, %	794	530	399	333
NPV, $	41,789,199	29,258,495	22,993,143	19,860,467
Cost-benefit ratio	9.79	7.16	5.84	5.18
IRR, %	43.26	37.10	33.23	31.01

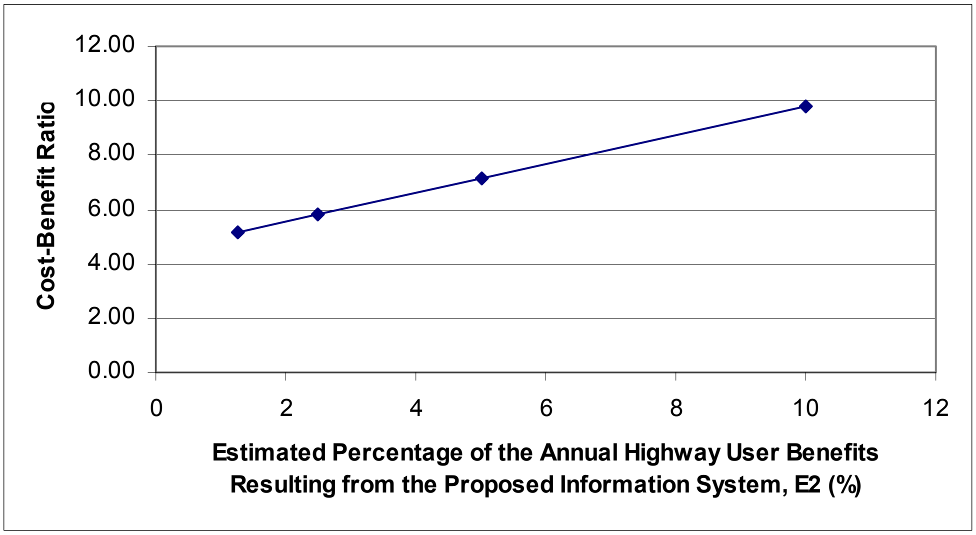

Figure A.1 Relationship Between Cost-Benefit Ratio and Input Parameter E2

Table A.2 Results of the Sensitivity Analysis of Input Parameter C1

	C1=1*(C1 of the base case)	C1=1.5*(C1 of the base case)	C1=2*(C1 of the base case)
Total discounted pavement life extension benefits, $	21,481,207	21,481,207	21,481,207
Total discounted highway user benefits, $	25,061,409	25,061,409	25,061,409
Total discounted benefits, $	46,542,616	46,542,616	46,542,616
Total discounted costs, $	4,753,417	5,090,519	5,427,620
Payback period, years	7	7	7
ROI, %	794	728	671
NPV, $	41,789,199	41,452,098	41,114,996
Cost-benefit ratio	9.79	9.14	8.58
IRR, %	43.26	41.69	40.25

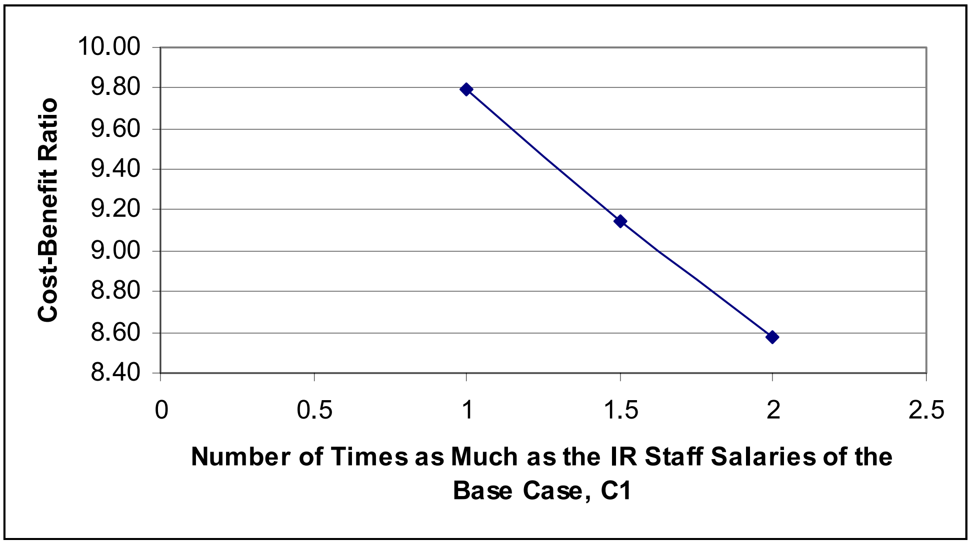

Figure A.2 Relationship Between Cost-Benefit Ratio and Input Parameter C1

Sensitivity Analysis of Input C2

Given that all other input parameters remain the same, the value of C2 is gradually increased from one to two. Table A.3 shows the results of the analysis. The total discounted costs are affected by the changes of C2. The payback periods remain the same 7 years for all values of C2. The ROI, NPV, cost-benefit ratio, and IRR are changed with the variation of C2. Figure A.3 illustrates the decrease of cost-benefit ratios with the increase of C2. Even if the value of C2 is two times as much as the original estimate, the cost-benefit ratio still remains high at 5.79.

Sensitivity Analysis of Input C3

To analyze the impact of C3, the value of C3 is gradually increased from one to two, given that all other input parameters remain the same. Table A.4 shows the results of the analysis. The total discounted costs are affected by the changes of C3. The payback periods remain the same 7 years across the range of C3. The ROI, NPV, cost-benefit ratio, and IRR are changed with the variation of C3. Figure A.4 illustrates the decrease of cost-benefit ratios with the increase of C3. Interestingly, even if the value of C3 is twice as much as the original estimate, the cost-benefit ratio still remains high at 9.62.

Sensitivity Analysis of C4

The value of C4 is increased from one to two, given that all other input parameters remain the same. Table A.5 shows the results of the analysis. The total discounted costs are affected by the changes of C4. The payback periods remain the same 7 years across the range of C4. The ROI, NPV, cost-benefit ratio, and IRR are changed with the variation of C4. Figure A.5 illustrates the decrease of cost-benefit ratios with the increase of C4. Despite the fact that the value of C4 is twice as much as the original estimate, the cost-benefit ratio still remains high at 8.52.

Table A.3 Results of the Sensitivity Analysis of Input Parameter C2

	C2=1*(C2 of the base case)	C2=1.5*(C2 of the base case)	C2=2*(C2 of the base case)
Total discounted pavement life extension benefits, $	21,481,207	21,481,207	21,481,207
Total discounted highway user benefits, $	25,061,409	25,061,409	25,061,409
Total discounted benefits, $	46,542,616	46,542,616	46,542,616
Total discounted costs, $	4,753,417	6,394,792	8,036,168
Payback period, years	7	7	7
ROI, %	794	539	388
NPV, $	41,789,199	40,147,824	38,506,449
Cost-benefit ratio	9.79	7.28	5.79
IRR, %	43.26	36.72	32.06

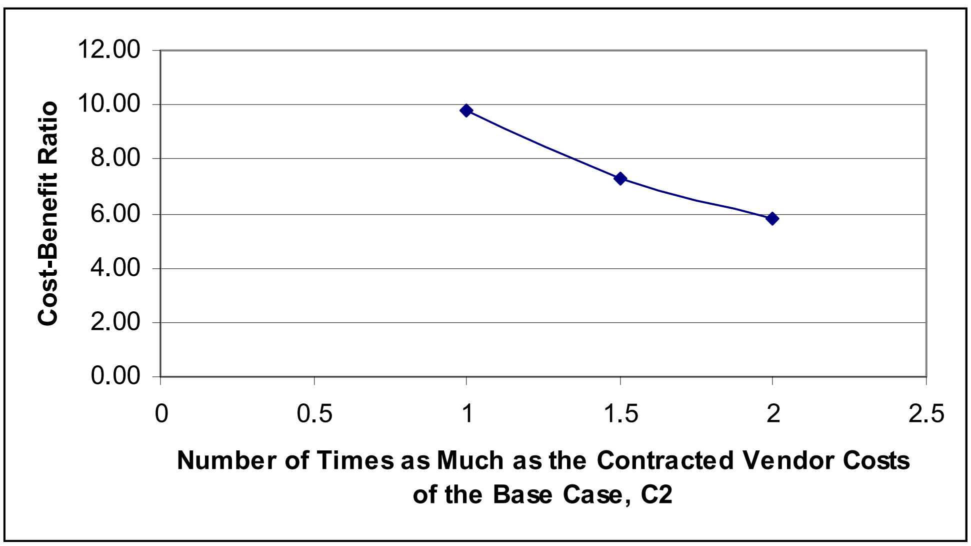

Figure A.3 Relationship Between Cost-Benefit Ratio and Input Parameter C2

Table A.4 Results of the Sensitivity Analysis of Input Parameter C3

	C3=1*(C3 of the base case)	C3=1.5*(C3 of the base case)	C3=2*(C3 of the base case)
Total discounted pavement life extension benefits, $	21,481,207	21,481,207	21,481,207
Total discounted highway user benefits, $	25,061,409	25,061,409	25,061,409
Total discounted benefits, $	46,542,616	46,542,616	46,542,616
Total discounted costs, $	4,753,417	4,796,103	4,838,790
Payback period, years	7	7	7
ROI, %	794	785	777
NPV, $	41,789,199	41,746,513	41,703,827
Cost-benefit ratio	9.79	9.70	9.62
IRR, %	43.26	43.05	42.85

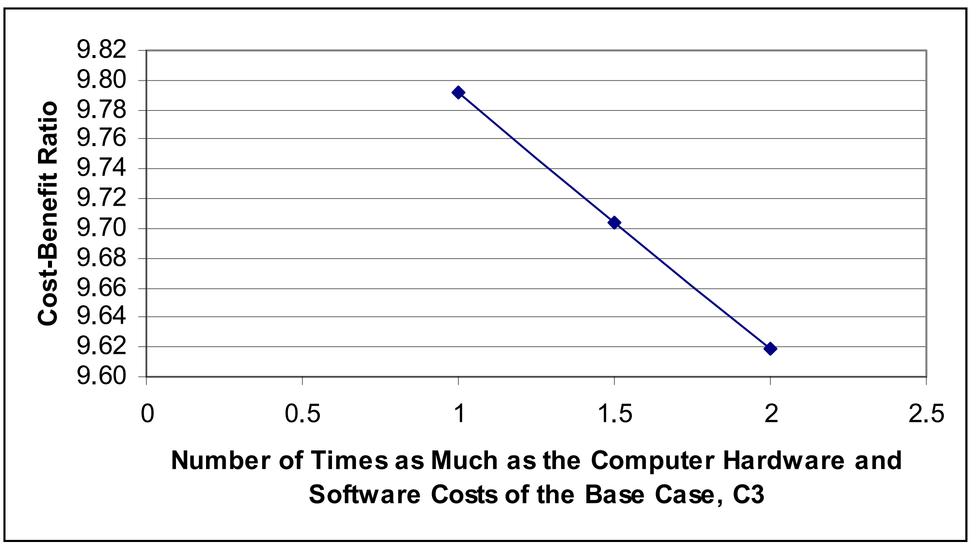

Figure A.4 Relationship Between Cost-Benefit Ratio and Input Parameter C3

Table A.5 Results of the Sensitivity Analysis of Input Parameter C4

	C4=1*(C4 of the base case)	C4=1.5*(C4 of the base case)	C4=2*(C4 of the base case)
Total discounted pavement life extension benefits, $	21,481,207	21,481,207	21,481,207
Total discounted highway user benefits, $	25,061,409	25,061,409	25,061,409
Total discounted benefits, $	46,542,616	46,542,616	46,542,616
Total discounted costs, $	4,753,417	5,108,962	5,464,508
Payback period, years	7	7	7
ROI, %	794	732	678
NPV, $	41,789,199	41,433,654	41,078,108
Cost-benefit ratio	9.79	9.11	8.52
IRR, %	43.26	43.07	42.88

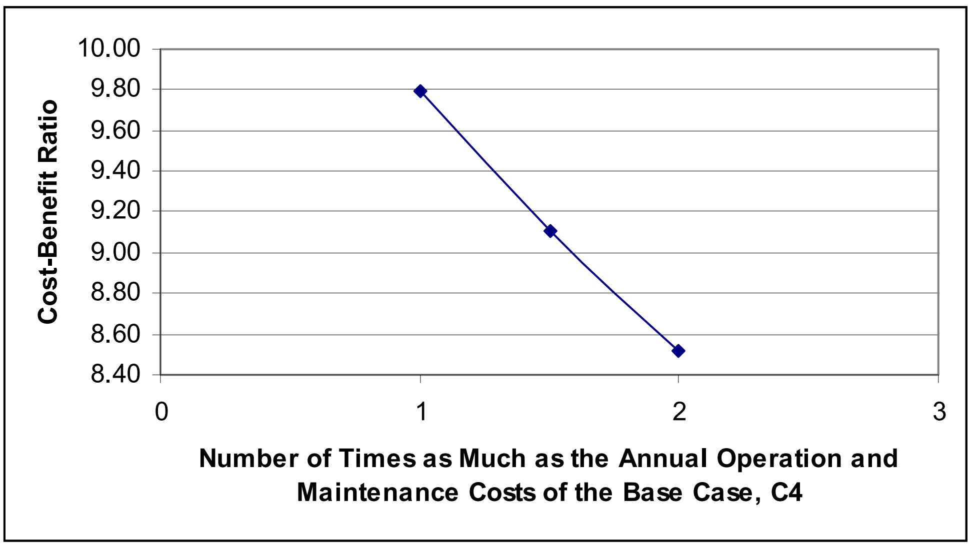

Figure A.5 Relationship Between Cost-Benefit Ratio and Input Parameter C4

Sensitivity Analysis of Discount Rate (I)

Given that all other input parameters remain the same, the value of I is gradually increased from 3.1 percent to 9 percent. Table A.6 shows the results of the analysis. The total discounted benefits and the total discounted costs are affected by the changes of I. The payback periods remain the same 7 years across the range of I. The ROI, NPV, cost-benefit ratio, and IRR are changed with the variation of I. Figure A.6 illustrates the decrease of cost-benefit ratios with the increase of I. Although the value of I is three times as much as the original estimate, the cost-benefit ratio still remains high at 7.94.

Sensitivity Analysis of Input Y

Given that all other input parameters remain the same, the value of Y is gradually increased from one to three. Table A.7 shows the results of the analysis. The total discounted benefits are significantly affected by the changes of Y. The total discounted costs are not affected by the changes of Y. The payback period, ROI, NPV, cost-benefit ratio, and IRR are significantly changed with the changes of Y. Figure A.7 illustrates the decrease of cost-benefit ratios with the increase of Y. Even if the value of Y is increased to 3 years, the cost-benefit ratio still remains high at 3.16. When the value of Y is increased to 4 years, which is beyond the analysis period, the cost-benefit ratio becomes less than one (i.e., the total discounted costs are greater than the total discounted benefits).

Table A.6 Results of the Sensitivity Analysis of Discount Rate (I)

	I=3.1%	I=5%	I=7%	I=9%
Total discounted pavement life extension benefits, $	21,481,207	18,740,819	16,279,755	14,182,065
Total discounted highway user benefits, $	25,061,409	21,864,289	18,993,048	16,545,743
Total discounted benefits, $	46,542,616	40,605,107	35,272,803	30,727,808
Total discounted costs, $	4,753,417	4,438,885	4,139,258	3,867,972
Payback period, years	7	7	7	7
ROI, %	794	729	665	607
NPV, $	41,789,199	36,166,223	31,133,545	26,859,836
Cost-benefit ratio	9.79	9.15	8.52	7.94
IRR, %	43.26	44.41	45.61	46.80

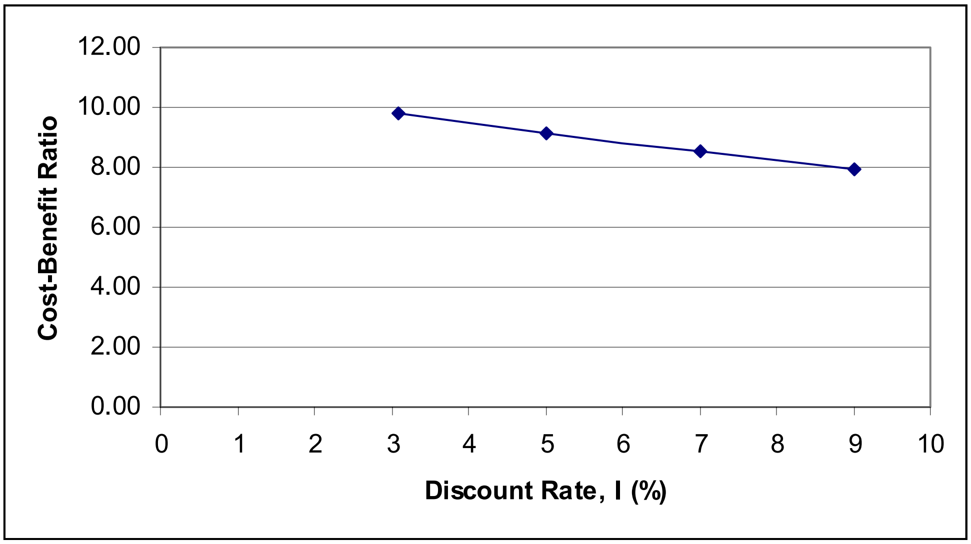

Figure A.6 Relationship Between Cost-Benefit Ratio and Discount Rate (I)

Table A.7 Results of the Sensitivity Analysis of Input Parameter Y

	Y=1	Y=2	Y=3
Total discounted pavement life extension benefits, $	21,481,207	14,101,126	6,942,947
Total discounted highway user benefits, $	25,061,409	16,451,313	8,100,105
Total discounted benefits, $	46,542,616	30,552,439	15,043,052
Total discounted costs, $	4,753,417	4,753,417	4,753,417
Payback period, years	7	8	9
ROI, %	794	458	131
NPV, $	41,789,199	25,799,022	10,289,635
Cost-benefit ratio	9.79	6.43	3.16
IRR, %	43.26	32.40	19.46

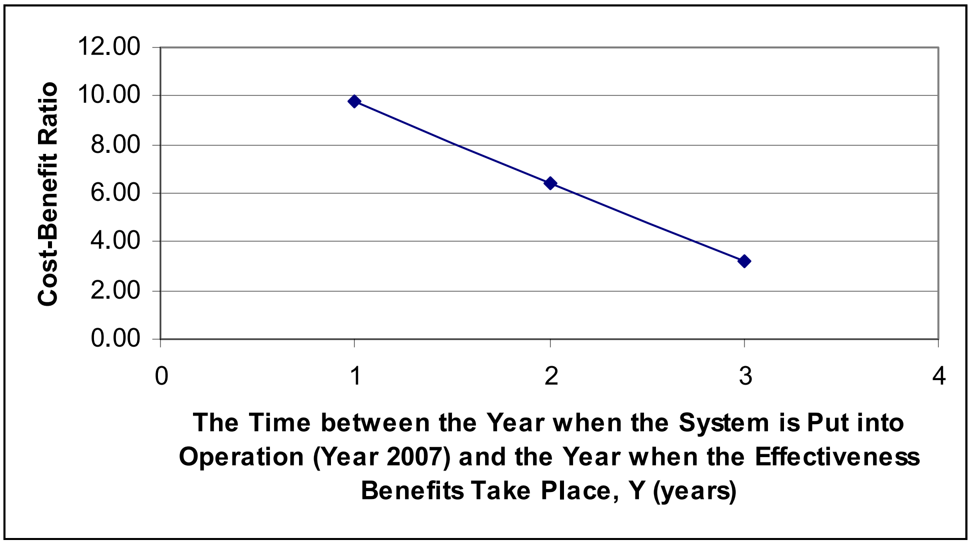

Figure A.7 Relationship Between Cost-Benefit Ratio and Input Parameter Y