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Life-cycle cost analysis

Ahmed mohamed ahmed Ibrahim
The American University in Cairo AUC

Life-Cycle Cost Analysis:
A Computer Aided Tool for the
Egyptian Construction Industry

AHMED MOHAMED
AHMED IBRAHIM

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LIFE-CYCLE COST ANALYSIS: A COMPUTER AIDED TOOL FOR THE EGYPTIAN CONSTRUCTION INDUSTRY

A Thesis Submitted to
the Interdisciplinary Engineering Programs
In Partial Fulfillment of Requirements for the Degree of
Master of Science in Construction Engineering

By
Ahmed Mohamed Ahmed Ibrahim

Bachelor of Science in Construction Engineering

Under the supervision of
Dr. A. Samer Ezeldin
Associate Professor, Construction Engineering

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has been approved by

Dr. Ahmed Samer Ezeldin, (Advisor)
Associate Professor, Construction Engineering Department, AUC [redacted]

Dr. Osama Hosny
Associate Professor, Faculty of Engineering, Helwan University

Dr. Ahmed Sherif
Associate Professor, Construction Engineering Department, AUC

Dr. Ezzat Fahmy
Professor & Director, Interdisciplinary Engineering Programs, AUC [redacted]

[redacted]	Dec 4, 2001	[redacted]	Dec. 6, 2001
Department Chair/ Program Director	Date	Dean	Date

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ABSTRACT

The American University in Cairo

LIFE-CYCLE COST ANALYSIS: A COMPUTER AIDED TOOL FOR THE EGYPTIAN CONSTRUCTION INDUSTRY

BY: Ahmed Mohamed Ahmed Ibrahim

Supervised by: Dr. A. Samer Ezeldin

The construction industry can be considered as an indication of the economical status of any country. In Egypt, the construction industry contributes to a large portion of the country's economy, where large amounts of money are spent yearly on various construction projects. Life-Cycle Cost Analysis(LCCA) is a well known worldwide technique used in cost saving. However, the technique is not well implemented in the construction field in Egypt. In an effort of measuring the application of the LCCA approach in Egypt, a survey questionnaire was conducted on a sample of 22 firms working in the field of construction. Analysis of the survey was established to expose the factors and reasons behind this low acceptance in an attempt to rationally assess the problem. Utilizing computer programming can incredibly enhance the implementation of LCCA. Therefore, a computer program (Path-A) utilizing LCCA is presented in this research. Not only does the system compare different project alternatives, but also monitors their effects on the project in its

entirety. The system was adopted to actual practices in the Egyptian market and abroad in an attempt to customize the software to the users in the construction industry. Sensitivity analysis using the system can be performed in order to assess the influence of different parameters on the Life-Cycle Cost of the project.

Keyword: Life-Cycle Costing, Life-Cycle Cost Analysis, Decision support, Computer software, Survey, Egypt, Questionnaire, Construction firms.

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Chapter 1

INTRODUCTION

1.1 INTRODUCTION

Life Cycle Costing(LCC) is mainly an economic assessment of an item, area, system, or facility considering all significant costs of ownership over an economical life, expressed in terms of equivalent dollars (Bull, 1993).

Various elements should be prepared before starting life cycle analysis. The facility economic life, the anticipated return on investment, the cost of money and operation modes, energy goals, aesthetic, flexibility, political aspects, etc. should be made available for the analyst.

Every element of the life cycle study can vary from owner to owner as well as from a place to another. Assume that an owner is planning to build a factory. The government has setup an investment tax credit for this type of facility. However, it requires retention of property by the owner for a minimum of ten years. The owner in hiring a consultant to do LCC Analysis (LCCA), would set a ten-year economic life for the project. The Minimum Attractive Rate of Return (MARR) for the project will be stated to be economically attractive.

On the other hand, suppose that the owner is a telephone company. It will own and operate the facility for its lifetime and would require a permanent type of construction, and since its profit is governed by law, the acceptable rate of return would be much lower than a factory. The two examples represent two different scenarios, yet explain how economic information for life cycle costing vary from a client to another.

1.2 PROBLEM STATEMENT

During the last few years, the Egyptian market attracted a large number of local and international investors. Three Billion and twelve Million Pounds was the amount of expenditure in the field of Housing and Communication, which is a four time increase from years 1986 to 1995 (International Monetary Fund, 1998). The rising of Build Own Operate and Transfer (BOOT) contract and Privatization concept were among the causes of the monitored increase. According to the Ministry of Planning, the yearly percent of increase in the construction industry is estimated to be 9.1% for the fourth 5-Year Plan GDP target for the years 1997/1998 to 2001/2002. The anticipated percent for the last year in the plan (2001/2002) is 7% (Ministry of Planning, 1998).

Any project is a group of variables that the owner should workout to reach the best combination. In BOOT and privatization projects investors are not only interested in the initial costs but also in Operation Maintenance and Repair (OM&R) costs. Thus, they require a global view over the whole project taking into consideration that all

future costs should include a range of variation to account for the prices fluctuation. This concept is rather new to the Egyptian market. It is essential to effectively assemble the different project components and alternatives in order to minimize the downstream costs. Finding a tool that can help in taking the right decisions after analyzing a great number of permutations for the project components and alternatives presents a serious challenge for the professionals in charge of these projects. The purpose of this thesis is to try to address the problem and present the construction professionals with an easy to use tool.

1.3 OBJECTIVES OF THE STUDY

Initial investment is no more the only important parameter for decision makers/takers. In addition to the initial cost of construction, the proprietor needs to study the costs of financing, operating, maintaining the project and replacing it at the end of its life. With the help of LCCA decision makers can get a preview on all project related costs. Through this thesis, the researcher is aiming to:

- Evaluate the application of Life Cycle Costing and its existing practices in the construction industry in Egypt for projects suitable for the application of LCC.
- Develop a step-by-step manual procedure that organizes, summarizes and demonstrates the use of LCC for construction projects.
- Develop a user friendly software program that applies LCC technique to evaluate costs for major construction projects. The software should be validated with case studies from the literature.

- Provide easy access for previously studied projects in saved files for future references.

1.4 METHODOLOGY

The afore-mentioned objectives are achieved through subsequent stages:

First: *Consult a selected sector of the Egyptian construction industry using a survey questionnaire.*

The questionnaire would be covering general information about the firms surveyed, the nature of the services offered, the volume of yearly work, the types of projects constructed, the application and use of Life Cycle Cost Analysis, the used LCCA software, and an optional question requesting an actual case study. The questionnaire is developed parallel to and based on the literature review mentioned in stage 2.

Second: *Conduct literature review concerning the different techniques of the Life Cycle Costing and their applications.*

The review includes up to date information in the field of Life Cycle Costing. A search of previously developed LCCA software is also considered through the literature review. Available computer programs dealing with LCCA in the international market are also reviewed.

Third: *Analyze the data.*

Data collected from the survey together with the Life Cycle Costing Principles and techniques will be used to develop a life-cycle costing system most suitable for practical use in the Egyptian construction industry.

Fourth: *Develop a software.*

Utilizing C++ programming language along with data collected from the survey and literature review an LCCA software is developed working under windows operating system through the following consecutive steps:

a) Analyze the system from a theoretical point of view and develop a working module. Then test the program for technical calculation errors.
b) Customize the first Beta version of the program to the Egyptian construction industry through a second questionnaire with a sample of the expected users of the software. This helps identifying possible limitations of the program as well as to measure the acceptance of such software in the Egyptian market.
c) Perform the required adjustments based on the feedback collected during phase (b).
d) Validation of the software through three main phases:
    - Applicating case studies and comparing the computer output with manual calculations and results collected from published papers. The first case study is Qena cement factory in Egypt. The other is a bridge employing an innovative construction material in the USA.
    - Conducting a follow-up questionnaire to measure the usefulness of the software as well as its acceptance in the Egyptian construction industry.
    - Measuring the software time and effort savings through computing the time required by expected users to solve typical cases using traditional methods versus utilizing the program.

1.5 CONTENTS AND ORGANIZATION

The thesis is composed of seven chapters. The first chapter introduces the thesis topic with an overview on the situation in Egypt. The problem statement is presented followed by the main objectives and a brief methodology.

A detailed coverage of the existing researches in the construction literature that are related to the LCCA practice and its applications is presented in chapter two. This chapter differentiates between different types of costs, shows the importance of predicting the future costs, summarizes the difficulties and uncertainties that face the application of LCC, and illustrates the application of LCC during the projects different phases. It also investigates the existence of LCC specialized software and tests their capabilities and limitations.

Chapter three is a field research on the awareness of a selected sector Egyptian market of the concepts and basis for applying LCCA. A questionnaire was developed and was used to call a group of engineers working in different Egyptian firms. Compiled data were analyzed to demonstrate the different LCC fields of application, the different parties involved in a LCC study, as well as the different constraints for producing LCC studies.

The fourth chapter is a thorough review of the concepts of LCC. The chapter starts by giving a briefing on why LCCA should be applied. The LCCA approach is presented starting with the preparation stages through calculation

stages and ending with selecting the best alternatives. The third part of this chapter focuses on classifying the project different costs and the methods of estimating each type of cost.

The development of a software program for LCC is presented in chapter five. Summary of the Life-Cycle Costs method is presented at the beginning. A manual system for calculating and documenting LCC supported with a set of tables is introduced. Finally the chapter provides an overview on the logic of the developed software program. A comparison between the developed software and the other available methods is then provided so as to assess the program utility. Subsequently, two case studies are provided in chapter six as a validation of the developed model.

The seventh and final chapter presents the conclusion including the characteristics of the LCC application in the Egyptian construction industry. A briefing on the advantages of the developed LCCA software program is presented in addition to highlights on further research and development of the software program.

Chapter 2

LITERATURE SURVEY

2.1 INTRODUCTION:

The use of Life Cycle Cost varies in different countries. The technique seems to have found more application in North America, according to Dell'Isola (1988), and Jelen and Black (1983). However the case is still being made in the USA for Life-Cycle Costing. As for Europe, the application of the technique is at about the same state as the USA.

This chapter presents an investigation in the construction literature that is linked to the LCCA practices and its applications. The chapter classifies the different types of costs, illustrates the importance of predicting the future costs, and highlights the difficulties and uncertainties which face the use of LCCA. The application of LCCA during the different project phases associated with numeric cases and achieved savings is then discussed. Finally the chapter investigates the existing LCCA specialized software programs and highlights their capabilities and limitations.

2.2 LCC HISTORICAL REVIEW:

The evidence for the use of the life cycle costing in practice varies in different countries. It also varies in the importance that is attached to the long-term policies and priorities regarding the infrastructure and its buildings. The technique seems to have found more application in North America, according to Dell'Isola and Kirk (1981) and Jelen and

Black (1983). This may stem from the different approaches and philosophies used for calculating the costs of construction work, which is very different to that used in the UK and in mainland Europe. Law (1984), however, states that the case is still being made in the USA for life cycle costing, Szoke (1986) suggests that, in Europe generally, the application of the technique is at about the same state as in the U.K. (Bull, 1993).

The LCC technique is based upon discounted cash flow analysis and has been borrowed from economic theory. It has been used in the investment appraisals of commercial and industrial activities. The interest in LCC in the construction industry dates back to the 1950s according to the research undertaken at the Building Research Establishment on 'Costs-in-use' (Stone,1960). Those involved in the design of projects became aware that their initial design solutions have an impact upon the long-term economics of building utilization. If the method of calculating total costs over the life span of a project was widely understood and applied, the decisions about its design, the use of components and the choice of materials could have regard not only to their initial costs, but also to the consequences of such capital expenditure in terms of life expectancy, future replacement, repairs and other running costs. In 1974 the British Standards Institution published BS 3811, described the sequence of life cycle phases from specification through eventual replacement. While this adopts

engineering terminology, the definitions used easily fit into the life phases of a construction project.

The increased interest in the use and development of the technique is indicated by the high intensity of literature that has been published over the last twenty years. The Royal Institution of Chartered Surveyors (RICS) has consistently supported its projected use into practice. It commissioned a major study of the principles and its possible applications (Flanagan et al., 1983), and has initiated further study through surveyors from the different specialist sub groupings within the RICS. This culminated in the publication of further reports in 1986 and 1987 (Bull, 1993). The Society of Chief Quantity Surveyors in Local Governments has prepared a report in the form of a practice manual. Architects on both sides of the Atlantic have also shown an interest in the technique, which resulted in publications by the American Institute of Architects (AIA, 1977) and the Royal Institute of British Architects (RIBA, 1986), as there are repercussions in the way in which they carry out their work.

While the principles of Life cycle costing and the associated evaluation methods can be easily demonstrated in theory, there are difficulties in applying the techniques in practice. These relate to a lack of knowledge and understanding , on the part of both practitioners and clients. Also, it relates to a number of uncertainties, particularly in respect of historic data, the long term future time

horizons and the policy issues of asset management. There is also a feeling of vogue regarding the application of the technique, and that in the future it might be relinquished in favor of a more novel form of analysis. The attention however, that it currently receives is a positive step forward for the construction industry.

2.3 TYPES OF COSTS:

To incorporate the Life Cycle Costing definition introduced in chapter one (Introduction), all "significant costs of ownership" are to be included. Although they can vary from one proprietor to another, significant costs can generally be classified as in Figure 2-1.

From this figure it can be noted that owner's cost can be categorized into eight different groups:

- Initial costs that associated with the development of the facility, including project costs (fees, real state, site, etc.) as well as construction costs.
- Financing costs that include the cost of any financing associated with the facilities capital costs.
- Operation (energy) costs that monitor such items as fuel, salaries, etc. needed to operate the facility or installation.
- Maintenance costs that take account of all the regular care, repair, and annual maintenance contracts.

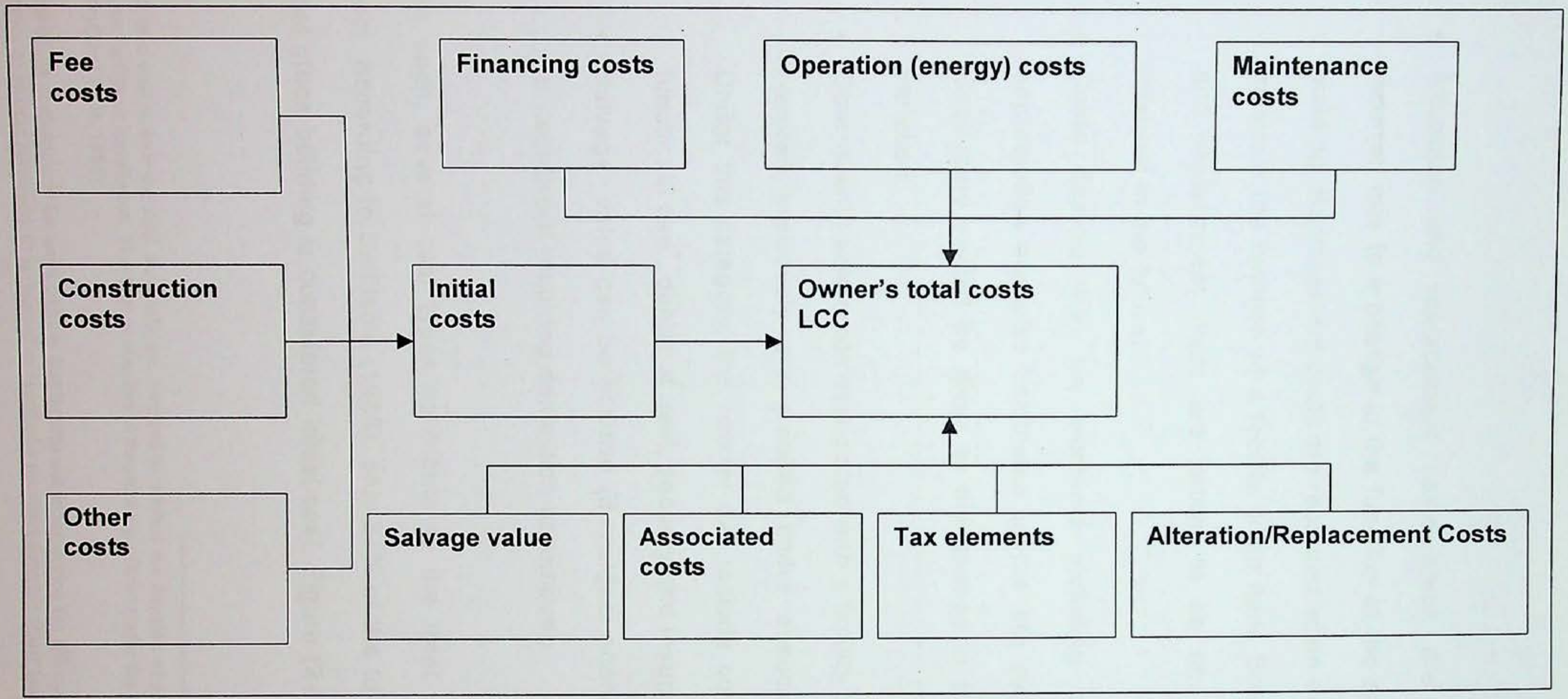

Figure (2-1): Life cycle cost elements (Dell'Isola, 1988).

- Alteration and replacement costs which are the costs incurred due to a change in the function of the space or the building. Replacement costs are recorded when owners try to maintain the function of a facility or an item. Both alteration and replacement costs are known to be one time cost incurred in the future.
- Costs dealing with tax elements including credits and depreciation are also calculated in the life cycle costing. Good care should be given to the change in the tax laws variation.
- Other identifiable costs associated with a facility decision not covered previously are grouped under associated costs. Under this category, the owner can include costs such as functional use[1], denial of use[2], security and insurance, etc.
- Salvage value can be positive (if residual economic value) or negative(if requiring demolition or removal).

As such, several cost types contribute to the total cost of any project. According to Dell'Isola (1988), only 37% of the total cost of a typical office building is considered initial cost. Figure (2-2) shows an

[1] Functional cost include the staff, materials, etc. required to perform the function of organization(s) using the facility or installation. This type is considered the most significant under the same category(Dell'Isola, 1988).

[2] Denial of use costs include the extra costs or lost income occurring during the life cycle because occupancy or income (production) is delayed as result of a previous decision (Dell'Isola, 1988).

example for cost of ownership using present worth concepts for a typical office building.

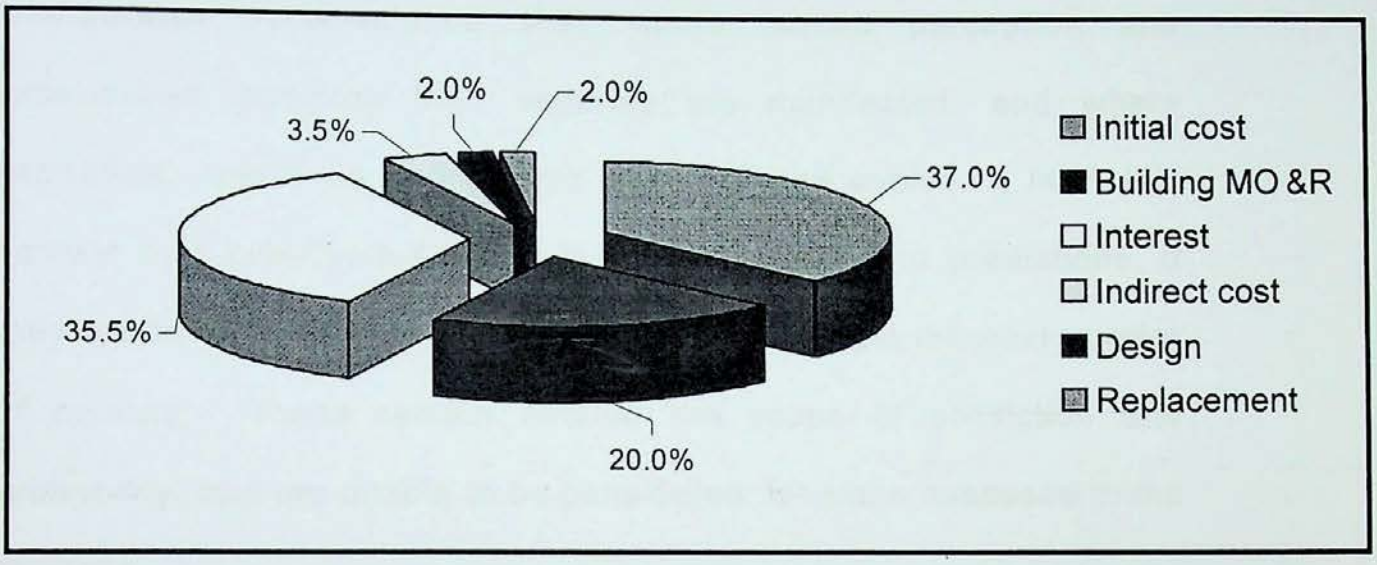

Fig 2-2: Cost of ownership for typical office building (Bull, 1993)

2.4 PREDICTING THE FUTURE:

The main hindrance associated with the application of LCC in practice is the requirement of forecasting a long way ahead in time. While this should not to be done in absolute terms, it must be performed with sufficient reliability to allow the selection of the project options that offer the lowest whole life economic solutions.

The major difficulties that face the application of life cycle costing in practice are therefore related to predicting the behavior of future events. While some of these events can, at least, be considered, analyzed and evaluated, there are other aspects that can not even be imagined today (Marshall, 1988). Weather forecasting, for example, has access to large amounts of data that has been systematically

collected over time, and is a result of extensive research programs. However, it is still unable to provide reliable forecasts of weather patterns for even a few days ahead. Life-Cycle Costing by comparison incorporates social-science skill, where human perception and experiences including their vagaries are manifested, and where aspiration, objectives and desires fluctuate and evolve. It is in this context that Life-Cycle Costing is to be applied, and predictions, if they are to be useful, need to be reliable for at least the next quarter of century. These remain outside the scope of prediction and probability, and are unable to be considered, let alone assessed in the analysis.

2.5 KINDS OF UNCERTAINTY:

There are a number of major difficulties that influence the implementation of Life Cycle Costing in the construction industry. Forecasting can only be carried out in the light of present knowledge. The future can only be predicted within the limits of present-day expectations (Bull,1993). Among the uncertainties faced when predicting the future are:

1. Life Expectancy: the life cycle time horizon of any anticipated project should be linked to current use expectations accompanied with the building. Therefore, unexpected

alteration in the use of the building will reflect on life expectancy.

2. Data Availability: among the most problems that prevent the LCC technique from being widely used is the shortage of appropriate, relevant and reliable historical cost information of similar projects.
3. Technological changes: this may vary the costs of operating, maintaining, and repairing a facility from the estimated cost during the LCC.
4. Policies and Decision making: specially in under developed and developing country where policies and major decisions cannot be predicted.
5. Fashion changes: these changes are very fast and more unpredictable than changes in technologies and are also subject to a degree of speculation.

2.6 THE LIFE CYCLE COSTING APPLICATION

The following are some of the main applications of life cycle costing associated with construction projects:

2.6.1 At Project pre-design phase

Life cycle costing can be used as a component of an investment appraisal. This is the systematic procedure to capital investment decisions regarding proposed projects. The way that future Cost-In-

Use are dealt with therefore largely depends on the expected ownership criteria of occupation, lease or sale, or indeed a combination of these alternatives(Bull, 1993). For example, highway bridges provide an excellent example that could benefit from stainless steel. Today, more than 200,000 bridges in the United States are in need for major repair. These bridges were designed to last for fourty five years, but are failing in twelve to eighteen years. The total Life-Cycle Cost of a given highway bridge if it is structured with stainless steel is ($15'700'000) rather than epoxy-coated carbon steel which costs ($17'938'170). Applying LCCA along with the study of the project can save about 12.5% of the total cost for a highway bridge(Life Cycle Issues & technologies, 1999).

2.6.2 At the Design Stage

Life Cycle Costing is perhaps most effective at this stage of the overall cost consequence of construction. It can be particularly effective at the conceptual and preliminary design stage, where changes could be made more easily, and where the resistance to such changes is less likely, in contrast to a design that is nearing completion(Portery, 93/94). In these circumstances, the designer may be reluctant to reduce part of the project even-though long-term cost saving can be realized. Applying LCCA in the selection of cooling equipment for a three-story office building resulted in selecting an alternative that saves 13% of the total LCC for the base case originally selected by the designer (Schaufelberger, 2000). While

such LCCA requires additional design funding, the additional investment can result in significant Life-Cycle Cost savings for the owner.

2.6.3 At the Construction Stage

While the major input of LCC is at the design stage, since its correct application here is likely to achieve the best in overall long-term economic saving, it should not be assumed that this is where the use of the technique ceases. At the construction phases, selecting the materials and equipment suppliers is a major area for LCC practices. According to M.F. Crawley and J.M. Bell (1999), for a pneumatic conveying system the evaluation of the initial cost of Dilute Phase System versus Fluidizing Dense-phase system would result in selecting the Dilute Phase System which has the least initial cost ($ 45'000 vs. $ 65'000). Yet considering the LCCA of the two systems would result in selecting Fluidizing Dense-phase system, with a total saving of 13% ($1'372'000.00 vs. $835'000.00).

2.6.4 During the Project's Use and Occupation

Life cycle costing has a role to play in the physical asset maintenance management. The cost attribute to maintenance does not remain uniform or static throughout the project's life. Maintenance costs therefore need to be reviewed at frequent intervals to assess their implications within the management of Cost-In-Use (Portery,1994). New costs shall be used to update the available database of the Cost-In-Use.

2.7 LIFE-CYCLE COSTING COMPUTER SOFTWARE

While searching the literature for a Life-Cycle Costs Analysis software programs, it was found that no software was developed specifically for this technique. In most cases, LCC models were included as a module in other software programs. For example, Life-Cycle Cost was included as a part of the Value engineering software developed in a previous master research at the American University in Cairo (EL-Senoussi, 2000). Yet, this type of program does not take into consideration many important concepts such as inflation. It, also, does not give a global view of the project Cost-In-Use as a whole.

In other situations, as will be noticed in the questionnaire section, manual calculations are used for computing the LCC for different alternatives. This leads to two main problems. First of all, manual calculations are not flexible enough for doing different changes such as project duration and adding or removing cost data. Secondly, it will never provide a proper documentation system for LCC future reference.

In an effort to improve the application of LCC practice, the United States National Institute of Standards and Technology (NIST) developed BridgeLCC 1.0, which is a Life Cycle Costing software for preliminary bridge design (Ehlen, 1996). The software is specially developed to be used in cases of bridges. Moreover, it requires the

user to have sufficient knowledge of bridge design in order to use the software.

Exploring the internet resulted in two ready LCCA software packages. Relex software, a professional software development company(www.relexsoftware.com), developed Relex LCC. Using Relex software, the user can produce an element breakdown structure. Select the elements that has alternatives then analyze the different alternatives to select the one with the least life cycle costs. Yet, the software does not perform a probability or reliability analysis. Moreover, it does not give the user the chance to view the effect of the selected alternatives on the project cost curve.

LccWare is another Life Cycle Cost Analysis Software developed by IsographDirect(www.isograph.com). Although the program can develop cost breakdown structure for the system and analyze the components that have alternatives, it does not give any confidence calculation for the selected option. Furthermore, the easiest way for LccWare data entering is through importing from excel spread sheets.

According to David Arditi(1999), a questionnaire was designed and mailed to those cities in the United States that indicated their use of Life-Cycle Cost Analysis. Part of the questionnaire was devoted for LCCA software. The collected information showed that most of the respondents(82%) do not use specialized LCCA Software, while some

of the rest specified using spread sheets and others did not specify any software program. The survey also revealed that 74% of the respondents suggested the development of formal guidelines for the method of application, 55% raised the generation and storage of data for the different parameters (discount rate, rate of inflation, user costs, etc.), and the third most selected option (42%) is the development of software.

Therefore, developing a software program specialized in LCCA will be a great asset for expanding the application of Life-Cycle Costing Technique, providing good documentation system, and aiding investors to conduct difficult studies.

Chapter 3

LIFE CYCLE COSTING IN THE EGYPTIAN CONSTRUCTION INDUSTRY

3.1 INTRODUCTION

Research data is used to help track performance and measure success at achieving goals. According to Carl MaDaniel, surveys have a high rate of usage in research compared to other means of collecting primary data (MaDaniel,1998). This is because surveys provide the researcher with answers for the need to know why, who and how seatrain practice is being carried.

This chapter presents a questionnaire that was designed for a selected sector of the construction market in Egypt. The selected sector is the one involved with projects where long term effect is of concern to original owners and professionals (ex: BOOT projects).The answers were analyzed to express the application of LCCA concepts. The main objectives of the questionnaire are:

a) Identify the intensity of utilizing of LCCA in specific construction types in Egypt,

b) Discover the main obstacles that hinder the use of LCCA,

c) Propose ideas for eliminating these obstacles,

d) Present ways to increase the application of LCCA in the field of construction.

Chapter three starts with a brief description of the questionnaire, its organization and structure. A description of the type of the companies participating in the questionnaire along with the reasons why they were chosen is then offered. A summary of the collected data is summed up with some interpretations from the applicants' answers and analysis.

3.2 SURVEY – QUESTIONNAIRE

3.2.1 Questionnaire Organization

Many researches, papers and articles use questionnaires as a tool of measurement. Sometimes the surveyor needs to measure the extend to which a specific phenomenon exists, while in other times, he needs to measure the knowledge of the population about a certain topic. The type and format of the questionnaire varies with the objectives of the surveyor. The format of the questionnaire at hand is considered a closed-ended questions questionnaire. A closed-end question is one that requires the respondent to make a selection from a list of responses. The main advantage of closed-ended questions is simply the avoidance of many of the problems of open-ended questions such as lies in the interpretation-processing area (MaDaniel,1998).

The questionnaire was developed to be short and to the point that would not affecting the type nor the quantity of the required data. The survey was divided into five main sections. The first section of the

questionnaire was used as an introductory section so as to introduce the applicant to the Life-Cycle Cost concept and to collect some general information of the applicant's firm.

Section two of the questionnaire captures the relation between LCC and project type, personnel involved in the technique, and the contract type. The method of conducting LCC; Simple Payback, Net Present Value, or Internal Rate of Return, was also presented in this section. Finally, this section tests the variation between the use of LCC methodology against the type of contract used.

Section three of the questionnaire allocate the problems most frequently faced in conducting LCC studies. Three suggested reasons were listed. The first was lack of information form previous projects. The second was time constraints from project schedule. The final was the difficulty of estimating the future costs of the project.

Section four is devoted for asking about a specific software program used for Life Cycle Costing. This was meant to support the idea of developing a new software program for LCCA.

Finally, section five deduces from the respondents a case study when his firm applied LCC. Some general information about the project, the element under consideration, the method used, and the

final result, were asked (the result of this part was used for testing the engine of the developed software in this thesis).

3.2.2 Data Collection

The questionnaire was addressed to a sample of twenty two selected companies working in various construction projects in Egypt. The selected sample was chosen to selectively represent the sector of the construction industry that would use LCCA. The involved firms are medium and large scale companies and were selected to represent the spectrum of parties participating in a given construction project as illustrated in table 3-1. These firms represent a combination of Consulting and Design firms (CD), Project Management firms (PM), construction firms (Contractor), and Investor (Owner) firms.

The participant groups were presented in this format so that each group will resemble at least one stage of the project economic life. The owners group represent the project pre-construction phase and the operation phase. The consulting group partially participate in the pre-design phase, mainly in the Design phase, and partially in the construction phase. The contractor group participate during the project construction phase. This way all the project phases are covered by the questionnaire.

To ensure that the survey is conducted on medium and large scale companies, a criterion of having at least ten millions Egyptian pounds of yearly volume of work was applied for selecting owner and contractor companies. While for the consulting group, the criterion was to have a yearly volume of work not less that one million Egyptian pounds.

To each firm, a questionnaire was addressed to at least one of the personnel involved with costing of projects. For example, the personnel who present BOOT and owner companies are involved in feasibility studies, while in the consultants and the contractors groups the questionnaires are handed over to engineers involved in bidding and cost control of the projects. Although, most of the questionnaires were conducted in a personal meeting with the participants, several questionnaires were faxed to companies with an introduction overview of the topic via a phone call.

A number of international companies that are involved in construction activities in Egypt or participating in a joint venture with an Egyptian firm are represented in this questionnaire. This is considered a strong point for the research since the foreign firms are working in Egypt and they will introduce different management techniques, such as LCCA, to local firms.

Table 3-1: Number of firms covered by the questionnaire vs. type of service offered:

Type of Service	CD	PM	Contractor	Owner
Total participating firms	7	6	8	7
Firms applying LCCA	5	4	5	6
Percentage to total	71%	67%	63%	86%

3.2.3 Results and Analysis

Twenty six engineers from different specializations representing twenty two different companies participated in the questionnaire. Nineteen out of the twenty two companies (eighty six percent) used the LCC method.

Table 3-2 demonstrate the relation between applying LCCA and the type of project under consideration. From the table, it is deduced that factories utilize the LCC method the most. This large percentage may be due to the availability of a large number of alternative systems and equipments in any industrial project that can do the same function. Therefore, LCC is used to select the best alternative.

Table 3-2: Type of projects vs. LCC analysis method

Type	Always	Often	Sometimes	Upon owner requisition	Never
Residential		63%	26%	11%	
Office Buildings	26%	37%	10%	27%	
Hospitals	13%	57%		30%	
Schools			16%	84%	
Factories	89%	5%		6%	
Power Plants	78%	5%		17%	

LCC can be the concern of different project parties. According to table 3-3, owners and consultants are the most interested in utilizing Life Cycle Costing.

Since they are the party who will incur the money, owners always request their consultants to perform LCCA. Notice that thirty three percent of the applicants claimed that suppliers never participate in LCC studies. This is a false indication since suppliers can be a very important source of Life-Cycle Costs data for the material supplied.

Table 3-3: Personnel involved in LCC

Type	Always	Often	Sometimes	Upon owner requisition	Never
Owner	100%				
Consultant	100%				
Project Manager	13%	30%		57%	
Contractor		22%		78%	
Supplier		40%		27%	33%

Ninety one percent of the selected construction sector stated that they use only the Net Present Value, while only thirty percent of them use simple payback, Net Present Value and Internal Rate of Return equally.

When asking about the phase in which an LCC study can be conducted, most of the participants agreed that the method is being applied during the design phase. While only two out of the twenty three engineers thought that LCC can be applied in any of the project phases.

The type of contract is one of the major items that can influence the application of LCCA. Seventy eight percent of the surveyed engineers stated that a BOOT contract is a contract that requires Life Cycle Cost Analysis.

No specific software programs were indicated as an existing LCC software. Only two of the participating engineers mentioned that they use

specially developed spread sheets for LCC calculation. This still cannot be considered an LCC software program.

As for the problems most frequently faced while conducting LCCA, seventy eight percent of the respondents said that the lack of information from previous projects due to an inadequate documentation system is the most difficult problem. On the other hand, thirty seven percent of them claimed that it is not easy to estimate future costs. Forty three percent of the applicants claimed that the very short design/construction period of the project is the reason for not applying Life Cycle Cost Analysis.

3.3 SUMMARY OF QUESTIONNAIRE RESULTS

In an effort to measure the extent to which Life-Cycle Cost Analysis technique is applied in the Egyptian construction industry, a survey was conducted and data was collected from twenty two selected companies.

It was found that eighty six percent of the surveyed companies apply Life Cycle Cost Analysis. Factories and power plants were the two project types with the highest frequency of the technique use. On the contrary, schools and residential projects had the lowest rate. It was also confirmed that owners and consultants are always the parties eager to carry out the analysis.

Although it is a powerful practice, Life Cycle Cost Analysis is faced with several problems. Seventy eight percent of the surveyed personnel assured that the lack of historical data of the project is always the nuisance for the

analyst. Ten out of twenty three engineers complained from the very short design/construction period of the project where it is difficult to add a new task of cost analysis.

There is a lack of software programs designed specially for LCCA and used in the Egyptian construction industry. This can be considered as one of the major problems that are facing the application of the technique. Therefore, developing a user-friendly software program specifically for Life-Cycle Cost analysis is the foreseen solution for eliminating the obstacles faced by the practice and to increase the use and application of LCCA practices in the Egyptian construction market.

CHAPTER 4

LIFE-CYCLE COSTING GUIDELINES

4.1 WHY USE LIFE-CYCLE COST ANALYSIS?

LCCA is particularly suitable for the evaluation of different design alternatives that satisfy a required level of building performance (including occupant comfort, safety, adherence to construction codes and engineering standards, system reliability, and even aesthetic considerations). But that may have different initial investment costs; different operating, maintenance, and repair (OM&R) costs; and possibly different lives. LCCA can be applied to any capital investment decision in which higher initial costs are traded for reduced future cost obligations. LCCA provides a significantly better assessment of the long-term cost effectiveness of a project than alternative economic methods that focus only on first costs or on operating-related costs in the short run.

Usually, there are a number of cost effective design alternatives for any given system. For example, thermal insulation can be installed over a wide range of thermal resistance values in walls and roofs. Window systems are available over a wide range of thermal conductivity values and with a variety of sun-blocking films. Many of these alternatives may be cost effective, but usually only one can actually be used in a given application. In such cases, LCCA can be used to identify the most cost-effective alternative for that application.

This is generally the alternative with the lowest life cycle cost (Schaufelberge, 2000).

LCCA stands in direct contrast to the Payback method of economic analysis. The Payback method generally focuses on how quickly the initial investment can be recovered, and as such is not a measure of long-term economic performance or profitability. The Payback method typically ignores all costs and savings occurring after the point in time in which payback is reached (Russell, 2000).

LCCA also requires additional understanding on the part of the analyst in concepts such as discounted cash flow, constant versus current dollars, and price escalation rates (Artto, 1997).

4.2 PRELIMINARY CONSIDERATIONS

Life-cycle cost analyses can range widely in complexity. The details of each project dictate the degree of complexity required for the LCCA and its documentation. Therefore, it is useful to spare some thought to planning the study before the data acquisition and computation phases.

4.2.1 Timing of Life-Cycle Cost Analysis

The planning, design, and construction process of a project comprises a series of decisions. These decisions possess an economic in nature, others involve political, social, or aesthetic considerations. Design decisions usually have the greatest impact on

total project costs early in this process. With each successive set of decisions, the tend is for less opportunity to make cost-saving changes in the design of a project or construction system (Macri, 2000). Therefore, the earlier LCC considerations are included in the planning and design process, the greater the potential cost savings that can be expected.

4.2.2 Level of Effort

Since economic analysis itself requires resource of time and money, the effort should be tailored to the needs of the project. The scope of an analysis might vary from a "back-of-the-envelope" study to a detailed analysis with thoroughly researched input data, supplementary measures of economic evaluation, complex uncertainty assessment, and extensive documentation (Macri, 2000). The greater the potential savings, the greater the feasibility of the project, and the greater the pressure to make a choice based on criteria other than economics, the more important it is to have a thoroughly researched, carefully performed, and well documented study.

4.2.3 Level of Documentation

LCC studies, whether small or large, need to be carefully documented in order to keep track of the evaluation process, to create a decision-supporting record, and to have information easily accessible for future studies. The format should be simple and easy to

understand (Carnahan, 1998). Table 4-1 provides a list of items to be documented in an LCCA report. The extent of the documentation should be related to the complexity of the decision and in proper proportion to the scale of the overall project.

Table 4-1 : List of Items to be Documented in LCCA (Carnahan, 1998)

1 Project Description
- General information
- Type of decision to be made
- Constraints

2 Alternatives
- Technical description
- Rational for including them
- Non-monetary considerations

3 Common Parameters
- Study Period
- Base date
- Service date
- Discount rate
- Treatment of inflation
- Operation assumptions

4 Cost Data and Related Factors
- Investment related costs
- Operating-related costs
- Timing of costs
- Cost data sources
- Uncertainty assessment

4 Computations
- Discounting
- Computation of life-cycle costs
- Computation of supplementary measure

5 Interpretation
- Results of LCC comparisons
- Uncertainty assessment
- Results of sensitivity analysis

6 Non-monetary Savings or Costs
- Description of intangibles

7 Other Considerations
- Narrative

8 Recommendations

4.3 DEFINE THE PROJECT AND STATE THE OBJECTIVE

The first step in a Life-Cycle Cost Analysis is to identify what should be analyzed. It is important to understand how the analysis will be utilized and what type of decision will be made in structuring the analysis and in selecting a method of economic evaluation.

4.3.1 Project Description

The project description should identify general information related to the building system being considered for design, replacement, or retrofit. This can include the type of project and activities within, occupant usage and comfort requirements, the types of energy and relevant rate schedules available at the building site. It should list the technical criteria and desirable design features by which candidate alternatives will be evaluated, as well as technical and regulatory constraints.

4.3.2 Type of Investment Decision

In order to define and delineate the requirements of the economic analysis, it is helpful to identify the type of investment decision to be made for the project. The following list identifies the five primary types of investment-related decisions(Artto, 1997). Table 4-2 lists examples for each of these investment types:

(1) Accept or reject a single project or system option

(2) Select an optimal efficiency level for a specific system

(3) Select an optimal system type from competing alternatives

(4) Select an optimal combination of interdependent systems

(5) Rank competing projects to allocate a limited budget

Table 4-2: Types of Economic Decisions and Examples (Artto, 1997):

1. **Accept or reject optional projects**
   - Add storm windows to existing single-pane windows
   - Install a solar water heater
   - Install a storm door
   - Install a night-setback thermostat
   - Install a water-saving commode

2. **Specify level of energy efficiency for a designated building system or component**
   - Specify insulation R-value in exterior wall
   - Specify seasonal efficiency rating of an air conditioning system
   - Specify size of collector area of a solar heating system
   - Specify annual fuel utilization efficiency for a furnace
   - Specify the U-value for a window system

3. **Select optimal system or component among competing designs**
   - Select type of heating and cooling system:
     electric heat pump or gas furnace with electric air conditioner
   - Select exterior wall construction:
     masonry or wood frame; rigid foam or mineral wool insulation
   - Select lighting fixture type

4. **Select optimal combination of interdependent systems or components**
   - Specify efficiency of heating and cooling systems and insulation R-values for building envelope
   - Specify type of lighting system and efficiency of heating and cooling systems
   - Select the size of a solar heating system and the efficiency of an auxiliary heating system

5. **Rank independent projects**
   - Select among numerous cost-effective energy and water conservation projects being proposed at a given government facility or institution
   - Select among numerous cost effective energy and water conservation proposals from two or more government facilities or institutions

4.4 IDENTIFY FEASIBLE ALTERNATIVES

When selecting project alternatives for economic evaluation, it makes good sense to focus on technical features who has potential economic consequences. It is expedient to look for alternatives that save future costs in return for a higher initial investment. It is essential to recognize that the problem solution can be no better than the best alternative identified for evaluation.

4.4.1 Identifying Constraints

Before identifying the alternatives to be evaluated, it is useful to consider any constraints that may exclude some alternatives from the economic analysis right at the outset. There may be physical, functional, safety-related, building-code-related, budgetary, and other constraints(Carnahan, 1998). For example, the building location may preclude the use of solar energy; natural gas may not be available at the building site; the building may be a historic building whose original appearance must be preserved. Identifying constraints before beginning the analysis will save the time and effort that would have to be spent analyzing alternatives that are not practical.

4.4.2 Identifying Technically Sound Alternatives

Once the overall project has been described, the next step is to identify all technically sound and practical alternatives. Acceptable alternatives must not degrade the overall building performance: they must be comfort, able compatible, reliable, serviceable, user-friendly, safe, and at a minimum, neutral with regard to occupant productivity

and design aesthetics. They must satisfy the technical performance specifications set out in the project description. They should not make a significant negative impact on usable space in the building.

However, there are practical limits to the extent to which the search for technically sound alternatives must be conducted. For example, a technically sound project alternative which has both higher initial costs and higher operation costs than other practical alternatives will not likely be cost effective. Such an alternative should not be considered further unless it offers benefits which are difficult to quantify in dollar terms but may nonetheless make it desirable from the investor's standpoint. For some project alternatives that are not formally considered for further analysis, it may still be wise to identify them and the basic reason for not fully evaluating them in the project documentation(Artto, 1997).

4.5 SET THE STUDY PERIOD

The study period for an LCCA is the time over which the costs and benefits related to a capital investment decision are of interest to the investor. Since different investors have different time perspectives with regard to a capital investment project, there is no one correct study period for a project. But the same body period must be used In computing the LCC of each project alternative being compared for a given purpose. The study period begins with the base date and includes the planning/construction period (if any) and the service period.

4.5.1 Base Date, Service Date, and Planning/Construction Period

Before establishing the relevant study period for an LCCA of two or more project alternatives, the analyst must first define the relevant base date and service date for the analysis. The planning/construction (P/C) period is the elapsed time between the base date and service date(Macri, 2000).

4.5.1.1 The base date

The base date is the point in time to which all project-related costs are discounted in an LCCA. The base date is usually the first day of the study period for the project, which in turn is usually the date that the LCCA is performed.

The simplest method of selecting a base date for a project analysis is to declare the year only (e.g., 1995). The implicit assumption in this case is that initial investment costs are incurred at the beginning of this year and that all future costs (whether investment-related or operation-related) are incurred during this year or during subsequent years throughout the study period, without assigning a particular date within those years. If the analysis warrants, the analyst can specify the month or even the exact day for the base date, and specify all future costs in the same manner. Use of the simpler method is generally preferred when conducting an LCCA without the aid of a software program. If future costs are specified by year only, it is recommended to discount those costs from the end of the year in which they occur.

Do not include "sunk costs." Sunk costs are costs that were incurred or committed to before the base date of LCCA. By definition, sunk costs cannot be changed by the selection of any project alternative and thus cannot affect its LCC or the LCC of competing alternatives. This is an especially important consideration when setting up the base case for an existing building or building system against which new alternatives are to be evaluated. Only costs to be incurred on or after the base date should be included in the base case. If scrapping the existing system to accommodate a new system will generate a positive (or negative) cash flow, this should be included in the analysis since it will occur on or after the base date(Macri, 2000).

4.5.1.2 The service date

The service date is the time during which the project is expected to be implemented; operating and maintenance costs are generally incurred after this date, not before. Energy and water costs incurred during construction or installation, or inherent in the building materials, are considered to be part of the initial investment cost and do not need to be specifically identified or evaluated in an LCCA. For a new building the service date is sometimes referred to as the occupancy date.

In a Simple LCCA, it may be convenient to assume that all initial investment costs are incurred on the base date and that the project (or building) is immediately put into service. That is, the base date

and the service date are assumed to be the same, as shown in figure 4-1. In a more complex analysis, the service date can occur later than the base date, as shown in figure 4-2. Manual calculations are more complex when the base date and service date do not coincide.

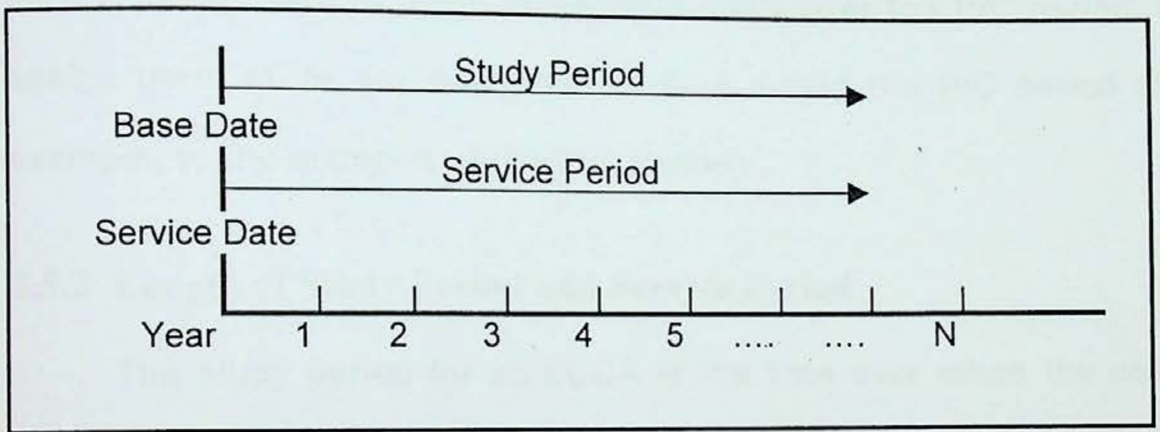

Figure 4-1: Coinciding study period and service period

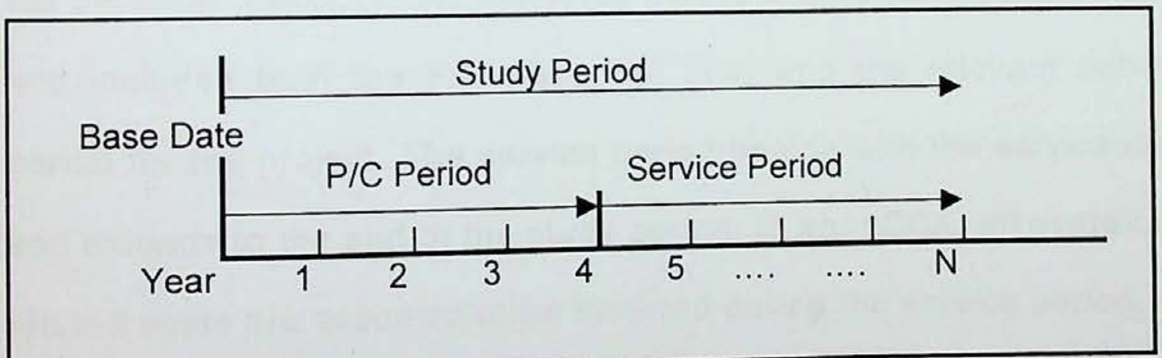

Figure 4-2: Phased-in Planning and Construction Period.

4.5.1.3 The planning / construction period

When there is a delay between the beginning of the study period and the service date, the intervening time is called the planning / construction (P/C) period. The P/C period is depicted in figure 4-2. In an LCCA only initial investment costs are incurred during the P/C period. One phase in initial investment costs over the P/C period, or assign them all to any one point of time during the P/C period (for example, to the midpoint of the P/C period).

4.5.2 Length of Study Period and Service Period

The study period for an LCCA is the time over which the costs and benefits related to a capital investment decision are of interest to the decision maker. Thus, the study period begins with the base date and includes both the P/C period (if any) and the relevant service period for the project. The service period begins with the service date and extends to the end of the study period. In an LCCA, all operation-related costs are assumed to be incurred during the service period.

Sometimes the study period will coincide with the life of the project, and sometimes it will not, depending on the time horizon of the investor. In case of Net Present Value(NPV) it is essential that one uses the same study period when evaluating mutually exclusive project alternatives(Macri, 2000).

4.5.2.1 Study period determined by expected system life

LCCA may focus on the system itself in determining an appropriate common service period and study period for evaluating system alternatives. This is usually the case when the expected life of the system is shorter than the time-horizon of the investor. The analyst should extend the life of any alternative which would end before the end of the common service period by assuming a replacement of some or all of its components one or more times during the service period. If he assumes such replacements, they will usually have a residual value at the end of the study period which one should include in his calculations

4.5.2.2 Study period determined by investor's time horizon

While system service life may be the basis for setting an appropriate service period in most LCC analyses, the time horizon of the investor should also be considered. This is especially true for leased buildings and for buildings that are expected to be sold or extensively renovated before the end of the service period based on the expected life of the alternatives. Keeping in mind the project study period, the estimate of the residual value of the project becomes more critical. (However, if the building is scheduled for demolition or rehabilitation at the end of the study period, the residual value may be zero.)

4.6 THE LCC METHOD AND SUPPLEMENTARY MEASURES OF ECONOMIC ANALYSIS

The LCC method is used to compute the LCC of a building system or a combination of interdependent systems. The LCC is the total cost of owning, operating, maintaining, and (eventually) disposing of the building system(s) over a given study period (usually related to the life span of the project), with all costs adjusted (discounted) to reflect the time-value of money. But the LCC of a building system has negligible value by itself. It is most useful when it can be compared to the LCC of other design alternatives which can perform the same function, in order to determine which alternative is most cost effective for this purpose (Russell, 2000). These alternatives are called "mutually exclusive" alternatives because only one alternative for each system evaluated can typically be selected for implementation.

For calculating LCC, several options are available. All are well documented and have been in use, since the early 1930s, in many different business sectors (Bull, 1993). The three most commonly used techniques in the building sector are as follows:

- *Simple payback:* The time taken for the return on an investment to repay the investment.
- *Net present value:* The sum of money that needs to be invested today to meet all future financial requirements as they arise throughout the life of the investment.

- *Internal rate of return:* The percentage earned on the amount of capital invested in each year of the life of the project after allowing for the repayment of the sum originally invested.

In calculating the LCC for a building system (or combination of systems), all future costs are generally discounted to their present-value equivalent (as of the Base Date) using the investor's minimum attractive rate of return (MARR) as the discount rate. The LCC can also be estimated in annual value terms. An annual value is the cost resulting from amortizing all project costs evenly over the study period, taking into account the time-value of money (Russell, 2000).

Table 4-3 lists 10 Key steps in the LCCA of a capital investment project.

Table 4-3: Key Steps in an LCC Analysis (Russell, 2000)

1. Define problem and state objective 2. Identify feasible alternatives 3. Establish common assumptions and parameters 4. Estimate costs and times of occurrence for each alternative 5. Discount future costs to present value 6. Compute and compare LCC for each alternative 7. Compute supplementary measures if required for project prioritization 8. Assess uncertainty of input data 9. Take into account effects for which dollar costs or benefits cannot be estimated 10. Advise on the decision

4.7 DISCOUNTING AND INFLATION IN LCC ANALYSIS

It is essential that the same discount rate and inflation treatment be employed in LCC analysis of multiple project alternatives. This section explains the fundamentals of discounting future costs to present value, the use of constant dollars in an economic analysis as a way of treating inflation, and the adjustment of future costs for real price escalation.

4.7.1 Discounting future amounts to present value

Project related costs occurring at different points in time must be discounted to their present value as of the base date before they can be combined into an LCC estimate for that project. The discount rate used to discount future cash flows to present value is based on the investor's time-value of money. In the private sector, the investor's discount rate is generally determined by the investor's minimum attractive rate of return (MARR) for investments of equivalent risk and duration. Since different investors have different investment opportunities, the appropriate discount rate can vary significantly from an investor to another (Portery, 1994).

4.7.2 Interest, Discounting, and Present Value

When choosing among potential project investments, there is a sensitivity to the timing of the cash flows generated by those investments. It is generally preferred via a dollar to be received (or saved) earlier rather than later (Portery, 1994). For example, it would

preferable to accommodate the annual yield schedule {\$100, \$100, \$100, \$100} to the annual yield schedule {0, 0, 0, \$400}, even though they both have the same total cash amount. An investor prefers cash receipt earlier than at a late time for two primary reasons: dollars generally loose purchasing power over time due to inflation, and cash amount received earlier can be reinvested earlier, thereby earning additional returns.

When a cash amount is invested at a given interest rate, the future value of that cash amount at any point in time can be calculated using the mathematics of compound interest (Sullivan, 1999). Suppose that an initial sum of P_0 dollar is invested for t years at a rate of interest i compounded annually. In one year, the yield would be IP_0, which is added to the principle, P_0, to give:

$$P_1 = P_0 + iP_0 = P_0 (1+i) \tag{4-1}$$

After t years, the future compound amount would be

$$P_t = P_0 (1+i)^t \tag{4-2}$$

Conversely, if it is known that interest rate and the value of an interest-earning amount at the end of the first year, the initial investment amount can be computed using the following equation:

$$P_0 = P_1 / (1+i)^1 \tag{4-3}$$

And if it is known that interest rate and the value of an interest-earning amount at the end of t year, the initial investment amount can be computed using the following equation

$$P_0 = P_t / (1+i)^t \quad (4\text{-}4)$$

The discount rate is a special type of interest rate which allows the investor to be indifferent between cash received at different points in time (Portery, 1994). The mathematics of discounting is identical to the mathematics of compound interest. The discount rate, d, is used similar to the interest rate, i, shown in equations 4.3 and 4.4 to find the present value, PV, of a cash amount received or paid at a future point in time. Thus, the present value can be calculated from a future amount received at the end of year t, F_t, using

$$PV = F_t / (1+d)^t \quad (4\text{-}5)$$

Project-related costs which occur at different points in time over a study period cannot be directly combined in calculating an LCC because the dollars spent at different times have different values to the investor. These costs must first be discounted to their present-value equivalent amounts; only then can the costs be summed to yield a meaningful LCC that can be compared with the LCC of other alternatives.

4.7.3 Discount formulae and discount factors

The discounting operations can be divided into two types:

(1) A method for discounting one-time amount to present value. The definition of one-time amounts includes costs occurring at irregular or non-annual intervals. Examples of one-time costs

are a capital replacement at the end of year eight, painting at five-year intervals, and a residual value at the end of the study period.

(2) A method for discounting a series of annually recurring amounts to a present value. Examples of annually recurring costs are routine maintenance costs occurring each year over the study period in the same amount (uniform amounts) and annual energy costs based on the same level of energy consumption from year to year but increasing from year to year at some known or estimated escalation rate (non-uniform amounts).

Discount factors can be pre-calculated to reduce the amount of work needed in a manual LCCA.

Once an investor decides that the LCC analysis of a project will be performed, the same discount rate should be used for the present-value calculations of all of the cost components for the base case and the alternatives (Artto, 1997). Different discount rates should not be used to calculate the present value of costs that will be added together or that will be compared with the cost competing alternatives.

4.7.4 Discounting When There is a Planning/Construction Period

For LCC analyses in which a planning/construction (P/C) period occurs before the service date, special consideration must be given to annually recurring costs before discounting them to present value. For one-time costs occurring at any time during the study period, the

Single Present Value(SPV) factor is used. That is, the present value at the base date is calculated with the appropriate SPV factor for the number of years between the base date and the time the cost is incurred. However, this is not the case with annually recurring costs. Annually recurring costs are not generally incurred during the P/C period, but instead are usually assumed to begin at the date the project is put into service. The use of a Uniform Present Value (UPV) factor based on the full study period, which includes the P/C period, would implicitly include the present-value calculation annually recurring costs that do not occur in the P/C period (Portery, 1994). To exclude those costs for the length of the P/C period, take the following steps:

(1) acquire (or calculate) the UPV factor for the number of years in the entire study period (including the P/C period).

(2) Look up (or calculate) the UPV factor for the years in the P/C period.

(3) calculate positive difference between the two factors as the appropriate UPV factor by which to multiply the annual recurring cost (specified in base-date prices).

This procedure will give the present value at the base date of the annually recurring costs over the service period only.

4.7.5 Adjusting for Inflation

Inflation reduces the purchasing power of the dollar over time; deflation increases it. When future amounts are stated in actual prices as of the era in which they are expected to occur, they are stated to be in current dollars. Current dollars are dollars of any one year's purchasing power, including inflation. That is, they reflect changes in the purchasing power of the dollar from year to year(Bull, 1993). In contrast, constant dollars are dollars of uniform purchasing power, exclusive of inflation. Constant dollars indicate what the same good or service would cost at different times if there were no change in the general price level -no general inflation or deflation- to change the purchasing power of the dollar.

To make a meaningful comparison between costs occurring at different points in time, those costs must be adjusted for changes in the purchasing power of the dollar. The formula in equation (4-5) can be modified to a factor which will take account of inflation. Inflation will increase costs at year t and therefore increase the present day investment level(Ball, 1993). The modified factor is known as the "Net Inflation Discount Rate" (NDR) where:

$$ndr = ((1+ \text{interest } \%) / (1+ \text{inflation}\%)) - 1 \qquad (4\text{-}6)$$

Therefore equation 4-5 becomes:

$$PV = Ft / (1+ndr)^t \qquad (4\text{-}7)$$

4.8 ESTIMATING COSTS FOR LCC ANALYSIS

4.8.1 Relevant effects

There are numerous costs associated with acquiring, operating, maintaining, and disposing of a building or building system. The costs to be included is one of the first decisions to be taken when performing a Life-Cycle Cost Analysis (LCCA). It is necessary assess at the economic effects that will result from each design alternative. To the extent feasible, these effects should be quantified in dollar terms. For effects that cannot be expressed in dollar amounts, a verbal account should be made so that they can be included in the analysis at least in a qualitative way.

It is not necessary to include all project-related costs in an LCCA of project alternatives. Only those costs that are relevant to the decision and significant in amount are required to perform a valid investment decision. Costs are relevant to the decision when they change from one alternative to another. Costs that are approximately equal for each alternative are not a determining factor in the choice among the alternatives, therefore, they can be omitted from the LCC calculation. Inclusion of such costs will not produce erroneous results but may incur data collection and analysis costs which could be avoided. Costs are significant when they are significant in making a credible difference in the LCC of a project alternative. Assessing the relevance and significance of project costs in an LCCA is largely a matter of engineering judgment(Carnahan, 1998).

Sunk costs should be excluded from an LCCA. These are costs that are incurred or committed to in the past and thus cannot be avoided by a future decision. For example, the cost of a recently replaced fuel tank for an oil heating system being converted to natural gas is a sunk cost, except for its salvage value (Macri, 2000).

4.8.2 Cost categories

There are various classifications for the cost components of an LCCA, depending on what role they play in the mechanics of the methodology. The most important categories in LCCA distinguish between investment-related and operational costs; initial and future costs; single costs and annually recurring costs.

4.8.2.1 Investment Costs vs. Operation Costs

Life-cycle costs typically include investment costs and operational costs. The distinction between investment and operation-related costs is useful when computing supplementary economic measures such as the Savings-to-Investment Ratio and Adjusted Internal Rate of Return. These measures evaluate savings in operation-related costs with respect to increases in capital investment costs. This distinction will not affect the LCC calculation itself, nor will it cause a project alternative to change from cost effective to a non-cost effective or vice versa. However, it may change its ranking relative to other independent projects when allocating a limited capital investment budget.

4.8.2.2 Initial investment costs vs. Future costs

The distinction between initial investment costs and future costs is most useful when computing the Simple or Discounted Payback measures. The costs incurred in the planning, design, construction and/or acquisition phase of a project are classified as initial investment costs. They usually occur before a building is occupied or a system is put into service. Those costs that arise from the operation, maintenance, repair, replacement, and use of a building or a system during its occupancy or service period are future costs. Residual values at the end of a system life, or at the end of the study period, are also future costs.

4.8.2.3 Single costs vs. Annually Recurring costs

It is useful to establish two categories of project-related costs based on their frequency of occurrence. This categorization determines the type of present-value equation to be used for discounting future cash flows to present value.

(1) single costs (one-time costs) occur at one or more times during the study period at non-annual intervals. Initial investment costs, replacement costs, residual values, maintenance costs scheduled at intervals longer than one year, and repair costs are usually treated as single costs.

(2) Annually recurring costs are amounts that occur regularly every year during the service period in approximately the same amount, or in an amount expected to change at some known rate. Energy

costs, water costs, and routine annual maintenance costs fall into this category.

4.8.3 Timing of cash-flow

LCC analysis requires that all project-related costs would be identified by time of occurrence as well as amount. However, it is a convention in LCCA to use simplifying models of cash flows rather than to attempt to reproduce the exact timing of all costs. Thus costs which may occur at different times during the year may all be treated as occurring at the same time each year, in order to simplify the discounting operations. Computer-assisted LCCA makes it more convenient to compute single costs from their actual time of occurrence during the year.

When using manual methods, it is usually sufficient to discount all costs from the end of the year in which they occur. With computer-aided analysis, the recommended method is to discount all single costs from the time of occurrence and to discount annually recurring costs from the end of each service year.

4.8.3.1 Cash-flow Diagrams

A cash-flow diagram for a project alternative, as shown in figure 4-3, provides a convenient way of visualizing all relevant costs and their timing. A horizontal time line represents the study period and marks each year and key dates; e.g., the base date, the occupancy or service date, and the end of the study period. Years can be marked in calendar-year terms (e.g., 1995) or in elapsed years from the base

date (e.g., 1, 2, 3,...). There is no standard convention for showing costs on a cash flow diagram, but positive costs are typically shown above the horizontal time-line, and negative costs (e.g., residual values) are shown below the time-line.

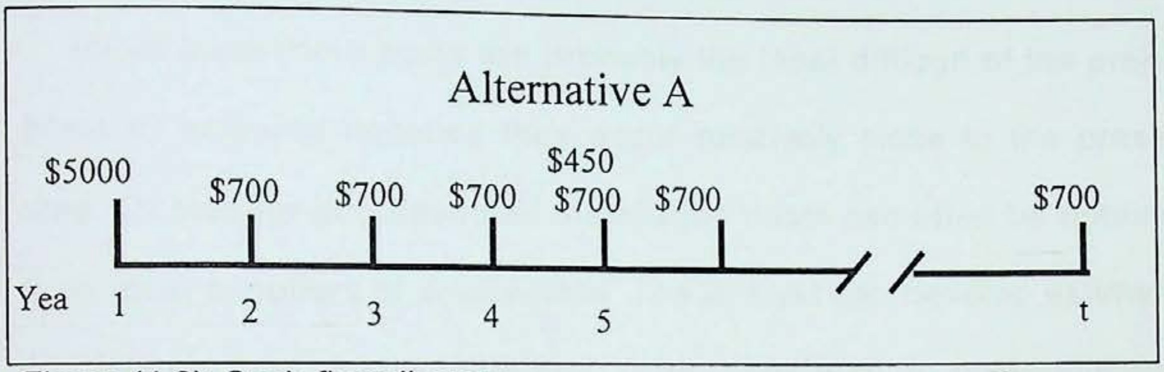

Figure (4-3): Cash-flow diagram

4.8.4 Using the Base-Date prices to estimate future costs

Most cost data for an LCCA are likely to be estimates. The analysis is often performed early in the decision-making process before detailed initial cost data are available. Future costs by their nature are uncertain. The difficult task of obtaining estimates of future costs is simplified by the fact that the LCC methodology bases future cost estimates on their corresponding cost as of the base date of the LCCA, usually the date on which the analysis is performed.

If there is reason to believe that the basic supply and demand conditions for a particular good or service remain the same as those for most other goods and services, it can be assumed that its price will change at roughly the rate of general price inflation. That is, the real price escalation rate is equal to zero(Bull, 1993). This means that in a constant-dollar analysis-where the rate of inflation is not included

in the computations, the future price of an item is identical to the base-date price.

4.8.5 Estimating investment-related costs

4.8.5.1 Estimating initial investment costs

Initial investment costs are probably the least difficult of the project costs to estimate because they occur relatively close to the present time. Quotes for purchase and installation costs can often be obtained from local suppliers or contractors. The analyst can develop estimates by adding unit costs obtained from construction cost-estimating guides.

Since the estimates are based on different underlying assumptions and have different emphases, it is recommended that analysts use the same data set for analyzing each of the alternatives being considered for a project in order to get consistent and comparable results.

Detailed estimates of construction costs are not necessary for preliminary economic analyses of alternative building designs or systems. Such estimates are usually not available until the design is quite advanced and the opportunity for cost-reducing design changes has been missed. For very large projects, an analyst may want to use a standard format for organizing construction cost data to facilitate the retrieval and review of the data.

4.8.5.2 Estimating Capital Replacement Costs

The number and timing of capital replacements depends on the estimated life of the system and the length of the service period. The analyst can use the same sources that provide cost estimates for initial investments to obtain estimates of replacement costs and expected lives. A good starting point for estimating future replacement costs is to use their cost as of the base date.

4.8.5.3 Estimating Residual Value

The residual value of a system (or component) is its value at the end of the study period, or at the time that it is replaced during the study period. Residual values can be based on value in place, resale value, salvage value, or scrap value, net of any selling, conversion, or disposal costs.

The residual value of a system at the end of its expected spin life is likely to be small or even negative (due to removal or disposal costs) if the system needs complete replacement or the building is being demolished. However, for systems with expected lives extending beyond the end of the study period, the residual value should be based on their value in place, not on their "salvage" value as if they were to be removed from the building at that point. A building system which is functioning in place adds significant value to the building and this value should be reflected in its residual value. As a general rule of thumb, the residual value of a system with remaining useful life in place can be calculated by linearly prorating its initial

costs. For example, for a system with an expected useful life of 15 years which was installed five years before the end of the study period, the residual value would be approximately 2/3 [=(15-5)/15] of its initial cost.

While estimating the residual value of a building system or component in constant dollars, using the initial cost as the starting point for the estimate, the analyst will not need to adjust the residual value for price changes between the base date and the time that the residual value is realized, unless the price of similar systems change at a rate significantly different than the rate of general inflation. If he is estimating the residual value in current dollars, he will need to adjust the residual value for general inflation and any real price increase (Artto, 1997).

When the study period is long, the residual value of the original system may be small and largely offset by disposal costs. Discounting further, diminishes its weight in the analysis, and so it is often less important to improve the estimate of a residual value than of other input values. But when the study period is short, the estimate of the residual value may become a critical factor in assessing the cost effectiveness of a capital investment project, and thus it should be given careful consideration. The residual value estimate for a capital replacement, needed to extend the life of an alternative to the length of a common study period, may also be a critical factor in the LCCA and thus care should be given in estimating this value.

4.8.6 Estimating Operation, Maintenance, and Repair Costs

Operating, maintenance, and repair (OM&R) costs are often more difficult to estimate than other building expenditures. Since operating schedules and standards of maintenance vary from building to building, there is great variation in these costs, even for buildings of the same type and age. It is therefore especially important to use engineering judgment when estimating these costs.

OM&R costs generally begin with the service date and continue through the service period. Some OM&R costs are annually recurring costs which are constant from year to year or change at some estimated rate per year. The present value of annual costs over the entire service period can be estimated using appropriate UPV factors or equation. Others are single costs which may occur only once or at non-annual intervals throughout the service period (Moussatche, 2000). These must be discounted individually to present value.

4.8.6.1 Estimating OM&R costs from cost estimating guides

Ongoing efforts to standardize OM&R costs have produced a number of helpful manuals and databases, examples of which are listed in table 4-4. Keep in mind that if OM&R costs are essentially the same for each of the project alternatives being considered, they do not have to be included in the LCCA.

4.8.6.2 Estimating OM&R costs from direct quotes

A more direct method of estimating OM&R costs is to obtain quotes from contractors and vendors. For cleaning services, for example, a practitioner can get quotes from contractors, based on prevalent practices in similar buildings. Maintenance and repair estimates for equipment can be based on manufacturers' recommended service and parts replacement schedules. These costs can be established for the initial year by obtaining direct quotes from suppliers. For a constant dollar analysis, the annual amount will be the same for the future years of the study period, unless, as is sometimes the case, OM&R costs are expected to rise as the system ages. In this latter case, the real (differential) escalation rate for that cost must also be included in the analysis.

4.8.7 Other relevant Costs or Benefits

4.8.7.1 Taxes and Finance Charges

Taxes need not be taken into consideration. Likewise, the cost of financing projects can be disregarded in an LCCA of this type unless the financing is specifically tied to the project. In private-sector analyses, these factors should be included if they are expected to make a significant difference in the outcome of the analysis.

4.8.7.2 Non-Monetary Benefits and Costs

Non-monetary benefits and costs are project-related effects for which one has no objective way of assigning a dollar value. Examples

of non-monetary effects may be the benefit derived from a particularly quiet HVAC system or from an expected, but hard to quantify, productivity gain due to improved lighting (Macri, 2000). These items, by their nature, are external to the LCCA, and thus do not directly affect the calculation of a project's cost effectiveness. Nevertheless, the analyst should consider significant non-monetary effects in his final investment decision, and they should be included in the project documentation.

4.8.8 Revenues

LCC analysis is most appropriately used to evaluate the relative costs of design alternatives which satisfy a particular set of performance requirements. It is not generally appropriate for evaluating the cost effectiveness of alternative revenue-producing projects, such as buildings constructed to produce rental income. For example, one would not use an LCCA to determine whether to build a 20-unit apartment building or a 40-unit building. These decisions are better evaluated using Cost-Benefit Analysis and Rate-of-Return measures. However, if there are small differences in revenue between one design alternative and another, they can be included in the LCCA by adding them to (when negative) or subtracting them from (when positive) annual operation-related costs.

Chapter 5

SYSTEM DEVELOPMENT AND OVERVIEW

The basic LCC method is the most straight forward method of accounting for present and future costs of a project over its life-cycle. When using the LCC method for evaluating buildings or building systems, analysts typically analyze two or more project alternatives for the same purpose (e.g. different R-values of insulation in an exterior wall or different HVAC systems), only one of which will be selected for implementation. To determine the relative cost effectiveness of these mutually exclusive alternatives, applicants need to compute the LCC for each alternative and the base case, compare them, and choose the alternative with the lowest LCC. Only when compared to the LCC of a base case or another alternative intended for the same purpose does the LCC provide useful information. The LCCs are comparable only if computed with the same economic assumptions and with the same study period, base date, and service date. In addition, it is essential that only alternatives that satisfy minimum performance requirements be considered for LCCA.

5.1 THE LIFE-CYCLE COST (LCC) METHOD

LCCA allows applicant to organize and compute the costs of acquiring, owning, operating, maintaining, and ultimately disposing of a building or a building system. Once the applicant has cost estimates, by year, for two or more competing alternatives, a discount

rate, and a study period, he is ready to calculate the LCC for each alternative. To calculate the LCC, first should compute the present value of each cost to be incurred during the study period, using the PV equations and/or the discount factors. Then one should sum these present values for each alternative to find its LCC. If other performance features are similar among the alternatives, the alternative with the lowest LCC is the preferred alternative; that is, it is the most cost effective alternative for the application studied.

5.1.1 GENERAL FORMULA FOR LCC

The following is the general formula for the LCC present-value model:

$$LCC = \sum_{T=0}^{T=n} (C_t / (1+d)^t) \qquad (5\text{-}1)$$

where:

LCC = Total LCC in present-value dollars of a given alternative,

Ct = Sum of all relevant costs, including initial and future costs, less any positive cash flows, occurring in year t,

N = Number of years in the study period, and

D = Discount rate used to adjust cash flows to present value.

5.1.2 LCC FORMULA FOR CONSTRUCTION PROJECTS

The general LCC formula shown in eq. (5-1) requires that all costs be identified by year and by amount. This general formula, while straightforward from a theoretical standpoint, can require extensive calculations, especially when the study period is more than a few years long and for annually recurring amounts, for which future costs

must first be calculated to include changes in prices. A simplified LCC formula for computing the LCC of construction projects can be stated as follows:

$$LCC = I + Repl - Res + E + W + OM\&R \quad (5.2)$$

where:

LCC = Total LCC in present-value dollars of a given alternative,

I = Present-value investment costs,

Repl = Present-value capital replacement costs,

Res = Residual Present Value,

E = Present-Value of energy costs,

w = Present-value water costs, and

OM&R = Present-value of operating, maintenance, and repair costs.

5.2 DEVELOPED MODULE

A frame work was developed to control the process of evaluating life cycle cost alternatives. Figure 5-1 provides module flow chart that illustrates the step by step procedure for applying LCCA. The diagram uses a set of forms for data collecting, evaluating and documenting the LCCA study. A complete set of the forms is provided in appendix B. The following are key points which should be recognized when using the LCC module for project evaluation:

- Choose among two or more mutually exclusive alternatives on the basis of lowest LCC.
- All alternatives must meet established minimum performance requirements.

- All alternatives must be evaluated using the same base date, service date, study period, and discount rate. positive cash flows (if any) must be subtracted from costs.
- Effects not measured in dollars must be either insignificant, uniform across alternatives, or accounted for in some other way.

5.3 LCC PROCEDURE

This section contains the manual procedure for performing and documenting Life-Cycle Cost Analysis. LCC can range widely in complexity. While it is recommended that the applicant uses a computer aided program in sophisticated cases, there are occasions when manual calculation procedure may be required. The tables provided in appendix B are guides to setting up, solving, and documenting such analysis. Moreover, this set of tables can be utilized in the data collection phase as a preparation for computer input.

The stepwise evaluation process followed by this procedure is based on the assumption that applicants are responsibly familiar with the Life-Cycle Costing methodology discussed formerly. This includes an understanding of the conceptual and computational requirements of present-value calculations, treatment of inflation, maximum study periods, and evaluation criteria. If this is the case the following instructions, together with the tables given in appendix B, will guide applicants through a Life-Cycle Cost Analysis in five steps:

- Project Identification
- Cash-Flow Diagram
- Input Data Summary
- Present Value Calculations
- Selection of the Best Alternative

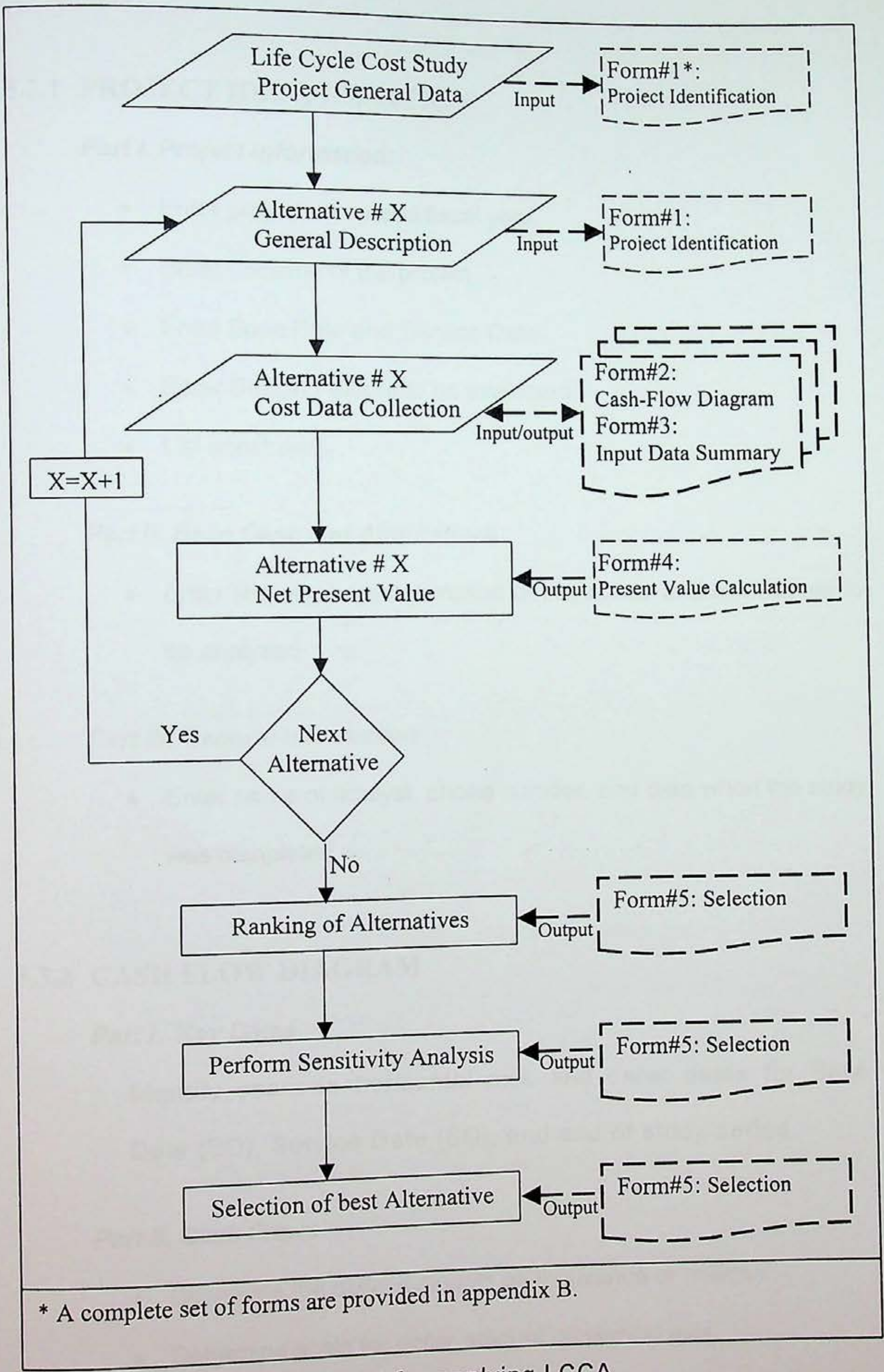

Figure 5-1: Module flow chart for applying LCCA.

5.3.1 PROJECT IDENTIFICATION

Part I. Project information:

- Enter project name and fiscal year
- Enter Location of the project
- Enter Base Date and Service Date
- Enter Design Feature to be evaluated
- List constraints

Part II. Base Case and Alternatives

- Enter title and brief description of base case and alternatives to be analyzed

Part III. General Information

- Enter name of analyst, phone number, and date when the study was completed

5.3.2 CASH FLOW DIAGRAM

Part I. Key Dates

Identify years in horizontal axis and enter dates for Base Date (BD), Service Date (SD), and end of study period.

Part II. Cash Flows

- Designate the dollar-amounts as thousands or millions.
- Determine scale for dollar amount on vertical axis.
- Enter anticipated cash flows:

- Cost as positive amounts above horizontal line.
- Benefits as negative amounts below horizontal line.

5.3.3 INPUT DATA SUMMARY

Part I. Identification of Alternative

Enter project title and identification data for alternative in the project identification table.

Part II. Analysis of Input Data

Col. (1) Enter types of costs or benefits as of the Base Date (BD)

One-time amount:

Example: Planning/Construction (P/C) or Acquisition costs, Capital replacement costs, Disposal Costs, Resale, Retention, or Salvage Value

Note: P/C or Acquisition costs may be assumed to occur in a lump sum at the beginning of the study period. All the one-time costs are assumed to occur at any time during the analysis period, the specific time depending on when they are actually expected to occur.

Annually recurring amounts:

Example: Routine OM&R Costs and Custodial Costs

Energy Cost: Electricity, distillate, residual, etc.,

Col.(2) Enter amounts as of the Base Date. (Designate as thousands or millions.)

Col.(3) For one time amounts, enter the number of years after the Base Date (BD) and the Service Date (SD) for which the costs or benefits occur.

For Annually recurring amounts, enter the number of annual payments expected over the length of the study period.

Col.(4) Designate as investment-related or non-investment-related.

Col.(5) List data sources on a separate sheet and enter referances here.

Col.(6) For the private sector enter the Minimum Attractive Rate of Return

Col. (7) For projects of the public sector calculate the Net Deduction Ratio (NDR).

5.3.4 PRESENT-VALUE CALCULATION

Part I. Identification of Alternatives

Enter project name and identification data for base case or alternative

Part II. Present Value Calculation

Col. (1) Enter costs and benefits by category (investment-related or operation related).

Col. (2) Enter amounts as of the Base Date (BD), from col. (2) of Input data summary.

Col. (3) Enter discount factors calculated using the rates from col. (6) or col. (7) of the input data summary.

Col. (4) Multiply amount (column (2)) by discount factor (column (3)) and enter present value in column (4)

Part III. Life-Cycle cost calculation

Col. (5) Sum all the investment-related costs (including resale, retention, or salvage values, if any, that have to be subtracted from costs)

Sum all operation-related costs

Add total investment-related costs and total operation-related costs and enter Total PV Life-Cycle Costs for alternative in bottom part of the table.

5.3.5 SELECTION OF ALTERNATIVE

Part I. Comparison of LCCs

- List all alternatives analyzed, their PV costs, and LCCs.
- Compare the LCCs and rank the alternatives in ascending order of their LCCs.
- Perform sensitivity analysis if there is uncertainty about the input values.

Part II. Sensitivity analysis

- Perform sensitivity analysis and enter results.
- Correct ranking of alternatives if appropriate.

Part III. Selection of preferred alternative

- If the selection is clear, enter the top-ranking alternative and document reasons.
- If the LCCs are nearly identical, consider non-quantifiable benefits or costs to assign the higher relative ranking. Document reasons.

Part III. Life-Cycle cost calculation

Col. (5) Sum all the investment-related costs (including resale, retention, or salvage values, if any, that have to be subtracted from costs)

Sum all operation-related costs

Add total investment-related costs and total operation-related costs and enter Total PV Life-Cycle Costs for alternative in bottom part of the table.

5.3.5 SELECTION OF ALTERNATIVE

Part I. Comparison of LCCs

- List all alternatives analyzed, their PV costs, and LCCs.
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5.4 PROPOSED SOFTWARE PROGRAM

Making use of new technologies for performing repetitive tasks saves time and effort. Previous studies are saved and could be retrieved in the future. Sensitivity analysis, testing probabilities and calculating statistics could also be performed.

Assume that an analyst has a project he wants to study. If one of the project elements has two alternatives, then the analyst has two paths to go through. If on the other hand five of the project elements have two alternatives each, four of the elements have three alternatives, and three elements have four alternatives, then the total number of paths that the analyst will have is 165'888 [2^5 X 3^4 X 4^3]. Although this is the case most of the times, no one will be able, without the aid of a software program to perform a study through all these paths to select the best path.

Path-A is a computer program developed to achieve this option. The name of the software, Path-A, was selected to reflect that the program suggests the best path suitable for the user from all given alternatives and all possible generated paths. The selection of the best path for the project is based on the lowest Life-Cycle Cost and a number of optional constraints that the user can use as will be discussed later. Henceforth, Path-A will be referred to as the Software or the computer program.

5.4.1 Software process model

There is a growing recognition that software evolves over a period of time. Business and product requirement often change as development proceeds, making a straight path to an end product unrealistic. Therefore, software engineers need a process model that has been explicitly designed to accommodate a product that evolve over time (Pressman, 2001).

Evolutionary process models are iterative. They are characterized in a manner that enables software engineers increasingly more complete versions of the software. So as to produce the software under consideration, a spiral model, figure 5-2, was used.

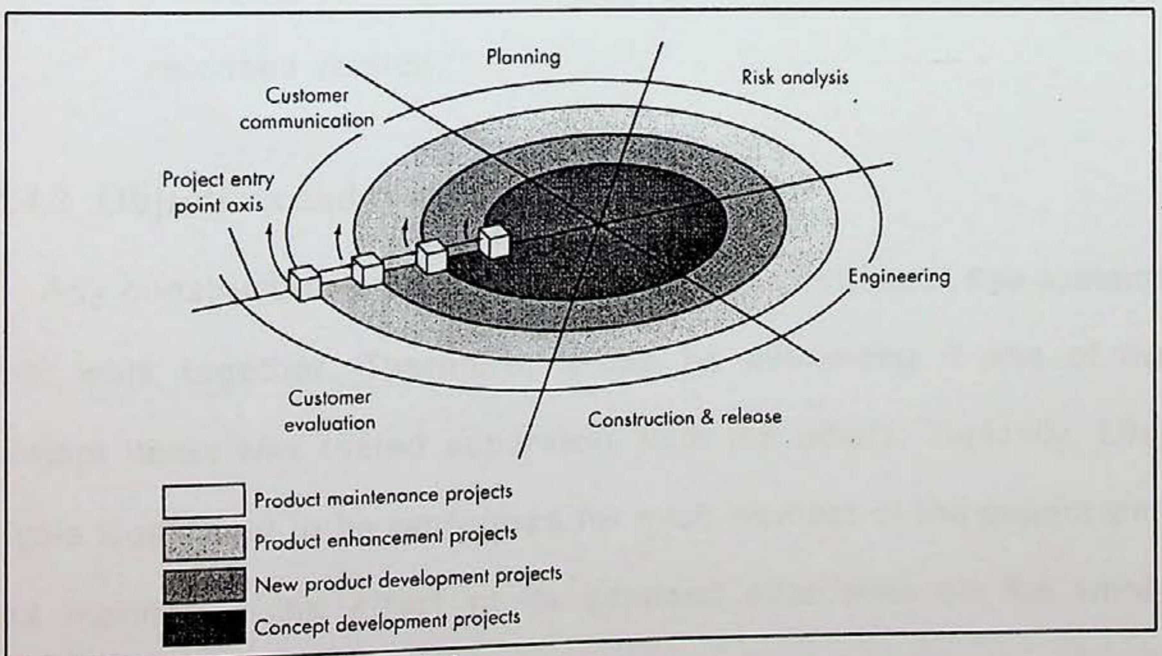

Figure 5-2: Spiral model

The spiral model is divided into a number of framework activities, also called task regions. The used model is divided into six task regions as follows:

- **Customer communication:** tasks required to establish effective communication between developer and customer.
- **Planning:** tasks required to define resources, timelines, and other project related information.
- **Risk analysis:** tasks required to assess both technical and management risks.
- **Engineering:** tasks required to build one or more representations of the application.
- **Construction and release:** tasks required to construct, test, install, and provide user support (e.g., documentation and training).
- **Customer evaluation:** tasks required to collect the customers' implications and recommendations on the released version.

5.4.2 Objectives and General Characteristics

Any construction project is a combination of different sub-systems that work together. Therefore, it can be misleading if one of the project items was tested separately from the others. Typically, Life-Cycle Cost used to be performed for each element of the project with out monitoring the effect of its selected alternative on the whole project.

The objective of this part is to provide LCC applicants with a user friendly software program that can minimize the time spent in

performing tedious work and increase the flexibility of utilizing the technique.

The main characteristics of the program are:

a) Capable to handle different LCC cases using the Present Value method,

b) Treat every project element along with its alternatives separately while monitoring the effect of the selected alternative on the whole project,

c) Calculate cost and cost cumulative curves for each time sequence of the project,

d) Calculate cost and cost cumulative curves for the whole project and develop all the possible alternative paths,

e) Supports the decision maker / taker to select the most appropriate cost curve for the expected financial status,

f) Good documentation system for future reference in similar cases.

5.4.3 Program Main Assumptions

The main assumption for the developing the software program are:

a) All alternatives for any items are technically accepted,

b) All costs are given with the same currency,

c) The user would provide the Minimum Attractive Rate of Return (MARR) in case of private projects,

d) In case of publicly-owned projects the user shall provide the inflation and the interest rates.

5.4.4 LCCA Software Model

After analyzing the data collected from the LCCA literature study and the survey questionnaire on the Egyptian construction market, an LCCA model was developed as shown in figure 5-3.

The model is divided into five main section. Section one classifies the different types of data into general project, item, alternative, costs and constraints information. All data types are interrelated and analyzed in the next section, preliminary analysis.

The processing phase is divided into two main sections. The preliminary analysis section calculates the NPV of all alternatives, ranks the different alternatives for each project item, generates all possible project paths, and finally selects the project cost curve that leads to the lowest cost.

The secondary analysis section starts by testing if the selected curve in the preliminary analysis stage meets the owners' requirement. The users constraints previously entered in the data stage are transformed into three levels of constrains; single condition, double condition and triple condition.

Finally the data output stage performs reliability analysis, lists selected alternatives, generates cost and cost cumulative curves, produces enveloping values, and provides alternative paths within Path A fluctuation.

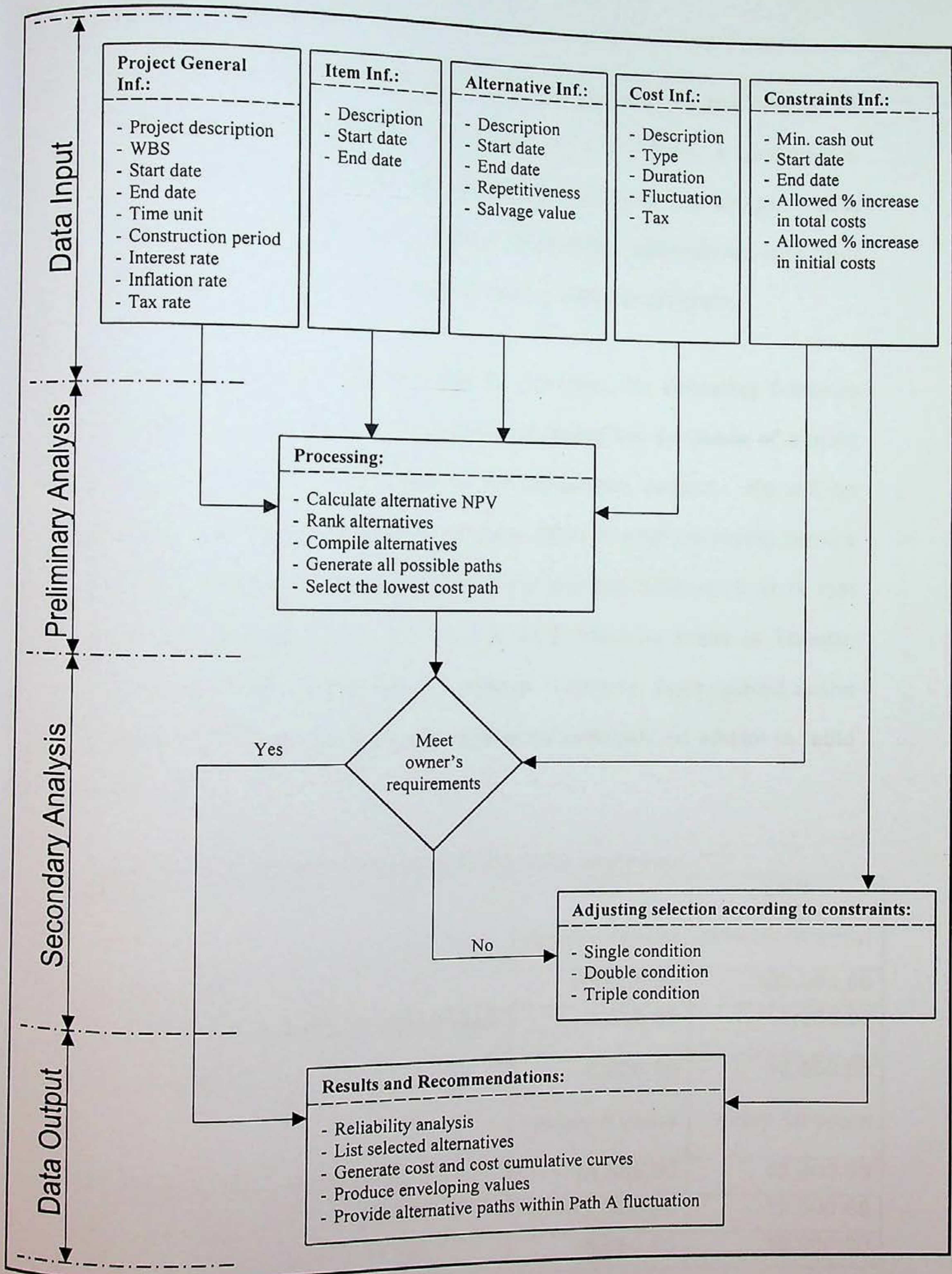

Figure 5-3: LCCA Software model

5.4.5 Software Input

There are two helpful steps that are suggested for the user to do before entering input data into software. First of all, a cost break-down structure should be developed to organize the program data input. The second step is to collect all possible alternatives with their related cost data to be ready for entering into the program.

To illustrate the use of Path-A, consider the following fictitious example. Assume that an investor is studying the purchase of a mold injection machine to be used in his small-size project. He will be utilizing the machine for external use. After market surveying for the different machines, he found that there are two different brands that meet his specifications. The first is XYZ which is made in Taiwan. While the other is LMN that is made in Germany. Data related to the different costs during machines' life were collected as shown in table (5-1).

Table (5-1): LCC for different Mold Injection machines.

Item	XYZ (Made in Taiwan)	LMN (Made in Germany)
Initial Cost at 1st year	88,000.00	105,000.00
Operation & maintenance cost / year	4,800.00	3,900.00
Repair Cost	6,000.00 every 5 years	12,500.00 every 10 years
Material cost for year 1 to 5	10,000.00	10,000.00
Material cost for year 6 to 10	12,500.00	12,500.00
Material cost for year 11 to 20	15,000.00	15,000.00

Figure 5-4 demonstrates the first screen for the program data input. General information such as project start and end dates, time unit, construction period, interest rate, inflation rate, and tax rate are required to be added to this screen. In this example, the study period is 20 years with a zero construction time. The used Minimum Attractive Rate of Return is 14.5%. Since the project is considered a small one, it has a tax exemption for the twenty years life time.

The next step in the data input phase is to start adding the different systems to the project. This is by adding the items of the cost break down structure (CBS) to the tree at the left part of the first window. When reaching the lowest level of the project Cost Breakdown Structure CBS, the user starts to add alternatives for each element.

Three types of costs are available so that the user can add any kind of cost to the discussed alternative. The different cost categories are the point cost, the linear cost and the custom cost.

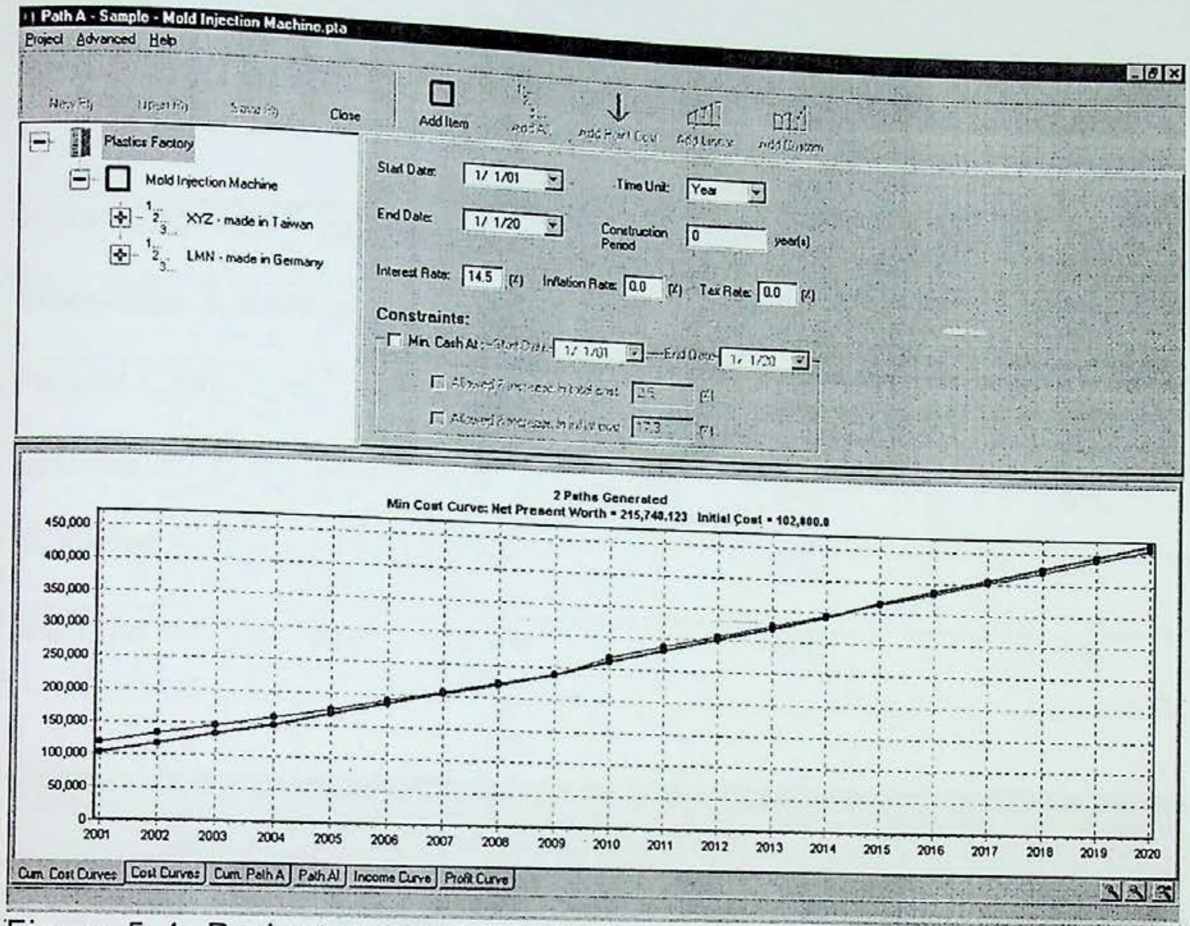

Figure 5-4: Project general information

There are uncertainties associated with the collected costs as shown in table (5-5). The LMN machine data is more certain since the machine was widely used in the country, while XYZ one is a newly introduced machine.

Table (5-2): LCC for different Mold Injection machines(data fluctuation)

Item	XYZ (Made in Taiwan)	LMN (Made in Germany)
Initial Cost at 1st year	9%	4%
Operation & maintenance cost / year	7.5%	3%
Repair Cost	9%	5%
Material cost for year 1 to 5	5%	5%
Material cost for year 6 to 10	5%	5%
Material cost for year 11 to 20	5%	5%

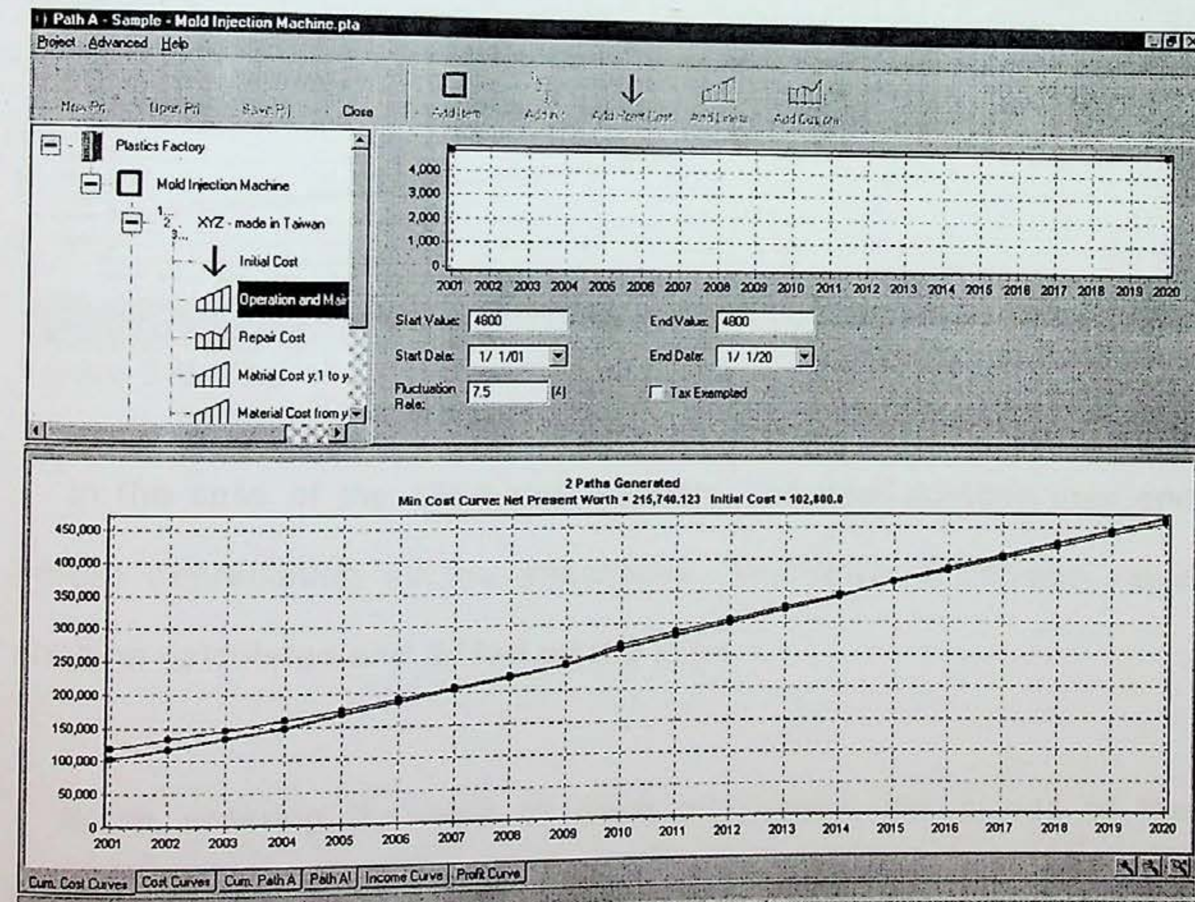

Figure 5-5: Data required for entering linear cost

Sometimes the duration of an alternative is less than the required duration of the item. In this case the user shall specify that the

alternative should be repeated by checking the desired selection box as shown in figure 5-6.

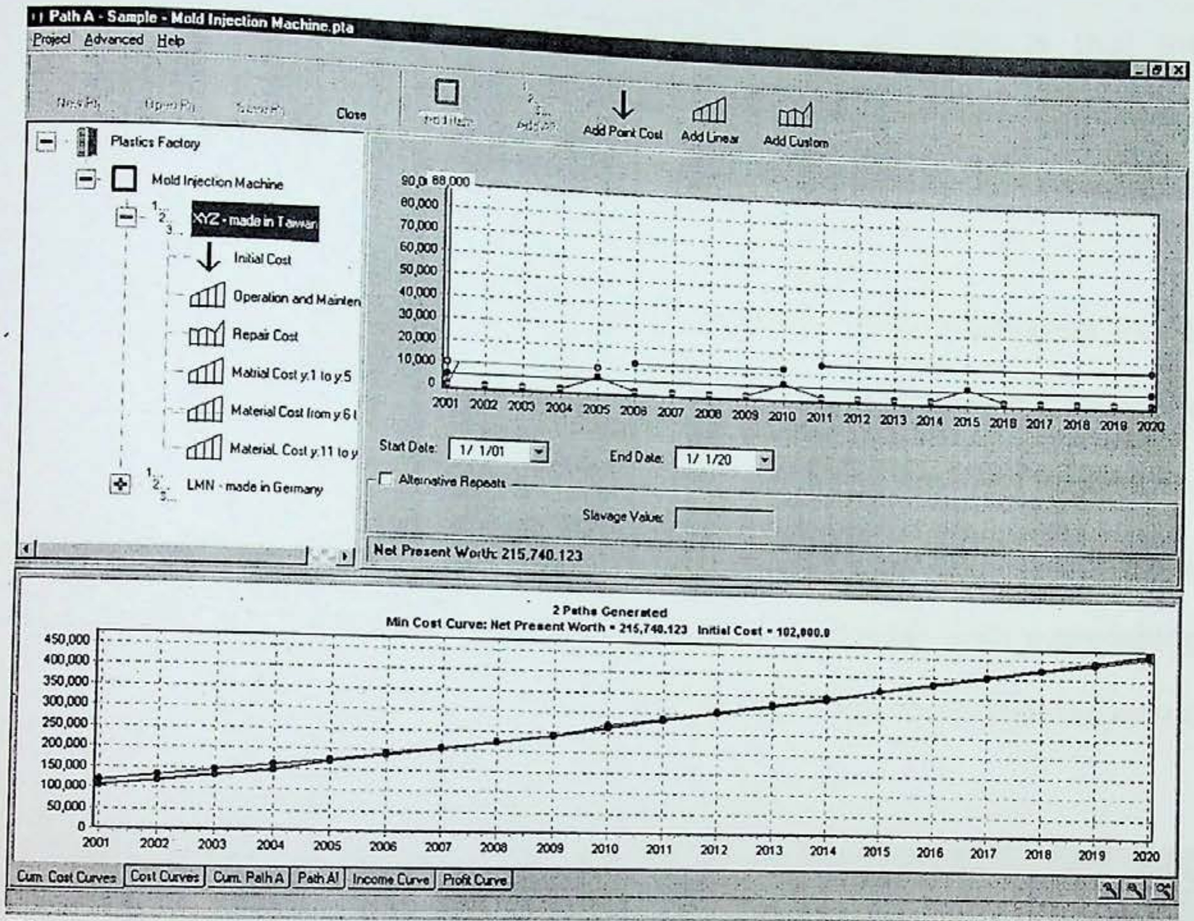

Figure 5-6: The alternative data input screen

In the case of the alternative repeats, the item duration may end before depreciating all the alternative. Therefore, a salvage value shall be calculated and added by the user.

While entering the data of each alternative, the curves at the bottom of the screen are automatically adjusted and the best alternative path is drawn in red. The calculated present value and the initial cost of the selected path are written at the top of the graph as illustrated in figure (5-5).

5.4.6 Software Output

Cumulative Path-A and Path-A are the two tabs devoted for the software output. The difference between the two tabs is that the cumulative one, as indicated by the name, displays the cumulative curve of the selected alternative.

The box named Path-A Alternative Names, gives a detailed list of the selected alternative for each item, in this example the selected alternative was XYZ made in Taiwan. Figure 5-7 is an illustration for the "Cumulative Path-A" and the selected Path-A Alternative Names. Notice that the selected curve is drawn associated with enveloping curves. The enveloped curves are drawn using the uncertain collected data.

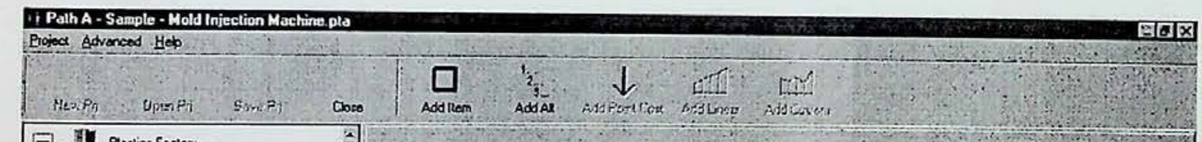

Figure 5-7: Program output tab "Cumulative Path-A"

5.4.7 Adding Project Constraints

Sometimes the LCCA face cases when the available cash for initial investment is less than the minimum required by the selected alternative; Path-A. Other times they may notice that there might be problems of sudden drops in the available cash during a certain period of the project and they need to reduce the costs during that recess.

Three types of constraints are provided by the software so as to account for such cases. Refer to figure 5-4 to notice that the section under the title constraints has three main levels:

Minimum cash at a period: checking this part will make the program find the path with the minimum cost at the specified duration regardless of its effect on the project initial cost or the project total present value.

Allowed Percentage Increase in Total Cost: this is a second level constraint where the user can specify to reduce the cost of a specific period of the project while limiting its effect on the project total cost.

Allowed Percentage Increase in initial Cost: this is also a second level constraint where the user can specify to decrease

the cost of a particular period of the project while restricting its effect on the project initial cost.

To illustrate the use of this facility assume that the investor requires the alternative that will yield the lowest cash out during the operation time; i.e. from year 15 to 20, without affecting the project total budget with more than 3.7% as shown in figure (5-8). The resulting alternative is now changed to LMN made in Germany.

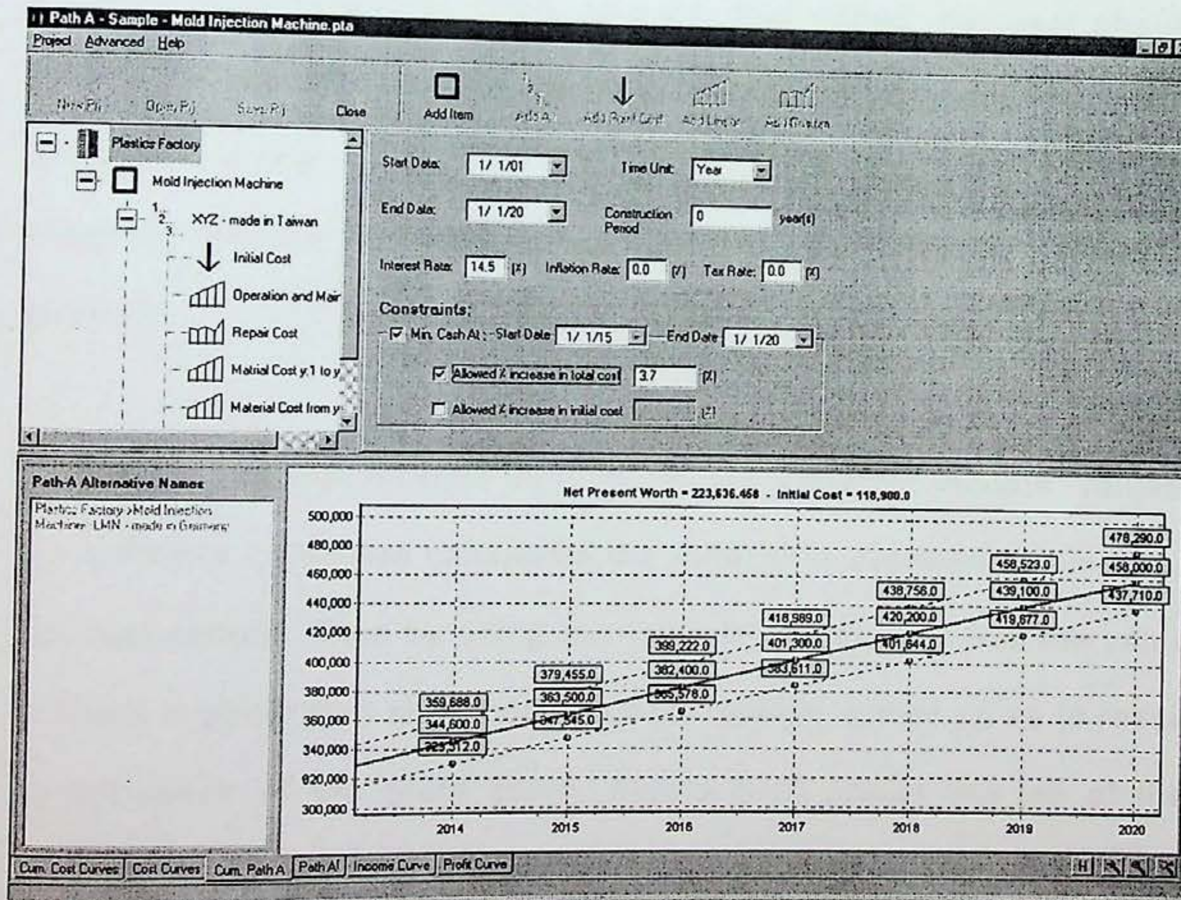

Fig 5-8: Adding project constraints

Utilizing the above mentioned types of constraints will add great facility to the program. The analysts, using the previous method, can easily perform cost curve management that will give credibility to the work.

5.4.8 Optional Add Ins

Although it is out of the scope of the thesis, Path-A initiates the idea of entering the income curve and then calculating the profit curve. This part may open a new area of research and development for the software and technique.

First of all, the software users should specify the tax rate that will be used in calculations. Then, at each cost added, the user should specify if it is tax exempted or not. The second step is to enter the expected income values per year . Figure 5-9 provides a list of the expected income from the project under consideration in the above example.

Just as the user finishes inputting all the expected income values, the software computes calculates the difference between income and the cost curves. Then by using the tax rate, a new cost has the value of taxes is generated and deducted from income curves so as to reach an indication of the profit curve. Figure 5-10 shows the tab of the profit curve. Notice that the project starts to give positive cash at the sixth year.

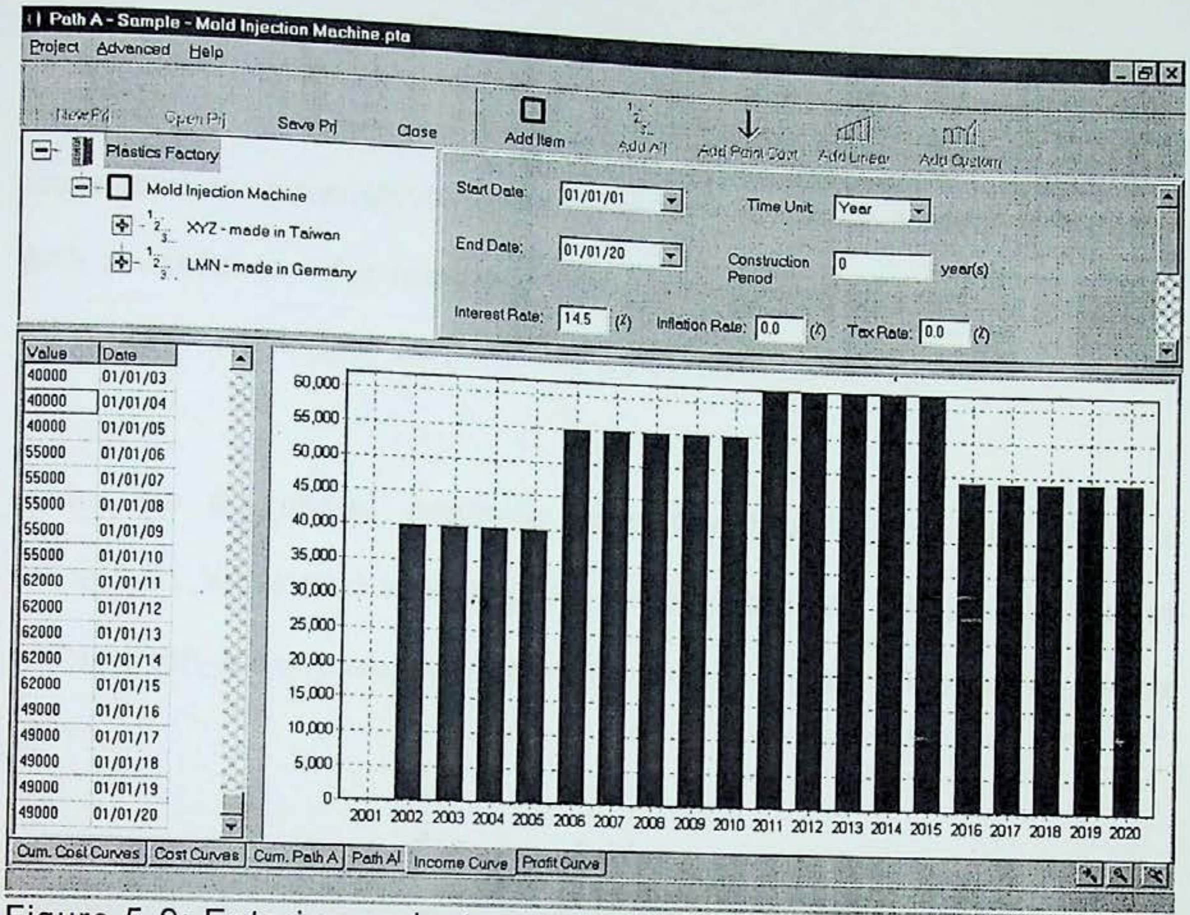

Figure 5-9: Entering project expected income

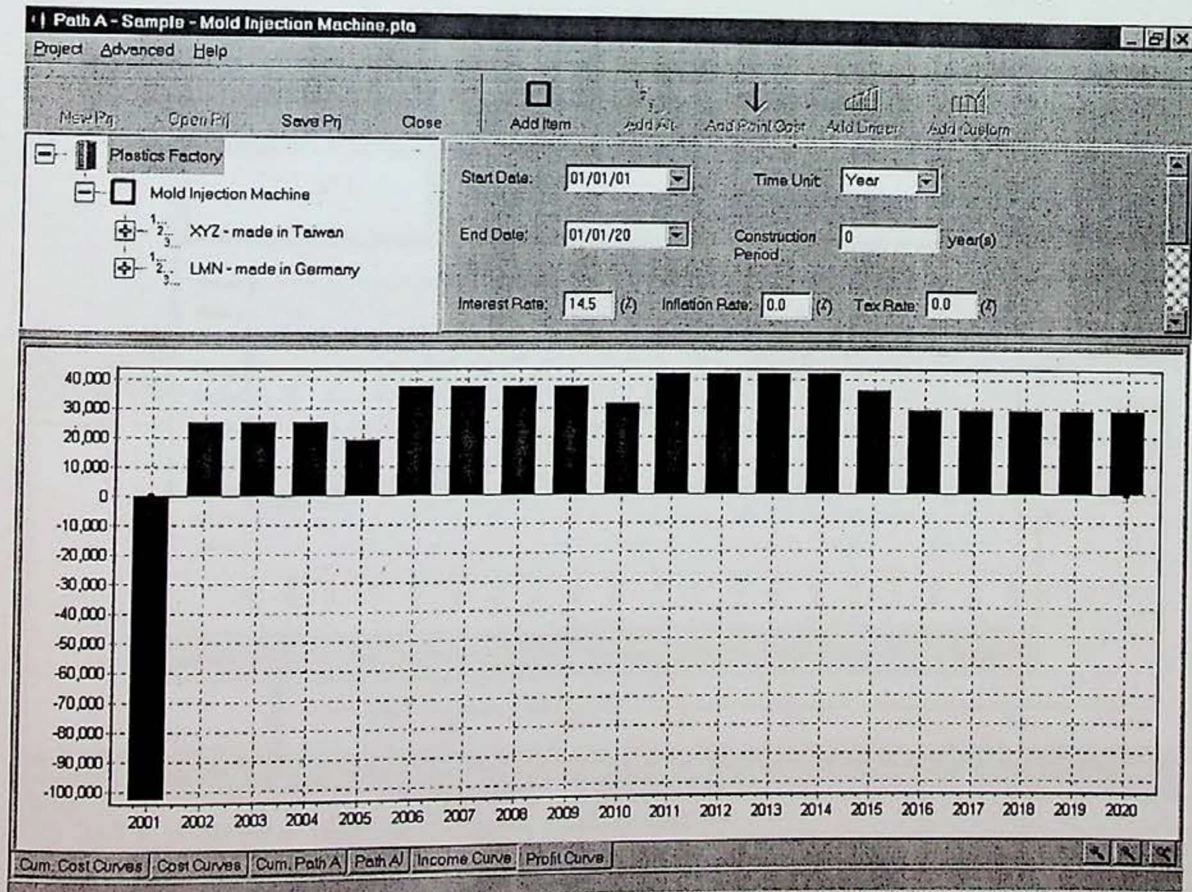

Figure 5-10: Profit curve tab

5.4.9 Curves within Path-A fluctuation

Since all the collected data are associated with different types of uncertainties, a sensitivity analysis is needed. Path-A provide the user with a useful tool for testing if there is any other alternative occurring within the enveloping cures of the selected alternative.

In the discussed example, consider the fluctuations given in table(5-2). Note that selecting the advanced menu followed by curves within Path-A fluctuation, a new window will appear as shown in figure (5-11).

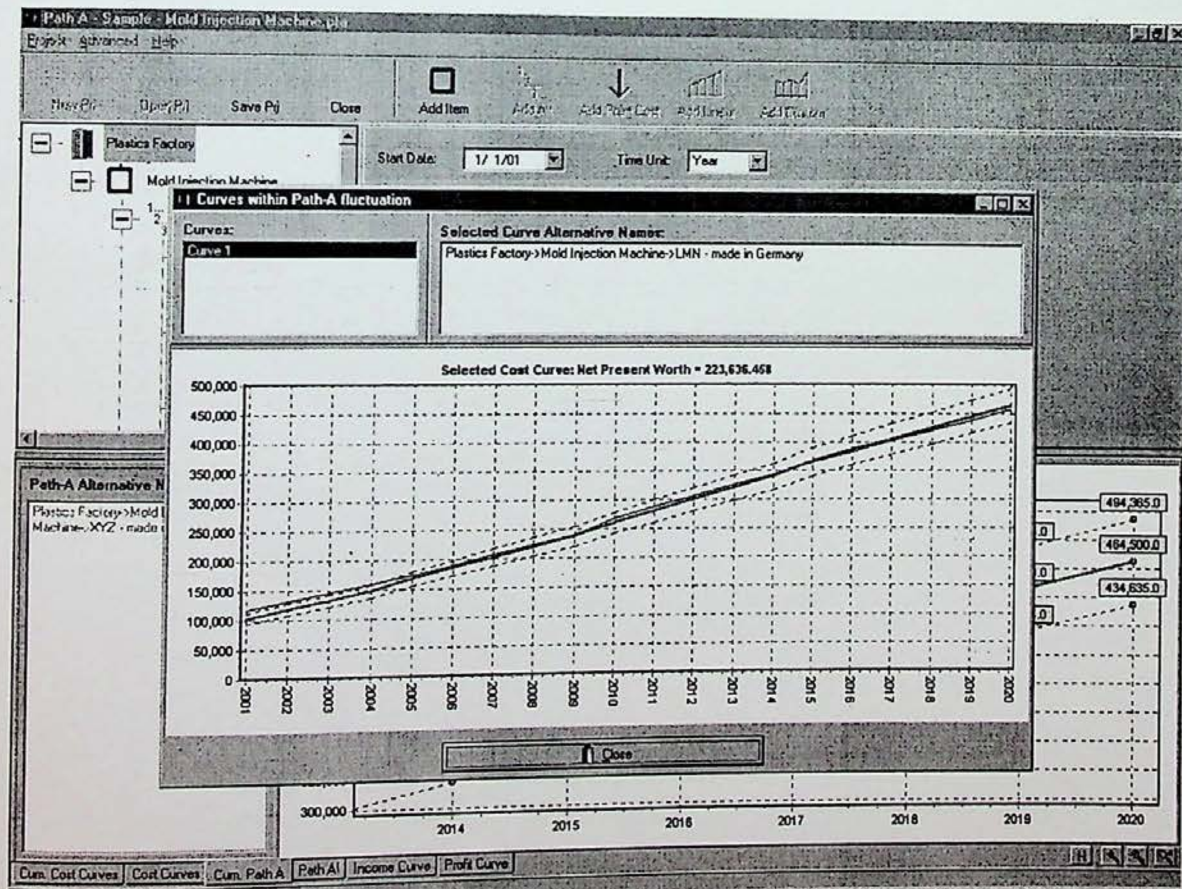

Fig 5-11: Curves within Path-A fluctuation

The new window shows that the curve of the LMN machine is within the enveloping curves of the XYZ machine. This means that the LMN collected data is more certain than the XYZ data, and the investor shall reconsider this decision and may take the German machine although its total LCC is greater than the other machine.

Chapter 6

VALIDATION OF MODEL - CASE STUDIES

In this chapter, the validation of the model is considered in three main sections. Section one of the validation considers the accuracy of results. Two case studies are presented to illustrate the use of Path-A as a powerful tool for assessing the Life-Cycle cost of any project. The results of path-A calculations are compared to results collected from published articles and manual calculations. Section two is allocated to measure the software time and effort saving through measuring the time consumed for analyzing a typical case for LCC study using Path-A and traditional practices. Finally, a follow up questionnaire was designed and distributed among LCCA Practitioners to evaluate the software, measure its usefulness, and collect recommendations.

6.1 ACCURACY OF RESULTS

6.1.1 Case Study 1: Qena Cement Factory

The project comprises the establishment of a 1.4 million tons per year cement plant near QENA city in Egypt. The scope of ARESCO's (the main contractor) work is concerned with the supply, manufacturing and purchase of equipment, project management, civil design including steel structure design, soil studies, supply of steel structures, civil construction work including the erection of steel structures, mechanical erection, electrical erection and

instrumentation installation.

The following is the basic information about the project:

Client: Misr Cement Company

Coming into Force Date: September 9th, 1999

Signing Date: January 12th, 2000

Plant Capacity: 1.4 Million ton per year Ordinary Portland Cement

Completion of Plant Works: January 8th, 2002

Provisional Acceptance: March 8th, 2002

Total Agreement Value: **EUR** 22,820,907 and **EGP** 161,915,108

Table (6-1) and figure (6-1) shows the agreement cost break down and the percentage of each project component. Notice that the local mechanical deliveries and mechanical erection compose 51% of the total project value. Table (6-2) shows a list of the project subcontractors versus the assigned tasks.

Table 6-1: Agreement Breakdown:

Item	EUR	EGP
Local Deliveries	9,397,907	38,252,108
Project Management	2,509,000	9,722,000
Civil Design	1,780,000	576,000
Erection	5,864,000	32,858,000
Civil	3,270,000	80,507,000

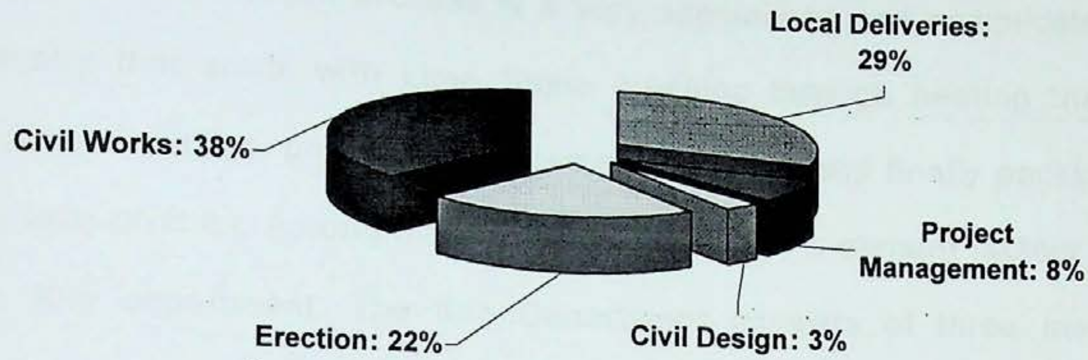

Figure 6-1: Agreement breakdown in Percentages.

Table 6-2: List of the project subcontractors:

Designer	Task
Heinzelmann - Swiss	Main Buildings
TCB	Kiln, By-Pass, Packing Plant, EI-rooms
COSMOS	Sub-Plant Service Buildings
CEC	CCR & Laboratory
ASEC-ENG	Structure Steel Shop-Drawings
ARESCO-TEBBIN	Secondary Steel Structure
Civil Subcontractor	**Task**
KOLALY	From Lime Stone Crusher up to Clinker Transport.
SIAC	From Clinker Storage up to Packing Plant.
Mechanical Subcontrctors	**Task**
ARESCO	Supply and erection of all steel structure works. supply and erection of all mechanical equipments.
Electrical Subcontrctors	**Task**
ASEC Automation	Supply and erection of all electrical works. Supply and erection of all instrumentation and control works.

6.1.1.1 Scope of the Case Study

Cement production process is a very specialized and complicated industry that starts with Lime Stone crushing through heating then cooling of clinker, producing the cement material, and finally packing the final product. Among the main departments of a cement factory is the Kiln department. The Kiln Department consists of three main elements; the Pre-heater building, the Kiln building, and the cooler building.

The case study in this research will tackle the cooler building. This building is mainly composed of structural system, mechanical system, electrical system, and instrumentation-control system. Each of these systems has subsystems that have different alternatives. Some of these alternatives were rejected from a technical point of view, while others were tested for Life-Cycle Cost.

The structural system with its components had alternatives that were rejected for technical reasons. For example, the super structure of the building could be concrete structure or steel structure. Yet for technical reasons, steel structure was chosen. Through the rest of this chapter the mechanical and the instrumentation-control systems along with their alternatives will be analyzed from the Life-Cycle cost perspective.

6.1.1.2 Case Study Description

During the design process, engineers proposed different alternatives for both the mechanical and instrumentation-control systems. Each of the alternatives was tested technically and then they were filtered to the technically accepted alternatives.

6.1.1.2.1 Civil works

The civil works of the cooler can be mainly divided into foundation works, super structure works and finishing works. Although each of them has different alternatives, the decision on the best alternative was for the technical reasons and the costs are estimated as follows:

a)	Foundation work (Isolated footing)	EURO	375'000.00
b)	Structural steel fabrication	EURO	140'000.00
c)	Structural steel erection	EURO	140'000.00
d)	Finishing works	EURO	12'000.00

6.1.1.2.2 Cooler mechanical system

The cooler mechanical system is composed of three main subsystems:

a) Heat Recuperation System

b) Dedusting System

c) Cooling System.

The LCC of each alternative is estimated based on previous experience and some data collected from other cement factories that use similar systems. Table 6-3 lists all alternatives along with their Life-Cycle Costs.

According to the project manager, the selected alternative for the heat recuperation system was the controlled flow grate, while electrostatic precipitator was selected as a dedusting system and the air cooling system for the cooling process.

6.1.1.2.3 Instrumentation-control system

The main alternatives for the instrumentation-control system are either Paneled Local Control System (PLC) or Distributed Control System. The estimated Life-Cycle Cost for each of the alternatives is listed as shown in table 6-3. The system finally used in the project was Distributed Control System.

Although the collected cost has uncertainties, it is a constant uncertainty per trade. That is the fluctuation of any of the fabricated items is 6%, the fluctuation of the erection 5%, while the operation and maintenance is 8% and the repair is 12%.

Table 6-3: List of all project items and their different alternatives vs. their LCC (All costs are estimated in EURO)

System	Fabrication	Erection	Operation	Maintenance	Repair
Mechanical System					
Heat recorpration system					
Alt (1) - Controled Flow Grates	2,621,000.00	1,116,500.00	22,500.00	10,000.00	40,000.00 every year
Alt (2) - Cross Bar System	3,800,000.00	1,450,000.00	14,000.00	6,000.00	20,000.00 every year
Dedusting System					
Alt (1) - Gravel Bed Filter	420,000.00	180,000.00	45,000.00	60,000.00	40,000.00 every year
Alt (2) - Electrostatic Precipitator	715,000.00	310,000.00	28,000.00	12,000.00	30,000.00 every year
Alt (3) - Bag House Filter	800,000.00	300,000.00	23,000.00	15,000.00	25,000.00 every year
Cooling Air System					
Alt (1) - Water Cooling System	1,500,000.00	650,000.00	18,000.00	40,000.00	27,000.00 every 6 years
Alt (2) - Air Cooling System	1,154,000.00	495,500.00	11,000.00	10,000.00	35,000.00 every 10 years
Instrumentation/ Control System					
Alt (1) - Paneled Local Control	500,000.00	285,000.00	18,000.00	6,000.00	10,000.00 every 3 years
Alt (2) - Distributed Control System	390,000.00	175,000.00	12,000.00	3,500.00	12,000.00 every 5 years

6.1.1.3 Program Data Input

Starting the program data input, some general information about the project should first be known:

a) The Minimum Acceptable Rate of Return(MARR) provided by the owner is 18% per year, and inflation of 3%,
b) The time unit of the project is year,
c) Project construction period is two years,
d) All the fabrications shall be finished in the first year of the construction period,
e) The study period for the project is thirty years,
f) The currency used is EURO.

The data listed in table 6-3, which is essential input for the program, were collected using the sheets developed in appendix B. Therefore the developed sheets are considered a back up and a documentation system for the LCCA study done on the project.

Figures 6-2 and 6-3 illustrate different program screens after data input. Notice that the present values of each alternative is automatically calculated and the curve for the best alternative is drawn in red.

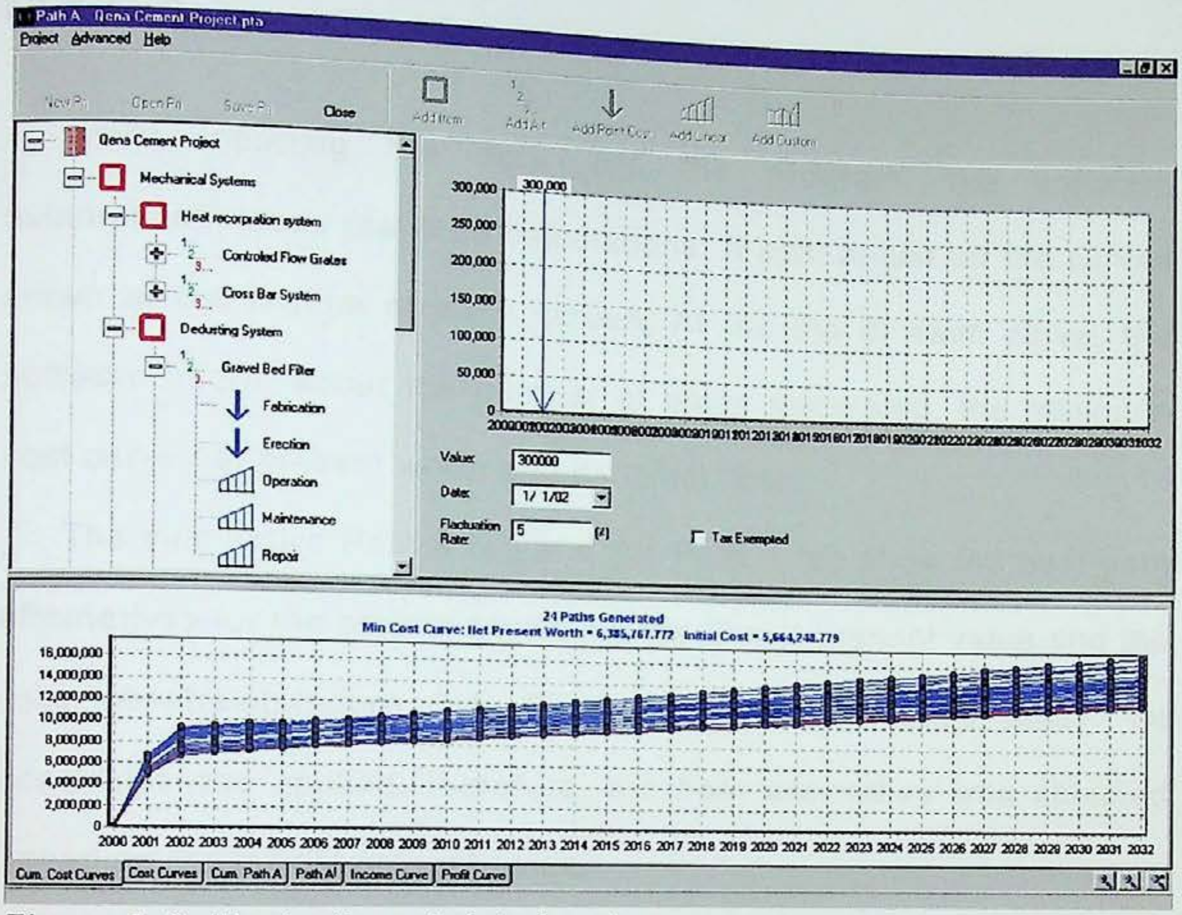

Figure 6-2: illustration of data input

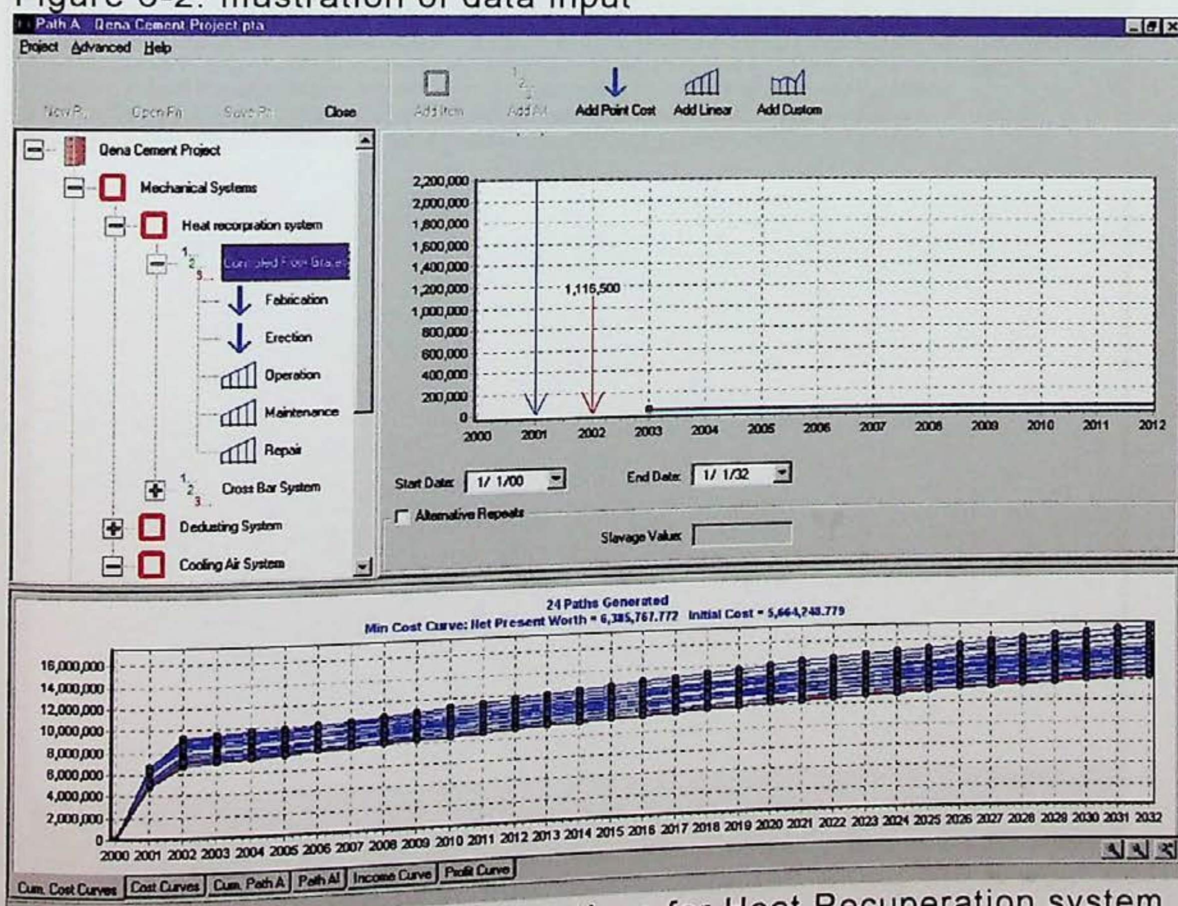

Figure 6-3: illustration of alternatives for Heat Recuperation system

6.1.1.4 Program Output

While inputting the data into the program, the software automatically does real-time calculations. It also adjust all the curves drawn at the bottom of each screen. At the top of each curve, the software inform about the number of paths generated, the minimum cost curve net present worth and its initial cost.

The cumulative Path A tab and the Path A tab show the best path alternatives for the project according the lowest present value and the user constraints(figure 6-4, Figure 6-5). In this case study, no constraint was applied, therefore, the best alternative was selected based on the lowest present value.

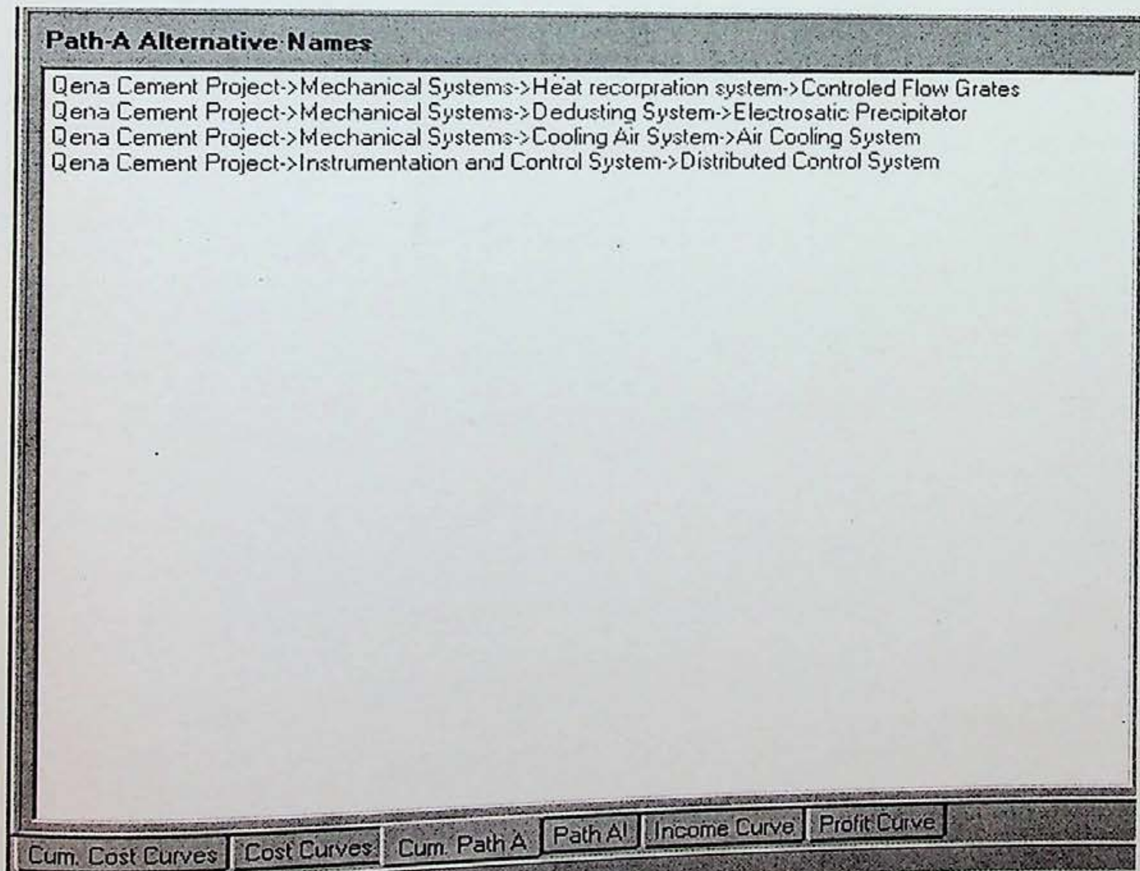

Figure 6-4: List of the best alternative selected along the lowest cost path.

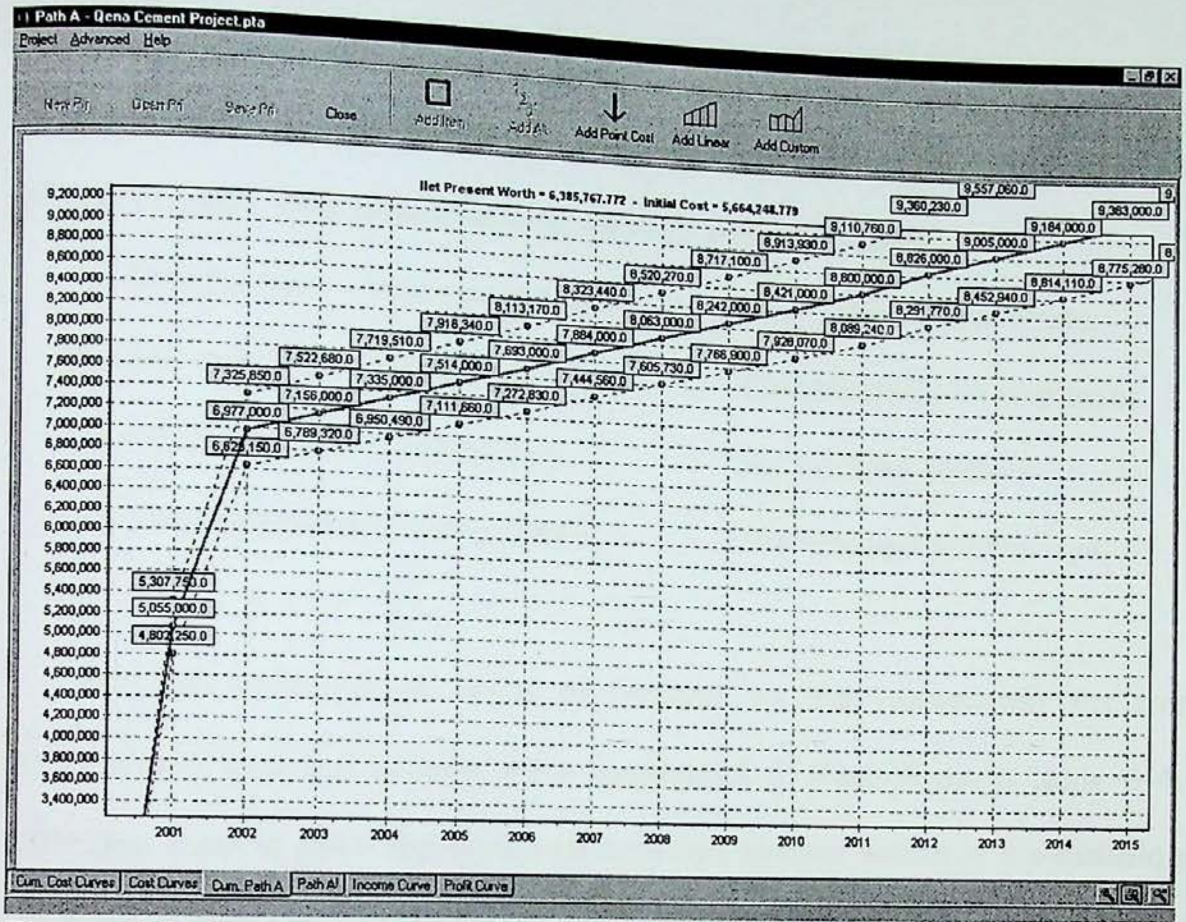

Figure 6-5: the cost curve for the selected alternative

6.1.1.5 Results and Discussion

Figure 6-4 shows the list of the selected alternative for each item of the project. The selected alternatives are as follows:

a) Mechanical – Recuperation sys.: Controlled Flow Grate

b) Mechanical – Dedusting sys. : Electrostatic Precipitator

c) Mechanical – Cooling sys. : Air cooling system

d) Instrumentation control sys. : Distributed control sys.

Manual calculations were performed by the researcher for the case study and the results were compared to Path-A as in table 6-4. The two means gave the same calculation results which is a validation of Path-A accuracy for results calculations.

Table 6-4: Comparison between Path-A and manual calculations.

Discipline	Path-A	Manual calc.
H.R.S.: *Controlled Flow Grates*	3,310,290	3,310,290
H.R.S.: *Cross Bar System*	4,420,189	4,420,189
Dedusting Sys.: *Gravel Bed Filter*	1,175,161	1,175,161
Dedusting Sys.: *Electro. Precipitator*	1,105,918	1,105,918
Dedusting Sys.: *Bag House Filter*	1,143,032	1,143,032
Cooling Sys.: *Water cooling*	1,979,001	1,979,001
Cooling Sys.: *Air Cooling*	1,422,750	1,422,750
Instrumentation: *Paneled local*	734,542	734,542
Instrumentation: *Distributed control*	546,811	546,811

Notice that since all the collected costs has the same fluctuation

range, for example the fluctuation of all fabrication costs is 6% for any of the alternatives, the cost fluctuation will have no impact on the taken decision.

Finally, the selected alternatives resulted from the software is the same of that selected by the company in the real life. This should give more credibility to the program. However, the program is more helpful since it gives a macro perspective on the whole project and the total life of the selected alternative. Another powerful aspect of the software is that it saves the cost data of the selected alternatives thus it can be monitored, updated and reused in further projects.

6.1.2 Case Study 2: North Carolina Bridge USA

This case study is presented to illustrate the use of Life-Cycle Costs for selection of a new technology construction material. Ehlen and Marshall(1996) provided a detailed study of a bridge using LCCA. This bridge is designed for two lanes of traffic over an existing four-lane interstate. Its deck is to be made of 210.9 kg/cm^2 steel-reinforced poured-in-place concrete. The study considers three new-technology bridge deck materials – all made of an FRP material, but all fabricated differently. The Life-Cycle Cost of each deck made from these materials is computed, along with the LCC of a deck made from a conventional concrete material (control case).

6.1.2.1 Provided Alternatives

The control case material/design is poured-in-place reinforced concrete. The three new-technology material alternatives are all made of FRP composites but have significantly different fabrication techniques. The FRP materials are:

1- SCRIMP (Seeman Composite Resin Infusion Molding Process): this is one form of vacuum-assisted resin transfer molding. E-glass fabric is laid in its final design configuration using a foam core and an external mold. Resin is then pulled through the cavities using vacuum pressure. Once the resin sets, the mold is removed. The foam remain as a permanent

but non-structural part of the deck.

2- Wood-Core Sandwich: Vertical Asian structural bamboo sections are assembled into a rigid "sandwich" core. The top, bottom, and sides are then covered with layers of fiberglass, and resin applied.

3- Pultruded Plank: Lineal planks are pultruded from resin-wetted fiberglass fabric and fiberglass strand. Once individual planks have set, three sections are then joined at their sides with key strips form a wider cross-section.

6.1.2.2 Program Data Input

The following assumptions were common for all material combinations:

1- The intended service life of the bridge is 40 years,
2- The real discount rate for computing the present value of all future costs is 3.0%,
3- Length of highway affected by bridge construction, maintenance, and disposal is 1 mile.

Tables (6-5),(6-6),(6-7) and (6-8) show the costs acquired for each of the four alternative materials through the desired life cycle. Figure (6-6) and (6-7) illustrate Path-A data input.

table 6-5: Life-Cycle Cost of Reinforced Concrete Deck

	Quantity	Unit	Unit Cost	First year of occurance	Last year of occurance	Annual Frequency of Occurance
Initial Construction						
Agency Costs	13,000.00	square Feet	$ 15.00	1	1	1
User Costs	1.00	Lump sum	$ 30,327.00			
Third Party Costs	-	-	-	-	-	-
Operation Maintenance & Repair						
Agency Costs						
Deck Inspection	1.00	Lump sum	$ 100.00	2	38	2
Supplementary Deck Inspection	1.00	Lump sum	$ 500.00	25	25	1
Resurface 5% of Deck	650.00	square Feet	$ 10.00	25	25	1
Resurface 2.5% of Deck	325.00	square Feet	$ 10.00	28	37	3
User Costs	40.00	Lump sum	$ 1,516.40	1	40	40
Third Party Costs	-	-	-	-	-	-
Disposal Cost						
Agency Costs	13,000.00	square Feet	$ 15.00	40	40	40
User Costs	1.00	Lump sum	$ 43,655.00	40	40	40
Third Party Costs	-	-	-	-	-	-

table 6-6: Life-Cycle Cost of SCRIMP FRP Deck

	Quantity	Unit	Unit Cost	First year of occurance	Last year of occurance	Annual Frequency of Occurance
Initial Construction						
Agency Costs						
Elemental Costs						
Factory Fab	13,000.00	square Feet	$ 30.00	1	1	
Shipping	1.00	Lump sum	$ 25,000.00	1	1	
On-site fab: bearings	1.00	Lump sum	$ 5,000.00	1	1	
On-site fab: install	600.00	Labor hour	$ 15.00	1	1	
F&I Metal Guard rail	472.00	lineal feet	$ 100.00	1	1	
F&I Median	236.00	lineal feet	$ 20.00	1	1	
Polymer concrete Asphalt	13,000.00	square Feet	$ 2.00	1	1	
New Technology Introduction Costs						
Predesign NTM Project formulation	50.00	Labor hour	$ 50.00	1	1	
Acadimic design consultant	1.00	Lump sum	$ 20,000.00	1	1	
Laboratory tests	1.00	Lump sum	$ 30,000.00	1	1	
Meeting with fabricator, review shop drawings	60.00	Labor hour	$ 50.00	1	1	
Field engineering, construction inspection	100.00	Labor hour	$ 50.00	1	1	
User Costs	1.00	Lump sum	$ 18,774.00	1	1	
Third Party Costs	-	-	-	-	-	-
Operation Maintenance & Repair						
Agency Costs (element costs)						
Deck Inspection	1.00	Lump sum	$ 100.00	2	40	
Supplementary Deck Inspection	1.00	Lump sum	$ 500.00	25	25	
Fiber patching	130.00	square Feet	$ 20.00	28	28	
Polymer Concrete Patching	650.00	square Feet	$ 20.00	25	25	
Agency Costs (New-Technology Introduction costs)						
Develop non-destructive evaluation plan	100.00	Labor hour	$ 50.00	1	1	
Inspect deck: once month/1st year	28.00	Labor hour	$ 30.00	1	1	0.083
Inspect deck: once every 6months/next 3 years	28.00	Labor hour	$ 30.00	2	4	0.167
User Costs	40.00	square Feet	$ 1,542.00	1	40	40
Third Party Costs	-	-	-	-	-	-
Disposal Cost						
Agency Costs (Disposal of deck L&E)	300.00	Labor hour	$ 45.00	40	40	
Agency Costs (Dump fee)	1.00	Lump sum	$ 9,500.00	40	40	
User Costs	1.00	Lump sum	$ 8,732.00	40	40	
Third Party Costs	-	-	-	-	-	-

table 6-7: Life-Cycle Cost of Wood-Core FRP Deck

	Quantity	Unit	Unit Cost	First year of occurance	Last year of occurance	Annual Frequency of Occurance
Initial Construction						
Agency Costs						
Elemental Costs						
Factory Fab	1.00	Lump sum	$ 129,000.00	1	1	
Shipping	1.00	Lump sum	$ 25,000.00	1	1	
5% beam surcharge	1.00	Lump sum	$ 6,750.00	1	1	
On-site fab: bearings	1.00	Lump sum	$ 5,000.00	1	1	
On-site fab: install	400.00	Labor hour	$ 15.00	1	1	
F&I Metal Guard rail	472.00	lineal feet	$ 100.00	1	1	
F&I Median	236.00	lineal feet	$ 20.00	1	1	
Polymer concrete Asphalt	13,000.00	square Feet	$ 2.00	1	1	
New Technology Introduction Costs						
Predesign NTM Project formulation	50.00	Labor hour	$ 50.00	1	1	
Acadimic design consultant	1.00	Lump sum	$ 20,000.00	1	1	
Laboratory tests	1.00	Lump sum	$ 30,000.00	1	1	
Meeting with fabricator, review shop drawings	60.00	Labor hour	$ 50.00	1	1	
Field engineering, construction inspection	100.00	Labor hour	$ 50.00	1	1	
User Costs	1.00	Lump sum	$ 14,441.00	1	1	
Third Party Costs	-	-	-	-	-	-
Operation Maintenance & Repair						
Agency Costs (element costs)						
Deck Inspection	1.00	Lump sum	$ 100.00	2	40	
Supplementary Deck Inspection	1.00	Lump sum	$ 500.00	25	25	
Fiber patching	130.00	square Feet	$ 20.00	28	28	
Polymer Concrete Patching	650.00	square Feet	$ 20.00	25	25	
Agency Costs (New-Technology Introduction costs)						
Develop non-destructive evaluation plan	100.00	Labor hour	$ 50.00	1	1	
Inspect deck: once month/1st year	28.00	Labor hour	$ 30.00	1	1	0.083
Inspect deck: once every 6months/next 3 years	28.00	Labor hour	$ 30.00	2	4	0.167
User Costs	40.00	square Feet	$ 1,542.00	1	40	40
Third Party Costs	-	-	-	-	-	-
Disposal Cost						
Agency Costs (Disposal of deck L&E)	200.00	Labor hour	$ 15.00	40	40	
Agency Costs (Dump fee)	1.00	Lump sum	$ 9,500.00	40	40	
User Costs	1.00	Lump sum	$ 26,192.00	40	40	
Third Party Costs	-	-	-	-	-	-

table 6-8: Life-Cycle Cost of Pultruded-Plank FRP Deck

	Quantity	Unit	Unit Cost	First year of occurance	Last year of occurance	Annual Frequency of Occurance
Initial Construction						
Agency Costs						
Elemental Costs						
Factory Fab	13,000.00	square Feet	$ 23.00	1	1	
Shipping	1.00	Lump sum	$ 25,000.00	1	1	
5% beam surcharge	1.00	Lump sum	$ 6,750.00	1	1	
On-site fab: bearings	1.00	Lump sum	$ 5,000.00	1	1	
On-site fab: install	13,000.00	square Feet	$ 5.00	1	1	
F&I Metal Guard rail	472.00	lineal feet	$ 100.00	1	1	
F&I Median	236.00	lineal feet	$ 20.00	1	1	
Polymer concrete Asphalt	13,000.00	square Feet	$ 2.00	1	1	
New Technology Introduction Costs						
Predesign NTM Project formulation	50.00	Labor hour	$ 50.00	1	1	
Acadimic design consultant	1.00	Lump sum	$ 20,000.00	1	1	
Laboratory tests	1.00	Lump sum	$ 30,000.00	1	1	
Meeting with fabricator, review shop drawings	60.00	Labor hour	$ 50.00	1	1	
Field engineering, construction inspection	100.00	Labor hour	$ 50.00	1	1	
User Costs	1.00	Lump sum	$ 30,327.00	1	1	
Third Party Costs	-	-	-	-	-	-
Operation Maintenance & Repair						
Agency Costs (element costs)						
Deck Inspection	1.00	Lump sum	$ 100.00	2	40	
Supplementary Deck Inspection	1.00	Lump sum	$ 500.00	25	25	
Deck Replacement	250.00	square Feet	$ 35.00	25	37	3
Polymer Concrete Patching	1,430.00	square Feet	$ 20.00	25	25	
Agency Costs (New-Technology Introduction costs)						
Develop non-destructive evaluation plan	40.00	Labor hour	$ 50.00	1	1	
Inspect deck: once month/1st year	28.00	Labor hour	$ 30.00	1	1	0.083
Inspect deck: once every 6months/next 3 years	28.00	Labor hour	$ 30.00	2	4	0.167
User Costs	40.00	square Feet	$ 1,708.70	1	40	40
Third Party Costs	-	-	-	-	-	-
Disposal Cost						
Agency Costs (Disposal of deck L)	200.00	Labor hour	$ 15.00	40	40	
Agency Costs (Dump fee)	1.00	Lump sum	$ 9,500.00	40	40	
User Costs	1.00	Lump sum	$ 21,828.00	40	40	
Third Party Costs	-	-	-	-	-	-

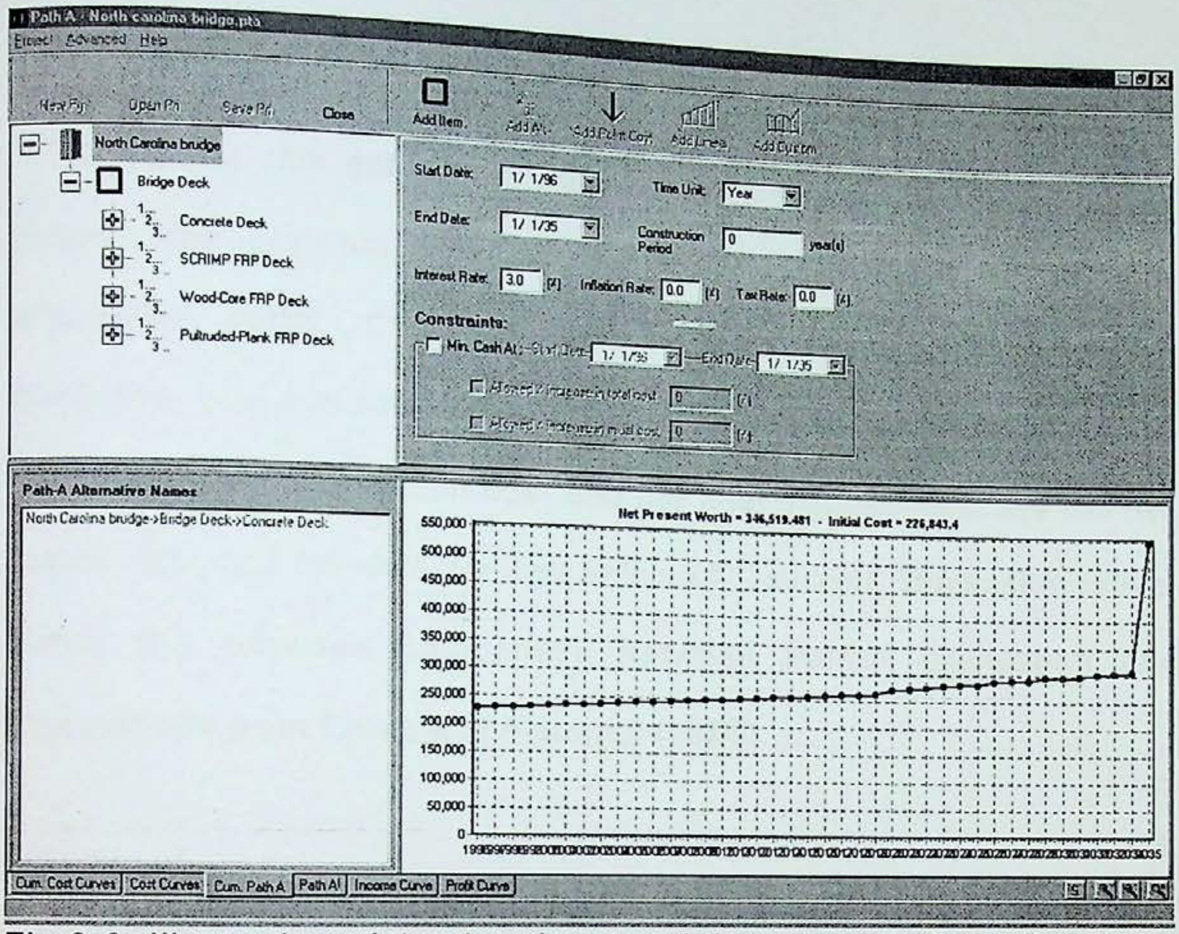

Fig 6-6: Illustration of the data input and the selected alternative

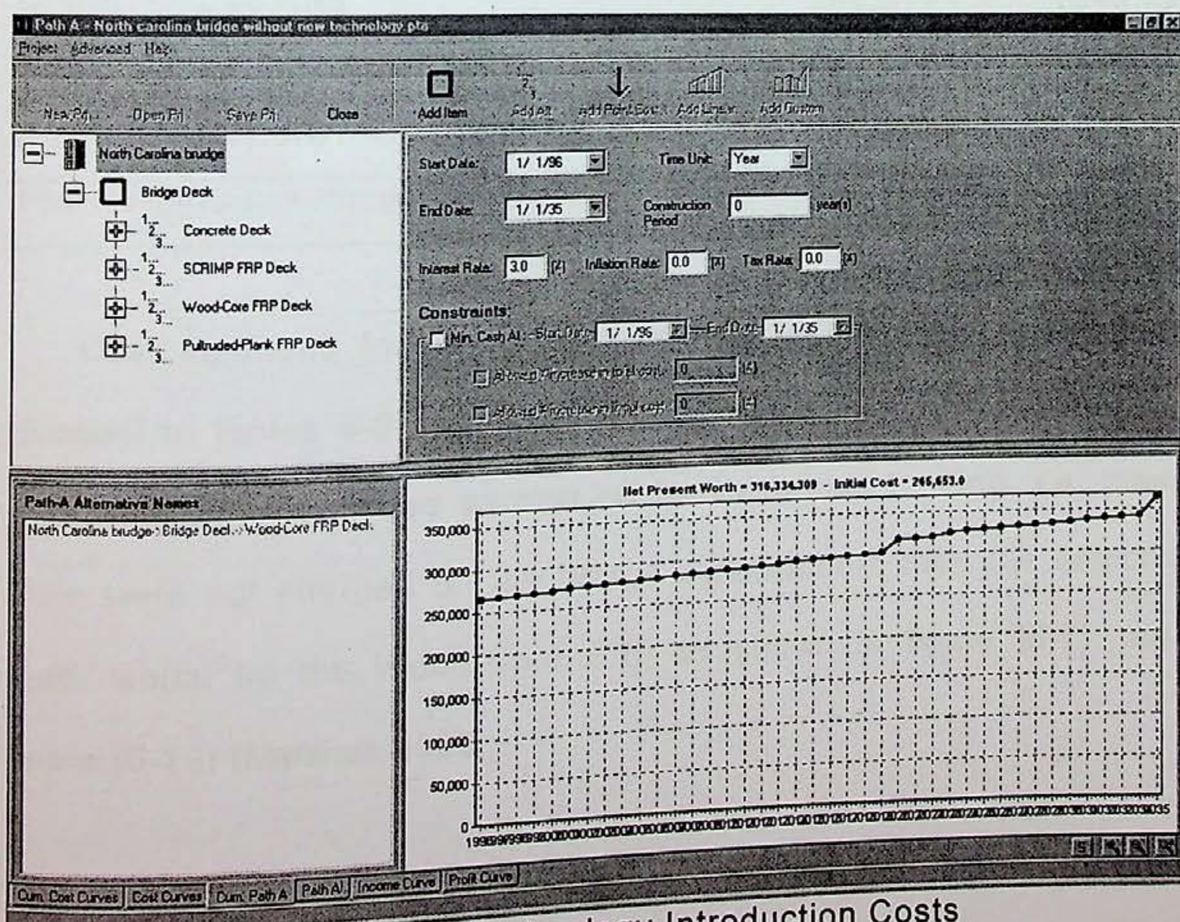

Fig 6-7: LCC without New Technology Introduction Costs

6.1.2.3 Results and Discussion

Analyzing the data input for the forty years Life Cycle of the project, the program selected the lowest LCC curve of the four alternative paths. Concrete Deck, with a net present worth of $346,519, was the selected alternative as shown in figure 6-6. notice that the initial construction cost and the final disposal cost are the two major cost components for the selected Concrete Deck alternative. Table 6-9 provides comparison between Path-A calculation and calculations from Ehlen and Marshall (1996).

Table 6-9: Comparison between Path-A and manual calculations.

Discipline	Path-A	Reference
Concrete Decking	**346,519**	**345,374**
FRP.: *SCRIMP FRP Deck*	659,824	634,335
FRP.: *Wood-Core FRP Deck*	396,666	401,163
FRP.: *Pultruded-Plank FRP Deck*	662,251	673,195

Cost elements for introduction of new technology materials are present in tables 6-6, 6-7 and 6-8. If New Technology Introduction costs were not included as part of normal bridge funding, i.e. these cost were not charged on the bridge construction, then the selected path would be the Wood-Core FRP as shown in figure (6-7) and table (6-10) (Marshall, 1996).

Table 6-10: Comparison between Path-A and manual calculations without new technology costs.

Discipline		
Concrete Decking	**Path-A**	**Reference**
	346,519	345,374
FRP.: *SCRIMP FRP Deck*		
	550,245	548,174
FRP.: *Wood-Core FRP Deck*		
	316,334	**314,789**
FRP.: *Pultruded-Plank FRP Deck*		
	589,002	586,821

6.2 VALIDATION FOR USEFULNESS OF SOFTWARE AND TIME SAVING

As a customer evaluation of Path-A, a follow-up questionnaire was distributed to a group of selected sample of eight end-users. The selected users are economic studies professionals working in the field of construction projects. Then a fictitious case study was developed and provided to the group. The time required for solving the problem using their traditional methods versus using Path-A was measured in an effort to assess the software time saving.

6.2.1 Validation For Usefulness Of Software

A secondary follow-up questionnaire was designed and distributed to a group of eight respondents who work in the economic studies of construction projects. A copy of the program software supported with a solved case study was provided to help the respondents evaluate the software.

The questionnaire was divided into three main sections. The first section is composed of closed-ended dichotomous questions for the evaluation of

software (MaDaniel, 1998). The second section is also composed of dichotomous questions to assess the usefulness of Path-A. The third part is an open ended question concerning giving recommendations to improve the value of the software.

Eighty seven percent of the respondents agreed that the provided solved case study is useful enough to run the program and to produce results. Fifty percent of the interviewed personnel said that the program is user-friendly software; they gave the program a ten on a scale of one to ten. The other fifty percent gave the program above seven on the same scale. Therefore, the program can be categorized as user-friendly software.

Seventy five percent of the respondents would consider using the software program in their practices, while all of them believe the software would lead to construction savings in their fields. Thus, section two leads to the conclusion that Path-A is a useful software for the Egyptian construction industry.

Two respondents recommended that the software should be connected to other programs for feasibility studies or other modules that enhance the program shall be developed. These concerns were included in the section of future recommendations for research.

6.2.2 Time Saving

A fictitious case study was produced and distributed to measure the time

and effort saved during the analysis. The eight questionnaire respondents examined the case using Path-A and their traditional calculation methods. All the users did not use Path-A except for the example provided with the follow up questionnaire. The time consumed for evaluating the given example using traditional methods and Path-A was measured as shown in table 6-11. The measured time is the time required for developing the case, entering data into the computer, evaluating all provided alternatives as well as producing curves and results similar to that produced by Path-A.

The produced example covers the electrical works included in an industrial project. The electrical works consist of five main items. First, the firefighting system that is composed of three main alternatives. Then the HVAC, pumping, elevators, and Power systems each is composed of two alternatives. Therefore, the example compromises forty eight different possible paths.

Table 6-11: Time saving in Path-A

Participant	Path-A	Traditional method	Saving
1	35 min.	1 hour 15 min.	40 min.
2	40 min.	1 hour 15 .min	35 min.
3	30 min.	1 hour 00 min.	30 min.
4	30 min.	1 hour 5 min.	35 min.
5	40 min.	1 hour 15 min.	35 min.
6	35 min.	1 hour 0 min.	25 min.
7	35min.	1 hour 00 min.	25 min.
8	35 min.	1 hour 10 min.	35 min.

From the results it can be noted that in typical cases Path-A can save up to 55% of the time and effort consumed in conducting an LCCA. Moreover, the more complicated the study under consideration the more efficient Path-A becomes.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS

This chapter considers the main outcomes of the research. It presents conclusions of the conducted research and recommendations for future works.

7.1 CONCLUSIONS

In an attempt to assess the application of life cycle costing and its existing practices in the construction industry in Egypt, a survey on a sample of twenty-two firms from a selected sector of the construction industry was conducted. This sector is the one involved with projects where long-term effect is of concern to owners or professionals. From the questionnaire results, it can be concluded that:

- Life-Cycle Cost concept is well recognized in the selected sector of construction industry in Egypt (86% of the surveyed companies use LCCA to compare two or more alternatives of the same element).
- Industrial projects where LCCA is mostly used are factory projects (89%) followed by power plant projects (78%).
- Education related construction projects have the lowest application of LCCA. 86% of the questionnaire respondents agreed that LCCA studies are performed in school projects only upon owners' request.

- All of the survey respondents agreed that owners and consultants are always participating in the LCCA practices.
- 33% of the interviewed personnel said that suppliers never participate in LCCA studies.
- According to 91% of the interviewed engineers, net present value is the most used technique for calculating LCCA.
- LCCA can be applied during any of the project phases, yet twenty out of the twenty two participants agreed that it is mostly used during the Design phase.
- No specific software programs were indicated as an existing LCCA software. Only two of the participating engineers mentioned that they use spreadsheets for LCCA calculation. This still cannot be considered an LCC software program.
- Seventy eight percent of the participants said that the lack of information from previous projects due to an inadequate documentation system is the most serious problem faced by LCCA practitioners.
- Finally, in contracts, such as BOOT contract, 78% of the surveyed firms recommended that investors should use LCCA.

The developed step-by-step LCCA manual procedure is essential for guaranteed success. Three main features are considered in the presented worksheet system:

- The worksheets are comprehensive, easy to use and easy to understand in order to minimize error.

- The standardized worksheets would provide a proper documentation system for all the alternatives and case studies produced.
- The worksheets provide full extensive information about each alternative to be used while entering the data later to the software program, Path-A.

The proposed software program, Path-A, presents a useful tool that helps decision makers / takers in making suitable construction selections. The main features of the software can be summarized as followed:

- The computer program provides an analytical tool that can evaluate different alternatives.
- It can also present a global view for the project.
- The software can go through all the project possibilities and develop all potential paths. Then it selects the project path that has the lowest net present value.
- Through three level of constraints, users can deviate from the lowest cost curve primarily selected by the software to the curve that mostly fits their available finance for initial investment or to suit certain financial plans.
- Previous case studies can be retrieved from saved files for future references.

As a validation of Path-A, a follow up questionnaire on the software was conducted with eight selected trial users to measure the usefulness of the produced model. The results of the questionnaire indicate that:

- The software is categorized as a user-friendly software.
- Path-A could be a useful software for the Egyptian construction industry. Seventy five percent of the respondents would consider using Path-A in their future studies
- Path-A can save more than fifty percent of the time and effort needed for conducting an LCCA. This percentage would increase for cases including great numbers of alternatives in an extensive LCCA.

Two case studies from the literature, where LCCA has been used, were introduced in chapter 6 to validate Path-A. The first case study analyzes the cooler building in a cement factory in Qena, Egypt. The building comprises four different interrelated systems. The total number of alternatives for all the systems is 9 alternatives. Path-A generated 24 possible paths out of the given alternatives. And finally it selected the lowest cost path (6,385,767.00 LE) for the cooling building. The program output was in agreement with the results of the originally selected alternatives by the designer of the project and the manual calculations of the researcher.

The second case study was tackling the argument of selecting an advanced construction material. The study considers the use of three

different FRP materials of bridge decking versus traditional concrete decking. The results of the study show that the traditional concrete decking material has the lowest LCC ($ 346,519.00) compared to the other three new materials alternatives. Yet, when ignoring the cost of developing a new construction material, the software selects the Wood-Core FRP deck with a total Life Cycle Cost of $ 316,334.00 and total savings of $30,185.00 (9% savings). These results are in perfect agreement with the output of the published study.

7.2 SUGGESTIONS FOR FUTURE STUDIES

Although the developed Life-Cycle Cost Analysis system is capable of carrying a comprehensive study on any project, the software can be enhanced by linking it to other computer programs such as Value Engineering software programs. Possible connection could also be made between Path-A and other software programs that produce feasibility studies so that the output of Path-A can be used as an input to such software programs.

Another potential area for enhancing Life-Cycle Cost Analysis is by introducing the probabilistic approach to the data. There are always uncertainties in the data collected and estimated for the project life. Predicting the future costs of operation, maintenance and repair cost is usually with a plus or a minus range. Any error in this estimate is converted to a risk taken by the investor. Using probabilistic analysis in calculating these estimates could reduce the taken risk.

Additional research work on published projects data could be carried out to evaluate the potential savings for different construction project categories (residential, commercial, heavy construction ...etc.) using Life Cycle Costing technique.

Path-A requires an input from the user so as to select the best group of alternatives for constructing the project. Therefore, using utility functions for modeling the decision maker personality will

greatly enhance the program and accelerate the decision making process. A possible area of research is in preparing a software program that can model the behavior of the decision taker and can be connected to Path-A so as to speed up the decision making process.

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APPENDIX A: Sample Questionnaire

<u>**Research Questionnaire**</u>

Name of consultant office/firm	:
Address	:
Phone #	:
Person filling out questionnaire	:
Position	:

Introduction: Life Cycle Costing (LCC) is mainly an economic assessment of an item, area, system, or facility considering all significant costs of ownership over an economic life, expressed in terms of equivalent dollars. It is also considered a mathematical method used to form or support a decision and is usually employed when deliberating on a selection of options.

1- What is the type of service/s offered by your office/firm?

2- Does your firm do LCC analysis?

If yes, check the trade on which LCC analysis is carried:

a- Civil works ( )
b- Electrical works ( )
c- Plumbing Works ( )
d- Mechanical Works ( )
e- Landscaping ( )
f- Infrastructure ( )
g- Others, specify ____________

3- What is the average annual volume of work conducted by the office/firm?

a- From L.E. 50,000 to 100,000
b- From L.E. 100,000 to 1,000,000
c- From L.E. 1000,000 to 10,000,000
d- More than L.E. 10,000,000

4- On what type of projects Does your firm/office conduct LCC analysis most frequently:

Type	**Always**	**Often**	**Sometimes**	**Upon owner requisition**	**Never**
Residential	( )	( )	( )	( )	( )

Office Buildings	( )	( )	( )	( )	( )
Hospitals	( )	( )	( )	( )	( )
Schools	( )	( )	( )	( )	( )
Factories	( )	( )	( )	( )	( )
Power Plants	( )	( )	( )	( )	( )
Others	( )	( )	( )	( )	( )

5- So as to perform LCC analysis, the personal who should be involved are:

Type	**Always**	**Often**	**Sometimes**	**Upon owner requisition**	**Never**
Owner	( )	( )	( )	( )	( )
Consultant	( )	( )	( )	( )	( )
Project Manager	( )	( )	( )	( )	( )
Contractor	( )	( )	( )	( )	( )
Supplier	( )	( )	( )	( )	( )
Others	( )	( )	( )	( )	( )

6- What method Does your firm use to carry LCC:

a- Simple payback
b- Net present value
c- Internal rate of return
d- Others, specify ____________ .

7- In your firm, at which stage of the project is LCC frequently applied:

a- feasibility study phase
b- preliminary design phase
c- detailed design phase
d- tendering phase
e- construction phase
f- Others, specify ____________ .

8- In a construction project, would the type of contract affect doing LCC:

a- Yes
b- No

If yes, which of the following type would require LCC:

a- Unit price contracts
b- Lump sum contracts
c- Cost plus contracts
d- BOOT contracts
e- Others, specify ____________ .

9- For what size of projects should LCC be studied

a- for project costing more than L.E. 100,000
b- for project costing more than L.E. 500,000
c- for project costing more than L.E.1000,000
d- all project sizes

10- Is there any specific software used for conducting LCC study

a- Yes (please specify)____________________.
b- NO

11- What are the problems most frequently faced when conducting LCC

a- Lack of data because of inappropriate documentation system of previous studies
b- It is not easy to predict future costs
c- Time constraints due to short design / construction period
d- Others, specify ____.

12- could you give an actual cases where your office preformed LCC study that affected the decision makers *:

a- Project Title

b- Project type

c- For which of the elements was LCC studied

d- What were the alternative under investigation

e- The method used in the analysis was
   i. Simple payback
   ii. Net present value
   iii. Internal rate of return
   iv. Others, specify _____________

f- The result of the study

* Supporting the case study with document would be appreciated.

List of companies surveyed and the type of service offerred

Company Name	Consulting / Design	Project management	contractor	Investor (owner)
Al Robaeia			*	
Alkan Construction			*	
Araibian Internaitonal Construction				
Aresco			*	
Arkedia				*
Asec	*	*		*
Benladen			*	*
BOOT				*
Cosmos	*			
Dar El Handassah Consultant	*	*		
Egydan		*		
El Khorafy Grouop			*	*
FLShmidth	*	*		
Hinziman	*			
Kavernar		*		
Kolaly			*	
Misr Cement Company				*
Nova				*
Osman Group Contracting			*	
Sabbour Associate	*	*		
Siac			*	
TCP	*			
Total Participating Firms	**7**	**6**	**8**	**7**
Total Firms Applying Life-Cycle Costing	**5**	**4**	**5**	**6**
Percentage Firms Applying LCCA	**71%**	**67%**	**63%**	**86%**

Research Questionnaire

Name of consultant office/firm	:
Address	:
Phone #	:
Person filling out questionnaire	:
Position	:

Introduction: Life Cycle Costing (LCC) is mainly an economic assessment of an item, area, system, or facility considering all significant costs of ownership over an economic life, expressed in terms of equivalent dollars. It is also considered a mathematical method used to form or support a decision and is usually employed when deliberating on a selection of options. A computer software (Path-A) that utilize LCC Analysis was developed by Eng. Ahmed Ibrahim as part of his research for the master degree. Worked examples and a copy of Path-A are provided with this survey so as to be evaluated. Your full co-operation and care in filling this questionnaire are highly appreciated.

Part A: Evaluation of the software

1. Did you find the provided solved cases useful to run the program?

   - ☐ YES
   - ☐ NO

2. Were you able to produce results using the software after consulting the solved example?

   - ☐ YES
   - ☐ NO

3. Categorize the software from 10 : User-friendly to 1 : Complicated

Part B: Usefulness of the software

4. Would you consider using the software in your practice?

   - ☐ YES
   - ☐ NO

5. Do you believe that the software would lead to construction savings in your field?

   - ☐ YES
   - ☐ NO

Part C: Recommendations

6. Do you have any recommendation to improve the value of the software to the construction industry?

APPENDIX B: LCCA Data Collection Tables

LIFE-CYCLE COST ANALYSIS

1. PROJECT IDENTIFICATION

PROJECT TITLE ______________________

LOCATION ______________________ *REGION* __________

BASE DATE __________ *SERVICE DATE* __________

DESIGN FEATURE ______________________

CONSTRAINTS ______________________

____

____

BASE CASE AND ALTERNATIVES FOR LCC ANALYSIS

(A) ______________________

(B) ______________________

(C) ______________________

(D) ______________________

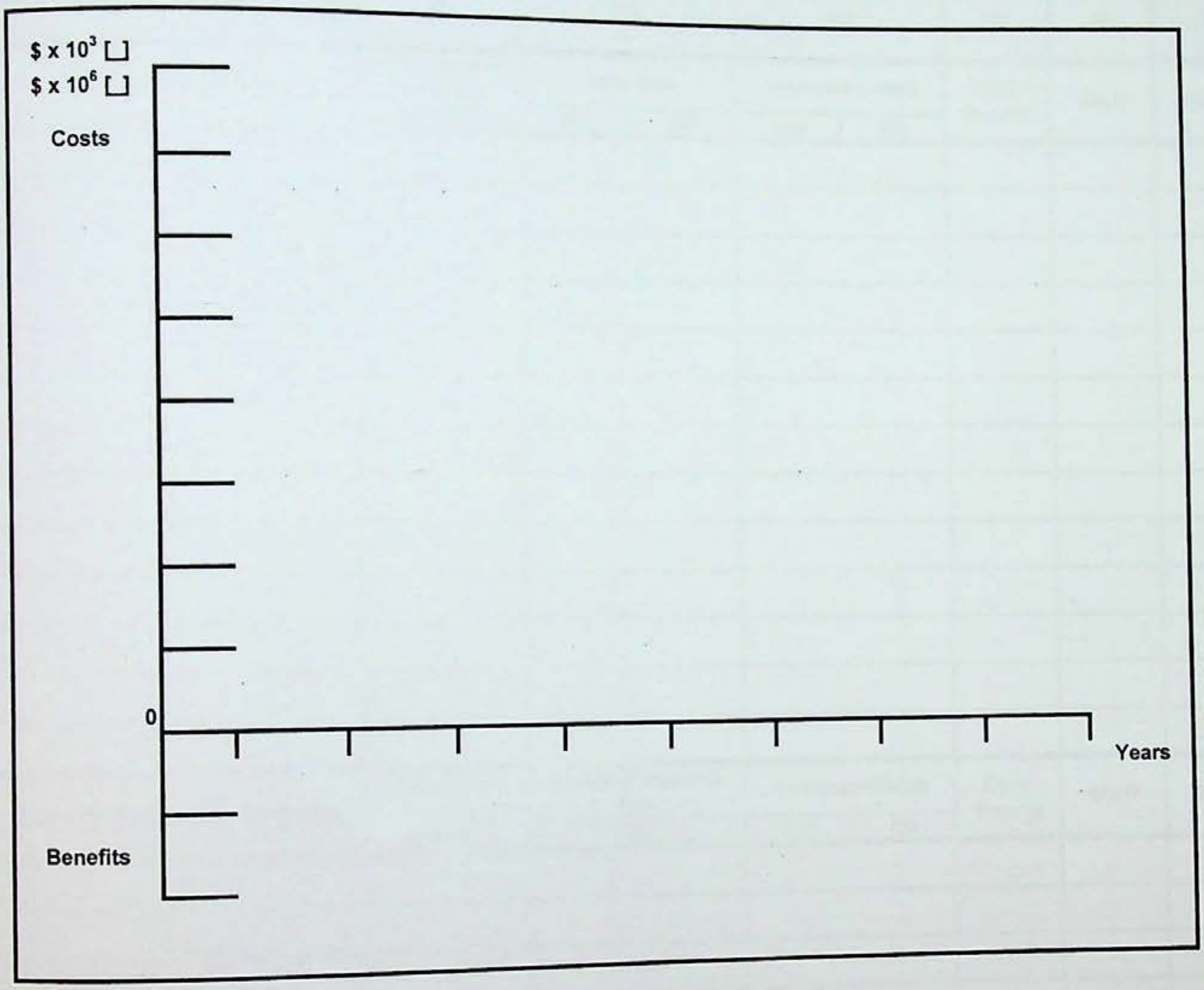
(E) ______________________

ANALYST __________ **PHONE** __________ **DATE OF STUDY** __________

LIFE-CYCLE COST ANALYSIS

2. CASH-FLOW DIAGRAM

Project Title ______________________________ **Alt. ID** ________



Comments: ______________________________

____

____

____

____

____

LIFE-CYCLE COST ANALYSIS

3. INPUT DATA SUMMARY

Project Title ______________________________ Alt. ID ________

TYPE OF COST OR BENEFIT (1)	(2)	(3)		(4)		(5)	(6)	(7)
One-Time Amounts	$-Amount on BD $ x 10^3 [ ] $ x 10^6 [ ]	Years from		Investment-Related		Data Source	MAR	NDR
		BD	SD	Yes	No			
Annually Recurring Amounts	$-Amount on BD $ x 10^3 [ ] $ x 10^6 [ ]	Number of Payments from		Investment-Related		Data Source	MAR	NDR
		SD		Yes	No			

BD = Base Date
SD = Service Date

LIFE-CYCLE COST ANALYSIS
4. PRESENT-VALUE CALCULATIONS

Project Title ______________________________ Alt. ID __________

(1) INVESTMENT-RELATED AMOUNTS	(2) $ - Amount on BD
	$ x 103 [ ]
	$ x 106 [ ]
		(3) Discount factor	(4) Present Value (4) = (2) x (3)	(5) PV TOTALS
				(5) = Summation of (4) by Type

				Initial Investment $ ________
				Capital Replacements + $ ________
				Disposal Costs + $ ________
				Salvage/Resale Value - $ ________
				Total INV. Related Costs $

OPERATION-RELATED AMOUNTS	$ - Amount on BD
	$ x 103 [ ]
	$ x 106 [ ]
		Discount factor	Present Value (4) = (2) x (3)	

				Annual OM & R $ ________
				Non-Annual MO & R + $ ________
				Other Costs +/- $ ________
				Total Operation Related Costs $
TOTAL PV LIFE-CYCLE COSTS				= $ ________

BD: Base Date

LIFE-CYCLE COST ANALYSIS

5. SELECTION

Project Title ______________________________

1. Alternatives Analyzed

Rank	Title/Description		Present Value [ ] $ x 103 [ ] $ x 106			
			Initial	OM & R	Other	Total LCC
A:						
B:						
C:						
D:						
E:						
F:						

2. Sensitivity Analysis [ ] needed [ ] not needed

Test #	Parameter Changed		New Rank Order					
	Name	Percent	A	B	C	D	E	F

3. Selection [ ] by LCC [ ] Other

Rank	Alternative No. & Title	Economic Advantages of Selected Alternative		Basis for Selection
		LCC Difference (= Net Savings)	Other (Initial, etc)	

Comments

APPENDIX C: LCCA Case Study

Data collection

Appendix C: Case Study Cost Tabulation (Ehlers, 1996)

Table C.1 Costs of Conventional Concrete Deck by Level

	Qtty	Umeas	U.C.	Start	End	Freq
L1: Initial Construction						
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Construct new deck	13000	sf	$15	1	1	1
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L2: User Costs						
L3: Elemental Costs						
Element 1						
Construction: driver delay, vehicle and accidents	21	days		1	1	1
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L1: OM&R						
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Deck inspection	1	ls	$100	2	38	2
Supplementary deck inspection	1	ls	$500	25	25	1
Resurface 5% of deck	650	sf	$10	25	25	1
Resurface 2.5% of deck	325	sf	$10	28	37	3
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.1 Costs of Conventional Concrete Deck by Level

	Qtty	Umeas	U.C.	Start	End	Freq
L2: User Costs						
L3: Elemental Costs						
Element 1						
Inspection: driver delay, vehicle and accidents	1	ls		2	38	2
Suppl. inspection: driver delay, vehicle and accidents	1	ls		25	25	1
Resurfacing: driver delay, vehicle and accidents	1	ls		25	25	1
Resurfacing: driver delay, vehicle and accidents	1	ls		28	37	3
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L1: Disposal						
L2: Agency Costs						
L3: Elemental Costs						
Element 1	13000	sf	$15	40	40	1
Disposal of deck						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: Elemental Costs						
Element 1	10	days		40	40	1
Disposal: driver delay, vehicle and accidents						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

L2: User Costs

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.1 Costs of Conventional Concrete Deck by Level

	Qtty	Umeas	U.C.	Start	End	Freq
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.2 Costs of SCRIMP FRP Deck by Level

	Qtty	Umeas	U.C.	Start	End	Freq
L1: Initial Construction						
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Factory fab	13000	sf	$30	1	1	
Shipping	1	ls	$25,000	1	1	
On-site fab: bearings	1	ls	$5,000	1	1	
On-site fab: install	600	lhrs	$15	1	1	
F&I metal guard rail	472	lf	$100	1	1	
F&I median	236	lf	$20	1	1	
Polymer concrete asphalt	13000	sf	$2	1	1	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
Pre-design NTM project formulation	50	lhrs	$50	1	1	
Academic design consultant	1	ls	$20,000	1	1	
Laboratory tests	1	ls	$30,000	1	1	
Meetings with fabricator, review shop drawings	60	lhrs	$50	1	1	
Field engineering, construction inspection	100	lhrs	$50	1	1	
L2: User Costs						
L3: Elemental Costs						
Element 1						
Construction: driver delay, vehicle and accidents	13		days	1	1	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.2 Costs of SCRIMP FRP Deck by Level

	Qtty	Umeas	U.C.	Start	End	Freq
L1: OM&R						
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Deck inspection	1	ls	$100	2	40	
Supplementary deck inspection	1	ls	$500	25	25	
Fiber patching	130	sf	$20	28	28	
Polymer concrete patching	650	sf	$20	25	25	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
Develop non-destructive evaluation plan	100	lhrs	$50	1	1	
Inspect deck: once month/1st year	28	lhrs	$30	1	1	0.083
Inspect deck: once every 6 months/next 3 years	28	lhrs	$30	2	4	0.
L2: User Costs						
L3: Elemental Costs						
Element 1						
Inspection: driver delay, vehicle and accidents	1	day		1	40	
Suppl. inspection: driver delay, vehicle and accidents	1	day		25	25	
Resurfacing: driver delay, vehicle and accidents	2	day		28	28	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.2 Costs of SCRIMP FRP Deck by Level

L1: Disposal	Qtty	Umeas	U.C.	Start	End	Freq
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Disposal of deck L&E	300	lmhrs	$45	40	40	
Dump fee	1	ls	$9,500	40	40	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L2: User Costs						
L3: Elemental Costs						
Disposal: driver delay, vehicle and accidents	2	days		40	40	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.3 Costs of Wood-Core FRP Deck by Level

L1: Initial Construction	Qtty	Umeas	U.C.	Start	End	Fre
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Factory fab	1	ls	$129,000	1	1	
Shipping	1	ls	$25,000	1	1	
5% beam surcharge	1	ls	$6,750	1	1	
On-site fab: bearings	1	ls	$5,000	1	1	
On-site fab: install	400	lhrs	$15	1	1	
F&I metal guard rail	472	lf	$100	1	1	
F&I median	236	lf	$20	1	1	
Polymer concrete asphalt	13000	sf	$2	1	1	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
Pre-design NTM project formulation	50	lhrs	$50	1	1	
Academic design consultant	1	ls	$20,000	1	1	
Laboratory tests	1	ls	$30,000	1	1	
Meetings with fabricator, review shop drawings	60	lhrs	$50	1	1	
Field engineering, construction inspection	100	lhrs	$50	1	1	
L2: User Costs						
L3: Elemental Costs						
Element 1						
Construction: driver delay, vehicle and accidents	10	days		1	1	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which eost occurs; E = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.3 Costs of Wood-Core FRP Deck by Level

	Qtty	Umeas	U.C.	Start	End	Fr
L1: Maintenance & Repair						
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Deck inspection	1	ls	$100	2	40	
Supplementary deck inspection	1	ls	$500	25	25	
Fiber patching	130	sf	$20	28	28	
Polymer concrete patching	650	sf	$20	25	25	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
Develop non-destructive evaluation plan	100	lhrs	$50	1	1	
Inspect deck: once month/1st year	28	lhrs	$30	1	1	0.0
Inspect deck: once every 6 months/next 3 years	28	lhrs	$30	2	4	
L2: User Costs						
L3: Elemental Costs						
Element 1						
Inspection: driver delay, vehicle and accidents	1	day		1	40	
Suppl. inspection: driver delay, vehicle and accidents	1	day		25	25	
Resurfacing: driver delay, vehicle and accidents	2		days	28	28	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lum sum; lhrs = labor hours; 1f = lineal feet.

Table C.3 Costs of Wood-Core FRP Deck by Level

L1: Disposal	Qtty	Umeas	U.C.	Start	End	Freq
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Disposal of deck L&E	200	lhrs	$15	40	40	
Dump fee	1	ls	$9,500	40	40	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L2: User Costs						
L3: Elemental Costs						
Element 1						
Disposal: driver delay, vehicle and accidents.	6	days		40	40	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.4 Costs of Pultruded-Plank FRP Deck by Level

L1: Initial Construction	Qtty	Umeas	U.C.	Start	End	Frec
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Factory fab	13000	sf	$23	1	1	
Shipping	1	ls	$25,000	1	1	
5% beam surcharge	1	ls	$6,750	1	1	
On-site fab: bearings	1	ls	$5,000	1	1	
On-site fab: install	13000	sf	$5	1	1	
F&I metal guard rail	472	lf	$100	1	1	
F&I median	236	lf	$20	1	1	
Polymer concrete asphalt	13000	sf	$2	1	1	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
Pre-design NTM project formulation	50	lhrs	$50	1	1	
Academic design consultant	1	ls	$20,000	1	1	
Laboratory tests	1	ls	$30,000	1	1	
Meetings with fabricator, review shop drawings	60	lhrs	$50	1	1	
Field engineering, construction inspection	100	lhrs	$50	1	1	
L2: User Costs						
L3: Elemental Costs						
Element 1						
Construction: driver delay, vehicle and accidents	21		days	1	1	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.4 Costs of Pultruded-Plank FRP Deck by Level

L1: Maintenance & Repair	Qtty	Umeas	U.C.	Start	End	Freq
L2: Agency Costs						
L3: Elemental Costs						
Element 1						
Deck inspection	1	ls	$100	2	40	
Supplementary deck inspection	1	ls	$500	25	25	
Deck replacement	250	sf	$35	25	37	
Polymer concrete patching	1430	sf	$20	25	25	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
Develop non-destructive evaluation plan	40	lhrs	$50	1	1	
Inspect deck: once month/1st year	28	lhrs	$30	1	1	0.083
Inspect deck: once every 6 months/next 3 years	28	lhrs	$30	2	4	0.
L2: User Costs						
L3: Elemental Costs						
Element 1						
Inspection: driver delay, vehicle and accidents	1	day		1	40	
Suppl. inspection: driver delay, vehicle and accidents	1	day		25	25	
Resurfacing: driver delay, vehicle and accidents	3	day		28	28	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L1: Disposal						
L2: Agency Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.

Table C.4 Costs of Pultruded-Plank FRP Deck by Level

	Qtty	Umeas	U.C.	Start	End	Freq
L3: Elemental Costs						
Element 1						
Disposal of deck - L	200	lhrs	$15	40	40	
Dump fee	1	ls	$9,500	40	40	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L2: User Costs						
L3: Elemental Costs						
Element 1						
Disposal: driver delay, vehicle and accidents	5	days		40	40	
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						
L3: 3rd Party Costs						
L3: Elemental Costs						
L3: Non-Elemental Costs						
L3: New-Technology Introduction Costs						

Legend: Qtty = quantity; Umeas = unit of measure; U.C. = unit cost; Start = first year in which cost occurs; End = last year in which cost occurs; Freq. = annual frequency with which cost occurs; sf = square feet; ls = lump sum; lhrs = labor hours; 1f = lineal feet.