A FORECASTING MODEL FOR MAINTENANCE AND REPAIR COSTS FOR OFFICE BUILDINGS

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A Thesis

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ABSTRACT

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Building operation and maintenance costs play a key role in the total ownership costs of buildings over their lifetime. Accurate forecasting of these costs can assist owners and asset managers in making appropriate investment decisions and budget allocation. However, the accurate maintenance/repair (M/R) costs are very difficult to determine due to the uncertain maintenance/repair activities and asset conditions over the life cycle of the buildings.

The present research presents a model developed to evaluate and forecast M/R costs of office buildings. This developed forecasting model considers the weights of the factors that influence the M/R costs as well as the related adjusting factors of these costs. The elements that make up the M/R costs of office buildings have been identified. Historical data of these elements published by Building Owners and Managers Association (BOMA) is adapted and analyzed. A simulation method is used to establish the probability distributions of the M/R costs. Six main factors influencing the total M/R costs and their associated elements have been defined. Analytic Hierarchy Process (AHP) method is employed to determine the weights of these influencing factors and their associated elements.

A prototype FTMRC (forecast total maintenance and repair costs) system is developed to implement the proposed forecasting model. The function-oriented design method is employed to implement the system. The prototype software is coded using Visual Basic Applications and operates in a Microsoft Windows® environment. There are eight components comprised in the FTMRC system. The evaluation, forecasting, and analyzing functionalities can be carried out by utilizing the proposed models and stored data. The FTMRC system also provides an analysis of the Net Present Value of M/R costs over the analyzed life span of office buildings. The FTMRC system further provides sensitivity analysis to assist users to recognize the most important variables affecting the Net Present Value of M/R costs. The system can also provide both numerical reports and graphical reports.

A numerical example from real industry is utilized to validate both the proposed forecasting model and the developed prototype. Mean absolute percent error (MAPE) method is used to evaluate the accuracy of the proposed forecasting model. The validation of the developed FTMRC system shows that this prototype can perform all the proposed system tasks and can provide users with an easy and efficient tool to forecast their future M/R expenditures and to have an overall view of their budget.

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NOMENCLATURE

W_{FC}	the weight of city factor
W_{FL}	the weight of location factor
W_{FO}	the weight of ownership factor
W_{FH}	the weight of height factor
W_{FS}	the weight of size factor
W_{FA}	the weight of age factor
K_{Aj}	age adjusting factors
W_{Aj}	the weights of different age ranges
$\overline{W_{Aj}}$	average weight of the elements in age category
K_{Sj}	size adjusting factors
W_{Sj}	the weights of different size ranges influencing the M/R costs of office buildings
$\overline{W_{Sj}}$	average weight of the elements in size category.
K_{Hj}	height adjusting factors
W_{Hj}	the weights of different height ranges influencing the M/R costs of office buildings
$\overline{W_{Hj}}$	average weight of the elements in height category.
K_{Oj}	ownership adjusting factors
W_{Oj}	the weights of different ownership influencing the M/R costs of office buildings
$\overline{W_{Oj}}$	average weight of the elements in ownership category.
K_{Lj}	location adjusting factors
W_{Lj}	the weights of different location influencing the M/R costs of office buildings
$\overline{W_{Lj}}$	average weight of the elements in location category.
K_{Cj}	city adjusting factors
W_{Cj}	the weights of different cities influencing the M/R costs of office buildings
$\overline{W_{Cj}}$	average weight of the elements in city category.
y	forecasting inflation rate
n	number of years between the forecast year and year 2001

ABBREVIATIONS

LCC	Life Cycle Costing
FM	Facility Management
MRC	Maintenance and Repair Costs
MRCD	Maintenance and Repair Costs in Downtown
MRCS	Maintenance and Repair Costs in Suburban
MRCP	Maintenance and Repair Costs in Private Sector
MRCG	Maintenance and Repair Costs in Government Sector
MRCH	Maintenance and Repair Costs Based on Height Analysis
MRCA	Maintenance and Repair Costs Based on Age Analysis
TMRC	Total Maintenance and Repair Costs
FTMRC	Forecasting Total Maintenance and Repair Costs
NPV	Net Present Value
TRA	Total Rental Area of Office Buildings
MAPE	Mean Absolute Percent Error

Chapter 1

INTRODUCTION

1.1 Definition

1.1.1 Life Cycle Costing

Life Cycle Costing (LCC) is an economic assessment of an item, area, system, or facility that considers all the significant costs of ownership over the economic life of the said item, area, system, or facility. LCC is a technique that satisfies the requirements of owners for the adequate analyses of total costs. The technique can be used in two ways: one is to assess the economic consequences of a given set of decisions that have already been made; another is to help provide a basis for choosing among two or more competing solutions. The latter use, choosing among alternatives, is of particular value in planning and design. LCC can also be defined as a cost-oriented estimating approach. It takes into consideration relevant building costs, such as capital, operations, maintenance, replacement and salvage value, etc. In sum, the LCC approach is an effective and sufficient tool for estimating a property value and managing its ongoing cost performance.

However, when attempting to apply life cycle costing concepts in the building industry, "owners and managers have been thwarted by the lack of both well-accepted methodology of documentation of information and sound data from which to arrive at appropriate decisions" (Al-Hajj 1999).

1.1.2 Maintenance and Repair Costs

Total cost means the ultimate costs to construct, operate, maintain, and replace a facility or system over a specific life cycle (Dell'Isola 1975). The life of the building will extend from 20 to 50 or more years. During this period the cost of operation and maintenance will equal or exceed the capital cost.

Al-Hajj (1999) defined the maintenance costs are the cost of keeping the building in good repair and working condition. They include painting, decorating and repairs. The study of maintenance and repair costs is an integral part of the overall LCC study of any building project (Al-Hajj 1999).

1.1.3 Office Building

Dell'Isola (1981) defined the concept of office building as that "building designed for or used as the offices of professional, commercial, industrial, religious, institutional, public, or semipublic persons or organizations" (Dell'Isola 1981).

An office building can be anything from a two-story suburban building to a 100-story urban high-rise. The office building is a complex building type whatever its size or type. The most important role of office buildings is as a home for the people who work there full time or part time (Katz 2002).

1.2 Research Objectives

The present research focuses on the maintenance and repair (M/R) costs of office buildings in Canada. The main objective of this research is to develop a forecasting model of M/R costs for office buildings. The sub-objectives include the following:

1. Determination of the main components that make up the M/R costs of office buildings
2. Development of a procedure to process the collected data and the development of the methods to treat these data
3. Development of the methods to determine the coefficients for the proposed M/R costs forecasting model
4. Development of the proposed forecasting model to facilitate owners and facility managers in evaluating and forecasting the M/R costs of their office buildings
5. Development of the methods to carry out the economic analyses of the total M/R costs of office buildings over their life cycles
6. Development of a prototype to implement the proposed M/R costs forecasting model and to assist users conducting a sensitivity analysis
7. Validation by utilizing a real case to test the proposed M/R costs forecasting model and the developed prototype

1.3 Proposed Research Methodology

In this study, a methodology has been proposed to develop a model for forecasting the realistic M/R costs of office buildings. The proposed methodology involves five main steps, namely:

- Conducting literature review
- Processing and analyzing collected data, determining more realistic values of M/R costs based on available historic data and through the use of a simulation method
- Determining factor weights as coefficients for the forecasting model
- Developing a model to forecast the M/R costs of office buildings
- Implementing and validating the proposed forecasting model and the developed system

The proposed research methodology is represented as shown in Figure 1.1. It can be seen that the step of data processing involves data collection, data analysis, data sorting and the use of Monte Carlo simulation. Analytical Hierarchy Process (AHP) method is used to determine the weights of variable factors that affect the M/R costs of office buildings.

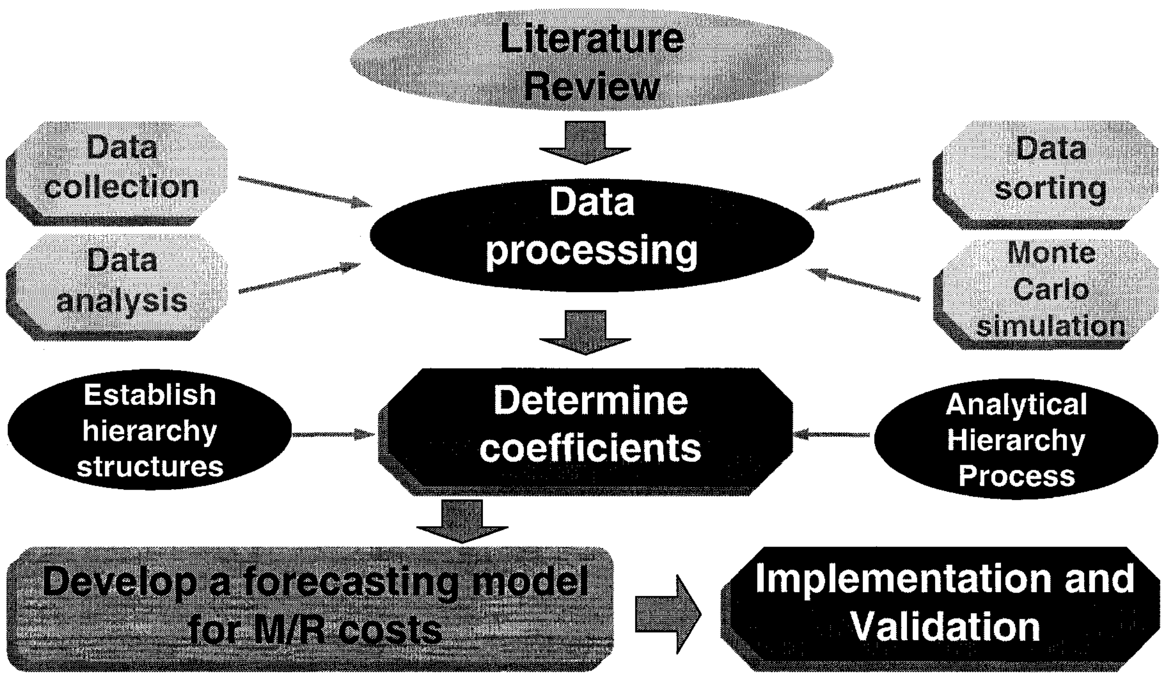


Figure 1. 1 Proposed Research Methodology

1.4 Thesis Organization

The thesis is organized into seven chapters:

Chapter Two presents the literature review of ownership costs, of maintenance and repair costs models, of life cycle costing analysis methods, of LCC applications, of the software for LCC, as well as of simulation methods.

Chapter Three describes the proposed procedure of data processing. This procedure involves data collection, analyzing, sorting, as well as data statistical processing. One of the stochastic methods, the Monte Carlo simulation method, was used to do the data treatment. Detailed descriptions of the data category establishment, the determination of distribution assumptions and the results of the M/R costs calculated by simulation software are provided.

Chapter Four describes the development of the M/R costs forecasting model. Also provided are detailed descriptions of the hierarchy structure establishment, and of the Analytic Hierarchy Process method employed to determine the weights of influencing factors. Also described are the developed M/R costs model and the formulas utilized to determine the coefficients for both weights and adjusting factors.

Chapter Five presents the system design and implementation, which includes the system design, the system algorithm introduction and the system implementation. Detailed descriptions of the system tasks, of the system architecture, of the system components, of the system functionalities and of the system algorithm are provided.

Chapter Six introduces the validation of the proposed M/R costs forecasting model and of the developed system by studying a numerical example. A detailed description of the validation process, a result comparison, a prototype demonstration and a sensitivity analysis application are provided.

Chapter Seven expresses the conclusions and contributions of the present research, as well as the recommendations for future work.

Chapter 2

LITERATURE REVIEW

2.1 General

One gains new insights by reviewing the past. The present chapter introduces what has already been done by others in the field of life cycle costing methods along with the applications, the components of the ownership costs, the facility management processes and models, and maintenance and repair costs models.

2.2 Life Cycle Costing (LCC)

Life cycle costing (LCC) has a long history of use in industry. LCC came about in the early 1960s in the U.S. Department of Defense. It is applied to virtually every new weapon system proposed or under development. In 1961, an important conference entitled "Methods of Building Cost Analysis" was sponsored by the Building Research Institute in Washington, D.C. The papers presented procedures for developing life cycle cost analyses for buildings and their enclosures, for lighting and heating, ventilating, and air-conditioning systems. LCC takes into consideration all cash flow items relevant to building costs, such as capital costs, operation and maintenance costs, replacement costs, annual income and salvage value, etc. Therefore, the LCC approach is an effective tool for determining an asset's value and for managing its ongoing cost performance. Three aspects of the application of LCC have been reviewed in the present review: LCC methods selected to implement the LCC calculation; the software used for LCC application; LCC applications.

2.2.1 LCC Methods

The LCC technique is a mathematical approach. Usually, it uses basic economic evaluation methods, such as the Net Present Value Method, Annual Worth Method, Savings/Investment Ratio(SIR) Method, etc to study the cash flow of the life cycle. Figure 2.1 shows one example of a cash flow profile.

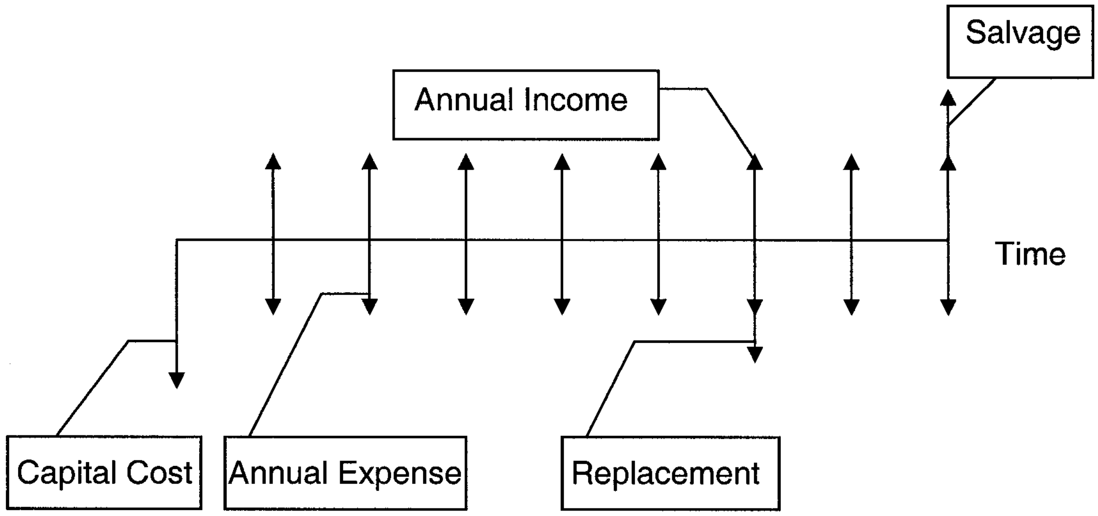


Figure 2. 1 Cash Flow of Life Span

2.2.1.1 Net Present Value Method

The Net Present Value method converts all cash flows to a single sum equivalent at time zero as shown in Figure 2.2. When this method is used, all income and expenditures, regardless of when they occur, are compared during a common year, that is, a baseline year. Future income and expenditures are properly discounted to reflect their time value. Once these future items are discounted, they may be compared properly to those incurring “today”, or during the “baseline year”. Once this discounting is accomplished, all income and costs are weighed on a common basis and may be added together to obtain a total present value.

NPV = PV(Annual Income) + PV(Salvage Value) - PV(Capital Cost) - PV(O&M cost) - PV(Financial Cost) (2.1)

Where,

NPV = the net present value

PV = the present values of all incomes and costs incurred throughout the life cycle

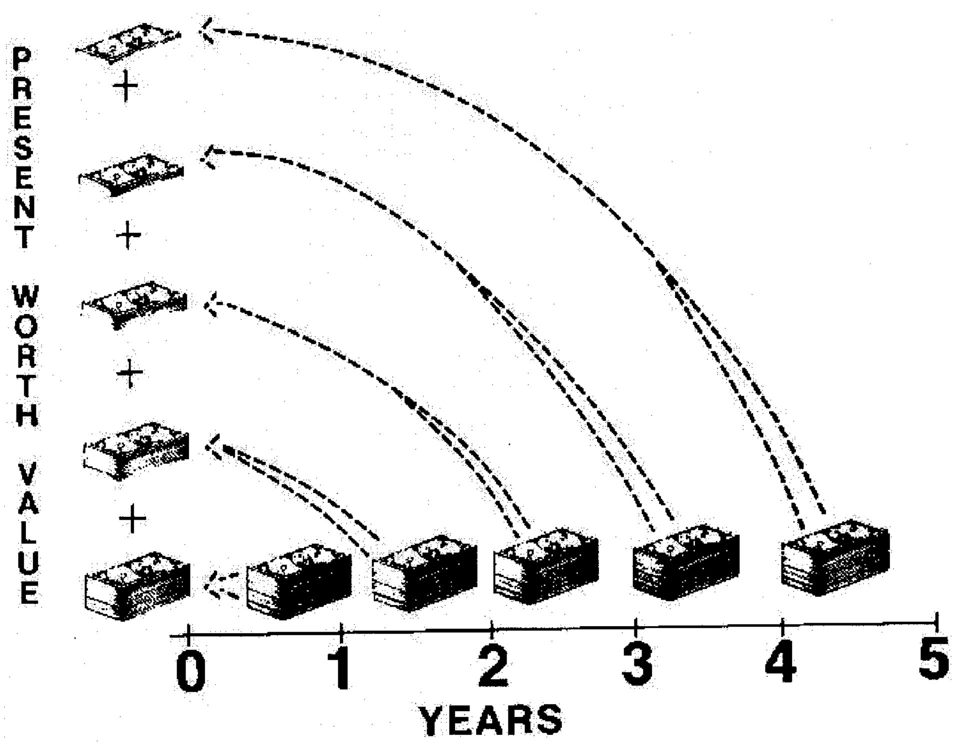


Figure 2. 2 Net Present Value Method

2.2.1.2 Annual Worth Method

The annual worth method converts all cash flows to an equivalent uniform annual series of cash flows over the planning horizon. By using this method, both present dollars and future dollars are converted to a uniform annual cost while taking into account the time value of money at a particular interest rate. All present and future costs are broken down into equivalent yearly payments throughout the life cycle. All the equivalent yearly costs are then added together to establish the total uniform annual cost.

When alternatives are compared, the same choice will be made regardless of whether the present worth method or the annual worth method is used. The same relative cost advantage will result from either method of calculation.

$$\textbf{AW} = \textbf{AW(Annual Income)} + \textbf{AW(Salvage Value)} - \textbf{AW(Capital Cost)} - \textbf{AW(O\&M cost)} - \textbf{AW(Financial Cost)} \quad \textbf{(2.2)}$$

Where,

AW = the annual worth of all income and costs incurred throughout the life cycle

2.2.1.3 Savings/Investment Ratio (SIR) Method

The savings/investment ratio method determines the ratio of the present worth of savings to the present worth of the investment. Since the SIR formulation is the present worth of net positive cash flows divided by the present worth of net negative cash flows, so for a project to be preferred over investing, the ratio must be greater than one.

SIR = PV(Savings) / PV(Investment) **(2.3)**

Where:

SIR = the savings/investment ratio for investment

PV(Savings) = the present worth of net positive cash flows

PV(Investment) = the present worth of net negative cash flows

2.2.1.4 Discussion

A fundamental criterion for evaluating an investment and comparing investment alternatives is the net present value (NPV) criterion. The net present value relationship gives the present value of all future cash flows. For any investment, if the net present value is positive, it should be accepted. In the case of negative net present value, other investment alternatives should be tried. Normally, one key objective of the investors is to maximize the net present value. For this goal, we can contribute to the maximization of the NPV by minimizing the total capital cost and the future costs associated with the physical systems of a building.

In the present research, the Net Present Value Method is employed to do LCC analysis. There are several assumptions:

- Construction period does not count in the life span.
- Cash flow arises at the end of the year in which they will occur.
- Financial cost will not be considered in the present research.
- Salvage value will not be considered in the present research.
- Depreciation will not be considered in the present research.
- Discount rate and inflation rate do not change during the analyzed life span.

2.2.2 Software for LCC Application

One main task of LCC analysis is the treatment of volumes of data. There are several softwares that have been developed for this purpose in the previous research. One of them is the creation of a prototype expert system for predicting the cost/time profiles of major construction elements. This prototype produces an estimate at an early design phase in the life of a school building construction project (J.Christian 1991). Another software called LCC-O(Life Cycle Costing of Office Buildings), written in C, has been developed. It addresses these issues at the preliminary design stage of an office building project (Khanduri et al. 1996). The software OFFICE_LCC98 has been designed to assist LCC analysis (Zhang et al. 1999). Visual Basic 5.0(VB5), Visual Basic Applications(VBA), MS-Excel and MS-Access Macros and modules, graphical design techniques, etc., have been applied in developing this software.

2.2.3 LCC Applications

There are many papers that describe their research by using the LCC method. The LCC application has a rather wide scope. According to the literature review, the LCC application has been used in the fields of building and construction projects, roofing, HVAC, flooring, facility management, infrastructure, etc.

1. LCC Application in Buildings and Construction Projects

The determination of economical rental rates of office buildings in real estate practice from the LCC point of view was studied in a thesis by Ke Zhang in 1999. It is noticed that there is a lack of replacement cost databases. However, eventually, replacement cost is significant to LCC practitioners and property managers (Zhang et al. 1999).

There is another LCC application that assesses the costs and benefits of adopting environment-friendly construction practices for social rented housing in Scotland. Two contrasted dwelling specifications, one for a conventional building and one for an environmentally responsible building, are compared using Life Cycle Analysis and Life Cycle Costing methodologies. An assessment is made of the environmental and economic implications of adopting environmentally conscious construction practices in social rented housing (Smith et al. 1997).

The development of a quantitative life cycle costing model and software for the assessment of the financial feasibility of office building projects at the preliminary design stage has been detailed in “Assessing office building life cycle costs at preliminary design stage”(Khanduri, A. C., Bedard, C., Alkass, S.). The model handles most of the technical data and financial factors that are required to determine the life cycle costs and economic feasibility of proposed buildings, with basic, minimum input. Three assessment factors are calculated: present worth, annual worth and savings/investment ratio (Khanduri et al. 1996).

According to “Life-cycle costing and its use in the Swedish building sector”, the LCC perspective is proving to be most useful during the design phase where the possibilities of cost reductions related to operation and maintenance are large.

The implication for expanding the use of LCC are considered for government, clients/developers, professionals (Sterner 2000).

The problems with the applications of life cycle costing in construction projects in Saudi Arabia have been discussed in the paper named “Assessment of the problems of application of life cycle costing in construction projects”. It was agreed by both government agencies and consultants that the chief cause for not applying life cycle costing is the client or management pressure to meet the deadlines for design approval. They also agreed that the lack of human and material resources are also another reason for not applying life cycle costing more extensively (Assaf et al. 2002).

2. LCC Application in Facility Management

The paper “Facilities management hospitality case study” discusses recent research on the benefits of facilities management (FM) in the hospitality industry and how the application of FM can contribute to the derivation of value by users, hotel owners, and employees. Factors such as life cycle costing, productivity, performance values, and legislative change drive FM. This paper argues that owners/owner managers in the hospitality business, who are more proactive in the management of their constructed facilities, achieve higher occupancy rates, profitability, and repeat of business (Okoroh et al. 2003).

Peter Fretty realizes that Life-cycle costing (LCC) is really the only way to predict the true cost of basic purchase decisions. The use of LCC can drastically reduce maintenance costs. However, the benefits come with challenges. To succeed with LCC, it is imperative that maintenance managers apply accurate and up-to-date cost and performance information (Fretty 2003).

Vangen discusses the benefits and specifics of outsourcing data storage and retrieval - both from the construction side and from the facilities management side of the life-cycle of a building or buildings. The lack of an integrated technology infrastructure in corporate real estate has been a long-standing source of gross inefficiencies in the construction and maintenance of buildings. These inefficiencies end up costing corporations hundreds of millions of dollars annually (Vangen 2001).

Life-cycle costing allows building owners and designers to evaluate trade-offs among capital and operating costs of a building. Through building audits, customer satisfaction surveys, and operational benchmarking, you can get a clear picture of how well your building reaches its goal (Suttell 2002).

Ceilings enclose space, define the interior environment, and regulate the acoustics of a facility. The variety of performance requirements in schools suggests that more durable materials might have higher capital, operational, or maintenance costs. However, expenses not normally associated with building materials can be reduced by selections based on Service Life Cycle Costing. An exposed structure - sealed or painted - is the most cost-effective ceiling system over a 50-year period, but its thermal and acoustical characteristics are not desirable for some educational activities (Moussatche and Languell-Urquhart 2001).

3. LCC Application in Other fields

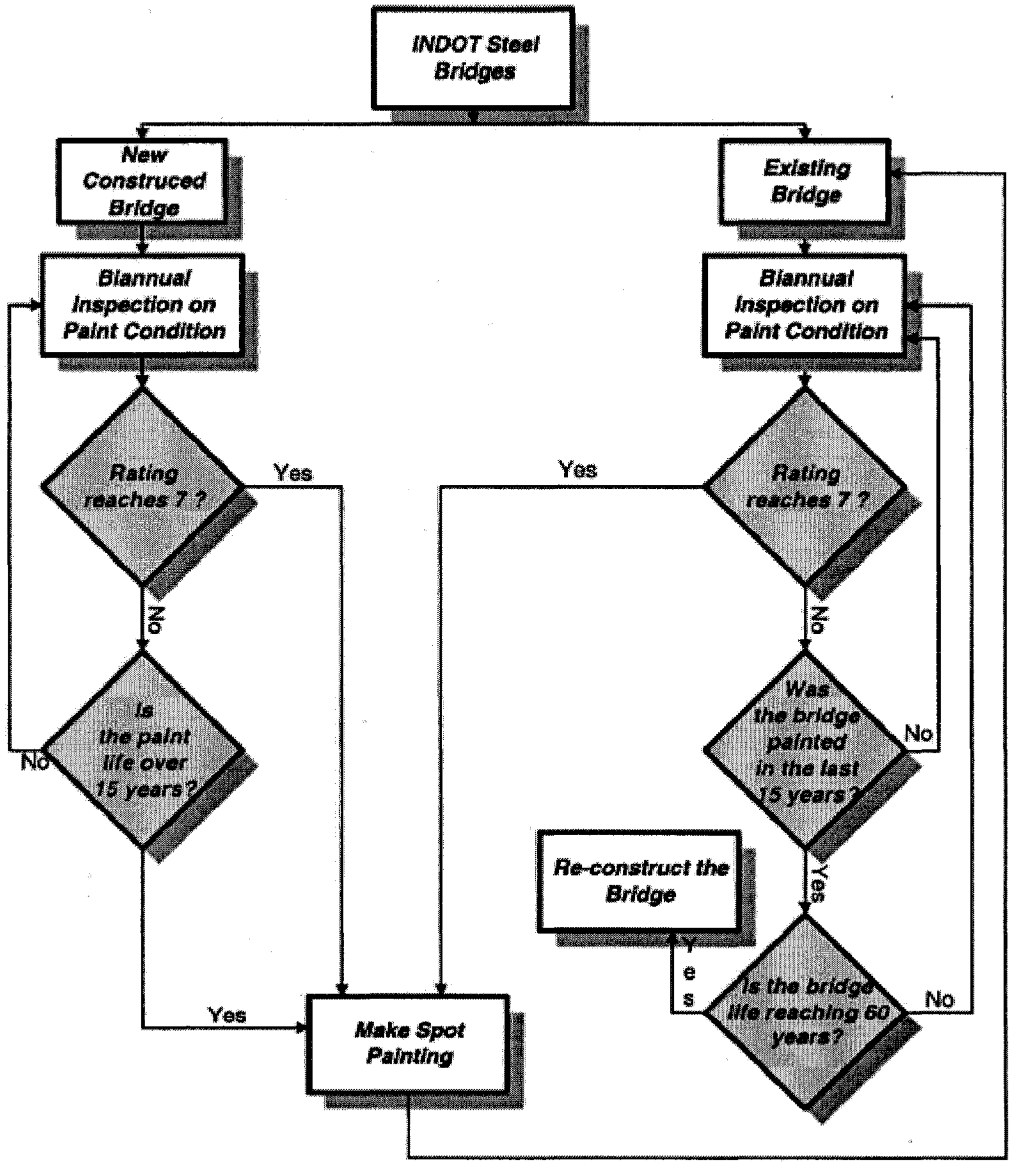


Figure 2. 3 Maintenance Plan Procedure (Zayed et al. 2002)

Figure 2.3 shows a proposed maintenance plan for steel bridge paint rehabilitation in the Indiana Department of Transportation (INDOT). The maintenance plan was developed based on the life cycle cost analysis for determination of the best rehabilitation scenario (Zayed et al. 2002).

The systematic research described in “Risk-based Life-cycle Costing of Infrastructure Rehabilitation and Construction Alternatives” by Ossama Salem, Simaan AbouRizk, Samuel Ariaratnam. In the developed life-cycle cost model, uncertainty is introduced through the parameters of the probability distributions fitted to infrastructure time-to-failure data. These parameters are input to the model using random sampling of variables from the fitted distributions. Monte Carlo simulation was utilized to present the quantified risk for the input variables as well as the uncertainty that accompanies the model output. The model identifies the basic cost elements that should be considered when evaluating life-cycle costs. In addition, the model identifies design and managerial factors that influence the values of these costs. (El-Diraby and Rasic 2004)

Accordingly, the cost of maintenance must be included in any calculation of life-cycle cost. For modern business enterprises, the hurdle rate for capital investment is almost always higher than 10 percent and, in most cases, a return greater than 20 percent is expected. Consequently, the time value of money places a much higher premium on the initial installed cost than originally expected.(Hoff 2001) Sound design, quality materials, proper installation, and timely maintenance are the keys to longevity and true low costs. (Hope 2001)

A framework for the integration of the process of managing maintenance of roofing systems is proposed by the Building Envelope Life Cycle Asset Management (BELCAM) project. One part of the project studied a framework for the maintenance management of roofing systems. Used in the research were the LCC analysis method, a probabilistic Markovian chain model, Risk-based multi-objective decision analysis, and Value-engineering (Hassanain 1999).

Fortune and Cox have done a large-sized quantity surveying on selection and use of building project contract price forecasting model in UK. The findings of their study reveal that Lifecycle cost models (67 per cent of model incidence) are being in general use of the new wave models (Fortune and Cox 2005).

2.3 Ownership Costs

2.3.1 Components of Ownership Costs

Lee and Wordsworth (Lee and Wordsworth 2000) indicated that ownership costs involve initial cost; operating cost; maintenance costs; energy costs; cleaning costs; overhead and management costs; utilization costs; and resale value.

Figure 2.4 shows the total overall cost of the ownership of a typical office building over a forty year life cycle. Wideman indicates that it is interesting to note that the initial costs are only one half of the total cost. Consequently, it is often a serious shortcoming in the programming, planning and design of facilities to focus only on the initial cost without regard to the present value of future maintenance and operating costs (Wideman 2000).

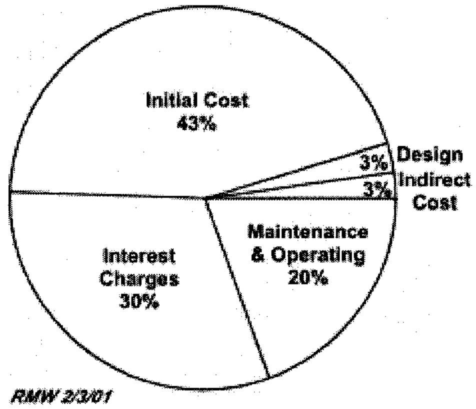


Figure 2. 4 Cost of Ownership (Wideman 2000)

It is stated that the important components of the full cost of ownership are the routine expenditures for needed maintenance, repairs, and planned replacement by Commission on Engineering and Technical Systems (CETS 1990). The characteristics of a building's design and construction, operating procedures, climate, location and age influence the need for maintenance and repair.

2.3.2 Total Expenses of Office Buildings

The total expenses of office buildings have been represented in BOMA EER (BOMA 2002). Figure 2.5 demonstrates the overall ratio of individual Operation Expenses and Fixed Expenses to the Total Expenses in the U.S. private sector.

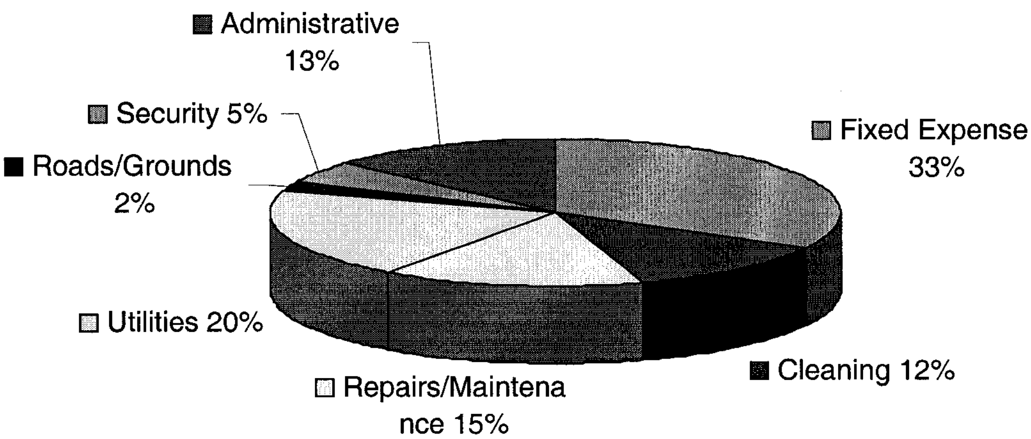


Figure 2. 5 Total Expense Ratio

2.3.3 M/R costs

Building maintenance now accounts for over half of the construction industry's output. (Lee and Wordsworth 2000)

Maintenance provision is an important facet of the total ownership costs of buildings. Recent research has demonstrated that the cost of operating and maintaining a building can be as much as five times the cost of capital over the life of the building (Boussabaine and Kirkham 2004). A review of Canadian construction statistics shows that $8.5 billion is spent annually on repairs and maintenance of buildings (Lounis et al. 1998). Maintenance and renovation works in the United Kingdom in 1986 for example were estimated to be about 46% of the total construction output (Kiang 1991). Building operation and maintenance costs can account for approximately 55% of the total cost through a 40 year life cycle (Flanegan 1987). It has also been demonstrated that, for some systems, maintenance and support account for up to 75% of overall life-cycle costs, see

(Booty 2003). In the case of the UK, the cost of maintenance has risen by 7.6% over the year 2002 (Booty 2003), and the total spending on building maintenance has increased by 66% in ten years in the period between 1986 and 1996 (BMI 1996).

In the pre-construction phase, considerations of maintenance requirements may lower the operations and maintenance costs of the facility. A study by (Yasser M. Dessouky 2002) has shown that an investment in the design process of $0.74/SQ.FT. is equivalent to an investment in the construction process of $2.70/SQ.FT.. Such an investment will prevent excess maintenance costs of $0.08/SQ.FT. for the life of the facility.

2.4 Facility Management Systems

2.4.1 FM Processes

Different maintenance management processes have been described in the former research studies. The Maintenance Management Framework (MMF) is one of them. It is a whole-of-government policy framework approved by the Queensland Government on 28 June 1999. The MMF maintenance management process, illustrated in Figure 2.6, is a generic process that assists departments in establishing a framework for the maintenance of Queensland Government buildings. Its objective is to achieve consistency in the planning, implementation and reporting of building maintenance.

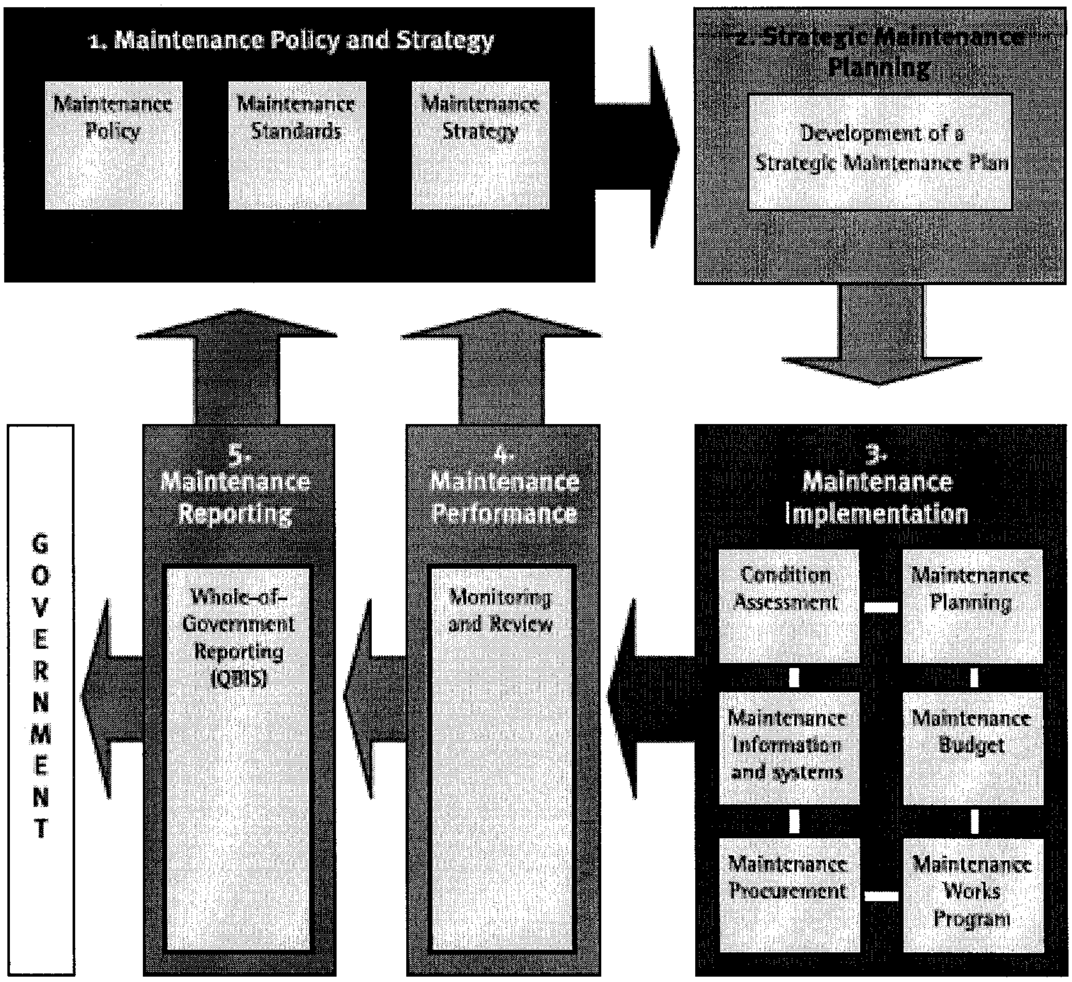


Figure 2. 6 Maintenance Management Process (www.build.qld.gov.au/amps/AmpsDocs/MMF_BMPD.pdf)

Another maintenance process is shown in the Figure 2.7. This Figure shows that determining and revising the routine maintenance activities to be performed on a regular basis is also a vital part of the maintenance process. The loop on the right hand side of this figure could be considered to be the short-term control loop. It is the loop that most traditional Maintenance Change exercises focus on. The loop on the left hand side, on the other hand, can be considered the Continuous Improvement loop. This loop focuses primarily on Maintenance Effectiveness, in the sense that in this loop, Maintenance activities are analyzed to determine whether the routine Maintenance activities being performed are optimal for the current operating context of the equipment.

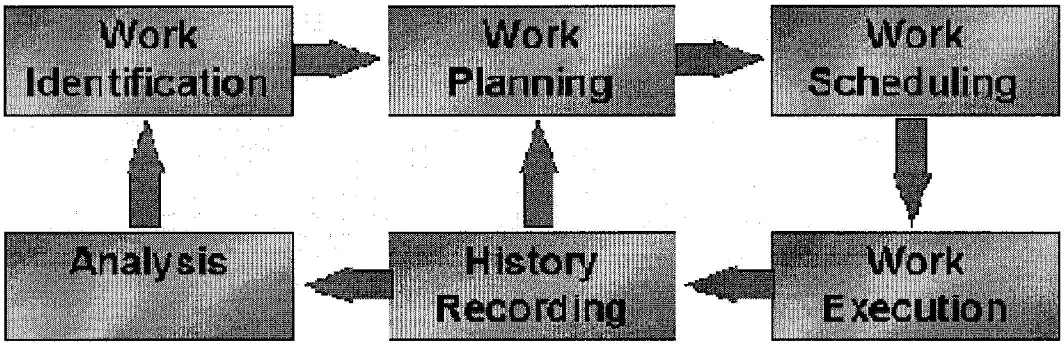


Figure 2. 7 Maintenance Process (Dunn 1996)

2.4.2 Facility Management Models

El-Haram and Horner (El-Haram and Horner 2003) developed a cost-effective maintenance strategy for existing building stock by applying integrated logistics support (ILS) techniques that can be used both at the design stage and throughout the life cycle of a project. The ILS techniques were developed by the US Ministry of Defence, and are embodied in MIL.STD-1388 (Defence 1983) and the UK DEF-STAN 00-60 (Defence 1996). Figure 2.8 shows a systematic framework for determining a cost-effective maintenance strategy.

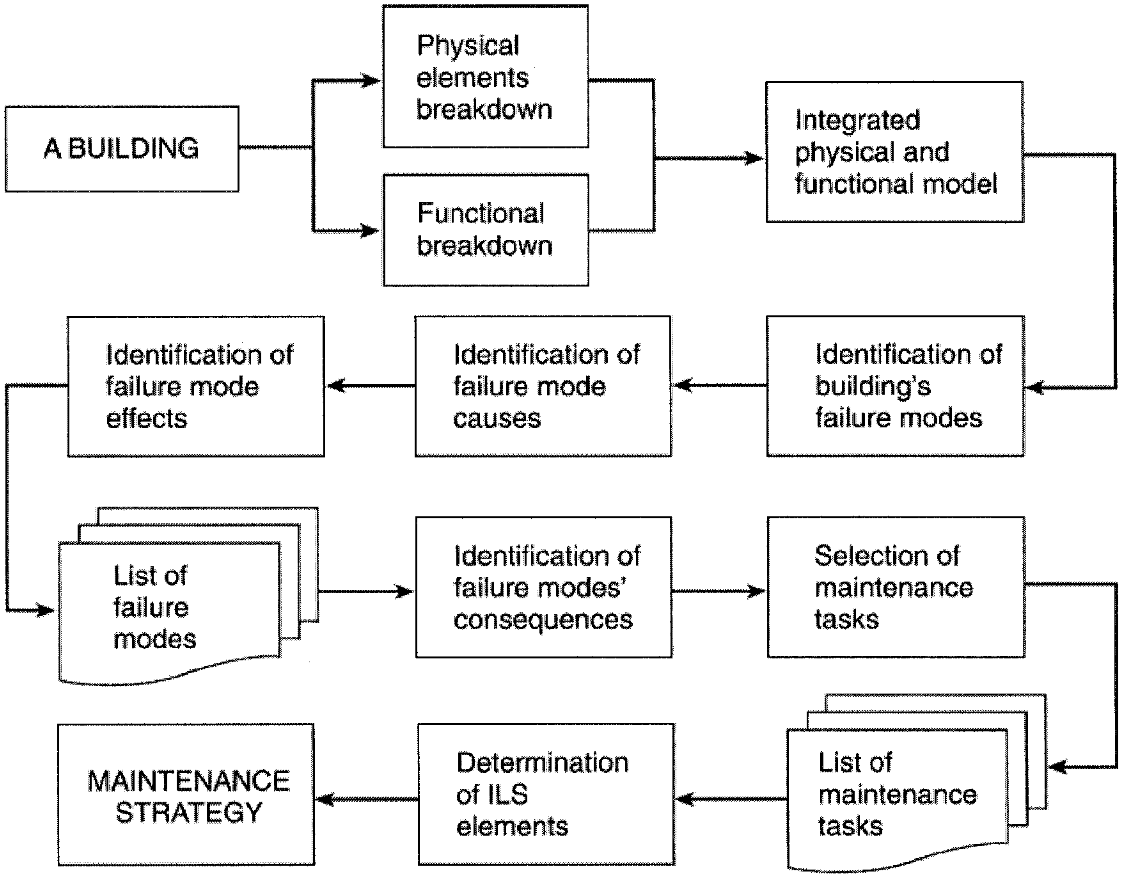


Figure 2. 8 Systematic approach to determine building maintenance strategy (El-Haram and Horner 2003)

El-Haram and Horner (2003) also developed a model, shown in Figure 2.9, that illustrates the physical elements of a building on to their associated functions. The physical elements of a building include three main parts: substructure, superstructure, and services. The principal function of a building can be broken down into subfunctions in order to serve one or more purposes defined by the users and their activities, such as environmental protection, health and hygiene, power and energy, etc. The functional model defines the reasons why the physical elements exist. Each physical element may fulfill more than one function (El-Haram and Horner 2003).

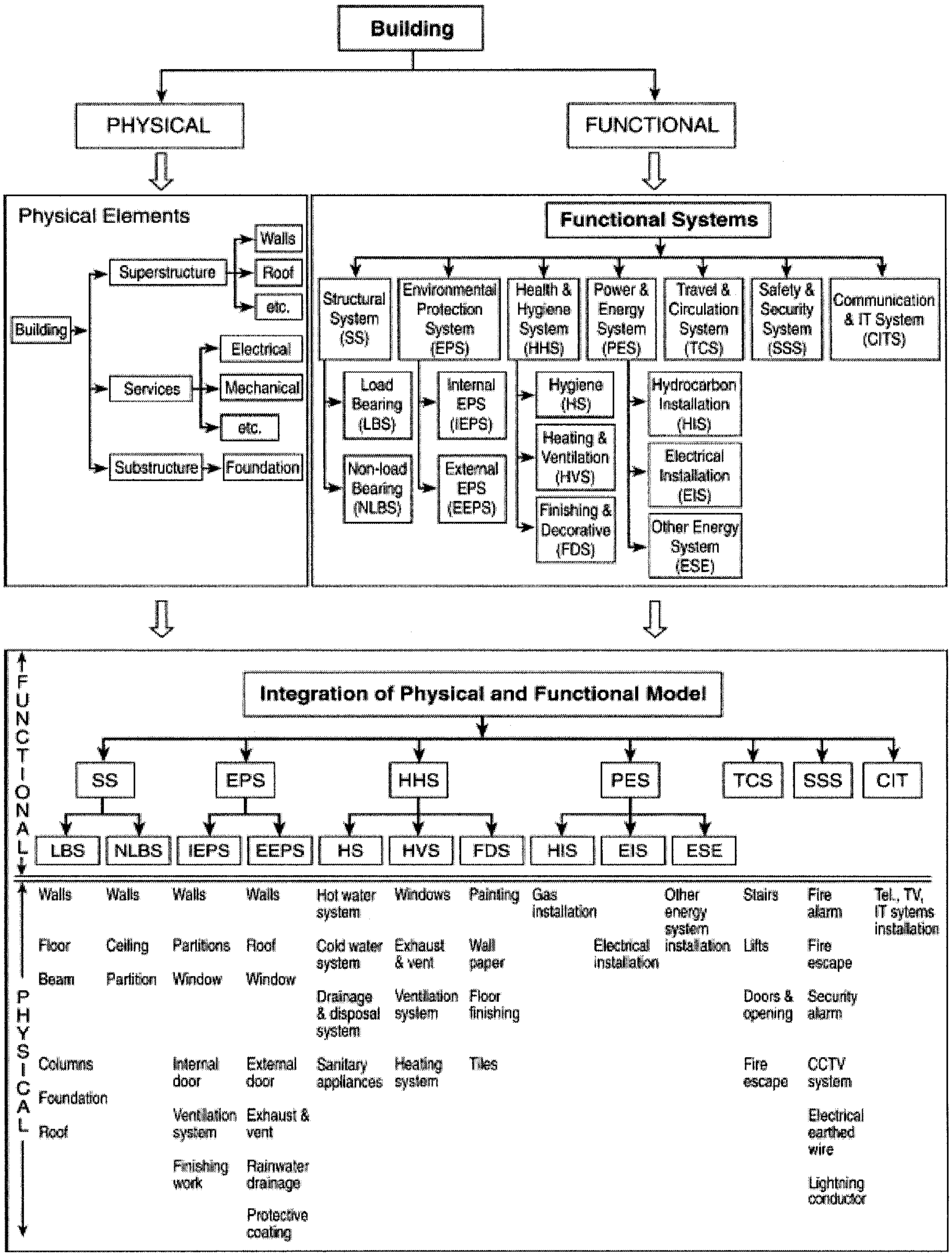


Figure 2. 9 Integration of physical and functional models (El-Haram and Horner 2003)

The maintenance costs can be reduced from the application of two ILS techniques: failure modes and effects analysis and reliability centered maintenance. The case study of a sample of 18 properties indicates that 18.5% of the total maintenance cost can be saved. Maintenance costs were saved by eliminating unnecessary maintenance tasks and avoiding inefficient replacement tasks. (El-Haram and Horner 2003)

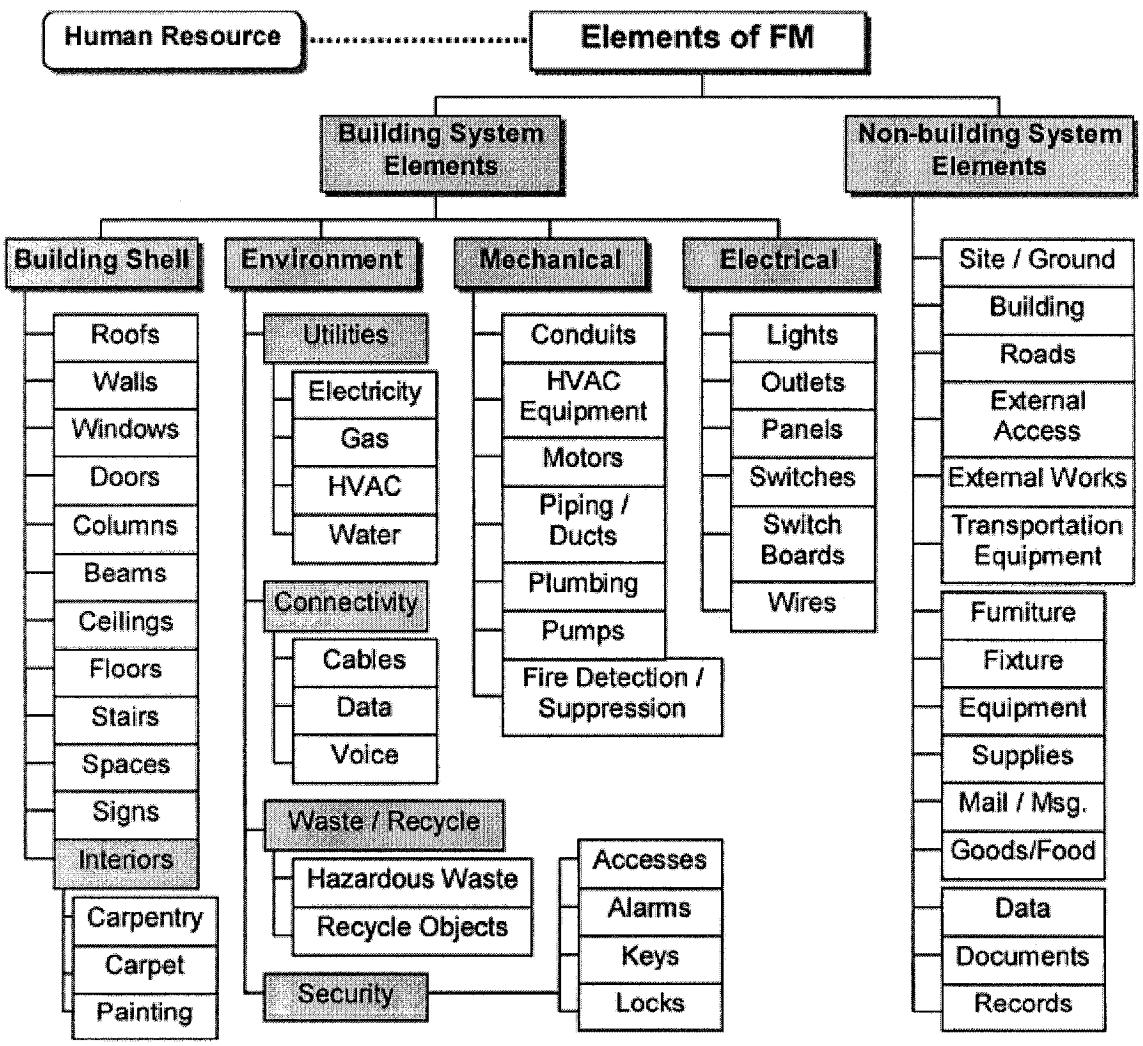


Figure 2. 10 FM Elements (Yu et al. 2000)

Yu et al. (2000) classified the elements of facility management into building systems and nonbuilding systems, with human resources considered to be a parallel element shown in Figure 2.10.

Current research founds that preventive maintenance policy is the most widely used for maintaining the building systems by the companies (Wu and Clements-Croome 2006). The result is shown in Figure 2.11.

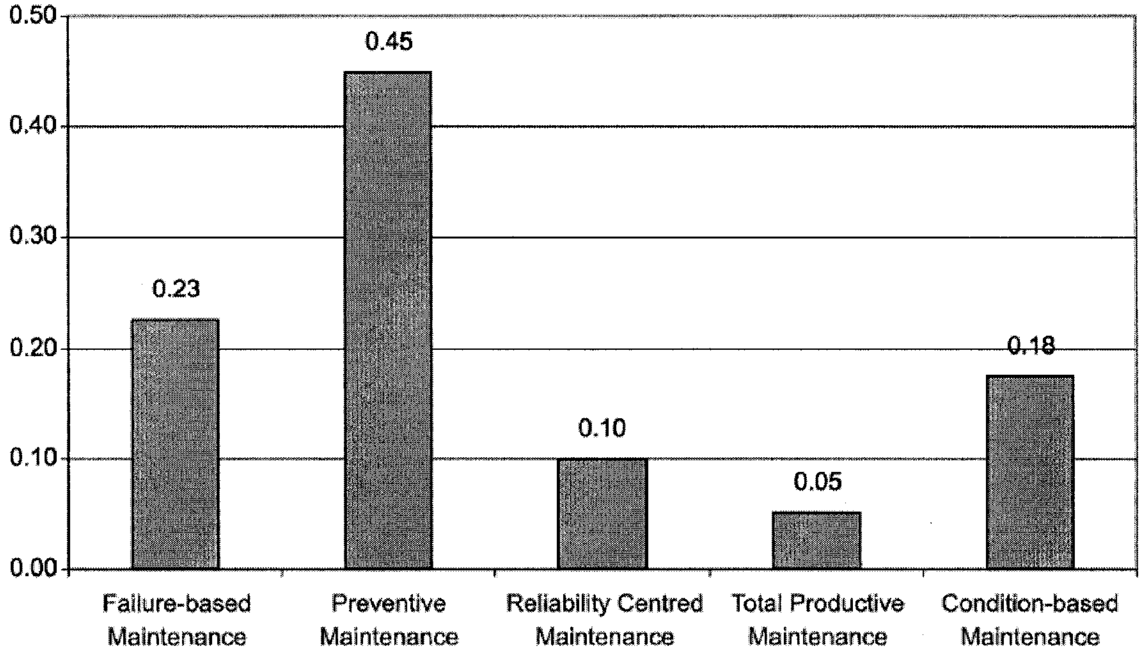


Figure 2. 11 Application of the Maintenance Policies (Wu and Clements-Croome 2006)

Wu et al. (2006) also developed a maintenance logic tree, shown in Figure 2.12, based on the Whole Building Design Guide website (Pride 2004).

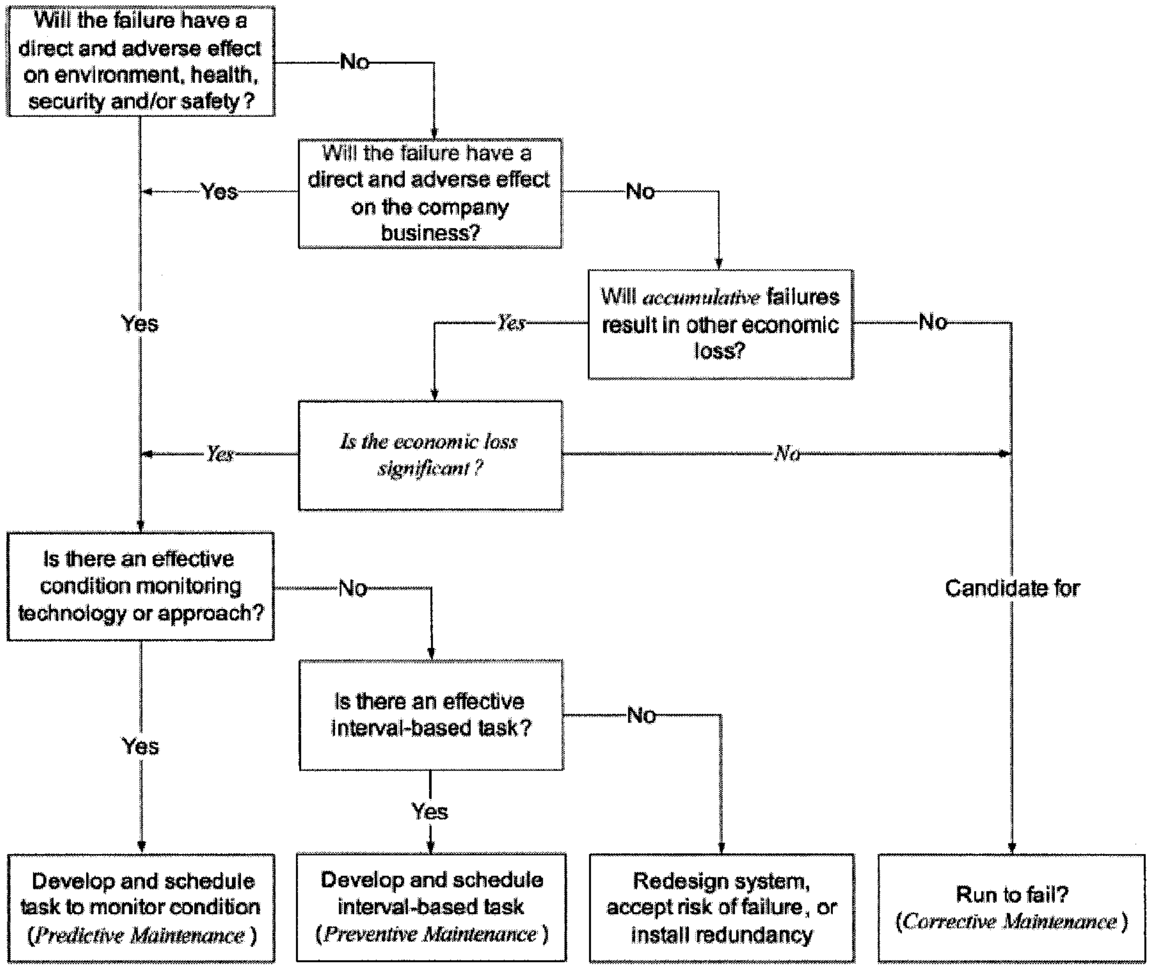


Figure 2. 12 Maintenance Logic Tree (Wu and Clements-Croome 2006)

2.4.3 M/R Costs Models

Kirkham et al. believe that decisions made during design can have a significant impact upon the future running and maintenance costs of buildings. Many efforts have been done on cost modelling by previous work. "All models rely to some extent on assumptions, whether explicit or implicit" (Kirkham et al. 1999). In the opinion of Kirkham et al., the selection of a model should be based on the characteristics of data, general knowledge of the problem to be modeled, general knowledge about boundary conditions of the model, errors that the model can generate, input and output targets and possible consequences, the understanding of accuracy, reliability, validaty, confidence and sensitivity of the model to be selected.

A maintenance costs model was introduced by Al-Hajj (1999) as shown in Equation (2.4). The methodology adopted to develop the model involves identifying a small number of cost elements which represent a consistent and high proportion of the total maintenance costs.

$$M_c = (1.37) \times \sum_{i=1}^{t} (d + f + s) \qquad \textbf{(2.4)}$$

Where,

M_c = Total maintenance cost

t = Time in years

d = Decoration costs

f = Fabric maintenance costs

s = Services maintenance costs

The result studied by Al-Hajj (1999) shows that the model can calculate the costs to an average accuracy of ±13% for total maintenance costs (Al-Hajj 1999).

2.5 Summary

Life Cycle Costing (LCC) is a critical technique that looks beyond the initial price of an item and takes into account the cost of maintaining and powering an asset over its entire operational life. It is becoming a crucial tool for any engineer involved in specifying components.(Howarth 2004) LCC analysis has been applied extensively in many fields. However, “LCC has yet to significantly enter the parlance of decision-making in contemporary building design” (Cole and Sterner 2000). Therefore there are some gaps between the theory and practice of Life-Cycle Cost analysis.

The purpose of an LCC analysis is to estimate the overall costs of project alternatives and to select the design that ensures that the facility will provide the lowest overall cost of ownership consistent with its quality and function (Fuller 2006). To utilize LCC analysis efficiently, the determination of ownership costs is crucial. Among the items of ownership costs, maintenance and repair costs play an important role.

Maintenance and repair activities are parts of the facility management of assets. The facility management process has been reviewed to establish a framework for the maintenance and repair of buildings. One M/R costs model and three facility management models from the literature are introduced. These models took into account most of the elements and functions of buildings. However, some factors that influence M/R costs, such as location, ownership, city, height, size and age, are not considered in these models. The present research will focus on establishing an M/R costs forecasting model and on determining the coefficients of the influence factors. An LCC method, the Net Present Value method, will be used for evaluate the total M/R costs throughout the analyzed life span of office buildings.

Chapter 3

PROPOSED PROCEDURE OF DATA PROCESSING

3.1 General

The accurate evaluation of total ownership costs of assets over their lifetime can assist investors in making appropriate investment decisions. However, the total ownership costs comprise several incurred costs throughout the life span of assets. It is difficult to evaluate all these costs together accurately. The proper way is to identify the components of the total ownership costs first and then evaluate them one by one. Hence, the main components of the total ownership costs are identified first in this chapter.

According to the literature review, operation and M/R costs play a key role among the components of the total ownership costs. The main objective of the present research is to develop a model for forecasting the M/R costs of office buildings in Canada. To achieve this objective, the historical data of the M/R costs of office buildings in Canada have been studied. The proposed procedure of data processing includes data collection, data sorting and analyzing, as well as the Monte Carlo simulation application.

3.2 Components of Total Ownership Costs

The components of total ownership costs can be described in a hierarchy structure as shown in Figure 3.1. The first level describes the main components of the ownership costs involving the capital cost, operation cost, M/R cost, renovation cost, disposal cost, etc. The second level shows the main elements of the maintenance/repair costs of office buildings. These elements include payroll, elevator, HVAC, electrical, structure/roof, plumbing, fire/life safety, general exterior, general interior and contract costs.

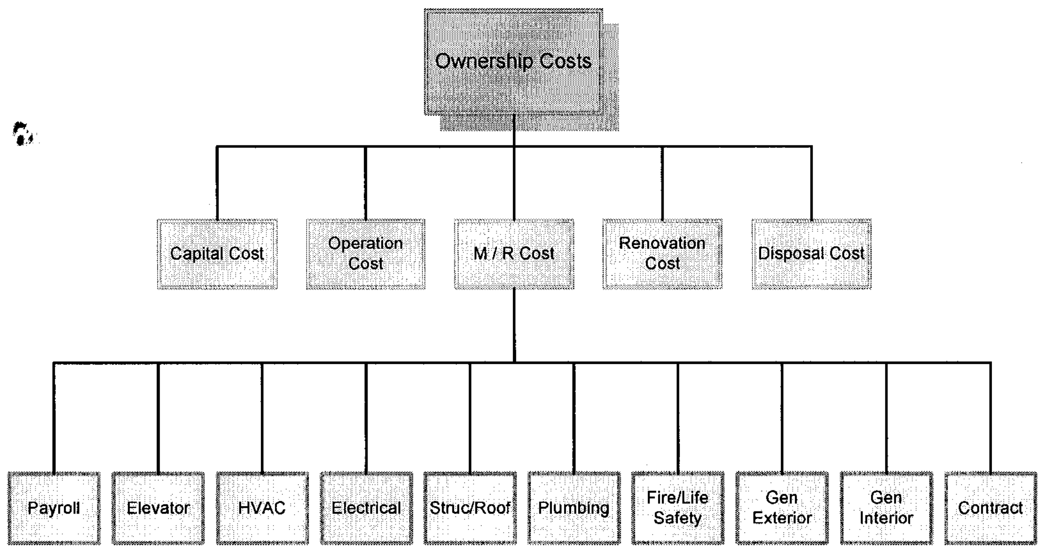


Figure 3. 1 Components of Total Ownership Costs

The contents of each element are described as follows:

Payroll: Payroll, taxes, fringe benefits for directly employed operating engineering and maintenance personnel, including salaried the operating or chief engineers.

Elevator: Includes all elevator contract services, fees, directly expensed tools/equipment, and supplies/materials/miscellaneous expenses.

HVAC: Includes all HVAC contract services, fees, directly expensed tools/equipment, and supplies/materials/miscellaneous expenses.

Electrical: Includes all electrical contract services, fees, directly expensed tools/equipment, and supplies/materials/miscellaneous expenses.

Structural/Roof: Includes contract services, fees and supplies/materials/miscellaneous expensed during the operating year.

Plumbing: Includes contract services, fees and supplies/materials/miscellaneous for domestic water and sewage services. Does not include piping for the mechanical system or the sprinkler/standpipe system.

Fire/Life Safety: Includes contract services, supplies/materials/miscellaneous, maintenance contracts, monitoring contracts, and fees.

General Exterior: Includes directly expensed outlays for building exteriors such as exterior window replacement, repainting, power washing, and so forth.

General Interior: Includes directly expensed outlays for building interiors such as pest control, signage, painting, music, carpet repairs, and other interior surface repairs.

Contract: Portion (dollar value) of the total repair/maintenance expenses that is outsourced or contracted out.

3.3 Data Collection

3.3.1 Data Collection Methods

The actual values of M/R costs can be collected from numerous sources. Historically, many data collection methods ranging from manual procedures to portable computers are utilized. There are many techniques that can be used to collect data when required. These include interviews and focus groups, case studies, surveys and questionnaires, experimentation, observations, measurements, photography, tests and assessments, secondary sources, and data reviews. No one data collection method is the best. Every method is appropriate for a particular purpose and yields information within a particular context. The choice of the data collection method and the technique used for the analysis depends on the type of data required and the purpose for which the data are used.

3.3.2 Data Sources

The sources of data collection for the purposes of the present research include:

- 2002 Building Owner and Manager Association (BOMA) Experience Exchange Report specific to United States and Canada
- IFMA Montreal Chapter
- BLJC company
- Statistics Canada

The detailed information taken from these data sources are described as follows:

1. BOMA *EER*

For over 80 years, BOMA's annual *Experience Exchange Report (EER)* has been the source of building performance data for the commercial real estate industry. Long considered the industry benchmark, the *EER* provides the most current, dependable information that exists. The 2002 BOMA *EER* provides published tables of operating income and expense data for over 4,000 office buildings located in 123 cities throughout North America. In total, this sample covers over 750 million square feet of office space in North America (BOMA 2002).

All data presented in BOMA *EER* is in dollars per square foot per year based on income and expense dollars incurred during the calendar/fiscal year 2001. Canada analyses are reported in Canadian dollars. Income calculation is based on office rentable square feet. Expense calculation is based on total building rentable square feet.

2. IFMA Montreal Chapter

"Launched in 1986, IFMA-Montreal is the active chapter within the Greater Montreal area for the International Facility Management Association, an organization that includes more than 18,000 members from 67 different countries" (IFMA-Montreal 2006)

The objective of IFMA is to bring together all those involved in the development and coordination of projects and services designed to provide an efficient working environment that respects and complies with a company's mission and activities as well as with the needs of all of their personnel. IFMA-Montreal aims at supporting facility managers, supervisors and/or operations officers actively involved in their office services, buildings, and facilities in all of their daily activities. IFMA-Montreal also maintains privileged relationships with a great number of partners within the Montreal area. The questionnaire survey of the present research has been done under the help of IFMA Montreal Chapter.

3. **BLJC Company**

BLJC Company (Brookfield LePage Johnson Controls) is the Canadian leader in workplace management services. BLJC has over 40 years of experience and manage in excess of 1 billion square feet of space worldwide with more than 75 locations in Canada. Some real cases for the case study in the present research are provided by BLJC Company. These cases include PROVIGO HEAD OFFICE, ERICSSON, etc.

4. **Statistics Canada**

Statistics Canada provides daily reports on the state of the economy and the social fabric of Canada. Statistics on health, literacy and crime make front-page news as the reports help monitor the tremendous changes happening in the country. Statistics Canada works in partnership with all sectors of the government, economy and society to identify and fulfill the information requirements of today and tomorrow. The information produced by Statistics

Canada is encyclopedic. It is a literal A to Z of every aspect of Canadian life and economy. Statistics Canada's data collection includes major themes, such as Agriculture, Environment, Health, Manufacturing, Prices, Primary industries, Social conditions, and Travel and Tourism. Information from Statistics Canada influences everything from government policy, to the location of schools and corner stores, to the investment patterns of the financial sector. Behind the deceptively simple numbers lie state-of-the-art computing technology and expertise in survey methodology and statistical methods (StatisticsCanada 2006).

The Consumer Price Index (CPI) is widely used as an indicator of the change in the general level of consumer prices or the rate of inflation. It is obtained by comparing through time, the cost of a fixed basket of commodities purchased by consumers. Table 3.1 shows the data of the Consumer Price Index (CPI) based on 3-month seasonally adjusted cumulative movement compounded to an annual rate (Index, 1992=100) from Statistics Canada. These data are used to figure out the inflation rate in the present research.

Table 3. 1 Consumer Price Index, Monthly (Index, 1992=100)

Time	Inflation Rate	Time	Inflation Rate	Time	Inflation Rate	Time	Inflation Rate	Time	Inflation Rate
1995/01	3.60	1996/01	1.20	1997/01	2.70	1998/01	2.20	1999/01	1.50
1995/02	4.40	1996/02	1.20	1997/02	1.90	1998/02	2.60	1999/02	1.10
1995/03	3.90	1996/03	2.70	1997/03	1.50	1998/03	1.90	1999/03	1.80
1995/04	3.90	1996/04	3.10	1997/04	1.10	1998/04	-0.70	1999/04	3.00
1995/05	3.10	1996/05	3.50	1997/05	0.40	1998/05	0.40	1999/05	3.30
1995/06	2.30	1996/06	1.90	1997/06	0.40	1998/06	0.70	1999/06	2.60
1995/07	1.50	1996/07	0.80	1997/07	0.70	1998/07	1.10	1999/07	1.50
1995/08	0.00	1996/08	0.40	1997/08	1.50	1998/08	0.70	1999/08	2.60
1995/09	0.40	1996/09	1.10	1997/09	1.10	1998/09	-0.40	1999/09	4.10
1995/10	0.00	1996/10	2.30	1997/10	1.10	1998/10	1.10	1999/10	3.30
1995/11	0.80	1996/11	3.40	1997/11	-0.40	1998/11	1.10	1999/11	1.80
1995/12	0.40	1996/12	3.40	1997/12	0.40	1998/12	1.90	1999/12	2.20
2000/01	1.80	2001/01	2.10	2002/01	0.00	2003/01	4.40	2004/01	3.00
2000/02	2.90	2001/02	0.70	2002/02	4.60	2003/02	5.10	2004/02	2.00
2000/03	3.30	2001/03	0.00	2002/03	4.50	2003/03	6.10	2004/03	1.00
2000/04	1.80	2001/04	3.90	2002/04	5.60	2003/04	0.00	2004/04	1.60
2000/05	1.40	2001/05	6.00	2002/05	3.80	2003/05	-2.90	2004/05	3.90
2000/06	1.80	2001/06	5.70	2002/06	3.40	2003/06	-2.60	2004/06	4.30
2000/07	4.70	2001/07	1.70	2002/07	3.40	2003/07	0.00	2004/07	2.90
2000/08	3.60	2001/08	-0.70	2002/08	5.50	2003/08	2.70	2004/08	0.30
2000/09	3.60	2001/09	0.30	2002/09	4.80	2003/09	3.00	2004/09	0.30
2000/10	2.80	2001/10	0.00	2002/10	4.10	2003/10	2.00	2004/10	1.90
2000/11	5.40	2001/11	-3.40	2002/11	3.70	2003/11	1.30	2004/11	3.20
2000/12	4.30	2001/12	-3.00	2002/12	2.70	2003/12	1.60	2004/12	2.90

3.3.3 The format of Analyses from BOMA *EER*

The basic format of the analyses contained in the BOMA *EER* consists of three sections. The first section provides income and expense Summary Data, the second section provides Occupancy Information, and the third section supplies Income/Expense Detail Data.

Table 3.2 shows a sample of the first section of the analysis format in BOMA *EER.* This section provides summary totals for 8 income and 12 expense categories. Income summary categories include Office Area, Retail Area, Other Area, Total Rent, Gross Parking Income, Tenant Services, Miscellaneous, and Total Income. There are two kinds of income and expense figures: the one is for the Total Building Rentable Area (Office + Retail + Other); the other is for Total Office Rentable Area only. The Summary Section also indicates the number of buildings reported in the analysis and the corresponding total building and total office square footage of those buildings.

For all the categories in this Section, five types of data are provided: Number of Buildings, Average, Median, Mid-Range Low, and Mid-Range High. The Number of Buildings (#BLDS) shows the exact number of buildings supplying data for each income or expense category. The Average is calculated by dividing the total dollars by total square footage of all the reported buildings. The Median is the number that lies at the midpoint of the data arrayed from the lowest value to the highest. The Mid-Range is an indication of the middle 50% of the data. The Mid-Range Low is the number below which 25% of the data items lie and the Mid-Range High is the number above which 25% of the data items lie.

Table 3. 2 A Sample of the First Section of Analysis Format in BOMA *EER*

[redacted]

	TOTAL BUILDING RENTAL AREA					TOTAL OFFICE RENTAL AREA			
	118 BLDS	17,653,070 SQ.FT.				16,562,568 SQ.FT.			
	#	DOLLARS/SQ.FT.		MID RANGE		DOLLARS/SQ.FT.		MID RANGE	
INCOME	BLDS	AVG	MEDIAN	LOW	HIGH	AVG	MEDIAN	LOW	HIGH
OFFICE AREA	115					19.54	16.11	12.46	22.06
RETAIL AREA	47	21.27	9.98	8.35	19.37				
OTHER AREA	11	8.15	7.01	6.35	7.96				
TOTAL RENT	113	19.56	15.89	12.40	21.41				
GROSS PARKING INC	65	1.21	1.04	0.55	1.28				
TENANT SERVICES	46	1.98	2.85	1.58	3.87				
MISCELLANE	64	0.25	0.13	0.04	0.30				
TOTAL INCOME	113	22.60	18.77	14.19	24.02				
EXPENSE									
CLEANING	118	1.33	1.25	0.94	1.59	1.37	1.27	0.96	1.59
REPAIR/MAINT	111	1.72	1.54	1.22	1.88	1.74	1.55	1.23	1.93
UTILITIES	115	2.21	1.92	1.59	2.52	2.28	1.96	1.62	2.54
ROADS/GROUNDS	88	0.16	0.12	0.04	0.42	0.17	0.12	0.05	0.42
SECURITY	107	0.40	0.22	0.10	0.39	0.42	0.23	0.10	0.41
ADMINISTRATIVE	118	0.83	0.59	0.20	0.96	0.89	0.61	0.21	1.01
TOTAL OPER EXP	118	6.31	5.83	4.79	6.64	6.72	6.09	4.95	6.81
FIXED EXPENSE	113	4.23	2.41	1.63	4.38	4.52	2.52	1.64	4.55
TOTAL OPER+FIX	118	10.79	8.43	6.94	10.74	11.50	8.65	7.10	11.47
DIR LEASING EXP	73	1.67	2.19	1.27	3.05	1.79	2.29	1.30	3.23
AMORT LEASING EXP	7	0.86	1.16	0.24	4.00	0.94	1.16	0.29	4.10
PARKING EXP	47	0.27	0.03	0.01	0.09	0.29	0.03	0.02	0.09

Table 3.3 expresses a sample of the second section of analysis format in BOMA *EER.* This Section provides information on the tenant and occupancy characteristics of the buildings reporting. The figure in the AVERAGE column is the statistical value, whereas the figure in the BLDS column represents the number of buildings reporting the occupancy item.

Table 3. 3 A Sample of the Second Section of Analysis Format in BOMA *EER*

OCCUPANCY INFO.	AVERAGE	BLDS
SQFT/OFFICE TENANT	9130.41	118
SQFT/RETAIL TENANT		
SQFT/OFFICE WORKER	274.43	57
SQFT/MAINTENANCE STAFF	66687.61	65
OFFICE OCCUPANCY (%)	91.99	81
RETAIL OCCUPANCY (%)	90.31	43
YR-END RENT ($)	21.05	72
GROSS PARKING INC/STALL ($)	1450.83	59
PARKING RATIO (STALLS/1000SF)	1.17	70
RENTABLE/GROSS SQFT	1.04	117
RENTABLE/USABLE SQFT	1.26	117
TOTAL BTUs	81002.63	2
CAPITALIZATION THRESHOLD ($)	25000.00	33
BUILDING HOURS	74.61	118

Table 3.4 shows a sample of the third section of analysis format in BOMA *EER.* This section provides income/expense detail information. These income and expenses are components of the summary categories given in the Income and Expenses Summary Section. Only an Average figure is given in this section for each detail category along with the Number of Buildings reporting in that category. All average income figures represent Total Office Rentable Area, and all average expense figures represent Total Building Rentable Area.

Table 3. 4 A sample of the third section of analysis format in BOMA *EER*

DETAIL	AVERAGE	BLDS	DETAIL	AVERAGE	BLDS	DETAIL	AVERAGE	BLDS	DETAIL	AVERAGE	BLDS	DETAIL	AVERAGE	BLDS
OFFICE RENT			ELEVATOR	0.16	109	**RDS/GDS**			GEN OFC EXP	0.12	74	DIR-TENANT IMP	1.30	64
BASE RENT	13.43	105	HVAC	0.36	113	RDS/GDS LANDSCAPE	0.04	33	EMP EXP	0.02	11	DIR-OTHER	0.53	60
PASS-THROUGHS	6.36	17	ELECTRICAL	0.08	74	RDS/GDS GARAGE	0.25	12	OTHER ADM EXP	0.06	63	AMORT-COMMISION	0.19	5
OPER COST ESCAL	7.20	59	STRUC/ROOF	0.10	100	RDS/GDS SNOW	0.03	20				AMORT-TENANT IMP	2.82	5
BASE RENT ESCAL			PLUMBING	0.06	109	RDS/GDS OTHER	0.08	85	**FIXED EXPENSES**			AMORT-BUY-OUTS		
LEASE CANCEL	2.22	2	FIRE/LIFE SAFETY	0.05	107				REAL ESTATE TAX	4.02	106	AMORT-OTHER		
RENT ABATEMENT	1.34	58	GEN EXTERIOR	0.08	106	**SEC**			BLDG INSURANCE	0.09	115			
			GEN INTERIOR	0.26	98	SEC PAYROLL	0.18	38	PERS PROP TAX	2.02	5	**PARKING**		
CLEANING			CONTRACT	1.16	29	SEC CONTRACT	0.26	48	OTHER TAX	0.13	10	IN HOUSE	0.04	43
PAYROLL	0.27	40				SEC EQUIPMENT	0.03	8	LICENSE FEE			CONTRACT	0.63	4
ROUTINE CONTRACT	1.11	106	**UTILITIES**			SEC OTHER	0.20	65	**LEASING EXPENSE**			SNOW		
SPEC CONTRACT	0.16	71	ELECTRICITY	1.60	115				PAYROLL			SHUTTLE		
SUP/MAT/MISC	0.08	19	GAS	0.39	48	**ADMINISTRATIVE**			ADV/PROMOTION	0.05	43	**TELECOMMUNICATIONS**		
TRASH REMOVAL	0.07	94	FUEL OIL	0.44	54	PAYROLL	0.20	72	TRAVEL	0.01	4	WIRE ACCESS	0.02	4
			STEAM	1.08	6	ALLOC ADMIN	0.27	4	DIR-COMMISSIONS	0.48	26	ROOF TOP	0.04	5
REPAIR/MAINT			CH WTR			MGMT FEES	0.84	56	DIR-BUY OUT			TOTAL INCOME	0.02	9
PAYROLL	0.70	103	WATER/SEWER	0.13	102	PROF FEES	0.04	68	PROF FEES	0.07	55	TOTAL EXPENSES		

3.3.4 Collected Data

The present research focuses on the M/R costs of office buildings. All the data related to the detailed costs of the maintenance and repair elements are collected from the third section of analyses in 2002 BOMA *EER*. These elements include payroll, elevator, HVAC, electrical, structure/roof, plumbing, fire/life safety, general exterior, general interior and contract. The data collected for this research represent 118 buildings with a total building rental area of 17,653,070 SQ.FT. in the Canada Private Sector and 219 buildings with a total building rental area of 23,620,664 SQ.FT. in the Canada Government Sector. Table 3.5 shows a sample of data collection.

Table 3. 5 A Sample of Data Collection

ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
Calgary, AB (D)	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil
Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil
Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59
Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil
Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78
Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13
Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil
Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83
West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil

3.4 Analyzing and sorting collected data

In this study the data analysis phase included the reviewing of the data for accuracy, completeness, and consistency. The data were then summarized and organized. A wide range of statistical data analysis methods were also considered. These included the analysis of variance, regression analysis, categorical data analysis, multivariate analysis, survival analysis, psychometric analysis, etc.

The collected data show that the M/R costs of office buildings in Canada vary from city to city, from the private sector to the government sector, from downtown areas to suburban areas, and they vary according to building heights, building ages, and building sizes. What is the numerical relationship between the M/R costs and these conditions? For the purpose of the present research the collected data were organized into eight categories. These categories are: Canada private sector city analyses (including both downtown and suburban), Canada government sector city analyses (including both downtown and suburban), Canada city analyses (all downtown), Canada city analyses (all suburban), Canada city analyses (including both the private sector and the government sector with all downtown and all suburban), height analysis, size analysis and age analysis.

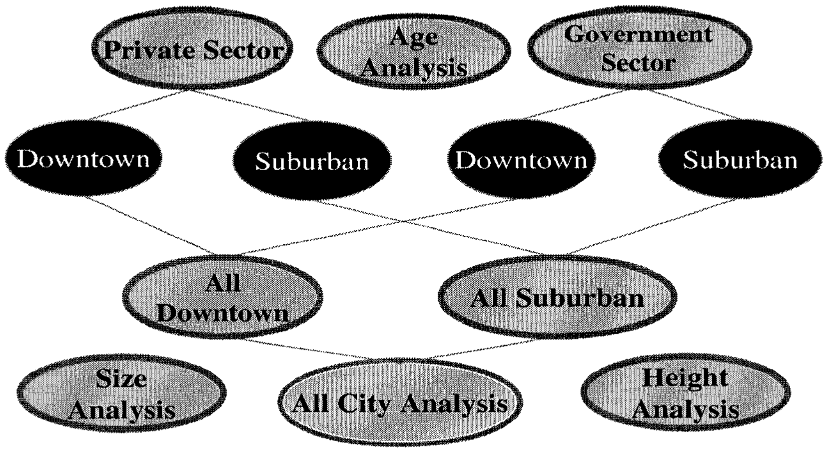


Figure 3. 2 Sorted Data Categories

Figure 3.2 shows these eight categories. The ***first*** category expresses all the maintenance and repair costs of office buildings reported by the Canada Private Sector. These office buildings are located in both downtown and suburban areas. Table 3.6 shows the collected data of the first category after being analyzed and sorted accordingly.

Table 3. 6 M/R Costs of Office Buildings (Canada Private Sector Based Analyses)

M/R COSTS OF OFFICE BUILDINGS REPORTED BY CANADA PRIVATE SECTOR (Unit: $/sq.ft.)											
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
DOWNTOWN	Calgary, AB (D)	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil
	Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil
	Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59
	Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil
	Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78
	Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13
	Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil
	Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83
	West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil
SUBURBAN	Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85
	Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	Nil
	Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	Nil
	Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88
	Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	Nil

The ***second*** category expresses all the maintenance and repair costs of office buildings reported in the Canada Government Sector. These office buildings are also located in both downtown and suburban areas. Table 3.7 shows the collected data of the second category after being analyzed and sorted accordingly.

Table 3. 7 M/R Costs of Office Buildings (Canada Government Sector Based Analyses)

M/R COSTS OF OFFICE BUILDINGS REPORTED BY CANADA GOVERNMENT SECTOR (Unit: $/sq.ft.)											
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
DOWNTOWN	Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	Nil
	Chicoutimi, PQ	0.97	0.06	0.18	0.12	Nil	0.01	0.10	Nil	0.97	Nil
	Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	Nil	1.30	Nil
	London, ON	0.36	0.30	0.31	0.19	Nil	0.01	0.12	Nil	0.74	Nil
	Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	Nil	0.79	Nil
	Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24
	Quebec, PQ	1.14	0.11	0.26	0.05	0.33	Nil	0.12	Nil	0.84	1.41
	Saint John, NB	0.92	0.21	0.20	0.01	Nil	Nil	0.05	Nil	0.66	Nil
	St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	Nil	1.32	Nil
	Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	Nil	0.68	Nil
	Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	Nil	1.99	Nil
	Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	Nil	0.45	Nil
	Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	Nil	0.25	Nil
	Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	Nil	0.83	Nil
SUBURBAN	Barrie, ON	1.86	0.38	0.28	0.08	Nil	0.01	0.10	Nil	1.44	Nil
	Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	Nil	1.09	Nil
	Fredericton, NB	1.11	0.18	1.02	Nil	0.98	0.44	0.34	Nil	1.52	Nil
	Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	Nil	0.98	Nil
	Kingston, ON	0.94	0.12	0.85	0.17	Nil	0.03	0.73	Nil	1.32	Nil
	Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	Nil	0.66	Nil
	Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	Nil	0.66	Nil
	Saint John, NB	1.27	Nil	0.34	Nil	1.21	Nil	0.04	Nil	1.81	Nil
	St. John's, NF	1.02	Nil	0.27	0.35	Nil	Nil	0.06	Nil	1.08	Nil
	Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	Nil	1.18	Nil
	Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	Nil	0.77	Nil
	Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	Nil	0.11	Nil
	White Horse, YT	Nil	0.19	0.39	0.05	Nil	Nil	0.06	Nil	0.98	Nil
	Yellowknife, NWT	1.88	0.20	0.99	0.29	Nil	0.21	0.05	Nil	1.39	Nil

The ***third*** category expresses all the maintenance and repair costs of office buildings reported in both Canada Private Sector and Canada Government

Sector that are located in downtown areas. Table 3.8 shows the collected data of the third category after being analyzed and sorted accordingly.

Table 3. 8 M/R Costs of Office Buildings (Canada City Based Analyses--All Downtown)

M/R COSTS OF OFFICE BUILDINGS IN DOWNTOWN IN CANADA (Unit: $/sq.ft.)											
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
GOVERNMENT SECTOR	Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	Nil
	Chicoutimi, PQ	0.97	0.06	0.18	0.12	Nil	0.01	0.10	Nil	0.97	Nil
	Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	Nil	1.30	Nil
	London, ON	0.36	0.30	0.31	0.19	Nil	0.01	0.12	Nil	0.74	Nil
	Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	Nil	0.79	Nil
	Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24
	Quebec, PQ	1.14	0.11	0.26	0.05	0.33	Nil	0.12	Nil	0.84	1.41
	Saint John, NB	0.92	0.21	0.20	0.01	Nil	Nil	0.05	Nil	0.66	Nil
	St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	Nil	1.32	Nil
	Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	Nil	0.68	Nil
	Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	Nil	1.99	Nil
	Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	Nil	0.45	Nil
	Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	Nil	0.25	Nil
	Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	Nil	0.83	Nil
PRIVATE SECTOR	Calgary, AB	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil
	Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil
	Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59
	Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil
	Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78
	Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13
	Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil
	Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83
	West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil

The ***fourth*** category expresses all the maintenance and repair costs of office buildings reported in both the Canada Private Sector and the Canada Government Sector that are located in suburban areas. Table 3.9 shows the collected data of the fourth category after being analyzed and sorted accordingly.

Table 3. 9 M/R Costs of Office Buildings (Canada City Based Analyses--All Suburban)

M/R COSTS OF OFFICE BUILDINGS IN SUBURBAN IN CANADA (Unit: $/sq.ft.)											
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
GOVERNMENT SECTOR	Barrie, ON	1.86	0.38	0.28	0.08	Nil	0.01	0.10	Nil	1.44	Nil
	Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	Nil	1.09	Nil
	Fredericton, NB	1.11	0.18	1.02	Nil	0.98	0.44	0.34	Nil	1.52	Nil
	Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	Nil	0.98	Nil
	Kingston, ON	0.94	0.12	0.85	0.17	Nil	0.03	0.73	Nil	1.32	Nil
	Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	Nil	0.66	Nil
	Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	Nil	0.66	Nil
	Saint John, NB	1.27	Nil	0.34	Nil	1.21	Nil	0.04	Nil	1.81	Nil
	St. John's, NF	1.02	Nil	0.27	0.35	Nil	Nil	0.06	Nil	1.08	Nil
	Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	Nil	1.18	Nil
	Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	Nil	0.77	Nil
	Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	Nil	0.11	Nil
	White Horse, YT	Nil	0.19	0.39	0.05	Nil	Nil	0.06	Nil	0.98	Nil
	Yellowknife, NWT	1.88	0.20	0.99	0.29	Nil	0.21	0.05	Nil	1.39	Nil
PRIVATE SECTOR	Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85
	Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	Nil
	Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	Nil
	Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88
	Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	Nil

The ***fifth*** category expresses all the maintenance and repair costs of office buildings reported in both the Canada Private Sector and the Canada Government Sector that are located in both downtown and suburban areas. Table 3.10 shows the collected data of the fifth category after being analyzed and sorted accordingly.

Table 3. 10 M/R Costs of Office Buildings (Canada City Based Analyses)

M/R COSTS OF OFFICE BUILDINGS IN CANADA (Unit: $/sq.ft.)											
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
GOVERNMENT SECTOR (DOWNTOWN)	Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	Nil
	Chicoutimi, PQ	0.97	0.06	0.18	0.12	Nil	0.01	0.10	Nil	0.97	Nil
	Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	Nil	1.30	Nil
	London, ON	0.36	0.30	0.31	0.19	Nil	0.01	0.12	Nil	0.74	Nil
	Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	Nil	0.79	Nil
	Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24
	Quebec, PQ	1.14	0.11	0.26	0.05	0.33	Nil	0.12	Nil	0.84	1.41
	Saint John, NB	0.92	0.21	0.20	0.01	Nil	Nil	0.05	Nil	0.66	Nil
	St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	Nil	1.32	Nil
	Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	Nil	0.68	Nil
	Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	Nil	1.99	Nil
	Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	Nil	0.45	Nil
	Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	Nil	0.25	Nil
	Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	Nil	0.83	Nil
GOVERNMENT SECTOR (SUBURBAN)	Barrie, ON	1.86	0.38	0.28	0.08	Nil	0.01	0.10	Nil	1.44	Nil
	Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	Nil	1.09	Nil
	Fredericton, NB	1.11	0.18	1.02	Nil	0.98	0.44	0.34	Nil	1.52	Nil
	Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	Nil	0.98	Nil
	Kingston, ON	0.94	0.12	0.85	0.17	Nil	0.03	0.73	Nil	1.32	Nil
	Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	Nil	0.66	Nil
	Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	Nil	0.66	Nil
	Saint John, NB	1.27	Nil	0.34	Nil	1.21	Nil	0.04	Nil	1.81	Nil
	St. John's, NF	1.02	Nil	0.27	0.35	Nil	Nil	0.06	Nil	1.08	Nil
	Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	Nil	1.18	Nil
	Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	Nil	0.77	Nil
	Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	Nil	0.11	Nil
	White Horse, YT	Nil	0.19	0.39	0.05	Nil	Nil	0.06	Nil	0.98	Nil
	Yellowknife, NWT	1.88	0.20	0.99	0.29	Nil	0.21	0.05	Nil	1.39	Nil
PRIVATE SECTOR (DOWNTOWN)	Calgary, AB	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil
	Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil
	Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59
	Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil
	Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78
	Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13
	Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil
	Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83
	West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil
PRIVATE SECTOR (SUBURBAN)	Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85
	Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	Nil
	Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	Nil
	Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88
	Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	Nil

The ***sixth*** category expresses all the maintenance and repair costs of office buildings reported according to the building heights. Table 3.11 shows the collected data of the sixth category after being analyzed and sorted accordingly.

Table 3. 11 M/R Costs of Office Buildings (Height Based Analyses)

M/R COSTS OF OFFICE BUILDINGS IN CANADA_HEIGHT BASED ANALYSES (Unit: $/sq.ft.)											
ITEMS		PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
LESS THAN 5 STORIES											
Private Sector	0-9 years	0.77	0.15	0.17	0.04	0.10	0.02	0.03	0.15	0.06	Nil
	10-19 years	0.55	0.10	0.33	0.08	0.05	0.04	0.07	0.12	0.25	Nil
	20-29 years	0.77	0.20	0.27	0.08	0.23	0.05	0.04	0.02	0.03	0.67
	30-39 years	0.97	0.23	0.30	Nil	0.44	0.09	0.06	0.01	0.10	Nil
	40-49 years	1.08	0.06	0.10	Nil	0.17	0.03	0.07	0.01	Nil	Nil
	50 years or more	0.68	0.11	0.11	Nil	0.22	0.04	0.04	0.01	0.03	Nil
Government Sector	0-9 years	1.46	0.18	0.20	0.39	1.59	0.04	0.08	Nil	0.64	Nil
	10-19 years	1.91	0.12	0.39	0.18	0.20	0.06	0.20	Nil	1.04	Nil
	20-29 years	0.68	0.10	0.26	0.15	0.19	0.04	0.10	Nil	0.76	Nil
	30-39 years	0.97	0.11	0.36	0.18	0.61	0.03	0.22	Nil	0.75	1.33
	40-49 years	0.86	0.19	0.43	0.26	0.37	0.08	0.15	0.03	1.03	1.50
	50 years or more	0.85	0.34	0.35	0.12	1.27	0.03	0.19	Nil	0.92	Nil
5-9 STORIES											
Private Sector	0-9 years	0.85	0.15	0.58	0.12	0.27	0.03	0.02	0.08	0.15	1.16
	10-19 years	0.63	0.15	0.14	0.04	0.09	0.03	0.03	0.08	0.08	Nil
	20-29 years	0.71	0.07	0.27	0.14	0.07	0.08	0.04	0.07	0.10	0.86
Government Sector	10-19 years	1.05	0.13	0.22	0.16	0.26	0.02	0.05	Nil	0.64	Nil
	20-29 years	1.38	0.08	0.24	0.12	0.05	Nil	0.04	Nil	Nil	Nil
	30-39 years	0.82	0.35	0.37	0.05	0.60	0.20	0.15	Nil	1.27	Nil
	40-49 years	0.75	0.23	1.07	0.30	0.26	0.02	0.12	Nil	1.31	Nil
	50 years or more	1.06	0.25	0.36	0.05	0.24	0.07	0.13	Nil	1.19	Nil
10-19 STORIES											
Private Sector	10-19 years	0.63	0.17	0.31	0.07	0.07	0.09	0.05	0.12	0.13	1.24
	20-29 years	0.78	0.12	0.35	0.06	0.09	0.04	0.05	0.09	0.11	0.92
Government Sector	20-29 years	0.47	0.30	0.44	0.40	0.38	0.05	0.22	Nil	1.01	Nil
	30-39 years	0.54	0.25	0.55	0.35	0.34	0.36	0.09	0.04	0.93	Nil
	40-49 years	0.70	0.33	0.27	0.04	0.21	0.10	0.09	Nil	1.58	Nil
	50 years or more	0.72	0.34	0.50	0.44	0.51	0.45	0.76	Nil	1.94	Nil
20-29 STORIES											
Private Sector	30-39 years	0.97	0.23	0.30	Nil	0.44	0.09	0.06	0.01	0.10	Nil
Government Sector	20-29 years	0.64	0.39	0.45	0.22	0.10	0.11	0.15	Nil	0.96	Nil

The ***seventh*** category expresses all the maintenance and repair costs of office buildings reported according to the building sizes. Table 3.12 shows the collected data of the seventh category after being analyzed and sorted accordingly.

Table 3. 12 M/R Costs of Office Buildings (Size Based Analyses)

M/R COSTS OF OFFICE BUILDINGS IN CANADA_SIZE BASED ANALYSES (Unit: $/sq.ft.)											
ITEMS		PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
LESS THAN 50,000 SQ.FT											
Private sector	0-9 years	Nil	0.17	0.20	Nil	0.08	0.05	0.08	0.13	0.10	Nil
	10-19 years	0.63	0.17	0.18	0.05	0.08	0.03	0.03	0.11	0.40	Nil
	20-29 years	1.02	0.18	0.24	Nil	0.19	0.07	0.03	0.02	0.02	0.57
	30-39 years	0.95	0.23	0.24	Nil	0.28	0.04	0.06	0.02	0.02	Nil
	50 years or more	0.77	0.13	0.11	Nil	0.33	0.04	0.06	0.02	0.03	Nil
Government sector	0-9 years	2.09	0.22	0.57	0.58	1.59	0.11	0.09	Nil	1.09	Nil
	10-19 years	1.23	0.11	0.33	0.12	0.62	0.02	0.29	Nil	1.12	Nil
	20-29 years	1.05	0.29	0.28	0.37	1.46	0.02	0.08	Nil	0.72	Nil
	30-39 years	0.92	0.18	0.30	0.19	0.65	0.03	0.06	Nil	0.88	Nil
	40-49 years	1.09	0.20	0.42	0.11	0.61	0.05	0.10	0.21	1.00	Nil
	50 years or more	0.90	0.26	0.24	0.06	2.71	0.04	0.24	Nil	1.31	Nil
50,000-99,999 SQ.FT											
Private sector	0-9 years	0.87	0.09	0.30	0.04	0.27	0.04	0.03	0.12	0.12	Nil
	10-19 years	0.72	0.09	0.23	0.07	0.08	0.03	0.06	0.12	0.13	Nil
	20-29 years	0.75	0.01	0.23	0.16	0.05	0.07	0.07	0.11	0.12	0.76
Government sector	20-29 years	0.69	0.13	0.25	0.35	0.11	0.01	0.08	Nil	0.66	Nil
	30-39 years	0.98	0.10	0.36	0.10	0.18	0.08	0.30	Nil	0.93	1.33
	40-49 years	0.74	0.25	0.48	0.21	0.52	0.02	0.28	Nil	1.29	Nil
	50 years or more	1.49	0.31	0.36	0.13	0.55	0.06	0.12	Nil	0.87	Nil
100,000-299,999 SQ.FT.											
Private sector	0-9 years	0.83	0.13	0.35	0.10	0.08	0.02	0.04	0.09	0.05	Nil
	10-19 years	0.63	0.18	0.26	0.09	0.07	0.09	0.04	0.10	0.13	1.00
	20-29 years	0.80	0.08	0.21	0.05	0.13	0.06	0.05	0.07	0.08	0.56
	30-39 years	0.65	0.12	0.25	0.11	0.12	0.05	0.07	0.08	0.10	0.63
Government sector	10-19 years	1.77	0.20	0.35	0.22	0.12	0.05	0.14	Nil	0.68	Nil
	20-29 years	0.89	0.10	0.38	0.17	0.20	0.04	0.13	Nil	0.76	Nil
	30-39 years	0.67	0.28	0.46	0.13	0.44	0.40	0.12	0.04	0.76	Nil
	40-49 years	0.83	0.24	0.66	0.19	0.27	0.07	0.09	Nil	1.45	Nil
	50 years or more	0.84	0.33	0.52	0.20	0.24	0.18	0.34	Nil	1.52	Nil
300,000-599,999 SQ.FT.											
Private sector	10-19 years	0.63	0.14	0.18	0.02	0.04	0.06	0.03	0.10	0.09	Nil
	20-29 years	Nil	0.16	0.35	0.27	0.03	0.04	Nil	0.08	0.10	Nil
Government sector	20-29 years	0.48	0.29	0.42	0.27	0.35	0.09	0.17	Nil	1.17	Nil
	30-39 years	0.37	0.35	0.66	0.43	0.24	0.03	0.08	Nil	1.22	Nil
	40-49 years	0.63	0.26	0.28	0.19	0.13	0.13	0.08	Nil	1.17	Nil
600,000 SQ.FT. OR MORE											
Government sector	20-29 years	0.55	0.37	0.40	0.31	0.14	0.08	0.19	Nil	0.85	Nil

The ***eighth*** category expresses all the maintenance and repair costs of office buildings reported according to the building ages. Table 3.13 shows the collected data of the eighth category after being analyzed and sorted accordingly.

Table 3. 13 M/R Costs of Office Buildings (Age Based Analyses)

M/R COSTS OF OFFICE BUILDINGS IN CANADA_AGE BASED ANALYSES (Unit: $/sq.ft.)											
ITEMS		PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT
0-9 YEARS											
Private Sector	< 50,000sqft	Nil	0.17	0.20	Nil	0.08	0.05	0.08	0.13	0.10	Nil
	50,000-99,999sqft	0.87	0.09	0.30	0.04	0.27	0.04	0.03	0.12	0.12	Nil
	100,000-299,999sqft	0.83	0.13	0.35	0.10	0.08	0.02	0.04	0.09	0.05	Nil
Government Sector	All Sizes	1.33	0.20	0.27	0.32	Nil	0.05	0.14	Nil	1.10	Nil
10-19 YEARS											
Private Sector	< 50,000sqft	0.63	0.17	0.18	0.05	0.08	0.03	0.03	0.11	0.40	Nil
	50,000-99,999sqft	0.72	0.09	0.23	0.07	0.08	0.03	0.06	0.12	0.13	Nil
	100,000-299,999sqft	0.63	0.18	0.26	0.09	0.07	0.09	0.04	0.10	0.13	1.00
	300,000-599,999sqft	0.61	0.14	0.18	0.02	0.04	0.06	0.03	0.10	0.09	Nil
Government Sector	< 50,000sqft	1.23	0.11	0.33	0.12	0.62	0.02	0.29	Nil	1.12	Nil
	100,000-299,999sqft	1.77	0.20	0.35	0.22	0.12	0.05	0.14	Nil	0.68	Nil
20-29 YEARS											
Private Sector	< 50,000sqft	1.02	0.18	0.24	Nil	0.19	0.07	0.03	0.02	0.02	0.57
	50,000-99,999sqft	0.75	0.01	0.23	0.16	0.05	0.07	0.07	0.11	0.12	0.76
	100,000-299,999sqft	0.80	0.08	0.21	0.05	0.13	0.06	0.05	0.07	0.08	0.56
	300,000-599,999sqft	Nil	0.16	0.35	0.27	0.03	0.04	Nil	0.08	0.10	Nil
Government Sector	< 50,000sqft	1.05	0.29	0.28	0.37	1.46	0.02	0.08	Nil	0.72	Nil
	50,000-99,999sqft	0.69	0.13	0.25	0.35	0.11	0.01	0.08	Nil	0.66	Nil
	100,000-299,999sqft	0.89	0.10	0.38	0.17	0.20	0.04	0.13	Nil	0.76	Nil
	300,000-599,999sqft	0.48	0.29	0.42	0.27	0.35	0.09	0.17	Nil	1.17	Nil
	600,000sft or more	0.55	0.37	0.40	0.31	0.14	0.08	0.19	Nil	0.85	Nil
30-39 YEARS											
Private Sector	< 50,000sqft	0.95	0.23	0.24	Nil	0.28	0.04	0.06	0.02	0.02	Nil
	100,000-299,999sqft	0.65	0.12	0.25	0.11	0.12	0.05	0.07	0.08	0.10	0.63
Government Sector	< 50,000sqft	0.92	0.18	0.30	0.19	0.65	0.03	0.06	Nil	0.88	Nil
	50,000-99,999sqft	0.98	0.10	0.36	0.10	0.18	0.08	0.30	Nil	0.93	1.33
	100,000-299,999sqft	0.67	0.28	0.46	0.13	0.44	0.40	0.12	0.04	0.76	Nil
	300,000-599,999sqft	0.37	0.35	0.66	0.43	0.24	0.03	0.08	Nil	1.22	Nil
40-49 YEARS											
Private Sector	All Sizes	0.94	0.02	0.10	0.03	0.07	0.04	0.03	0.10	0.10	0.21
Government Sector	< 50,000sqft	1.09	0.20	0.42	0.11	0.61	0.05	0.10	0.21	1.00	Nil
	50,000-99,999sqft	0.74	0.25	0.48	0.21	0.52	0.02	0.28	Nil	1.29	Nil
	100,000-299,999sqft	0.83	0.24	0.66	0.19	0.27	0.07	0.09	Nil	1.45	Nil
	300,000-599,999sqft	0.63	0.26	0.28	0.19	0.13	0.13	0.08	Nil	1.17	Nil
50 YEARS OR MORE											
Private Sector	All Sizes	0.48	0.26	0.19	0.14	0.22	0.06	0.07	0.08	0.15	Nil
Government Sector	< 50,000sqft	0.90	0.26	0.24	0.06	2.71	0.04	0.24	Nil	1.31	Nil
	50,000-99,999sqft	1.49	0.31	0.36	0.13	0.55	0.06	0.12	Nil	0.87	Nil
	100,000-299,999sqft	0.84	0.33	0.52	0.20	0.24	0.18	0.34	Nil	1.52	Nil

3.5 Maintenance and Repair Costs Analyses

3.5.1 Data treatment by statistical method

3.5.1.1 Statistical Methods

After being analyzed and sorted, the collected historic data are ready for the maintenance and repair cost analyses. Both deterministic and stochastic methods can be used in applying M/R cost analyses. When using a deterministic method, a simple statistical approach will be applied. The M/R cost of each category should be the average value of all data collected in this category. That is, the MRC should be the summation of all the average values of the 10 detailed M/R cost items: payroll, elevator, HVAC, electrical, structure/roof, plumbing, fire/life safety, general exterior, general interior and contract costs.

When the model is complex or involves more than a couple of uncertain parameters, the stochastic method should be used. A stochastic model involves probability or randomness that is introduced later in 3.5.2.

3.5.1.2 Data Treatment

Based on the categories sorted in 3.4, all data has been treated for M/R cost analyses. The **AVERAGE, LOWEST, HIGHEST AND STANDARD DEVIATION** values of the M/R costs of all items are calculated. Table 3.14 shows the M/R cost analysis of the first category. **MRCP** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in the Canada private sector.

Table 3. 14 M/R Cost Analysis of the First Category

M/R COSTS OF OFFICE BUILDINGS REPORTED BY CANADA PRIVATE SECTOR (Unit: $/sq.ft.)												
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
DOWNTOWN	Calgary, AB (D)	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil	1.43
	Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil	1.53
	Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59	4.21
	Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil	1.51
	Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78	2.68
	Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13	2.80
	Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil	1.69
	Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83	2.56
	West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil	2.15
SUBURBAN	Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85	2.30
	Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	Nil	1.53
	Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	Nil	1.17
	Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88	2.22
	Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	Nil	1.02
SUM		10.15	2.01	3.72	1.18	1.74	0.83	0.58	1.00	1.73	6.06	28.80
AVERAGE		0.73	0.14	0.27	0.11	0.12	0.06	0.04	0.07	0.12	1.01	2.67
LOWEST		0.35	0.01	0.04	0.04	0.03	0.03	0.02	0.01	0.01	0.78	MRCP
HIGHEST		1.38	0.34	0.67	0.24	0.36	0.13	0.08	0.17	0.73	1.59	
STANDARD DEVIATION		0.24	0.09	0.15	0.08	0.12	0.03	0.02	0.05	0.19	0.31	

Table 3.15 gives the M/R cost analysis of the second category. **MRCG** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in the Canada government sector.

Table 3. 15 M/R Cost Analysis of the Second Category

M/R COSTS OF OFFICE BUILDINGS REPORTED BY CANADA GOVERNMENT SECTOR (Unit: $/sq.ft.)												
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
DOWNTOWN	Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	Nil	2.17
	Chicoutimi, PQ	0.97	0.06	0.18	0.12	Nil	0.01	0.10	Nil	0.97	Nil	2.41
	Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	Nil	1.30	Nil	3.11
	London, ON	0.36	0.30	0.31	0.19	Nil	0.01	0.12	Nil	0.74	Nil	2.03
	Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	Nil	0.79	Nil	2.89
	Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24	6.01
	Quebec, PQ	1.14	0.11	0.26	0.05	0.33	Nil	0.12	Nil	0.84	1.41	4.26
	Saint John, NB	0.92	0.21	0.20	0.01	Nil	Nil	0.05	Nil	0.66	Nil	2.05
	St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	Nil	1.32	Nil	2.82
	Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	Nil	0.68	Nil	1.84
	Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	Nil	1.99	Nil	4.33
	Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	Nil	0.45	Nil	5.76
	Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	Nil	0.25	Nil	2.25
	Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	Nil	0.83	Nil	4.04
SUBURBAN	Barrie, ON	1.86	0.38	0.28	0.08	Nil	0.01	0.10	Nil	1.44	Nil	4.15
	Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	Nil	1.09	Nil	3.10
	Fredericton, NB	1.11	0.18	1.02	Nil	0.98	0.44	0.34	Nil	1.52	Nil	5.59
	Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	Nil	0.98	Nil	3.63
	Kingston, ON	0.94	0.12	0.85	0.17	Nil	0.03	0.73	Nil	1.32	Nil	4.16
	Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	Nil	0.66	Nil	1.71
	Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	Nil	0.66	Nil	2.61
	Saint John, NB	1.27	Nil	0.34	Nil	1.21	Nil	0.04	Nil	1.81	Nil	4.67
	St. John's, NF	1.02	Nil	0.27	0.35	Nil	Nil	0.06	Nil	1.08	Nil	2.78
	Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	Nil	1.18	Nil	4.89
	Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	Nil	0.77	Nil	4.74
	Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	Nil	0.11	Nil	1.82
	White Horse, YT	Nil	0.19	0.39	0.05	Nil	Nil	0.06	Nil	0.98	Nil	1.67
	Yellowknife, NWT	1.88	0.20	0.99	0.29	Nil	0.21	0.05	Nil	1.39	Nil	5.01
SUM		28.68	5.85	11.87	4.88	8.38	1.61	3.89	0.10	27.59	3.65	96.50
AVERAGE		1.06	0.23	0.42	0.19	0.42	0.07	0.14	0.05	0.99	1.83	5.39
LOWEST		0.36	0.06	0.17	0.01	0.01	0.01	0.04	0.04	0.11	1.41	MRCG
HIGHEST		2.85	0.75	1.23	0.47	2.17	0.44	0.73	0.06	1.99	2.24	
STANDARD DEVIATION		0.59	0.13	0.31	0.13	0.53	0.10	0.14	0.01	0.45	0.59	

Table 3-16 shows the M/R cost analysis of the third category. **MRCD** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in downtown in Canada.

Table 3. 16 M/R Cost Analysis of the Third Category

M/R COSTS OF OFFICE BUILDINGS IN DOWNTOWN IN CANADA (Unit: $/sq.ft.)												
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
GOVERNMENT SECTOR	Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	Nil	2.17
	Chicoutimi, PQ	0.97	0.06	0.18	0.12	Nil	0.01	0.10	Nil	0.97	Nil	2.41
	Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	Nil	1.30	Nil	3.11
	London, ON	0.36	0.30	0.31	0.19	Nil	0.01	0.12	Nil	0.74	Nil	2.03
	Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	Nil	0.79	Nil	2.89
	Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24	6.01
	Quebec, PQ	1.14	0.11	0.26	0.05	0.33	Nil	0.12	Nil	0.84	1.41	4.26
	Saint John, NB	0.92	0.21	0.20	0.01	Nil	Nil	0.05	Nil	0.66	Nil	2.05
	St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	Nil	1.32	Nil	2.82
	Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	Nil	0.68	Nil	1.84
	Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	Nil	1.99	Nil	4.33
	Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	Nil	0.45	Nil	5.76
	Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	Nil	0.25	Nil	2.25
	Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	Nil	0.83	Nil	4.04
PRIVATE SECTOR	Calgary, AB	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil	1.43
	Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil	1.53
	Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59	4.21
	Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil	1.51
	Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78	2.68
	Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13	2.80
	Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil	1.69
	Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83	2.56
	West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil	2.15
SUM		20.20	5.04	8.36	3.04	4.30	1.20	2.19	0.58	13.84	7.98	66.53
AVERAGE		0.88	0.22	0.36	0.15	0.22	0.06	0.10	0.05	0.60	1.33	3.96
LOWEST		0.36	0.06	0.12	0.01	0.01	0.01	0.03	0.01	0.01	0.78	MRCD
HIGHEST		2.43	0.75	1.23	0.47	0.79	0.18	0.28	0.11	1.99	2.24	
STANDARD DEVIATION		0.41	0.14	0.28	0.12	0.20	0.04	0.07	0.04	0.54	0.55	

Table 3-17 shows the M/R cost analysis of the fourth category. **MRCS** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in suburban areas in Canada.

Table 3. 17 M/R Cost Analysis of the Fourth Category

M/R COSTS OF OFFICE BUILDINGS IN SUBURBAN IN CANADA (Unit: $/sq.ft.)												
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
GOVERNMENT SECTOR	Barrie, ON	1.86	0.38	0.28	0.08	Nil	0.01	0.10	Nil	1.44	Nil	4.15
	Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	Nil	1.09	Nil	3.10
	Fredericton, NB	1.11	0.18	1.02	Nil	0.98	0.44	0.34	Nil	1.52	Nil	5.59
	Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	Nil	0.98	Nil	3.63
	Kingston, ON	0.94	0.12	0.85	0.17	Nil	0.03	0.73	Nil	1.32	Nil	4.16
	Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	Nil	0.66	Nil	1.71
	Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	Nil	0.66	Nil	2.61
	Saint John, NB	1.27	Nil	0.34	Nil	1.21	Nil	0.04	Nil	1.81	Nil	4.67
	St. John's, NF	1.02	Nil	0.27	0.35	Nil	Nil	0.06	Nil	1.08	Nil	2.78
	Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	Nil	1.18	Nil	4.89
	Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	Nil	0.77	Nil	4.74
	Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	Nil	0.11	Nil	1.82
	White Horse, YT	Nil	0.19	0.39	0.05	Nil	Nil	0.06	Nil	0.98	Nil	1.67
	Yellowknife, NWT	1.88	0.20	0.99	0.29	Nil	0.21	0.05	Nil	1.39	Nil	5.01
PRIVATE SECTOR	Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85	2.30
	Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	Nil	1.53
	Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	Nil	1.17
	Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88	2.22
	Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	Nil	1.02
SUM		18.63	2.82	7.23	3.02	5.82	1.24	2.28	0.52	15.48	1.73	58.77
AVERAGE		1.04	0.17	0.38	0.18	0.42	0.08	0.12	0.10	0.81	0.87	4.16
LOWEST		0.35	0.01	0.04	0.04	0.01	0.01	0.02	0.08	0.07	0.85	MRCS
HIGHEST		2.85	0.38	1.02	0.39	2.17	0.44	0.73	0.17	1.81	0.88	
STANDARD DEVIATION		0.64	0.10	0.27	0.12	0.63	0.11	0.17	0.04	0.57	0.02	

Table 3-18 shows the M/R cost analysis of the fifth category. **MRC** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in Canada.

Table 3. 18 M/R Cost Analysis of the Fifth Category

M/R COSTS OF OFFICE BUILDINGS IN CANADA (Unit: $/sq.ft.)												
	ITEMS	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
GOVERNMENT SECTOR (DOWNTOWN)	Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	Nil	2.17
	Chicoutimi, PQ	0.97	0.06	0.18	0.12	Nil	0.01	0.10	Nil	0.97	Nil	2.41
	Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	Nil	1.30	Nil	3.11
	London, ON	0.36	0.30	0.31	0.19	Nil	0.01	0.12	Nil	0.74	Nil	2.03
	Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	Nil	0.79	Nil	2.89
	Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24	6.01
	Quebec, PQ	1.14	0.11	0.26	0.05	0.33	Nil	0.12	Nil	0.84	1.41	4.26
	Saint John, NB	0.92	0.21	0.20	0.01	Nil	Nil	0.05	Nil	0.66	Nil	2.05
	St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	Nil	1.32	Nil	2.82
	Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	Nil	0.68	Nil	1.84
	Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	Nil	1.99	Nil	4.33
	Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	Nil	0.45	Nil	5.76
	Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	Nil	0.25	Nil	2.25
	Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	Nil	0.83	Nil	4.04
GOVERNMENT SECTOR (SUBURBAN)	Barrie, ON	1.86	0.38	0.28	0.08	Nil	0.01	0.10	Nil	1.44	Nil	4.15
	Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	Nil	1.09	Nil	3.10
	Fredericton, NB	1.11	0.18	1.02	Nil	0.98	0.44	0.34	Nil	1.52	Nil	5.59
	Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	Nil	0.98	Nil	3.63
	Kingston, ON	0.94	0.12	0.85	0.17	Nil	0.03	0.73	Nil	1.32	Nil	4.16
	Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	Nil	0.66	Nil	1.71
	Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	Nil	0.66	Nil	2.61
	Saint John, NB	1.27	Nil	0.34	Nil	1.21	Nil	0.04	Nil	1.81	Nil	4.67
	St. John's, NF	1.02	Nil	0.27	0.35	Nil	Nil	0.06	Nil	1.08	Nil	2.78
	Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	Nil	1.18	Nil	4.89
	Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	Nil	0.77	Nil	4.74
	Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	Nil	0.11	Nil	1.82
	White Horse, YT	Nil	0.19	0.39	0.05	Nil	Nil	0.06	Nil	0.98	Nil	1.67
	Yellowknife, NWT	1.88	0.20	0.99	0.29	Nil	0.21	0.05	Nil	1.39	Nil	5.01
PRIVATE SECTOR (DOWNTOWN)	Calgary, AB	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	Nil	1.43
	Kelowna Area, BC	0.70	0.20	0.36	Nil	0.34	0.06	0.04	0.01	0.02	Nil	1.53
	Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59	4.21
	Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	Nil	1.51
	Prince George, BC	0.97	0.34	0.24	Nil	0.24	0.05	0.04	0.01	0.01	0.78	2.68
	Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13	2.80
	Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	Nil	1.69
	Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83	2.56
	West Prince Rupert,BC	1.38	0.14	0.14	Nil	0.36	0.07	0.03	0.01	0.02	Nil	2.15
PRIVATE SECTOR (SUBURBAN)	Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85	2.30
	Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	Nil	1.53
	Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	Nil	1.17
	Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88	2.22
	Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	Nil	1.02
SUM		38.83	7.86	15.59	6.06	10.12	2.44	4.47	1.10	29.32	9.71	125.30
AVERAGE		0.95	0.20	0.37	0.16	0.30	0.07	0.11	0.07	0.70	1.21	4.13
LOWEST		0.35	0.01	0.04	0.01	0.01	0.01	0.02	0.01	0.01	0.78	
HIGHEST		2.85	0.75	1.23	0.47	2.17	0.44	0.73	0.17	1.99	2.24	MRC
STANDARD DEVIATION		0.52	0.12	0.28	0.12	0.43	0.08	0.12	0.04	0.56	0.51	

Table 3-19 shows the M/R cost analysis of the sixth category. **MRCH** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in Canada based on height analyses. **MRCH1** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the heights of which are less than five stories. **MRCH2** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the heights of which are 5-9 stories. **MRCH3** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the heights of which are 10-19 stories. **MRCH4** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the heights of which are 20-29 stories.

Table 3. 19 M/R Cost Analysis of the Sixth Category

M/R COSTS OF OFFICE BUILDINGS IN CANADA_HEIGHT BASED ANALYSES (Unit: $/sq.ft.)												
ITEMS		PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
LESS THAN 5 STORIES												
Private Sector	0-9 years	0.77	0.15	0.17	0.04	0.10	0.02	0.03	0.15	0.06	Nil	1.49
	10-19 years	0.55	0.10	0.33	0.08	0.05	0.04	0.07	0.12	0.25	Nil	1.59
	20-29 years	0.77	0.20	0.27	0.08	0.23	0.05	0.04	0.02	0.03	0.67	2.36
	30-39 years	0.97	0.23	0.30	Nil	0.44	0.09	0.06	0.01	0.10	Nil	2.20
	40-49 years	1.08	0.06	0.10	Nil	0.17	0.03	0.07	0.01	Nil	Nil	1.52
	50 years or more	0.68	0.11	0.11	Nil	0.22	0.04	0.04	0.01	0.03	Nil	1.24
Government Sector	0-9 years	1.46	0.18	0.20	0.39	1.59	0.04	0.08	Nil	0.64	Nil	4.58
	10-19 years	1.91	0.12	0.39	0.18	0.20	0.06	0.20	Nil	1.04	Nil	4.10
	20-29 years	0.68	0.10	0.26	0.15	0.19	0.04	0.10	Nil	0.76	Nil	2.28
	30-39 years	0.97	0.11	0.36	0.18	0.61	0.03	0.22	Nil	0.75	1.33	4.56
	40-49 years	0.86	0.19	0.43	0.26	0.37	0.08	0.15	0.03	1.03	1.50	4.90
	50 years or more	0.85	0.34	0.35	0.12	1.27	0.03	0.19	Nil	0.92	Nil	4.07
SUM		11.55	1.89	3.27	1.48	5.44	0.55	1.25	0.35	5.61	3.50	34.89
AVERAGE		0.96	0.16	0.27	0.16	0.45	0.05	0.10	0.05	0.51	1.17	3.89
LOWEST		0.55	0.06	0.10	0.04	0.05	0.02	0.03	0.01	0.03	0.67	MRCH1
HIGHEST		1.91	0.34	0.43	0.39	1.59	0.09	0.22	0.15	1.04	1.50	
STANDARD DEVIATION		0.38	0.08	0.11	0.11	0.49	0.02	0.07	0.06	0.42	0.44	
5-9 STORIES												
Private Sector	0-9 years	0.85	0.15	0.58	0.12	0.27	0.03	0.02	0.08	0.15	1.16	3.41
	10-19 years	0.63	0.15	0.14	0.04	0.09	0.03	0.03	0.08	0.08	Nil	1.27
	20-29 years	0.71	0.07	0.27	0.14	0.07	0.08	0.04	0.07	0.10	0.86	2.41
Government Sector	10-19 years	1.05	0.13	0.22	0.16	0.26	0.02	0.05	Nil	0.64	Nil	2.53
	20-29 years	1.38	0.08	0.24	0.12	0.05	Nil	0.04	Nil	Nil	Nil	1.91
	30-39 years	0.82	0.35	0.37	0.05	0.60	0.20	0.15	Nil	1.27	Nil	3.81
	40-49 years	0.75	0.23	1.07	0.30	0.26	0.02	0.12	Nil	1.31	Nil	4.06
	50 years or more	1.06	0.25	0.36	0.05	0.24	0.07	0.13	Nil	1.19	Nil	3.35
SUM		7.25	1.41	3.25	0.98	1.84	0.45	0.58	0.23	4.74	2.02	22.75
AVERAGE		0.91	0.18	0.41	0.12	0.23	0.06	0.07	0.08	0.68	1.01	3.74
LOWEST		0.63	0.07	0.14	0.04	0.05	0.02	0.02	0.07	0.08	0.86	MRCH2
HIGHEST		1.38	0.35	1.07	0.30	0.60	0.20	0.15	0.08	1.31	1.16	
STANDARD DEVIATION		0.24	0.09	0.30	0.08	0.18	0.06	0.05	0.01	0.58	0.21	
10-19 STORIES												
Private Sector	10-19 years	0.63	0.17	0.31	0.07	0.07	0.09	0.05	0.12	0.13	1.24	2.88
	20-29 years	0.78	0.12	0.35	0.06	0.09	0.04	0.05	0.09	0.11	0.92	2.61
Government Sector	20-29 years	0.47	0.30	0.44	0.40	0.38	0.05	0.22	Nil	1.01	Nil	3.27
	30-39 years	0.54	0.25	0.55	0.35	0.34	0.36	0.09	0.04	0.93	Nil	3.45
	40-49 years	0.70	0.33	0.27	0.04	0.21	0.10	0.09	Nil	1.58	Nil	3.32
	50 years or more	0.72	0.34	0.50	0.44	0.51	0.45	0.76	Nil	1.94	Nil	5.66
SUM		3.84	1.51	2.42	1.36	1.60	1.09	1.26	0.25	5.70	2.16	21.19
AVERAGE		0.64	0.25	0.40	0.23	0.27	0.18	0.21	0.08	0.95	1.08	4.29
LOWEST		0.47	0.12	0.27	0.04	0.07	0.04	0.05	0.04	0.11	0.92	MRCH3
HIGHEST		0.78	0.34	0.55	0.44	0.51	0.45	0.76	0.12	1.94	1.24	
STANDARD DEVIATION		0.12	0.09	0.11	0.19	0.17	0.18	0.28	0.04	0.74	0.23	
20-29 STORIES												
Private Sector	30-39 years	0.97	0.23	0.30	Nil	0.44	0.09	0.06	0.01	0.10	Nil	2.20
Government Sector	20-29 years	0.64	0.39	0.45	0.22	0.10	0.11	0.15	Nil	0.96	Nil	3.02
SUM		1.61	0.62	0.75	0.22	0.54	0.20	0.21	0.01	1.06	Nil	5.22
AVERAGE		0.81	0.31	0.38	0.22	0.27	0.10	0.11	0.01	0.53	1.21	3.94 MRCH4

Table 3-20 shows the M/R cost analysis of the seventh category. **MRCS** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in Canada based on size analyses. **MRCS1** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the gross square footage of which is less than 50,000 sq.ft. **MRCS2** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the gross square footage of which is 50,000-99,999 sq.ft. **MRCS3** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the gross square footage of which is 100,000-299,999 sq.ft. **MRCS4** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the gross square footage of which is 300,000-599,999 sq.ft. **MRCS5** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the gross square footage of which is 600,000 sq.ft. or more.

Table 3. 20 M/R Cost Analysis of the Seventh Category

M/R COSTS OF OFFICE BUILDINGS IN CANADA_SIZE BASED ANALYSES (Unit: $/sq.ft.)												
ITEMS		PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
LESS THAN 50,000 SQ.FT												
Private Sector	0-9 years	Nil	0.17	0.20	Nil	0.08	0.05	0.08	0.13	0.10	Nil	0.81
	10-19 years	0.63	0.17	0.18	0.05	0.08	0.03	0.03	0.11	0.40	Nil	1.68
	20-29 years	1.02	0.18	0.24	Nil	0.19	0.07	0.03	0.02	0.02	0.57	2.34
	30-39 years	0.95	0.23	0.24	Nil	0.28	0.04	0.06	0.02	0.02	Nil	1.84
	50 years or more	0.77	0.13	0.11	Nil	0.33	0.04	0.06	0.02	0.03	Nil	1.49
Government Sector	0-9 years	2.09	0.22	0.57	0.58	1.59	0.11	0.09	Nil	1.09	Nil	6.34
	10-19 years	1.23	0.11	0.33	0.12	0.62	0.02	0.29	Nil	1.12	Nil	3.84
	20-29 years	1.05	0.29	0.28	0.37	1.46	0.02	0.08	Nil	0.72	Nil	4.27
	30-39 years	0.92	0.18	0.30	0.19	0.65	0.03	0.06	Nil	0.88	Nil	3.21
	40-49 years	1.09	0.20	0.42	0.11	0.61	0.05	0.10	0.21	1.00	Nil	3.79
	50 years or more	0.90	0.26	0.24	0.06	2.71	0.04	0.24	Nil	1.31	Nil	5.76
SUM		10.65	2.14	3.11	1.48	8.60	0.50	1.12	0.51	6.69	0.57	35.37
AVERAGE		1.07	0.19	0.28	0.21	0.78	0.05	0.10	0.09	0.61	0.57	3.95
LOWEST		0.63	0.11	0.11	0.05	0.08	0.02	0.03	0.02	0.02	0.57	
HIGHEST		2.09	0.29	0.57	0.58	2.71	0.11	0.29	0.21	1.31	0.57	MRCS1
STANDARD DEVIATION		0.40	0.05	0.13	0.20	0.82	0.03	0.08	0.08	0.51	Nil	
50,000-99,999 SQ.FT												
Private Sector	0-9 years	0.87	0.09	0.30	0.04	0.27	0.04	0.03	0.12	0.12	Nil	1.88
	10-19 years	0.72	0.09	0.23	0.07	0.08	0.03	0.06	0.12	0.13	Nil	1.53
	20-29 years	0.75	0.01	0.23	0.16	0.05	0.07	0.07	0.11	0.12	0.76	2.33
Government Sector	20-29 years	0.69	0.13	0.25	0.35	0.11	0.01	0.08	Nil	0.66	Nil	2.28
	30-39 years	0.98	0.10	0.36	0.10	0.18	0.08	0.30	Nil	0.93	1.33	4.36
	40-49 years	0.74	0.25	0.48	0.21	0.52	0.02	0.28	Nil	1.29	Nil	3.79
	50 years or more	1.49	0.31	0.36	0.13	0.55	0.06	0.12	Nil	0.87	Nil	3.89
SUM		6.24	0.98	2.21	1.06	1.76	0.31	0.94	0.35	4.12	2.09	20.06
AVERAGE		0.89	0.14	0.32	0.15	0.25	0.04	0.13	0.12	0.59	1.05	3.68
LOWEST		0.69	0.01	0.23	0.04	0.05	0.01	0.03	0.11	0.12	0.76	
HIGHEST		1.49	0.31	0.48	0.35	0.55	0.08	0.30	0.12	1.29	1.33	MRCS2
STANDARD DEVIATION		0.28	0.10	0.09	0.10	0.21	0.03	0.11	0.01	0.47	0.40	
100,000-299,999 SQ.FT.												
Private Sector	0-9 years	0.83	0.13	0.35	0.10	0.08	0.02	0.04	0.09	0.05	Nil	1.69
	10-19 years	0.63	0.18	0.26	0.09	0.07	0.09	0.04	0.10	0.13	1.00	2.59
	20-29 years	0.80	0.08	0.21	0.05	0.13	0.06	0.05	0.07	0.08	0.56	2.09
	30-39 years	0.65	0.12	0.25	0.11	0.12	0.05	0.07	0.08	0.10	0.63	2.18
Government Sector	10-19 years	1.77	0.20	0.35	0.22	0.12	0.05	0.14	Nil	0.68	Nil	3.53
	20-29 years	0.89	0.10	0.38	0.17	0.20	0.04	0.13	Nil	0.76	Nil	2.67
	30-39 years	0.67	0.28	0.46	0.13	0.44	0.40	0.12	0.04	0.76	Nil	3.30
	40-49 years	0.83	0.24	0.66	0.19	0.27	0.07	0.09	Nil	1.45	Nil	3.80
	50 years or more	0.84	0.33	0.52	0.20	0.24	0.18	0.34	Nil	1.52	Nil	4.17
SUM		7.91	1.66	3.44	1.26	1.67	0.96	1.02	0.38	5.53	2.19	26.02
AVERAGE		0.88	0.18	0.38	0.14	0.19	0.11	0.11	0.08	0.61	0.73	3.41
LOWEST		0.63	0.08	0.21	0.05	0.07	0.02	0.04	0.04	0.05	0.56	
HIGHEST		1.77	0.33	0.66	0.22	0.44	0.40	0.34	0.10	1.52	1.00	MRCS3
STANDARD DEVIATION		0.35	0.09	0.14	0.06	0.12	0.12	0.09	0.02	0.58	0.24	
300,000-599,999 SQ.FT.												
Private Sector	10-19 years	0.63	0.14	0.18	0.02	0.04	0.06	0.03	0.10	0.09	Nil	1.29
	20-29 years	Nil	0.16	0.35	0.27	0.03	0.04	Nil	0.08	0.10	Nil	1.03
Government Sector	20-29 years	0.48	0.29	0.42	0.27	0.35	0.09	0.17	Nil	1.17	Nil	3.24
	30-39 years	0.37	0.35	0.66	0.43	0.24	0.03	0.08	Nil	1.22	Nil	3.38
	40-49 years	0.63	0.26	0.28	0.19	0.13	0.13	0.08	Nil	1.17	Nil	2.87
SUM		2.11	1.20	1.89	1.18	0.79	0.35	0.36	0.18	3.75	Nil	11.81
AVERAGE		0.53	0.24	0.38	0.24	0.16	0.07	0.09	0.09	0.75	1.21	3.75
LOWEST		0.37	0.14	0.18	0.02	0.03	0.03	0.03	0.08	0.09	Nil	
HIGHEST		0.63	0.35	0.66	0.43	0.35	0.13	0.17	0.10	1.22	Nil	MRCS4
STANDARD DEVIATION		0.13	0.09	0.18	0.15	0.14	0.04	0.06	0.01	0.60	Nil	
600,000 SQ.FT. OR MORE												
Government Sector	20-29 years	0.55	0.37	0.40	0.31	0.14	0.08	0.19	Nil	0.85	Nil	2.89
SUM		0.55	0.37	0.40	0.31	0.14	0.08	0.19	Nil	0.85	Nil	2.89
AVERAGE		0.55	0.37	0.40	0.31	0.14	0.08	0.19	0.07	0.85	1.21	4.17 MRCS5

Table 3-21 shows the M/R cost analysis of the eighth category. **MRCA** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings in Canada based on age analyses. **MRCA1** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the ages of which are 0-9 years. **MRCA2** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the ages of which are 10-19 years. **MRCA3** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the ages of which are 20-29 years. **MRCA4** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the ages of which are 30-39 years. **MRCA5** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the ages of which are 40-49 years. **MRCA6** gives the annual maintenance and repair unit cost ($/sq.ft.) of office buildings the ages of which are 50 years or more.

Table 3. 21 M/R Cost Analysis of the Eighth Category

M/R COSTS OF OFFICE BUILDINGS IN CANADA_AGE BASED ANALYSES (Unit: $/sq.ft.)												
ITEMS		PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM
0-9 YEARS												
Private Sector	< 50,000sqft	Nil	0.17	0.20	Nil	0.08	0.05	0.08	0.13	0.10	Nil	0.81
	50,000-99,999sqft	0.87	0.09	0.30	0.04	0.27	0.04	0.03	0.12	0.12	Nil	1.88
	100,000-299,999sqft	0.83	0.13	0.35	0.10	0.08	0.02	0.04	0.09	0.05	Nil	1.69
Government Sector	All Sizes	1.33	0.20	0.27	0.32	Nil	0.05	0.14	Nil	1.10	Nil	3.41
SUM		3.03	0.59	1.12	0.46	0.43	0.16	0.29	0.34	1.37	Nil	7.79
AVERAGE		1.01	0.15	0.28	0.15	0.14	0.04	0.07	0.11	0.34	1.21	3.51
LOWEST		0.83	0.09	0.20	0.04	0.08	0.02	0.03	0.09	0.05	Nil	
HIGHEST		1.33	0.20	0.35	0.32	0.27	0.05	0.14	0.13	1.10	Nil	MRCA1
STANDARD DEVIATION		0.28	0.05	0.06	0.15	0.11	0.01	0.05	0.02	0.51	Nil	
10-19 YEARS												
Private Sector	< 50,000sqft	0.63	0.17	0.18	0.05	0.08	0.03	0.03	0.11	0.40	Nil	1.68
	50,000-99,999sqft	0.72	0.09	0.23	0.07	0.08	0.03	0.06	0.12	0.13	Nil	1.53
	100,000-299,999sqft	0.63	0.18	0.26	0.09	0.07	0.09	0.04	0.10	0.13	1.00	2.59
	300,000-599,999sqft	0.61	0.14	0.18	0.02	0.04	0.06	0.03	0.10	0.09	Nil	1.27
Government Sector	< 50,000sqft	1.23	0.11	0.33	0.12	0.62	0.02	0.29	Nil	1.12	Nil	3.84
	100,000-299,999sqft	1.77	0.20	0.35	0.22	0.12	0.05	0.14	Nil	0.68	Nil	3.53
SUM		5.59	0.89	1.53	0.57	1.01	0.28	0.59	0.43	2.55	1.00	14.44
AVERAGE		0.93	0.15	0.26	0.10	0.17	0.05	0.10	0.11	0.43	1.00	3.28
LOWEST		0.61	0.09	0.18	0.02	0.04	0.02	0.03	0.10	0.09	1.00	
HIGHEST		1.77	0.20	0.35	0.22	0.62	0.09	0.29	0.12	1.12	1.00	MRCA2
STANDARD DEVIATION		0.47	0.04	0.07	0.07	0.22	0.03	0.10	0.01	0.41	Nil	
20-29 YEARS												
Private Sector	< 50,000sqft	1.02	0.18	0.24	Nil	0.19	0.07	0.03	0.02	0.02	0.57	2.34
	50,000-99,999sqft	0.75	0.01	0.23	0.16	0.05	0.07	0.07	0.11	0.12	0.76	2.33
	100,000-299,999sqft	0.80	0.08	0.21	0.05	0.13	0.06	0.05	0.07	0.08	0.56	2.09
	300,000-599,999sqft	Nil	0.16	0.35	0.27	0.03	0.04	Nil	0.08	0.10	Nil	1.03
Government Sector	< 50,000sqft	1.05	0.29	0.28	0.37	1.46	0.02	0.08	Nil	0.72	Nil	4.27
	50,000-99,999sqft	0.69	0.13	0.25	0.35	0.11	0.01	0.08	Nil	0.66	Nil	2.28
	100,000-299,999sqft	0.89	0.10	0.38	0.17	0.20	0.04	0.13	Nil	0.76	Nil	2.67
	300,000-599,999sqft	0.48	0.29	0.42	0.27	0.35	0.09	0.17	Nil	1.17	Nil	3.24
	600,000sft or more	0.55	0.37	0.40	0.31	0.14	0.08	0.19	Nil	0.85	Nil	2.89
SUM		6.23	1.61	2.76	1.95	2.66	0.48	0.80	0.28	4.48	1.89	23.14
AVERAGE		0.78	0.18	0.31	0.24	0.30	0.05	0.10	0.07	0.50	0.63	3.15
LOWEST		0.48	0.01	0.21	0.05	0.03	0.01	0.03	0.02	0.02	0.56	
HIGHEST		1.05	0.37	0.42	0.37	1.46	0.09	0.19	0.11	1.17	0.76	MRCA3
STANDARD DEVIATION		0.21	0.12	0.08	0.11	0.45	0.03	0.06	0.04	0.42	0.11	
30-39 YEARS												
Private Sector	< 50,000sqft	0.95	0.23	0.24	Nil	0.28	0.04	0.06	0.02	0.02	Nil	1.84
	100,000-299,999sqft	0.65	0.12	0.25	0.11	0.12	0.05	0.07	0.08	0.10	0.63	2.18
Government Sector	< 50,000sqft	0.92	0.18	0.30	0.19	0.65	0.03	0.06	Nil	0.88	Nil	3.21
	50,000-99,999sqft	0.98	0.10	0.36	0.10	0.18	0.08	0.30	Nil	0.93	1.33	4.36
	100,000-299,999sqft	0.67	0.28	0.46	0.13	0.44	0.40	0.12	0.04	0.76	Nil	3.30
	300,000-599,999sqft	0.37	0.35	0.66	0.43	0.24	0.03	0.08	Nil	1.22	Nil	3.38
SUM		4.54	1.26	2.27	0.96	1.91	0.63	0.69	0.14	3.91	1.96	18.27
AVERAGE		0.76	0.21	0.38	0.19	0.32	0.11	0.12	0.05	0.65	0.98	3.75
LOWEST		0.37	0.10	0.24	0.10	0.12	0.03	0.06	0.02	0.02	0.63	
HIGHEST		0.98	0.35	0.66	0.43	0.65	0.40	0.30	0.08	1.22	1.33	MRCA4
STANDARD DEVIATION		0.24	0.10	0.16	0.14	0.20	0.15	0.09	0.03	0.48	0.49	
40-49 YEARS												
Private Sector	All Sizes	0.94	0.02	0.10	0.03	0.07	0.04	0.03	0.10	0.10	0.21	1.64
Government Sector	< 50,000sqft	1.09	0.20	0.42	0.11	0.61	0.05	0.10	0.21	1.00	Nil	3.79
	50,000-99,999sqft	0.74	0.25	0.48	0.21	0.52	0.02	0.28	Nil	1.29	Nil	3.79
	100,000-299,999sqft	0.83	0.24	0.66	0.19	0.27	0.07	0.09	Nil	1.45	Nil	3.80
	300,000-599,999sqft	0.63	0.26	0.28	0.19	0.13	0.13	0.08	Nil	1.17	Nil	2.87
SUM		4.23	0.97	1.94	0.73	1.60	0.31	0.58	0.31	5.01	0.21	15.89
AVERAGE		0.85	0.19	0.39	0.15	0.32	0.06	0.12	0.16	1.00	0.21	3.44
LOWEST		0.63	0.02	0.10	0.03	0.07	0.02	0.03	0.10	0.10	0.21	
HIGHEST		1.09	0.26	0.66	0.21	0.61	0.13	0.28	0.21	1.45	0.21	MRCA5
STANDARD DEVIATION		0.18	0.10	0.21	0.08	0.24	0.04	0.10	0.08	0.53	Nil	
50 YEARS OR MORE												
Private Sector	All Sizes	0.48	0.26	0.19	0.14	0.22	0.06	0.07	0.08	0.15	Nil	1.65
Government Sector	< 50,000sqft	0.90	0.26	0.24	0.06	2.71	0.04	0.24	Nil	1.31	Nil	5.76
	50,000-99,999sqft	1.49	0.31	0.36	0.13	0.55	0.06	0.12	Nil	0.87	Nil	3.89
	100,000-299,999sqft	0.84	0.33	0.52	0.20	0.24	0.18	0.34	Nil	1.52	Nil	4.17
SUM		3.71	1.16	1.31	0.53	3.72	0.34	0.77	0.08	3.85	Nil	15.47
AVERAGE		0.93	0.29	0.33	0.13	0.93	0.09	0.19	0.08	0.96	1.21	5.14
LOWEST		0.48	0.26	0.19	0.06	0.22	0.04	0.07	0.08	0.15	Nil	
HIGHEST		1.49	0.33	0.52	0.20	2.71	0.18	0.34	0.08	1.52	Nil	MRCA6
STANDARD DEVIATION		0.42	0.04	0.15	0.06	1.20	0.06	0.12	Nil	0.61	Nil	

Table 3-22 shows the M/R costs of office buildings based on different cities in Canada.

Table 3. 22 M/R costs city based analysis

M/R COSTS OF OFFICE BUILDINGS IN CANADA_CITY BASED ANALYSES (Unit: $/sq.ft.)												
ITEM	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM	MRCC
Barrie, ON	1.86	0.38	0.28	0.08	0.30	0.01	0.10	0.07	1.44	1.21	5.73	5.73
Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	1.21	3.38	2.77
Calgary, AB	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	1.21	2.64	
Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85	2.30	
Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	0.07	1.09	1.21	4.38	4.38
Chicoutimi, PQ	0.97	0.06	0.18	0.12	0.30	0.01	0.10	0.07	0.97	1.21	3.99	3.99
Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	1.21	1.53	1.53
Fredericton, NB	1.11	0.18	1.02	0.16	0.98	0.44	0.34	0.07	1.52	1.21	7.03	7.03
Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	0.07	1.30	1.21	4.39	4.65
Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	0.07	0.98	1.21	4.91	
Kelowna Area, BC	0.70	0.20	0.36	0.16	0.34	0.06	0.04	0.01	0.02	1.21	1.53	1.53
Kingston, ON	0.94	0.12	0.85	0.17	0.30	0.03	0.73	0.07	1.32	1.21	5.74	5.74
London, ON	0.36	0.30	0.31	0.19	0.30	0.01	0.12	0.07	0.74	1.21	3.61	3.61
Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	0.07	0.66	1.21	2.99	2.99
Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	0.07	0.79	1.21	4.17	4.19
Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59	4.21	
Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24	6.01	3.70
Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	1.21	2.72	
Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	1.21	2.38	
Prince George, BC	0.97	0.34	0.24	0.16	0.24	0.05	0.04	0.01	0.01	0.78	2.84	2.84
Quebec, PQ	1.14	0.11	0.26	0.05	0.33	0.07	0.12	0.07	0.84	1.41	4.40	4.40
Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	0.07	0.66	1.21	3.89	3.89
Saint John, NB	0.92	0.21	0.20	0.01	0.30	0.07	0.05	0.07	0.66	1.21	3.70	5.04
Saint John, NB	1.27	0.20	0.34	0.16	1.21	0.07	0.04	0.07	1.81	1.21	6.38	
St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	0.07	1.32	1.21	4.10	4.37
St. John's, NF	1.02	0.20	0.27	0.35	0.30	0.07	0.06	0.07	1.08	1.21	4.63	
Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	0.07	1.18	1.21	6.17	6.17
Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	0.07	0.77	1.21	6.02	6.02
Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	0.07	0.68	1.21	3.12	3.12
Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	0.07	1.99	1.21	5.61	3.54
Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13	2.80	
Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88	2.22	
Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	0.07	0.45	1.21	7.04	3.82
Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	0.07	0.11	1.21	3.10	
Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	1.21	2.90	
Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	1.21	2.23	
Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	0.07	0.25	1.21	3.53	3.05
Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83	2.56	
West Prince Rupert,BC	1.38	0.14	0.14	0.16	0.36	0.07	0.03	0.01	0.02	1.21	3.52	3.52
White Horse, YT	0.95	0.19	0.39	0.05	0.30	0.07	0.06	0.07	0.98	1.21	4.27	4.27
Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	0.07	0.83	1.21	5.32	5.32
Yellowknife, NWT	1.88	0.20	0.99	0.29	0.30	0.21	0.05	0.07	1.39	1.21	6.59	6.59
AVERAGE												4.21

3.5.2 Simulation application

3.5.2.1 Introduction

Simulation has been used in the construction industry as an academic tool since the late 1960s. The application of simulation has been used extensively in the evaluation of construction projects (Daniel W. Halpin 1999).

Simulation is frequently applied to improve production processes where the system has many random interacting components. A few research projects have been carried out in the past to determine the optimum maintenance intervals and to minimize maintenance costs by using simulation models and other methods (see (Feldman 1992; K.A.H. Kobbacy 1997; Thomas 1985; W. Chien 1997). A Markov model has also been used in the past to determine usage rates and to optimize maintenance policies and intervals that minimize cost as in the case study for building maintenance (Winden 1998).

3.5.2.2 Monte Carlo Simulation

Monte Carlo simulation is a method for repetitively evaluating a deterministic model using sets of random numbers as inputs and using probability statistics to investigate problems. The inputs are randomly generated from probability distributions to simulate the processing of data from an actual situation. So, the distribution should be chosen for the inputs that most closely match the collected data. The results generated from the simulation can be represented as probability distributions, histograms, etc. Figure 3.3 shows the principle of a Monte Carlo simulation method.

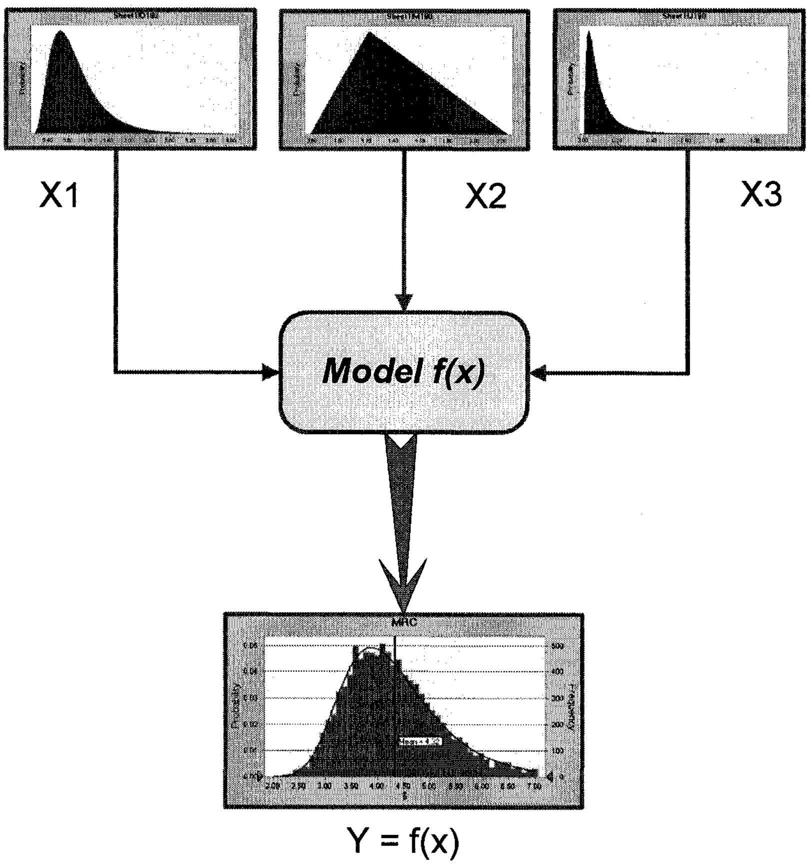


Figure 3. 3 Principle of Monte Carlo Simulation Method

The steps of Monte Carlo simulation application are shown below:

Step 1: A parametric model is created as in Equation (3.1).

$$\mathbf{y = f\,(x_1, x_2, x_3)} \qquad \textbf{(3.1)}$$

Step 2: A set of random numbers are generated as inputs based on the probability distributions of the parameters, i.e. X_{j1}, X_{j2}, X_{j3}.

Step 3: The model is evaluated and the results are stored as y_j..

Step 4: The summary statistics of the results are attained as outputs by repeating Step 2 and Step 3 for a certain number of times.

According to this principle, a parametric model is created in the present research to evaluate the M/R costs as in Equation (3.2).

$$\mathbf{MRC(T) = X_{PL} + X_{ER} + X_{HC} + X_{EL} + X_{SR} + X_{PG} + X_{FL} + X_{GE} + X_{GI} + X_{CT}} \qquad \mathbf{(3.2)}$$

Where

MRC(T) --- The M/R cost of the Tth category of sorted data

X_{PL} --- The M/R cost of PAYROLL item

X_{ER} --- The M/R cost of ELEVATOR item

X_{HC} --- The M/R cost of HVAC item

X_{EL} --- The M/R cost of ELECTRICAL item

X_{SR} --- The M/R cost of STRUC/ROOF item

X_{PG} --- The M/R cost of PLUMBING item

X_{FL} --- The M/R cost of FIRE/LIFE SAFETY item

X_{GE} --- The M/R cost of GEN EXTERIOR item

X_{GI} --- The M/R cost of GEN INTERIOR item

X_{CT} --- The M/R cost of CONTRACT item

When applying the Monte Carlo simulation method to evaluate the M/R costs, a set of random numbers is generated first as inputs based on the probability distributions of all the items. The results are then stored as outputs $MRC(T)_j$. Therefore, the Equation (3.2) is turned into Equation (3.3).

$$\mathbf{MRC(T)_j = X_{jPL} + X_{jER} + X_{jHC} + X_{jEL} + X_{jSR} + X_{jPG} + X_{jFL} + X_{jGE} + X_{jGI} + X_{jCT}} \qquad \mathbf{(3.3)}$$

Where X_{jPL}, X_{jER}, X_{jHC}, X_{jEL}, X_{jSR}, X_{jPG}, X_{jFL}, X_{jGE}, X_{jGI}, X_{jCT} are a set of random numbers of X_{PL}, X_{ER}, X_{HC}, X_{EL}, X_{SR}, X_{PG}, X_{FL}, X_{GE}, X_{GI}, X_{CT}. **MRC(T)**$_j$ is a statistical summary of all the stored results from repeating the model evaluation for j = 1 to n. The mean value of **MRC(T)**$_j$ probability distribution is the most likely value of the M/R cost in the Tth category.

3.5.2.3 Distribution Assumption

In the present work the probability distributions of the M/R costs of the elements are assumed to be either triangular or lognormal. The three values, highest, lowest, and the average based on the available data collected from BOMA, were assigned to generate triangular distribution. Standard deviation was used to define lognormal distribution. These distributions provided the basis for the simulation calculation. Figure 3.4 is an example of lognormal distribution. In this distribution, the mean value is 0.95 and the standard deviation is 0.52.

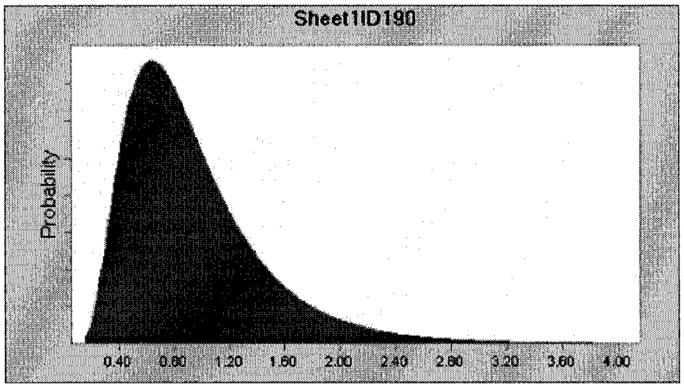


Figure 3. 4 Lognormal Distribution

Figure 3.5 is an example of triangular distribution. In this distribution, the minimum value is 0.78, the likeliest value is 1.21 and the maximum value is 2.24.

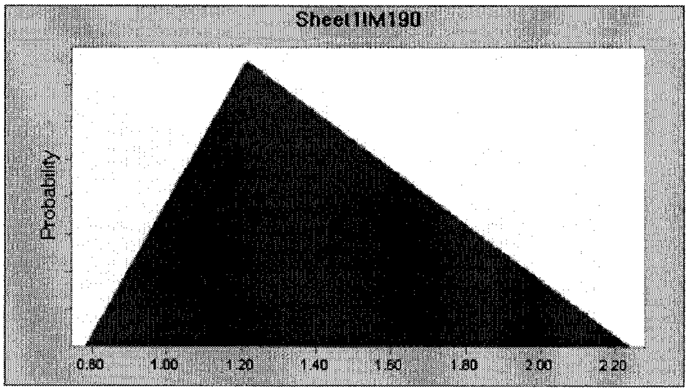


Figure 3. 5 Triangular Distribution

An example of the element distribution assumptions is shown in Appendix 1.

3.5.2.4 Simulation Results

Crystal Ball software is the easiest way to perform Monte Carlo simulations in the spreadsheets. Crystal Ball automatically calculates thousands of different "what if" cases, saving the inputs and results of each calculation as individual scenarios. The analysis of these scenarios reveals the range of possible outcomes and their probability of occurring.

Figure 3.6 shows the result of the M/R cost probability distribution provided by the computer simulation on the basis of data shown in Table 3.18. The mean value ($4.32) of MRC indicates that the most likely M/R unit cost of office buildings in Canada is $4.32/sq.ft.

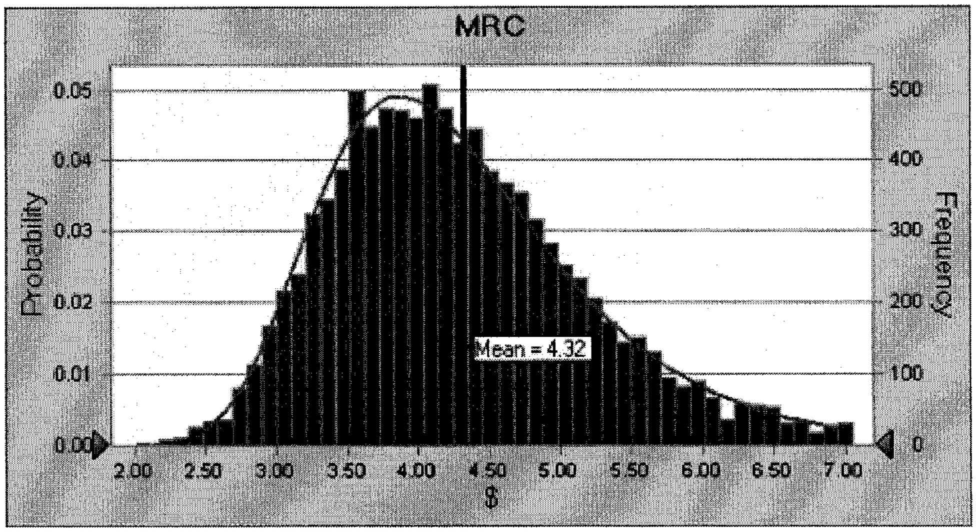


Figure 3. 6 Probability Distribution of M/R Costs

An example of the simulation result of the maintenance/repair cost forecast is also shown in Appendix 1. Table 3. 23 to Table 3. 28 show the results of data processing performed by stochastic simulation calculation.

Table 3. 23 M/R Costs of Office Buildings Based On Ownership Factor

ITEMS	OWNERSHIP	M/R COSTS ($/sq.ft.)
MRCP	PRIVATE	2.79
MRCG	GOVERNMENT	5.43
AVERAGE		**4.11**

Table 3. 24 M/R Costs of Office Buildings Based On Location Factor

ITEMS	LOCATION	M/R COSTS ($/sq.ft.)
MRCD	DOWNTOWN	4.10
MRCS	SUBURBAN	4.27
AVERAGE		**4.19**

Table 3. 25 M/R Costs of Office Buildings Based On Height Factor

ITEMS	HEIGHT RANGE	M/R COSTS ($/sq.ft.)
MRCH1	LESS THAN 5 STORIES	3.86
MRCH2	5-9 STORIES	3.81
MRCH3	10-19 STORIES	4.33
MRCH4	20-29 STORIES	3.94
AVERAGE		**3.99**

Table 3. 26 M/R Costs of Office Buildings Based On Size Factor

ITEMS	SIZE RANGE	M/R COSTS ($/sq.ft.)
MRCS1	< 50,000 SQ.FT.	3.96
MRCS2	50,000-99,999 SQ.FT.	3.71
MRCS3	100,000-299,999 SQ.FT.	3.44
MRCS4	300,000-599,999 SQ.FT.	3.72
MRCS5	600,000 SQ.FT. OR MORE	4.17
AVERAGE		**3.80**

Table 3. 27 M/R Costs of Office Buildings Based On Age Factor

ITEMS	AGE RANGE	M/R COSTS ($/sq.ft.)
MRCA1	0-9 YEARS	3.55
MRCA2	10-19 YEARS	3.26
MRCA3	20-29 YEARS	3.17
MRCA4	30-39 YEARS	3.69
MRCA5	40-49 YEARS	3.46
MRCA6	50 YEARS OR MORE	5.21
AVERAGE		**3.72**

Table 3. 28 Summary of M/R Costs of Office Buildings Based On Six Factors

FACTORS	M/R COSTS ($/sq.ft.)
CITY	4.21
LOC	4.19
OWNERSHIP	4.11
HEIGHT	3.99
SIZE	3.80
AGE	3.72

3.6 Summary

In this chapter, the proposed procedure of data processing is introduced. The procedure involves data collection, analyzing, sorting, as well as data statistical processing. One of the stochastic methods, the Monte Carlo simulation method, was used to do the data treatment. A set of results from the data treatment express the M/R unit costs of office buildings based on different categories and different affecting factors. The results obtained in this chapter will be used to generate the weights of the influencing factors and the related adjusting factors for the proposed model of forecasting the M/R costs of office buildings. This model is introduced in Chapter 4.

Chapter 4

PROPOSED M/R COSTS FORECASTING MODEL

"When first faced with a complex problem, we may be overwhelmed by its size and by the amount of detail involved. Our first instinct is to decompose the problem into smaller and more manageable parts: we then subdivide those parts into smaller parts, and so on. This, in essence, gives rise to a hierarchy. Hierarchies are thus a consequence of the effort of the human mind to seek understanding."

Thomas L. Saaty

4.1 General

This Chapter presents the proposed Maintenance/Repair costs forecasting model. A decision making method, Analytic Hierarchy Process (AHP), is used to generate the weights of all the cost influencing factors and all the adjusting factors of the related elements.

In this chapter, AHP theory is first introduced. A hierarchy structure consisting of levels for grouping the influencing factors and respected multi-criteria of M/R costs has been established. Meanwhile the paired comparisons are made. The weights expressing the priorities of these elements are obtained. A formula for evaluating total M/R costs with these weights is generated. Inflation rate is determined based on the historical data from Statistics Canada. A proposed M/R costs forecasting model is then established.

4.2 Determine the Weights of Influencing Factors

The total M/R costs of office buildings can be forecasted by considering the influence of city, location, ownership, height, size and age factors of these buildings. To quantify the influence of these factors, the weights of the influencing factors should be determined. The process to determine the weights of influencing factors is introduced in the following sections.

4.2.1 Proposed Methodology

4.2.1.1 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) was developed in the 1970's by Dr. Thomas Saaty and continues to be the most highly regarded and widely used decision-making theory. AHP is a general theory of measurement. Specially, AHP is widely used to derive priorities in multi-criteria decision-making. This method is based on three principles: Decomposition, Measurement of preferences and Synthesis.(Saaty 2001)

Decomposition breaks a problem down into manageable elements that are treated individually. It begins with implicit descriptors of the problem (the goal) and proceeds logically to criteria (or states of nature) in terms of which outcomes are evaluated. The result of this phase is a hierarchic structure consisting of levels for grouping issues together as to importance or influence with respect to the elements in the adjacent level above. A relative ratio scale of measurement is derived from paired comparisons of the elements in the level above. Pairwise comparisons are made to establish relations within the structure. The paired comparison matrix attempts to capture the relative dominance of one element over another with respect to an attribute that they have in common. These global priorities are obtained by successively weighting and adding from the upper level to the bottom level of the hierarchy. The outcome of the synthesis is a multi-linear (and hence nonlinear) form whose complexity depends on the number of elements in each level and on the number of levels in the hierarchy.

To the analyst, AHP appears similar to a weighted average method, but it yields more information, a more accurate assessment, and a measure of consistency.

AHP allows a better, easier, and more efficient identification of selection criteria, their weighting, and analysis.

In applying the AHP, the first step is ***decomposition***, or the structuring of the problem into a hierarchy. The next step is ***comparative judgment.*** The question to ask when comparing two criteria is of the following kind: of the two criteria or factors being compared, which is considered more important by the decision makers who are making the decision?

4.2.1.2 A Hierarchy of the Factors

AHP is a nonlinear framework that consists of taking several factors into consideration simultaneously. In applying the AHP, the first step is to represent the problem as a hierarchy, which is called ***decomposition***. (Saaty 2001)

The maintenance and repair costs of office buildings may vary according to several different categories: ownership, location, city, age, size and height. Each category has its own elements. There are two elements, the government sector and the private sector, in the ownership category. There are another two elements, downtown and suburban areas, in the location category. Twenty-eight cities are considered as the elements in the sub-level of the city category in the present research. These cities are the following: Barrie, ON; Calgary, AB; Charlottetown, PEI; Chicoutimi, PQ; Edmonton, AB; Fredericton, NB; Halifax, NS; Kelowna Area, BC; Kingston, ON; London, ON; Moncton, NB; Montreal, PQ; Ottawa, ON; Prince George, BC; Quebec, PQ; Rimouski, PQ; Saint John, NB; St. John's, NF; Sudbury, ON; Summerside, PEI; Thunder Bay, ON; Toronto, ON; Vancouver, BC; Victoria, BC; West Prince Rupert, BC; White Horse, YT; Winnipeg, MB; Yellowknife, NWT. There are six different building-age periods as elements in the sub-level of the age category: 0-9 years; 10-19 years; 20-29 years; 30-39 years; 40-49 years; 50 years or more. In the sub-level of the size category, five different size ranges are considered as elements: less than 50,000 SQ.FT.; 50,000-99,999 SQ.FT.; 100,000-299,999 SQ.FT.; 300,000-599,999 SQ.FT.; 600,000 SQ.FT. or more. Four different heights are considered as the elements in the height category: less than 5 stories; 5-9 stories; 10-19 stories and 20-29 stories.

The six categories and their related elements have been expressed as a hierarchical structure shown in Figure 4.1. There are two levels in this structure. Level 1 expresses the six categories of the factors that influence the M/R costs of office buildings. Level 2 shows the related elements of each category.

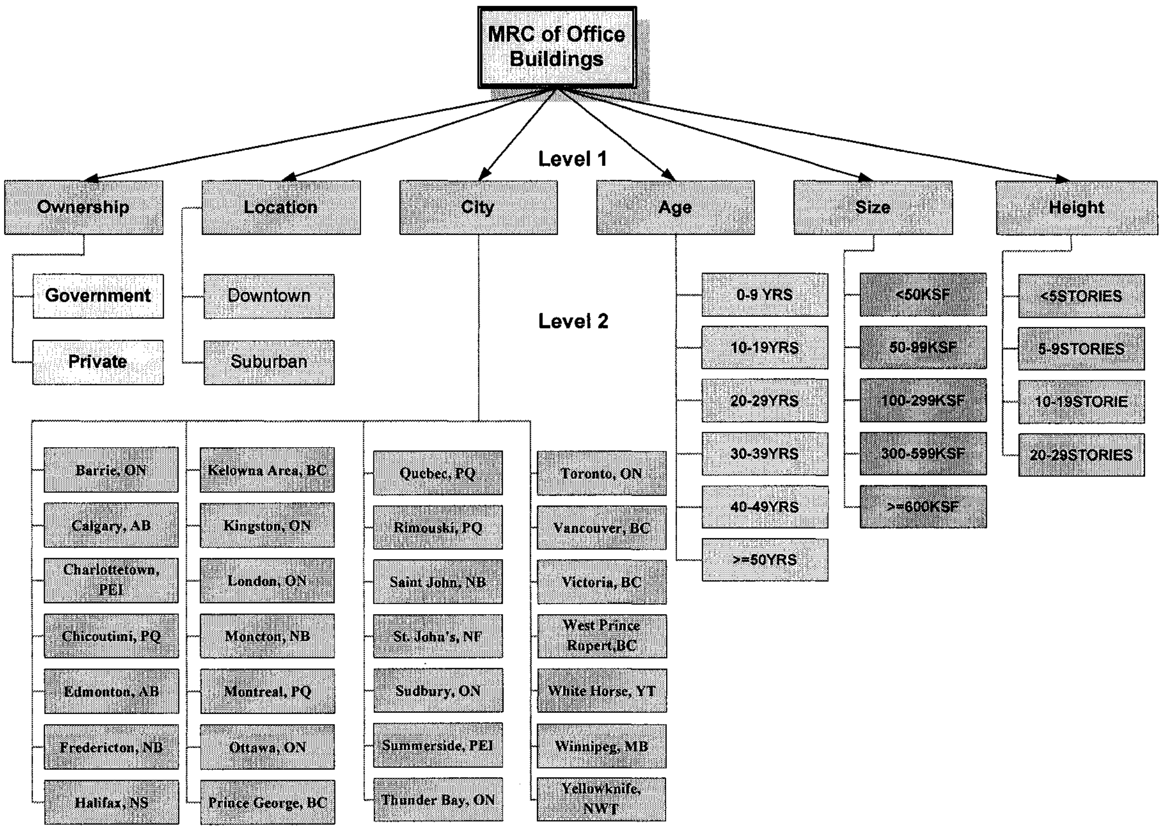


Figure 4. 1 Hierarchy of influence factors on M/R costs of office buildings

4.2.1.3 Comparative Judgment and Formulae

The next step in applying the AHP is ***comparative judgment.*** These judgments are made in the framework of a matrix used to set priorities as an estimate of relative magnitudes associated with the elements being compared (Saaty 2001).

AHP provides a way to input judgments and measurements in order to derive ratio scale priorities for the factors and elements by making pairwise comparisons of importance on a common property or criterion. Each criterion has a local (immediate) and global priority. The sum of all the criteria beneath a given parent criterion in each level of the model must equal one.

As described in 4.2.1.2, Figure 4.1 shows a hierarchy structure that conceptually indicates the relationship of the influencing factors of the M/R costs of office buildings and their related elements. The pairwise comparisons are made in this section. Judgments of importance of one factor or element over another are represented numerically to establish quantifiable relations within the structure. The factors on Level 1 in Figure 4.1 are arranged in a matrix with the relative importance of one factor over another. Table 4.1 shows the square matrix of pairwise comparisons of the factor importance influencing the M/R costs of office buildings.

Table 4. 1 The Pairwise Comparison of Importance of Influencing Factors

FACTORS	CITY	LOCATION	OWNERSHIP	HEIGHT	SIZE	AGE	W_F
CITY	(C,C)	(C,L)	(C,O)	(C,H)	(C,S)	(C,A)	W_{FC}
LOCATION	(L,C)	(L,L)	(L,O)	(L,H)	(L,S)	(L,A)	W_{FL}
OWNERSHIP	(O,C)	(O,L)	(O,O)	(O,H)	(O,S)	(O,A)	W_{FO}
HEIGHT	(H,C)	(H,L)	(H,O)	(H,H)	(H,S)	(H,A)	W_{FH}
SIZE	(S,C)	(S,L)	(S,O)	(S,H)	(S,S)	(S,A)	W_{FS}
AGE	(A,C)	(A,L)	(A,O)	(A,H)	(A,S)	(A,A)	W_{FA}
SUM	S_C	S_L	S_O	S_H	S_S	S_A	1.000

The comparisons in the table indicate the importance of one factor compared with another one. For example, (L, C) indicates the importance of the location factor over the city factor. Meanwhile, (C, L) is the reciprocal of (L, C), which indicates the importance of the city factor over the location factor. The value in the cell in which the number of the row equals the number of the column is always one. For example, (C, C) = 1 because the importance of the city factor in the row is the same as the number in the column.

The weights of the six influencing factors shown in Table 4.1 can be calculated by normalizing the comparisons (divided by the sums of the columns, and average across rows to get the relative weights of each factor with regards to the factors). The process of weights calculation can be described as in the following equations:

$$\mathbf{W_{FC} = [(C, C)/S_C+(C, L)/S_L+(C, O)/S_O+(C, H)/S_H+(C, S)/S_S+(C, A)/S_A]/6} \quad \textbf{(4.1)}$$

Where,

W_{FC} = the weight of city factor influencing the M/R costs of office buildings,

(C, C) = the importance of the city factor over the city factor, which value is 1, (C, L) = the importance of the city factor over the location factor,

(C, O) = the importance of the city factor over the ownership factor,

(C, H) = the importance of the city factor over the height factor,

(C, S) = the importance of the city factor over the size factor,

(C, A) = the importance of the city factor over the age factor,

S_C = the sum of the column of the city factor,

S_L = the sum of the column of the location factor,

S_O = the sum of the column of the ownership factor,

S_H = the sum of the column of the height factor,

S_S = the sum of the column of the size factor,

S_A = the sum of the column of the age factor.

$$\mathbf{W_{FL} = [(L, C)/S_C+(L, L)/S_L+(L, O)/S_O+(L, H)/S_H+(L, S)/S_S+(L, A)/S_A]/6} \qquad \mathbf{(4.2)}$$

Where,

W_{FL} = the weight of the location factor influencing the M/R costs of office Buildings,

(L, C) = the importance of the location factor over the city factor,

(L, L) = the importance of the location factor over the location factor, which value is 1,

(L, O) = the importance of the location factor over the ownership factor,

(L, H) = the importance of the location factor over the height factor,

(L, S) = the importance of the location factor over the size factor,

(L, A) = the importance of the location factor over the age factor.

$$W_{FO} = [(O, C)/S_C+(O, L)/S_L+(O, O)/S_O+(O, H)/S_H+(O, S)/S_S+(O, A)/S_A]/6 \qquad (4.3)$$

Where,

W_{FO} = the weight of the ownership factor influencing the M/R costs of Office buildings,

(O, C) = the importance of the ownership factor over the city factor,

(O, L) = the importance of the ownership factor over the location factor,

(O, O) = the importance of the ownership factor over the ownership factor, which value is 1,

(O, H) = the importance of the ownership factor over the height factor,

(O, S) = the importance of the ownership factor over the size factor,

(O, A) = the importance of the ownership factor over the age factor.

$$W_{FH} = [(H, C)/S_C+(H, L)/S_L+(H, O)/S_O+(H, H)/S_H+(H, S)/S_S+(H, A)/S_A]/6 \qquad (4.4)$$

Where,

W_{FH} = the weight of the height factor influencing the M/R costs of office Buildings,

(H, C) = the importance of the height factor over the city factor,

(H, L) = the importance of h the eight factor over the location factor,

(H, O) = the importance of the height factor over the ownership factor,

(H, H) = the importance of the height factor over the height factor, which value is 1,

(H, S) = the importance of the height factor over the size factor,

(H, A) = the importance of the height factor over the age factor.

$$W_{FS} = [(S, C)/S_C+(S, L)/S_L+(S, O)/S_O+(S, H)/S_H+(S, S)/S_S+(S, A)/S_A]/6 \quad (4.5)$$

Where,

W_{FS} = the weight of the size factor influencing the M/R costs of office Buildings,

(S, C) = the importance of the size factor over the city factor,

(S, L) = the importance of the size factor over the location factor,

(S, O) = the importance of the size factor over the ownership factor,

(S, H) = the importance of the size factor over the height factor,

(S, S) = the importance of the size factor over the size factor, which value is 1,

(S, A) = the importance of the size factor over the age factor,

$$W_{FA} = [(A, C)/S_C+(A, L)/S_L+(A, O)/S_O+(A, H)/S_H+(A, S)/S_S+(A, A)/S_A]/6 \quad (4.6)$$

Where,

W_{FA} = the weight of the age factor influencing the M/R costs of office Buildings,

(A, C) = the importance of the age factor over the city factor,

(A, L) = the importance of the age factor over the location factor,

(A, O) = the importance of the age factor over the ownership factor,

(A, H) = the importance of the age factor over the height factor,

(A, S) = the importance of the age factor over the size factor,

(A, A) = the importance of the age factor over the age factor, which value is 1.

4.2.2 Determine Factor Weights

In Chapter 3, Table 3.23 to Table 3.28 showed the M/R costs of office buildings of different categories calculated by stochastic simulation calculation. These costs are used to determine the weights of the influencing factors and of the further adjusting factors.

The M/R costs in Table 3.28 are used to generate the pairwise comparisons of the importance of the six influencing factors. The higher the value of the M/R cost of the factor, the greater the importance of this factor. For example, the M/R cost in the city category is $4.21/sq.ft. whereas the M/R cost in the age category is $3.72/sq.ft. From the cost point of view, the importance of the city factor relative to the age factor is (C, A) = 4.21/3.72 = 1.132. Meanwhile, the importance of the age factor over the city factor is (A, C) = 3.72/4.21 = 0.884. The matrix of pairwise comparisons of the six factors and the weights that were converted from the matrix are shown in Table 4. 2. The weights have been calculated by using Equation (4.1) to (4.6).

Table 4. 2 Weights of influencing factors

FACTORS	CITY	LOCATION	OWNERSHIP	HEIGHT	SIZE	AGE	W_F
CITY	**1.000**	1.005	1.024	1.056	1.108	1.132	**0.175**
LOCATION	0.995	**1.000**	1.019	1.051	1.103	1.126	**0.174**
OWNERSHIP	0.976	0.981	**1.000**	1.031	1.082	1.105	**0.171**
HEIGHT	0.947	0.951	0.970	**1.000**	1.049	1.071	**0.166**
SIZE	0.903	0.907	0.925	0.954	**1.000**	1.022	**0.158**
AGE	0.884	0.888	0.905	0.934	0.979	**1.000**	**0.155**
SUM	5.704	5.732	5.843	6.026	6.320	6.456	**1.000**

The consistency ratio (CR) is developed by Saaty (Saaty 2000) to aid the decision on revising the matrix or not. To get a sufficient consistent matrix, CR should meet the requirements described as follows (n is the dimension of the matrix):

$n = 3$: CR ≤ 5%,

$n = 4$: CR ≤ 8%,

$n \geq 5$: CR ≤ 10%.

If the CR of a matrix meets above requirements, the matrix is consistent. Otherwise the matrix should be revised.

The consistency ratio (CR) can be calculated using Equation (4.7).

$$CR = \frac{CI}{RI} \tag{4.7}$$

Where,

CR = Consistency Ratio,

CI = Consistency Index (the measurement of the deviation from a consistent matrix),

RI = Random Index (a random number according to the size of the matrix shown in Table 4.3).

Table 4. 3 Random Index

Matrix	3×3	4×4	5×5	6×6	7×7
RI	0.58	0.90	1.12	1.24	1.32

The consistency index (CI) can be calculated using Equation (4.8).

$$\mathbf{CI = (\lambda_{max} - n) / (n - 1)} \qquad \mathbf{(4.8)}$$

Where,

CI = Consistency Index,

λ_{max} = the maximal eigenvalue of the matrix containing weights associated with all the elements,

n = number of considered elements.

The matrix shown in Table 4.2 is a reciprocal matrix with λ_{max} = n. Therefore, the consistency ratio: CR = 0, indicates that the matrix is totally consistent.

4.3 Determine Adjusting Factors

Besides the six influencing factors, there are many further elements that can affect the total M/R costs. The adjusting factors of these elements should be determined for the proposed M/R costs forecasting model.

As shown in Figure 4.1, Level 2 expresses the elements of each category in Level 1. Within each category, the pairwise elements were compared according to their importance in the matrix. Six matrices along with the six categories were studied in this research. These matrices and the weights of all the elements that were converted from the matrices, as well as the related adjusting factors, are determined as follows:

As an example, the process of determining the age adjusting factor has been described step by step below.

Step 1. Determine the pairwise comparison and the weights of elements in the age category as shown in Table 4.4. Table 4.4 represents the matrix of pairwise comparisons of importance of the elements along with the age category generated according to the data in Table 3.27. All the weights of the elements can be calculated by using the method described in Section 4.2.

Table 4. 4 The Pairwise Comparison of Elements in Age Category

AGE	0-9 YRS	10-19YRS	20-29YRS	30-39YRS	40-49YRS	>=50YRS	W_A
0-9 YRS	**1.000**	1.089	1.120	0.962	1.026	0.681	**0.159**
10-19YRS	0.918	**1.000**	1.028	0.883	0.942	0.626	**0.146**
20-29YRS	0.893	0.972	**1.000**	0.859	0.916	0.608	**0.142**
30-39YRS	1.039	1.132	1.164	**1.000**	1.066	0.708	**0.165**
40-49YRS	0.975	1.061	1.091	0.938	**1.000**	0.664	**0.155**
>=50YRS	1.468	1.598	1.644	1.412	1.506	**1.000**	**0.233**
SUM	6.293	6.853	7.047	6.054	6.457	4.288	**1.000**

Step 2. Calculate the average weight of all the elements in the age category as $\overline{W_{Aj}}$ shown in Table 4.5 based on Equation (4.9).

Table 4. 5 Average Weight of the Elements in Age Category

AGE	0-9 YRS	10-19YRS	20-29YRS	30-39YRS	40-49YRS	>=50YRS	W_A	K_A
0-9 YRS	**1.000**	1.089	1.120	0.962	1.026	0.681	W_{A1}	K_{A1}
10-19YRS	0.918	**1.000**	1.028	0.883	0.942	0.626	W_{A2}	K_{A2}
20-29YRS	0.893	0.972	**1.000**	0.859	0.916	0.608	W_{A3}	K_{A3}
30-39YRS	1.039	1.132	1.164	**1.000**	1.066	0.708	W_{A4}	K_{A4}
40-49YRS	0.975	1.061	1.091	0.938	**1.000**	0.664	W_{A5}	K_{A5}
>=50YRS	1.468	1.598	1.644	1.412	1.506	**1.000**	W_{A6}	K_{A6}
SUM	6.293	6.853	7.047	6.054	6.457	4.288	**1.000**	$\overline{W_{Aj}}$

$$\overline{W_{Aj}} = (W_{A1} + W_{A2} + W_{A3} + W_{A4} + W_{A5} + W_{A6}) / 6 \qquad (4.9)$$

Step 3. Calculate the age adjusting factor based on the weights and the average weight as in Equation (4.10).

$$\mathbf{K_{Aj} = W_{Aj}} \,/\, \overline{W_{A\,j}} \qquad \textbf{(4.10)}$$

Where,

K_{Aj} = age adjusting factors, j = 1 to 6,

W_{Aj} = the weights of different age ranges influencing the M/R costs of office buildings, j = 1 to 6,

$\overline{W_{A\,j}}$ = average weight of the elements in the age category.

The weights of the elements in the age category and the relative age adjusting factors are calculated and shown in Table 4.6.

Table 4. 6 Age Adjusting Factor

AGE	0-9 YRS	10-19YRS	20-29YRS	30-39YRS	40-49YRS	>=50YRS	W_A	K_A
0-9 YRS	**1.000**	1.089	1.120	0.962	1.026	0.681	**0.159**	**0.952**
10-19YRS	0.918	**1.000**	1.028	0.883	0.942	0.626	**0.146**	**0.874**
20-29YRS	0.893	0.972	**1.000**	0.859	0.916	0.608	**0.142**	**0.850**
30-39YRS	1.039	1.132	1.164	**1.000**	1.066	0.708	**0.165**	**0.989**
40-49YRS	0.975	1.061	1.091	0.938	**1.000**	0.664	**0.155**	**0.927**
>=50YRS	1.468	1.598	1.644	1.412	1.506	**1.000**	**0.233**	**1.397**
SUM	6.293	6.853	7.047	6.054	6.457	4.288	**1.000**	**0.167**

The pairwise comparisons of the importance of the elements in the size category have been generated based on data in Table 3.26. They are shown in Table 4.7. The size adjusting factor can be determined as in Equation (4.11).

$$\mathbf{K_{Sj} = W_{Sj}} \,/\, \overline{W_{S\,j}} \qquad \textbf{(4.11)}$$

Where,

K_{Sj} = the size adjusting factors, j = 1 to 5,

W_{Sj} = the weights of different size ranges influencing the M/R costs of office buildings, j = 1 to 5,

$\overline{W_{Sj}}$ = the average weight of the elements in the size category.

The weights of the elements in size category and the relative size adjusting factors are calculated and shown in Table 4.7.

Table 4. 7 Size Adjusting Factor

SIZE	<50,000 SQ.FT.	50,000-99,000 SQ.FT.	100,000-299,000 SQ.FT.	300,000-599,000 SQ.FT.	>=600,000 SQ.FT.	W_S	K_S
<50KSF	**1.000**	1.067	1.151	1.065	0.950	**0.208**	**1.042**
50,000-99,000 SQ.FT.	0.937	**1.000**	1.078	0.997	0.890	**0.195**	**0.976**
100,000-299,000 SQ.FT.	0.869	0.927	**1.000**	0.925	0.825	**0.181**	**0.905**
300,000-599,000 SQ.FT.	0.939	1.003	1.081	**1.000**	0.892	**0.196**	**0.979**
>=600,000 SQ.FT.	1.053	1.124	1.212	1.121	**1.000**	**0.219**	**1.097**
SUM	4.798	5.121	5.523	5.108	4.556	**1.000**	**0.200**

The pairwise comparisons of importance of the elements in the height category are shown in Table 4.8. This table has been generated based on data in Table 3.25. The height adjusting factor can be determined as in Equation (4.12).

$$K_{Hj} = W_{Hj} / \overline{W_{Hj}} \qquad \textbf{(4.12)}$$

Where,

K_{Hj} = height adjusting factors, j = 1 to 4,

W_{Hj} = the weights of different height ranges influencing the M/R costs of office buildings, j = 1 to 4,

$\overline{W_{Hj}}$ = the average weight of the elements in the height category.

The weights of the elements in the height category and the relative height adjusting factors are calculated and shown in Table 4.8.

Table 4. 8 Height Adjusting Factor

HEIGHT		<5STORIES	5-9STORIES	10-19STORIES	20-29STORIES	W_H	K_H
Deterministic Method	<5STORIES	**1.000**	1.040	0.907	0.987	**0.245**	**0.981**
	5-9STORIES	0.961	**1.000**	0.872	0.949	**0.236**	**0.943**
	10-19STORIE	1.103	1.147	**1.000**	1.089	**0.270**	**1.082**
	20-29STORIES	1.013	1.053	0.918	**1.000**	**0.248**	**0.994**
	SUM	4.077	4.241	3.697	4.025	**1.000**	**0.250**
Stochastic Method	<5STORIES	**1.000**	1.013	0.891	0.980	**0.242**	**0.969**
	5-9STORIES	0.987	**1.000**	0.880	0.967	**0.239**	**0.956**
	10-19STORIE	1.122	1.136	**1.000**	1.099	**0.272**	**1.087**
	20-29STORIES	1.021	1.034	0.910	**1.000**	**0.247**	**0.989**
	SUM	4.130	4.184	3.681	4.046	**1.000**	**0.250**

The pairwise comparisons of importance of the elements in the ownership category are shown in Table 4.9. This table has been generated based on data in Table 3.23. The ownership adjusting factor can be determined as in Equation (4.13).

$$K_{Oj} = W_{Oj} / \overline{W_{Oj}} \quad \textbf{(4.13)}$$

Where,

K_{Oj} = ownership adjusting factors, j = 1 to 2,

W_{Oj} = the weights of different ownership influencing the M/R costs of office buildings, j = 1 to 2,

$\overline{W_{Oj}}$ = the average weight of the elements in the ownership category.

The weights of the elements in the ownership category and the relative ownership adjusting factors are calculated out and shown in Table 4.9.

Table 4. 9 Ownership Adjusting Factor

OWNERSHIP	PRIVATE	GOVERNMENT	W_O	K_O
PRIVATE	**1.000**	0.514	**0.339**	**0.679**
GOVERNMENT	1.946	**1.000**	**0.661**	**1.321**
SUM	2.946	1.514	**1.000**	**0.500**

The pairwise comparisons of importance of the elements in the location category are shown in Table 4.10. This table has been generated based on data in Table 3.24. The location adjusting factor can be determined as in Equation (4.14).

$$K_{Lj} = W_{Lj} / \overline{W_{Lj}} \quad \textbf{(4.14)}$$

Where,

K_{Lj} = the location adjusting factors, j = 1 to 2,

W_{Lj} = the weights of different location influencing the M/R costs of office buildings, j = 1 to 2,

$\overline{W_{Lj}}$ = average weight of the elements in location category.

The weights of the elements in the location category and the relative location adjusting factors are calculated and shown in Table 4.10.

Table 4. 10 Location Adjusting Factor

LOCATION	DOWNTOWN	SUBURBAN	W_L	K_L
DOWNTOWN	**1.000**	0.960	**0.490**	**0.980**
SUBURBAN	1.041	**1.000**	**0.510**	**1.020**
SUM	2.041	1.960	**1.000**	**0.500**

Table 4.11 shows the M/R costs of office buildings in different cities.

Table 4. 11 M/R Costs for City Category

CITIES	PAYROLL	ELEVATOR	HVAC	ELECTRICAL	STRUC/ ROOF	PLUMBING	FIRE/LIFE SAFETY	GEN EXTERIOR	GEN INTERIOR	CONTRACT	SUM	MRCC
Barrie, ON	1.86	0.38	0.28	0.08	0.30	0.01	0.10	0.07	1.44	1.21	5.73	**5.73**
Calgary, AB	0.52	0.33	0.34	0.29	0.02	0.03	0.17	0.04	0.43	1.21	3.38	**2.77**
Calgary, AB	0.71	0.13	0.12	0.24	0.04	0.03	0.07	0.04	0.05	1.21	2.64	
Calgary, AB	0.60	0.05	0.40	0.08	0.11	0.03	0.02	0.08	0.08	0.85	2.30	
Charlottetown, PEI	0.94	0.17	0.26	0.30	0.23	0.04	0.07	0.07	1.09	1.21	4.38	**4.38**
Chicoutimi, PQ	0.97	0.06	0.18	0.12	0.30	0.01	0.10	0.07	0.97	1.21	3.99	**3.99**
Edmonton, AB	0.70	0.01	0.21	0.24	0.06	0.13	0.02	0.08	0.08	1.21	1.53	**1.53**
Fredericton, NB	1.11	0.18	1.02	0.16	0.98	0.44	0.34	0.07	1.52	1.21	7.03	**7.03**
Halifax, NS	0.82	0.20	0.25	0.02	0.31	0.09	0.12	0.07	1.30	1.21	4.39	**4.65**
Halifax, NS	1.29	0.20	0.23	0.11	0.56	0.01	0.25	0.07	0.98	1.21	4.91	
Kelowna Area, BC	0.70	0.20	0.36	0.16	0.34	0.06	0.04	0.01	0.02	1.21	1.53	**1.53**
Kingston, ON	0.94	0.12	0.85	0.17	0.30	0.03	0.73	0.07	1.32	1.21	5.74	**5.74**
London, ON	0.36	0.30	0.31	0.19	0.30	0.01	0.12	0.07	0.74	1.21	3.61	**3.61**
Moncton, NB	0.36	0.27	0.23	0.09	0.03	0.01	0.06	0.07	0.66	1.21	2.99	**2.99**
Montreal, PQ	1.13	0.22	0.34	0.16	0.14	0.03	0.08	0.07	0.79	1.21	4.17	**4.19**
Montreal, PQ	0.70	0.20	0.67	0.07	0.04	0.09	0.05	0.07	0.73	1.59	4.21	
Ottawa, ON	0.64	0.33	0.49	0.26	0.25	0.18	0.21	0.06	1.35	2.24	6.01	**3.70**
Ottawa, ON	0.55	0.18	0.38	0.05	0.03	0.05	0.05	0.11	0.11	1.21	2.72	
Ottawa, ON	0.38	0.10	0.22	0.04	0.03	0.03	0.04	0.17	0.16	1.21	2.38	
Prince George, BC	0.97	0.34	0.24	0.16	0.24	0.05	0.04	0.01	0.01	0.78	2.84	**2.84**
Quebec, PQ	1.14	0.11	0.26	0.05	0.33	0.07	0.12	0.07	0.84	1.41	4.40	**4.40**
Rimouski, PQ	1.06	0.15	0.25	0.29	0.11	0.01	0.08	0.07	0.66	1.21	3.89	**3.89**
Saint John, NB	0.92	0.21	0.20	0.01	0.30	0.07	0.05	0.07	0.66	1.21	3.70	**5.04**
Saint John, NB	1.27	0.20	0.34	0.16	1.21	0.07	0.04	0.07	1.81	1.21	6.38	
St. John's, NF	0.87	0.16	0.17	0.07	0.09	0.02	0.12	0.07	1.32	1.21	4.10	**4.37**
St. John's, NF	1.02	0.20	0.27	0.35	0.30	0.07	0.06	0.07	1.08	1.21	4.63	
Sudbury, ON	0.67	0.26	0.43	0.06	2.17	0.06	0.06	0.07	1.18	1.21	6.17	**6.17**
Summerside, PEI	2.85	0.14	0.43	0.31	0.01	0.09	0.14	0.07	0.77	1.21	6.02	**6.02**
Thunder Bay, ON	0.63	0.16	0.17	0.03	0.11	0.02	0.04	0.07	0.68	1.21	3.12	**3.12**
Toronto, ON	0.52	0.28	0.32	0.16	0.79	0.14	0.13	0.07	1.99	1.21	5.61	**3.54**
Toronto, ON	0.84	0.11	0.33	0.04	0.08	0.04	0.04	0.08	0.11	1.13	2.80	
Toronto, ON	0.66	0.01	0.18	0.08	0.06	0.07	0.08	0.10	0.10	0.88	2.22	
Vancouver, BC	2.43	0.75	1.12	0.19	0.55	0.05	0.22	0.07	0.45	1.21	7.04	**3.82**
Vancouver, BC	0.69	0.13	0.21	0.39	0.22	0.02	0.05	0.07	0.11	1.21	3.10	
Vancouver, BC	0.85	0.14	0.15	0.08	0.14	0.09	0.04	0.10	0.10	1.21	2.90	
Vancouver, BC	0.35	0.26	0.04	0.09	0.04	0.05	0.03	0.09	0.07	1.21	2.23	
Victoria, BC	0.98	0.16	0.31	0.47	0.01	0.03	0.04	0.07	0.25	1.21	3.53	**3.05**
Victoria, BC	0.76	0.14	0.28	0.17	0.17	0.04	0.03	0.05	0.09	0.83	2.56	
West Prince Rupert,BC	1.38	0.14	0.14	0.16	0.36	0.07	0.03	0.01	0.02	1.21	3.52	**3.52**
White Horse, YT	0.95	0.19	0.39	0.05	0.30	0.07	0.06	0.07	0.98	1.21	4.27	**4.27**
Winnipeg, MB	0.81	0.19	1.23	0.37	0.26	0.07	0.28	0.07	0.83	1.21	5.32	**5.32**
Yellowknife, NWT	1.88	0.20	0.99	0.29	0.30	0.21	0.05	0.07	1.39	1.21	6.59	**6.59**

The pairwise comparisons of importance of the elements in the city category are shown in Table 4.12. This table has been generated based on data in Table 4.11. The city adjusting factor can be determined as in Equation (4.15).

$$K_{Cj} = W_{Cj} / \overline{W_{Cj}} \qquad \textbf{(4.15)}$$

Where,

K_{Cj} = the city adjusting factors, j = 1 to 28,

W_{Cj} = the weights of different cities influencing the M/R costs of office buildings, j = 1 to 28,

$\overline{W_{Cj}}$ = the average weight of the elements in the city category.

The weights of the elements in the city category and the relative city adjusting factors are calculated and shown in Table 4.12.

Table 4. 12 City Adjusting Factor

CITIES	Barrie, ON	Calgary, AB	Charlottetown, PEI	Chicoutimi, PQ	Edmonton, AB	Fredericton, NB	Halifax, NS	Kelowna Area, BC	Kingston, ON	London, ON	Moncton, NB	Montreal, PQ	Ottawa, ON	Prince George, BC
Barrie, ON	**1.000**	2.069	1.308	1.436	3.745	0.815	1.232	3.745	0.998	1.587	1.916	1.368	1.549	2.018
Calgary, AB	0.483	**1.000**	0.632	0.694	1.810	0.394	0.596	1.810	0.483	0.767	0.926	0.661	0.749	0.975
Charlottetown, PEI	0.764	1.581	**1.000**	1.098	2.863	0.623	0.942	2.863	0.763	1.213	1.465	1.045	1.184	1.542
Chicoutimi, PQ	0.696	1.440	0.911	**1.000**	2.608	0.568	0.858	2.608	0.695	1.105	1.334	0.952	1.078	1.405
Edmonton, AB	0.267	0.552	0.349	0.383	**1.000**	0.218	0.329	1.000	0.267	0.424	0.512	0.365	0.414	0.539
Fredericton, NB	1.227	2.538	1.605	1.762	4.595	**1.000**	1.512	4.595	1.225	1.947	2.351	1.678	1.900	2.475
Halifax, NS	0.812	1.679	1.062	1.165	3.039	0.661	**1.000**	3.039	0.810	1.288	1.555	1.110	1.257	1.637
Kelowna Area, BC	0.267	0.552	0.349	0.383	1.000	0.218	0.329	**1.000**	0.267	0.424	0.512	0.365	0.414	0.539
Kingston, ON	1.002	2.072	1.311	1.439	3.752	0.817	1.234	3.752	**1.000**	1.590	1.920	1.370	1.551	2.021
London, ON	0.630	1.303	0.824	0.905	2.359	0.514	0.776	2.359	0.629	**1.000**	1.207	0.862	0.976	1.271
Moncton, NB	0.522	1.079	0.683	0.749	1.954	0.425	0.643	1.954	0.521	0.828	**1.000**	0.714	0.808	1.053
Montreal, PQ	0.731	1.513	0.957	1.050	2.739	0.596	0.901	2.739	0.730	1.161	1.401	**1.000**	1.132	1.475
Ottawa, ON	0.646	1.336	0.845	0.927	2.418	0.526	0.796	2.418	0.645	1.025	1.237	0.883	**1.000**	1.303
Prince George, BC	0.496	1.025	0.648	0.712	1.856	0.404	0.611	1.856	0.495	0.787	0.950	0.678	0.768	**1.000**
Quebec, PQ	0.768	1.588	1.005	1.103	2.876	0.626	0.946	2.876	0.767	1.219	1.472	1.050	1.189	1.549
Rimouski, PQ	0.679	1.404	0.888	0.975	2.542	0.553	0.837	2.542	0.678	1.078	1.301	0.928	1.051	1.370
Saint John, NB	0.880	1.819	1.151	1.263	3.294	0.717	1.084	3.294	0.878	1.396	1.686	1.203	1.362	1.775
St. John's, NF	0.763	1.578	0.998	1.095	2.856	0.622	0.940	2.856	0.761	1.211	1.462	1.043	1.181	1.539
Sudbury, ON	1.077	2.227	1.409	1.546	4.033	0.878	1.327	4.033	1.075	1.709	2.064	1.473	1.668	2.173
Summerside, PEI	1.051	2.173	1.374	1.509	3.935	0.856	1.295	3.935	1.049	1.668	2.013	1.437	1.627	2.120
Thunder Bay, ON	0.545	1.126	0.712	0.782	2.039	0.444	0.671	2.039	0.544	0.864	1.043	0.745	0.843	1.099
Toronto, ON	0.618	1.278	0.808	0.887	2.314	0.504	0.761	2.314	0.617	0.981	1.184	0.845	0.957	1.246
Vancouver, BC	0.667	1.379	0.872	0.957	2.497	0.543	0.822	2.497	0.666	1.058	1.278	0.912	1.032	1.345
Victoria, BC	0.532	1.101	0.696	0.764	1.993	0.434	0.656	1.993	0.531	0.845	1.020	0.728	0.824	1.074
West Prince Rupert, BC	0.614	1.271	0.804	0.882	2.301	0.501	0.757	2.301	0.613	0.975	1.177	0.840	0.951	1.239
White Horse, YT	0.745	1.542	0.975	1.070	2.791	0.607	0.918	2.791	0.744	1.183	1.428	1.019	1.154	1.504
Winnipeg, MB	0.928	1.921	1.215	1.333	3.477	0.757	1.144	3.477	0.927	1.474	1.779	1.270	1.438	1.873
Yellowknife, NWT	1.150	2.379	1.505	1.652	4.307	0.937	1.417	4.307	1.148	1.825	2.204	1.573	1.781	2.320
SUM	20.558	42.527	26.895	29.524	76.993	16.757	25.333	76.993	20.523	32.632	39.398	28.115	31.838	41.479

Quebec, PQ	Rimouski, PQ	Saint John, NB	St. John's, NF	Sudbury, ON	Summerside, PEI	Thunder Bay, ON	Toronto, ON	Vancouver, BC	Victoria, BC	West Prince Rupert, BC	White Horse, YT	Winnipeg, MB	Yellowknife, NWT	W_C	K_C
1.302	1.473	1.137	1.311	0.929	0.952	1.837	1.619	1.500	1.879	1.628	1.342	1.077	0.869	**0.049**	**1.351**
0.630	0.712	0.550	0.634	0.449	0.460	0.888	0.782	0.725	0.908	0.787	0.649	0.521	0.420	**0.024**	**0.653**
0.995	1.126	0.869	1.002	0.710	0.728	1.404	1.237	1.147	1.436	1.244	1.026	0.823	0.665	**0.037**	**1.033**
0.907	1.026	0.792	0.913	0.647	0.663	1.279	1.127	1.045	1.308	1.134	0.934	0.750	0.605	**0.034**	**0.941**
0.348	0.393	0.304	0.350	0.248	0.254	0.490	0.432	0.401	0.502	0.435	0.358	0.288	0.232	**0.013**	**0.361**
1.598	1.807	1.395	1.609	1.139	1.168	2.253	1.986	1.840	2.305	1.997	1.646	1.321	1.067	**0.060**	**1.658**
1.057	1.195	0.923	1.064	0.754	0.772	1.490	1.314	1.217	1.525	1.321	1.089	0.874	0.706	**0.039**	**1.096**
0.348	0.393	0.304	0.350	0.248	0.254	0.490	0.432	0.401	0.502	0.435	0.358	0.288	0.232	**0.013**	**0.361**
1.305	1.476	1.139	1.314	0.930	0.953	1.840	1.621	1.503	1.882	1.631	1.344	1.079	0.871	**0.049**	**1.354**
0.820	0.928	0.716	0.826	0.585	0.600	1.157	1.020	0.945	1.184	1.026	0.845	0.679	0.548	**0.031**	**0.851**
0.680	0.769	0.593	0.684	0.485	0.497	0.958	0.845	0.783	0.980	0.849	0.700	0.562	0.454	**0.025**	**0.705**
0.952	1.077	0.831	0.959	0.679	0.696	1.343	1.184	1.097	1.374	1.190	0.981	0.788	0.636	**0.036**	**0.988**
0.841	0.951	0.734	0.847	0.600	0.615	1.186	1.045	0.969	1.213	1.051	0.867	0.695	0.561	**0.031**	**0.872**
0.645	0.730	0.563	0.650	0.460	0.472	0.910	0.802	0.743	0.931	0.807	0.665	0.534	0.431	**0.024**	**0.670**
1.000	1.131	0.873	1.007	0.713	0.731	1.410	1.243	1.152	1.443	1.250	1.030	0.827	0.668	**0.037**	**1.038**
0.884	**1.000**	0.772	0.890	0.630	0.646	1.247	1.099	1.018	1.275	1.105	0.911	0.731	0.590	**0.033**	**0.917**
1.145	1.296	**1.000**	1.153	0.817	0.837	1.615	1.424	1.319	1.652	1.432	1.180	0.947	0.765	**0.043**	**1.188**
0.993	1.123	0.867	**1.000**	0.708	0.726	1.401	1.234	1.144	1.433	1.241	1.023	0.821	0.663	**0.037**	**1.030**
1.402	1.586	1.224	1.412	**1.000**	1.025	1.978	1.743	1.615	2.023	1.753	1.445	1.160	0.936	**0.052**	**1.455**
1.368	1.548	1.194	1.378	0.976	**1.000**	1.929	1.701	1.576	1.974	1.710	1.410	1.132	0.914	**0.051**	**1.420**
0.709	0.802	0.619	0.714	0.506	0.518	**1.000**	0.881	0.817	1.023	0.886	0.731	0.586	0.473	**0.026**	**0.736**
0.805	0.910	0.702	0.810	0.574	0.588	1.135	**1.000**	0.927	1.161	1.006	0.829	0.665	0.537	**0.030**	**0.835**
0.868	0.982	0.758	0.874	0.619	0.635	1.224	1.079	**1.000**	1.252	1.085	0.895	0.718	0.580	**0.032**	**0.901**
0.693	0.784	0.605	0.698	0.494	0.507	0.978	0.862	0.798	**1.000**	0.866	0.714	0.573	0.463	**0.026**	**0.719**
0.800	0.905	0.698	0.805	0.571	0.585	1.128	0.994	0.921	1.154	**1.000**	0.824	0.662	0.534	**0.030**	**0.830**
0.970	1.098	0.847	0.977	0.692	0.709	1.369	1.206	1.118	1.400	1.213	**1.000**	0.803	0.648	**0.036**	**1.007**
1.209	1.368	1.056	1.217	0.862	0.884	1.705	1.503	1.393	1.744	1.511	1.246	**1.000**	0.807	**0.045**	**1.254**
1.498	1.694	1.308	1.508	1.068	1.095	2.112	1.862	1.725	2.161	1.872	1.543	1.239	**1.000**	**0.056**	**1.554**
26.773	30.283	23.373	26.957	19.092	19.568	37.756	33.277	30.838	38.623	33.466	27.588	22.143	17.876	**1.000**	**0.036**

4.4 M/R Costs Evaluation Model

There are some variables that have been considered in the proposed M/R costs evaluating model in the present research. These variables include: the basic M/R cost of office buildings in Canada, the quantified influence of the city factor, location factor, ownership factor, height factor, size factor and age factor, as well as the rental area of office buildings. The proposed M/R costs evaluating model is represented as in Equation (4.16).

$$\mathbf{TMRC = MRC*(W_{FC}*K_{Cj} + W_{FL}*K_{Lj} + W_{FO}*K_{Oj} + W_{FH}*K_{Hj} + W_{FS}*K_{Sj} + W_{FA}*K_{Aj}) *TRA} \quad \textbf{(4.16)}$$

Where:

TMRC---Total M/R costs of office buildings (based on 2001 data) ($),

MRC --- M/R unit cost of office buildings in Canada (based on 2001 data) ($/SQ.FT.),

W_{FC} = the weight of the city factor influencing theM/R costs of office buildings,

W_{FL} = the weight of the location factor influencing the M/R costs of office buildings,

W_{FO} = the weight of ownership factor influencing M/R costs of office buildings,

W_{FH} = the weight of the height factor influencing the M/R costs of office buildings,

W_{FS} = the weight of the size factor influencing the M/R costs of office buildings,

W_{FA} = the weight of the age factor influencing the M/R costs of office buildings,

K_{Cj} = the city adjusting factors, j = 1 to 28,

K_{Lj} = the location adjusting factors, j = 1 to 2,

K_{Oj} = the ownership adjusting factors, j = 1 to 2,

K_{Hj} = the height adjusting factors, j = 1 to 4,

K_{Sj} = the size adjusting factors, j = 1 to 5,

K_{Aj} = the age adjusting factors, j = 1 to 6,

TRA ---Total rental area of office buildings (SQ.FT.).

4.5 M/R Costs Forecasting Model

The concept of "time value of money" indicates that the "purchasing power" of money changes along with the time changing. Inflation rate is usually considered to reflect the changing rate. The M/R costs forecasting model in this research involves the inclusion of the inflation rate, which is required to forecast the future maintenance/repair costs. To this end, the data extracted from Statistics Canada has been analyzed to acquire the annual inflation rate as shown in Table 3.1. The proposed M/R costs forecasting model is represented as in Equation (4.17).

$$\mathbf{FTMRC = TMRC*(1+y)^n} \qquad \mathbf{(4.17)}$$

Where,

FTMRC = Forecast total M/R costs of office buildings (based on 2001 data) ($)

TMRC = Total M/R costs of office buildings (based on 2001 data) ($)

y = Forecasting inflation rate (%)

n = Number of years between the forecast year and the year 2001

4.6 Summary

In this chapter the proposed M/R costs evaluation and forecasting models have been presented. Each category identified in Chapter 3 is represented as a factor influencing the M/R costs of office buildings. The Analytic Hierarchy Process (AHP) method is used to determine the weights of these influencing factors and their associated elements. A set of equations is developed to calculate the weights based on the pairwise comparisons generated by the AHP method. Another set of equations is also developed to determine the adjusting factors along with each category. Afterwards, the M/R costs forecasting model has been developed by integrating all the influencing factors, the M/R costs baseline (MRC), and the total rental area of office buildings. A prototype implementation is described in Chapter 5 for implementing the proposed forecasting model.

Chapter 5

SYSTEM IMPLEMENTATION

5.1 General

This chapter describes the FTMRC system design and implementation. The FTMRC system has been developed to implement the M/R costs forecasting model that was presented in Chapter 4. As a prototype software, the FTMRC system operates in a Microsoft Windows@ environment. The system tasks are demonstrated first. Afterwards the system implementation involving system assumptions, system architecture, system components and the system algorithm are introduced separately in the present chapter.

5.2 System Tasks

The FTMRC system has been developed to help owners and facility managers to evaluate the future expenditure of maintaining and repairing the office buildings. It provides the functions of the input, output of project information and finical information. The FTMRC system can also provide the facilities to determine the weights and adjusting factors to evaluate the M/R costs of office buildings and to forecast the future expenditures of maintaining and repairing the office buildings based on the developed equations as described in Chapter 4. The system should be accessible by the owner and facility manager users.

The following interdependent tasks are performed by the system:

- Allow owners and facility managers to input the information about the office buildings
- Allow owners and facility managers to input the finical information
- Allow owners and facility managers to view the summary of the information of the office buildings and the finical information
- Allow owners and facility managers to forecast the M/R costs for the office buildings
- Allow owners and facility managers to evaluate the total M/R costs over the life span of office buildings
- Allow owners and facility managers to recognize the factor that most affects the total M/R costs over the life span of office buildings

5.3 System Implementation

The prototype FTMRC system is implemented utilizing the function-oriented design method and is coded using Visual Basic Applications. The prototype software operates in a Microsoft Windows@ environment. The system implementation is presented in the following sections.

5.3.1 System Assumptions

There are some assumptions concerning the design of the system. These assumptions include the following:

1. The basic M/R unit cost of office buildings is based on the reported data for office buildings in 2001 in Canada from BOMA *EER* 2002.
2. There are six factors influencing the total M/R costs of office buildings. These factors include the city, location, ownership, height, size and age factors.
3. The summation of the weights of the six influencing factors mentioned above is 1.
4. The M/R costs of office buildings are further adjusted by the adjusting factors of elements related to the six influencing factors.
5. The total M/R costs of office buildings are based on total building rental area.
6. The inflation rate and the discount rate are considered constant input by users.
7. The maintenance and repair expenditures occur at the end of each year in the cash flows over the life span of the office buildings.
8. There are three factors that are analyzed for the sensitivity analysis of the NPV (MRC) model: the life span, discount rate, and forecasting of the total maintenance and repair costs.

5.3.2 System Architecture

Most systems are usually quite complex. A system architecture is necessary for the system design. The system architecture describes the system behaviour and the internal structure of the system. The system architecture shows the basic organization of the system. Almost all of the ways in which a system interacts with its users, applications, and its data flow are dependent upon the architecture. Figure 5.1 illustrates the architecture of the proposed FTMRC system. The heart of the system is the reference data and data storage, which are implemented in tabulated formats in MS-Excel. The user-friendly graphical interfaces allow users to interact with the system by inputting data to the data storage and retrieval from the reference data. Three functionalities play the key roles of evaluating, forecasting and analyzing the total M/R costs of office buildings. The system can also provide both numerical reports and graphical reports. The detailed components of the system are described in section 5.3.3.

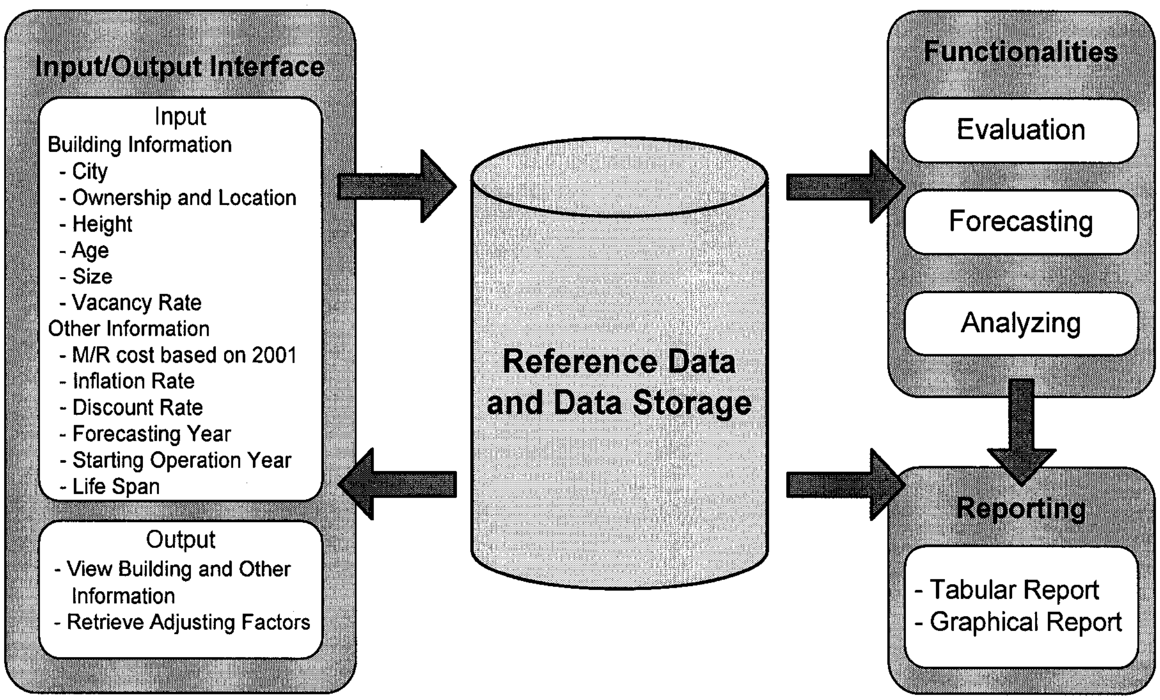


Figure 5. 1 The FTMRC System Architecture

5.3.3 System Components

The proposed FTMRC system has the following eight components: user interfaces, input/output, reference data, data storage, evaluation, forecasting, analyzing and reporting. These components and their relationships are shown in Figure 5.2.

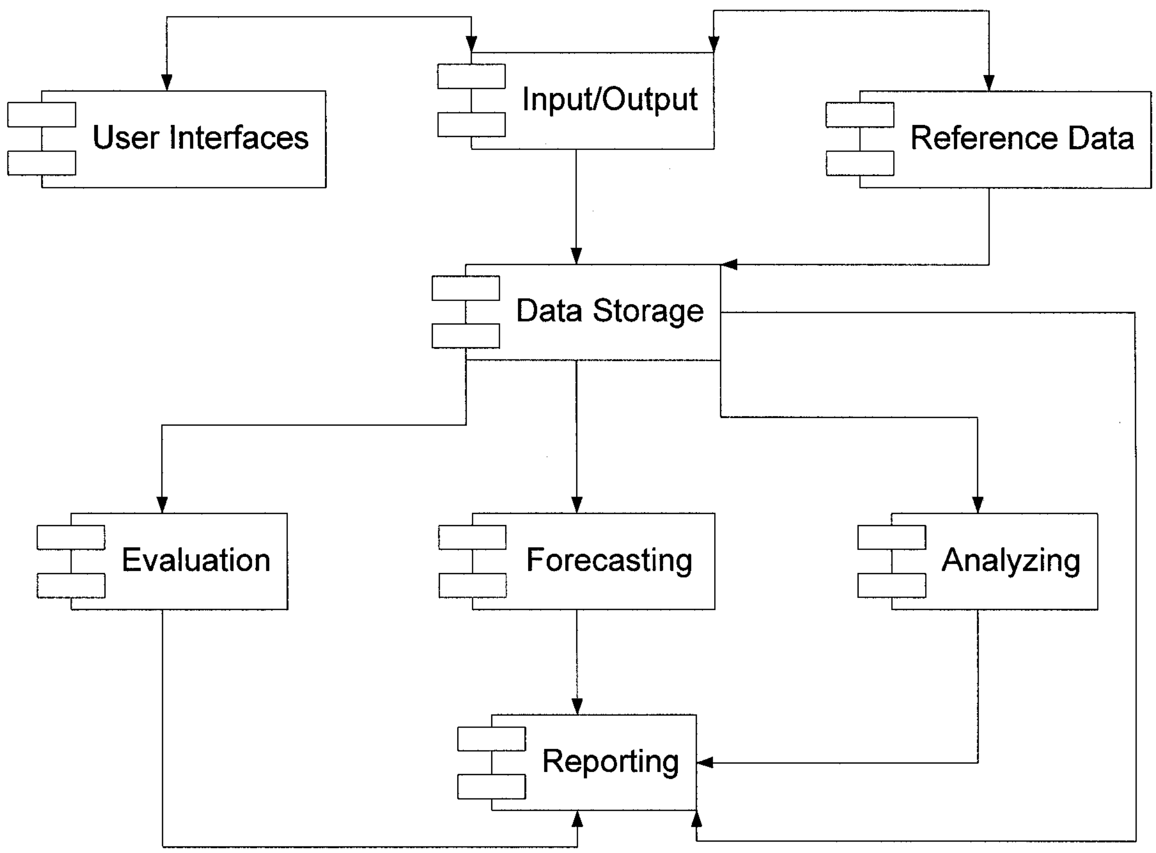


Figure 5. 2 The FTMRC System Components

The details of the components are introduced as follows:

5.3.3.1 Graphical User Interface (GUI)

The Graphical User Interface (GUI) allows users to interact with the system and facilitates data input. There are eight user-friendly graphical interfaces in the FTMRC system: the login, the city factor information, the ownership and location factors information, the height factor information, the size factor information, the age factor information, the other input and the net present value interfaces.

1. LOGIN INTERFACE

The first user interface is LOGIN, as illustrated in Fig 5.3. To log in, it is necessary to enter the user ID and password into the corresponding text boxes. After entering the correct information in the appropriate text boxes, click on the **Login** button. If the user name or password is misspelled accidentally, users will be prompted to re-enter the information. Users could clear the login name and password by clicking on the **Reset** button. The dialog window of the LOGIN interface closes if users click on the **Close** button. After a successful login, the city factor information interface shown in Fig 5.4 is displayed.

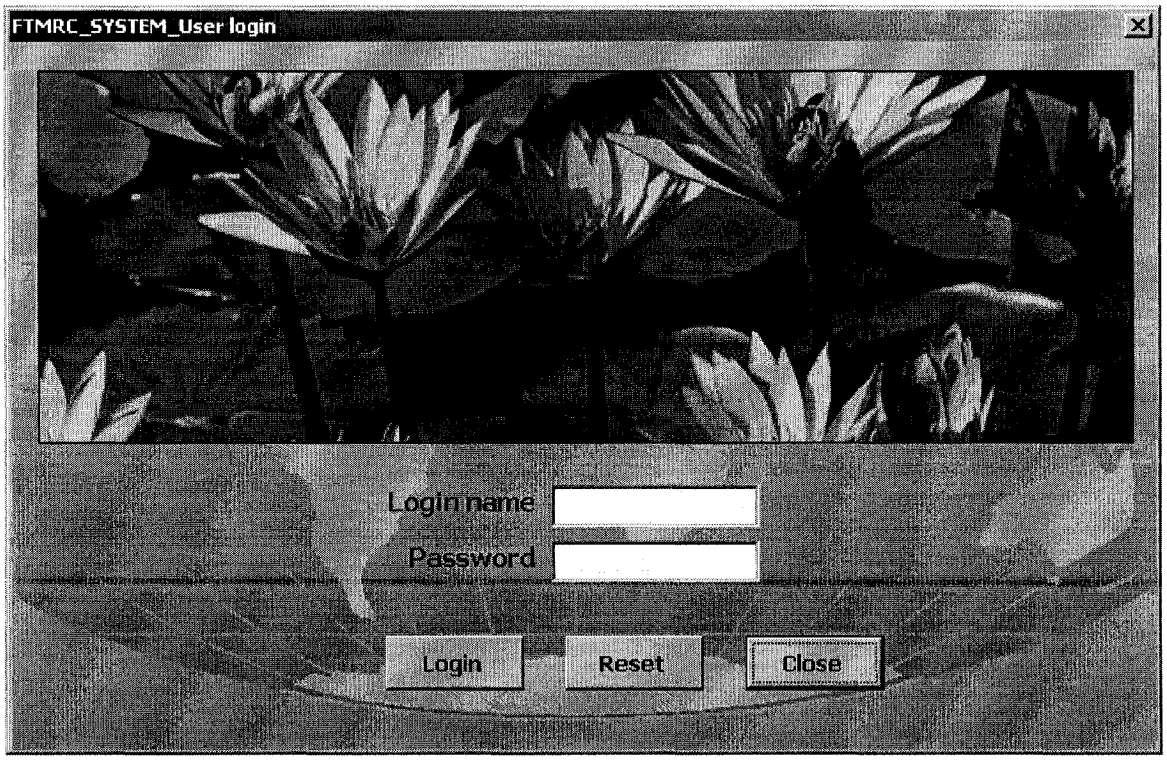


Figure 5. 3 User Login Interface

2. CITY FACTOR INFORMATION INTERFACE

The city factor information interface as shown in Figure 5.4 is composed of three parts: the top part allows users to input the building name. The lower-left part is a list of cities in Canada reported in BOMA *EER.* Users can select the city corresponding to their cases. The lower-right part shows the output of the city information and the city factor. After selecting the city, the user clicks on the **Get Values** button. The city information is viewed and the city adjusting factor is retrieved in the appropriate text boxes on the right. The ownership and location factor information interface as shown in Fig 5.5 is displayed when users click on the **OK** button after completing the input/output of the city factor information. The four buttons: **Get Values**, **OK**, **Reset** and **Close** are utilized in the same way in the other following interfaces.

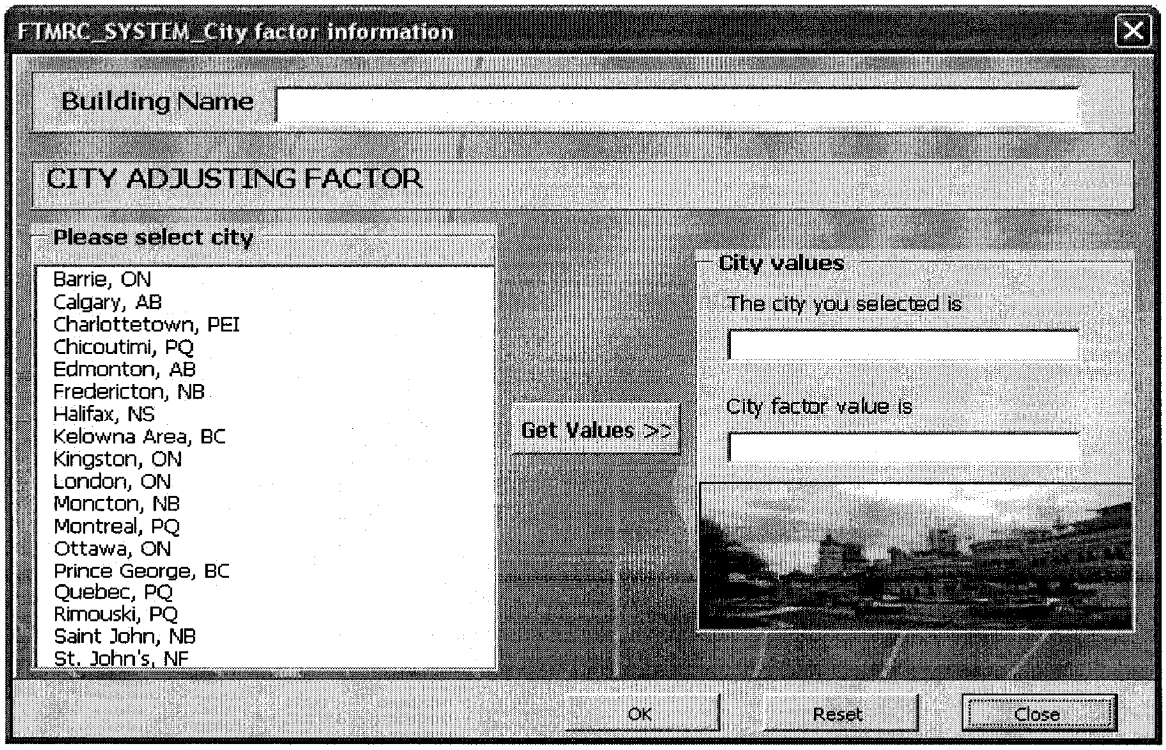


Figure 5. 4 City Factor Information Interface

3. OWNERSHIP AND LOCATION FACTOR INFORMATION INTERFACE

The ownership and location factor information interface as shown in Figure 5.5 is composed of four parts: the top part allows users to input the information of the owner. The middle-left part provides the selection of ownership. The lower-left part provides the selection of location. The lower-right part shows the output of the ownership factor and the location factor corresponding to the information input in the left parts.

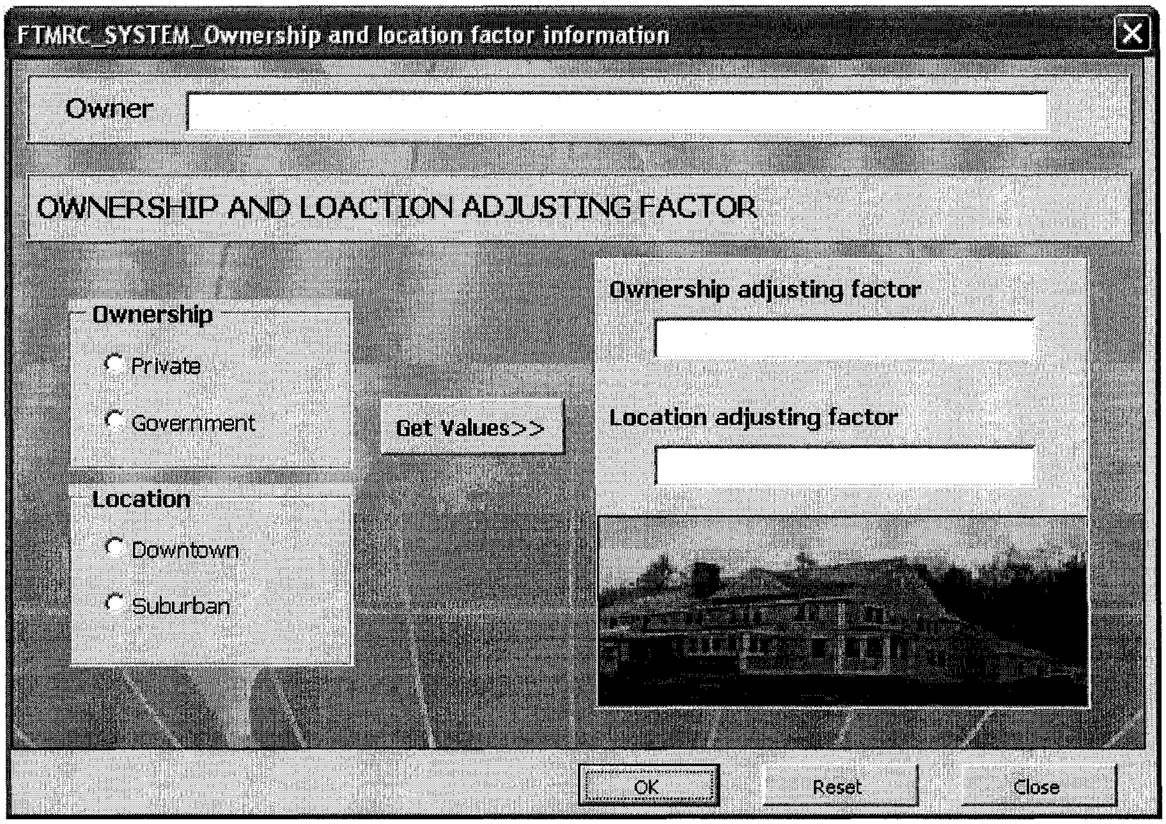


Figure 5. 5 Ownership and Location Factor Information Interface

4. HEIGHT FACTOR INFORMATION INTERFACE

The height factor information interface as shown in Figure 5.6 is composed of two parts: the left part is a list of height ranges. Users can select the appropriate height ranges among them. The right part shows the output of the height information and the height factor.

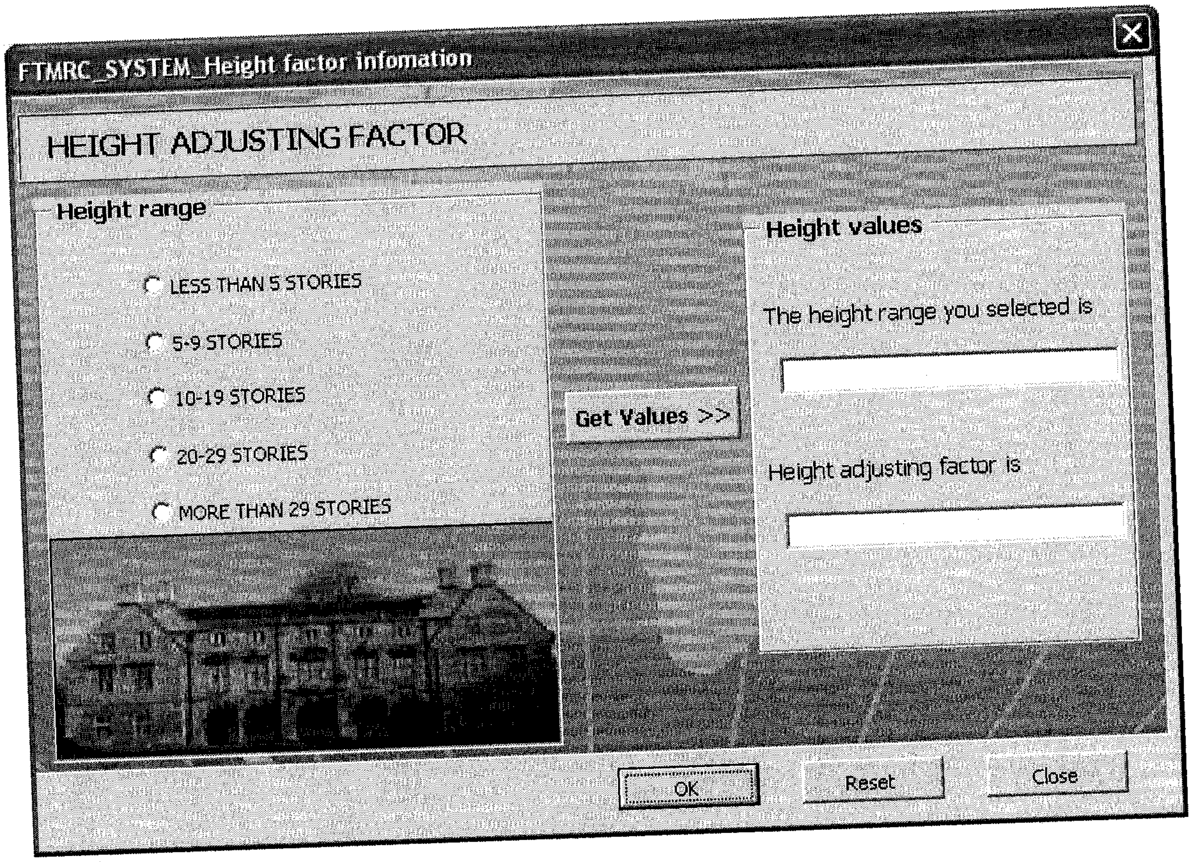


Figure 5. 6 Height Factor Information Interface

5. AGE FACTOR INFORMATION INTERFACE

The age factor information interface as shown in Figure 5.7 is composed of two parts: the left part is a list of age ranges. Users can select the appropriate age range and then retrieve the height information and the height factor as the output in the right part.

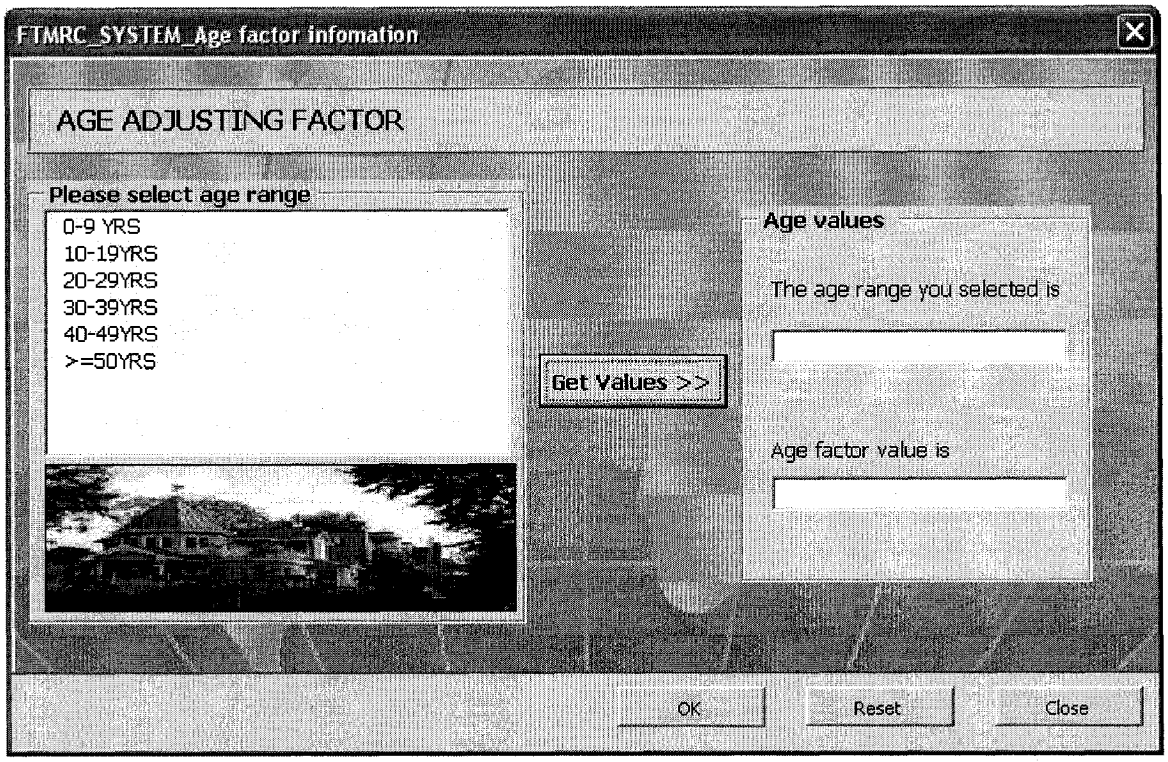


Figure 5. 7 Age Factor Information Interface

6. SIZE FACTOR INFORMATION INTERFACE

The size factor information interface as shown in Figure 5.8 is composed of three parts: the top part allows users to input the information of the building gross square footage of the building. The lower-left part is a list of size ranges. Users can select the appropriate size range. The lower-right part shows the information of the building gross square footage of the building and the corresponding size range, as well as the size factor.

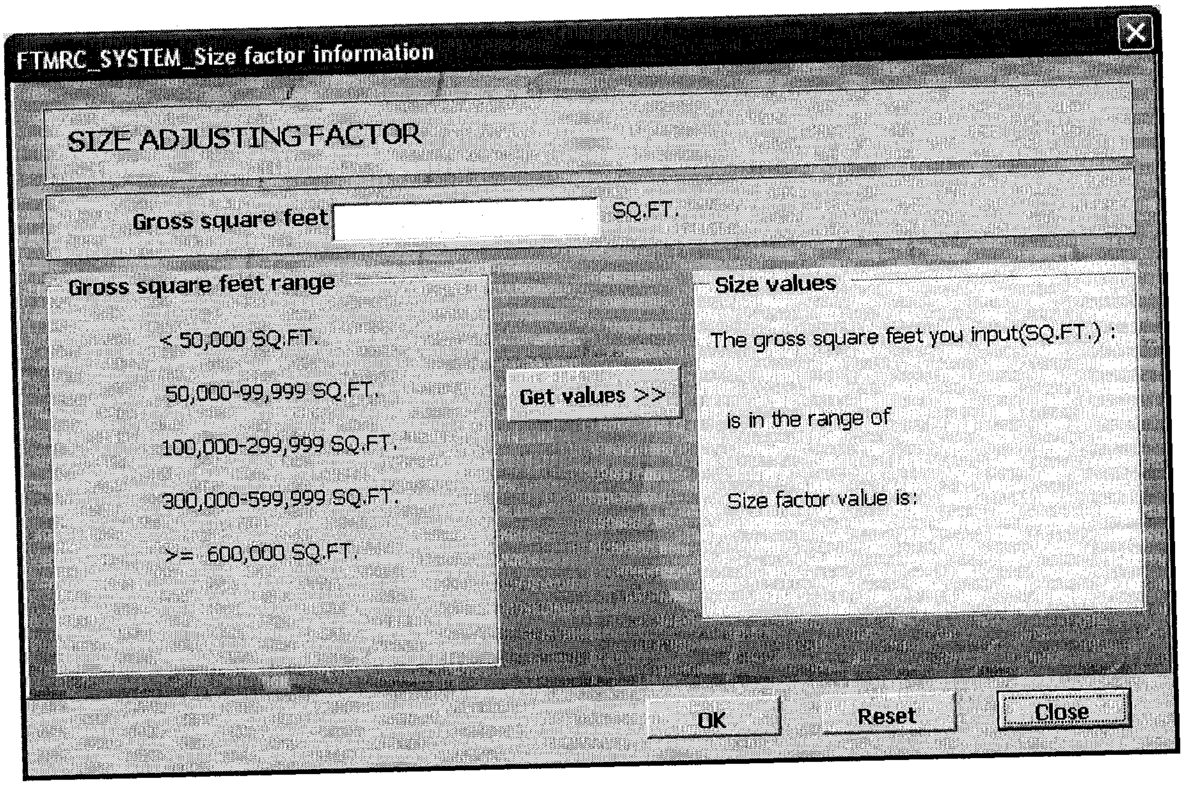


Figure 5. 8 Size Factor Information Interface

7. OTHER INPUT INTERFACE

Another input interface as shown in Figure 5.9 is designed to allow the input of the other needed information for evaluating and forecasting total maintenance and repair costs of office buildings. The other input includes:

1. The MRC which refers to the basic maintenance and repair unit cost of office buildings in Canada based on the result in Chapter 3.

2. The vacancy rate, which is needed to calculate the total rental area of office buildings.

3. The forecasting year, which indicates the year for which the users want to forecast the M/R costs of their office buildings.

4. The inflation rate, which is needed by the FTMRC forecasting model.

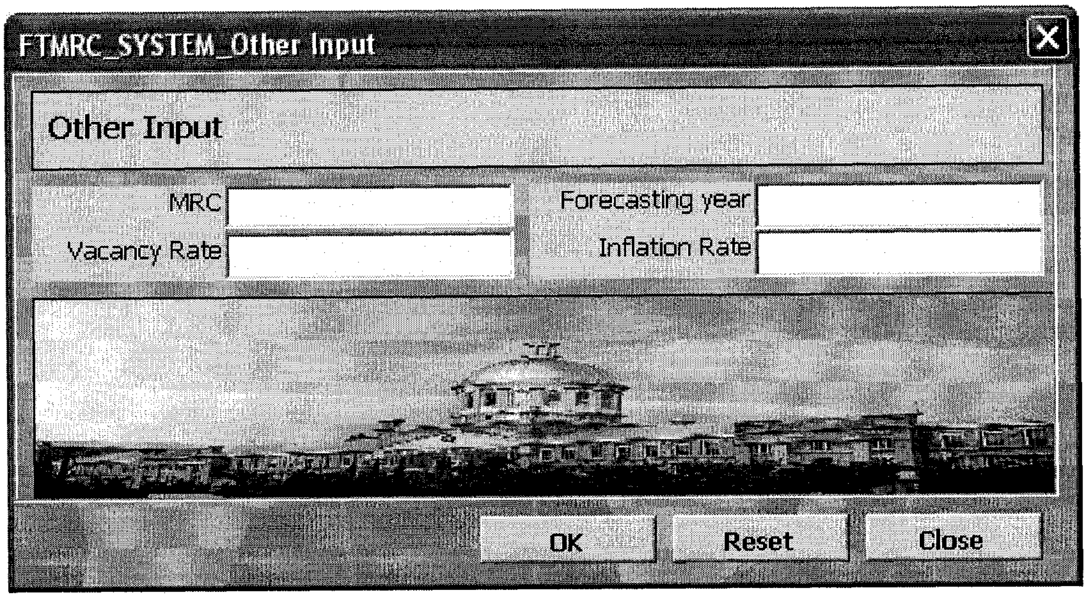


Figure 5. 9 Other Input Interface

8. NET PRESENT VALUE INTERFACE

The net present value interface as shown in Figure 5.10 is designed for the input of the related information for analyzing total maintenance and repair costs of office buildings throughout their analyzed life span by means of the Net Present Value (NPV) method. The related information includes the following:

1. The ***Discount rate,*** which is needed by the NPV model.

2. The ***Year of the building starting to operate,*** which refers to the year in which the office building started to be put in use.

3. The ***Building life span,*** which refers to the number of the years for economic analysis.

After entering the necessary information in the appropriate text boxes, the user clicks on the **View Input summary** button and the InputSummary window is displayed as shown in Figure 5.13.

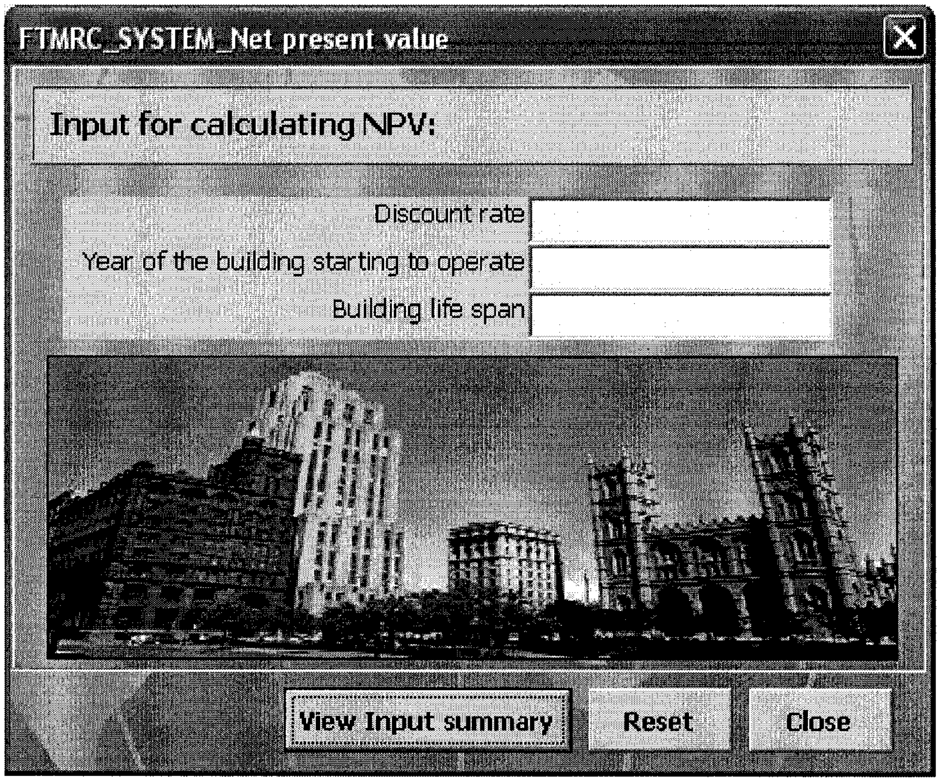


Figure 5. 10 Net Present Value Interface

5.3.3.2 Input/Output

The input/output component is a very important part allowing users to interact with the system. All the results of the total M/R costs evaluation, forecasting and analyzing depend on the building information and other related information that is input by the users. Figure 5.11 shows an example of building information input. This screen shows that the gross square footage of the building is 489,500 SQ.FT. According to the input information, the output as shown in Figure 5.12 can be retrieved from the reference data.

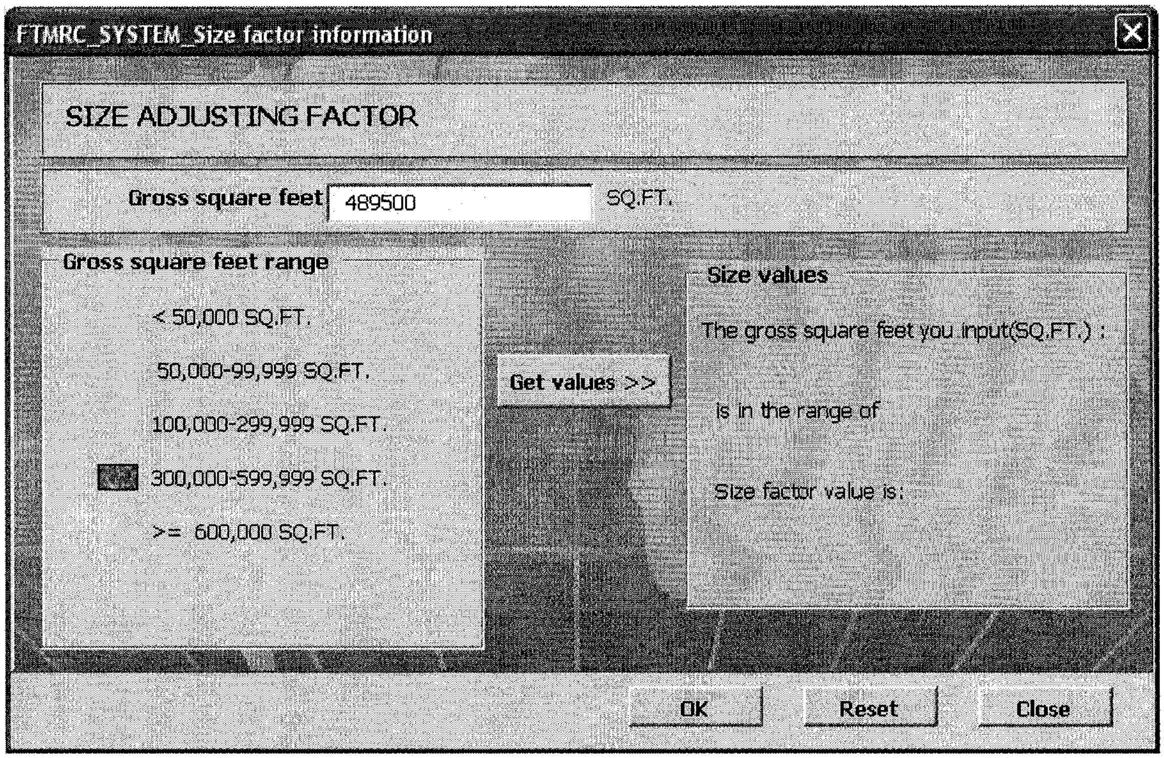


Figure 5. 11 Building Information Input

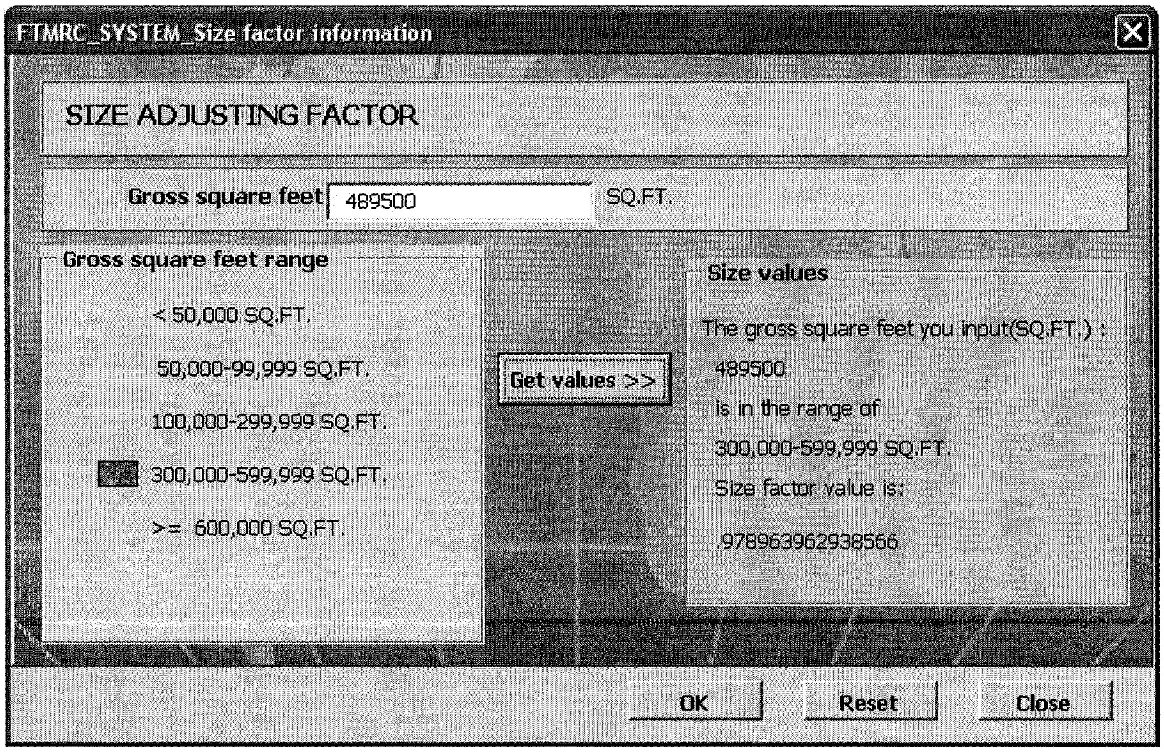


Figure 5. 12 Output of Size Adjusting Factor

5.3.3.3 Reference Data and Data storage

The data storage and reference data component can be considered as the heart of the system. All the input data are stored in data storage which is named "InputSummary" in the FTMRC system. These data include the information about office buildings input by users and the adjusting factors retrieved from the reference data. The system operation relies on the stored data in the data storage. Figure 5.13 shows an example of the data storage. The value of the Total Maintenance and Repair Cost (TMRC) is calculated and stored in the appropriate cell in the InputSummary after clicking on the **Calculate TMRC** button. Clicking on the **Calculate FTMRC** button gives the system command to calculate the Forecasting Total Maintenance and Repair Cost (FTMRC) and to store the results in the appropriate cell in the InputSummary. The Net Present Value (NPV) is calculated by clicking on the **NPV** button. The result is also stored in the appropriate cell in the InputSummary.

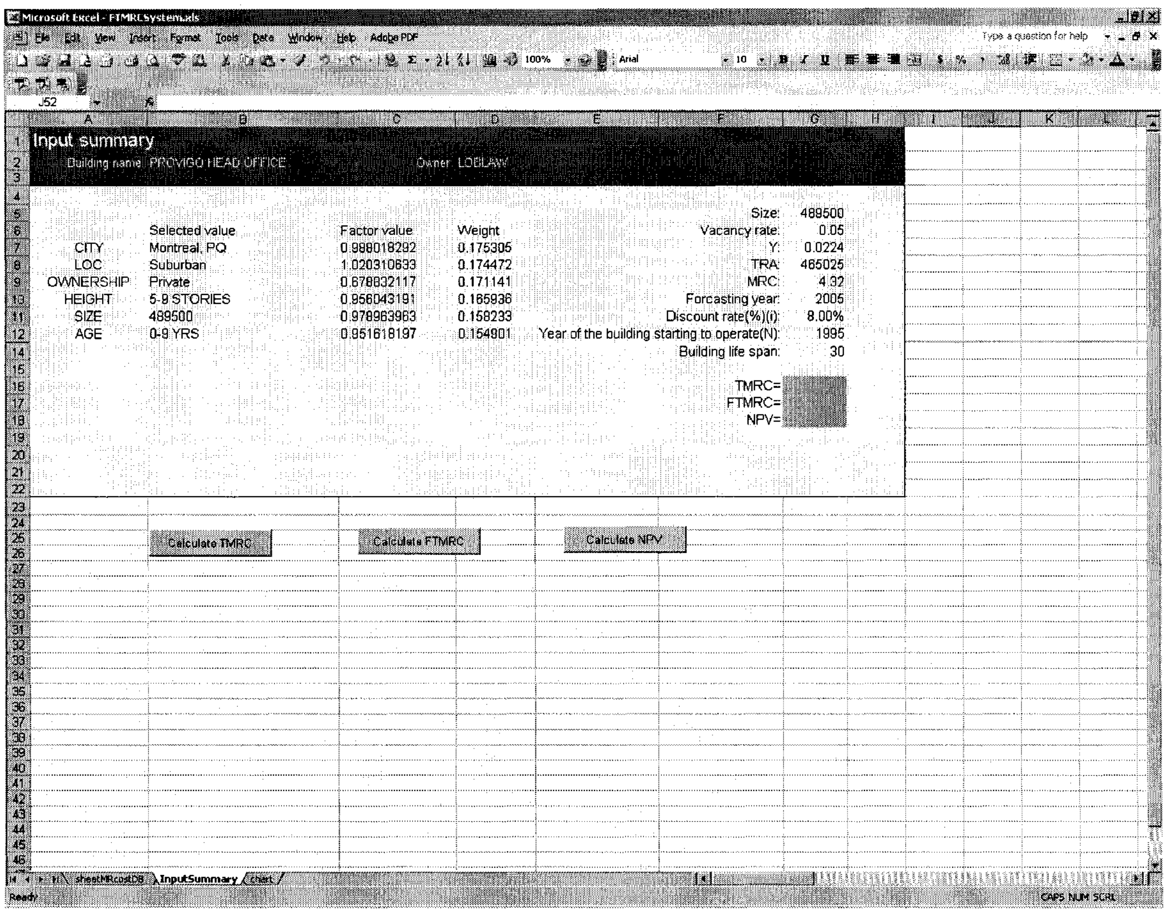
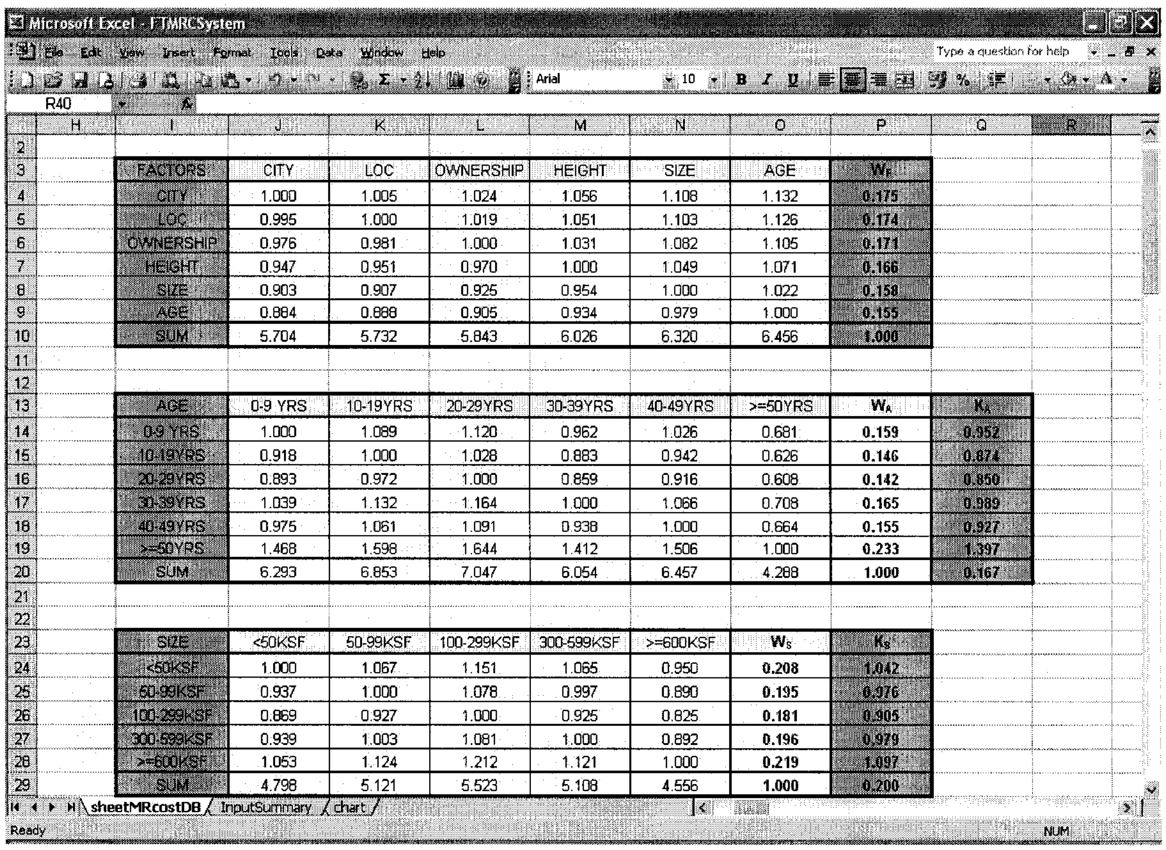


Figure 5. 13 Data Storage

Figure 5.14 shows an example of reference data. The reference data is implemented in Excel tabular format based on the results of the AHP method represented in Chapter 4. It is connected with interfaces by utilizing macros. Once the user enters the data by using the graphical dialog windows, the system can find the appropriate adjusting factors from the reference data according to the input data. It can retrieve these factors to the interfaces as well as data storage.



FACTORS	CITY	LOC	OWNERSHIP	HEIGHT	SIZE	AGE	W_F
CITY	1.000	1.005	1.024	1.056	1.108	1.132	0.175
LOC	0.995	1.000	1.019	1.051	1.103	1.126	0.174
OWNERSHIP	0.976	0.981	1.000	1.031	1.082	1.105	0.171
HEIGHT	0.947	0.951	0.970	1.000	1.049	1.071	0.166
SIZE	0.903	0.907	0.925	0.954	1.000	1.022	0.158
AGE	0.884	0.888	0.905	0.934	0.979	1.000	0.155
SUM	5.704	5.732	5.843	6.026	6.320	6.456	1.000

AGE	0-9 YRS	10-19YRS	20-29YRS	30-39YRS	40-49YRS	>=50YRS	W_A	K_A
0-9 YRS	1.000	1.089	1.120	0.962	1.026	0.681	0.159	0.952
10-19YRS	0.918	1.000	1.028	0.883	0.942	0.626	0.146	0.874
20-29YRS	0.893	0.972	1.000	0.859	0.916	0.608	0.142	0.850
30-39YRS	1.039	1.132	1.164	1.000	1.066	0.708	0.165	0.989
40-49YRS	0.975	1.061	1.091	0.938	1.000	0.664	0.155	0.927
>=50YRS	1.468	1.598	1.644	1.412	1.506	1.000	0.233	1.397
SUM	6.293	6.853	7.047	6.054	6.457	4.288	1.000	0.167

SIZE	<50KSF	50-99KSF	100-299KSF	300-599KSF	>=600KSF	W_S	K_S
<50KSF	1.000	1.067	1.151	1.065	0.950	0.208	1.042
50-99KSF	0.937	1.000	1.078	0.997	0.890	0.195	0.976
100-299KSF	0.869	0.927	1.000	0.925	0.825	0.181	0.905
300-599KSF	0.939	1.003	1.081	1.000	0.892	0.196	0.979
>=600KSF	1.053	1.124	1.212	1.121	1.000	0.219	1.097
SUM	4.798	5.121	5.523	5.108	4.556	1.000	0.200

Figure 5. 14 Reference Data

5.3.3.4 Evaluation, Forecasting and Analyzing

Three functionalities (evaluation, forecasting, and analyzing) are the major components of the FTMRC system. The evaluation functionality is designed to evaluate the total M/R costs of the specific office buildings according to the input characteristics of the buildings by utilizing Equation (4.13). The forecasting functionality is designed to forecast the total M/R costs of the specific office buildings in the specific year by using Equation (4.14). The analyzing functionality is designed to calculate the Net Present Value (NPV) of the total M/R costs during the analyzed life span of the office buildings and to do the sensitivity analysis. The analyzing model is illustrated as Equation (5.1).

$$\textbf{NPV(MRC)} = \sum_{K=1}^{m} \text{FTMRC}_K \, (1+i)^{-K} \qquad \textbf{(5.1)}$$

Where,

NPV(MRC) = Net present value of M/R costs of office buildings over the analyzed lifetime ($),

$FTMRC_K$ = the forecasted M/R cost of the k^{th} year since the office building was put into use ($),

i = discount rate (%),

k = number of the year when the total M/R cost has been forecasted throughout the analyzed life span of office buildings, k = 1 to m,

m = analyzed life span.

The aim of a sensitivity analysis is to determine the most risk variable. Three variables have been studied for sensitivity analysis in the FTMRC system: discount rate i, life span m and the forecast M/R costs $FTMRC_K$.

5.3.3.5 Reporting

The FTMRC system provides not only a tabular report, but also a graphic report to display the results of the system operation. The tabular reports include the following: all the input information about the office buildings, all the weights of the influencing factors, the retrieved adjusting factors, other input information, and the results of the system operation. The graphical report shows the result of a sensitivity analysis in a chart format as shown in Figure 5.15.

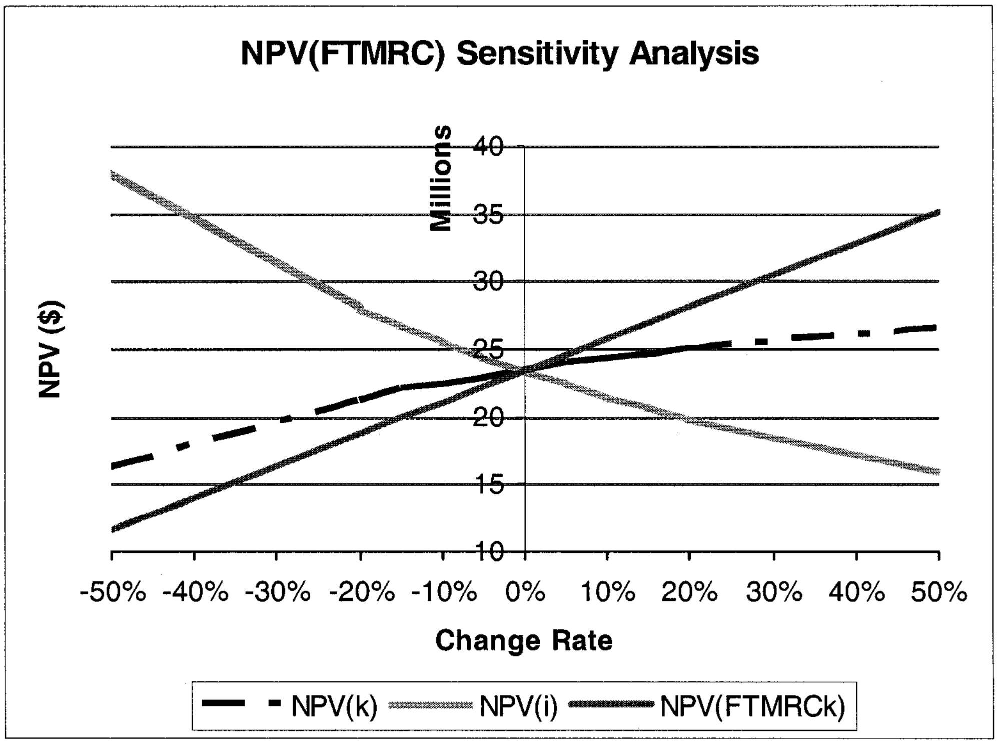


Figure 5. 15 Graphical Report

5.3.4 System Algorithm

The system algorithm is developed based on the proposed model described in Chapter 4. It is used to evaluate, forecast and analyze the total M/R costs for office buildings. When the system starts, the necessary data are input and the related adjusting factors are retrieved from the reference data using Visual Basic Applications in the environment of MS Excel. Once the data are available, the system provides the city adjusting factor, location adjusting factor, ownership adjusting factor, height adjusting factor, size adjusting factor and age adjusting factor. The weights of the six influencing factors are stored in the data storage. Based on these factor weights, adjusting factors and other information data, the system can evaluate and forecast the total M/R costs of office buildings according to Equation (4.13) and (4.14). Then the Net present Value method is employed in this system to calculate the total M/R costs over the analyzed life span of the buildings, as well as the sensitivity analysis. Both a numerical format and a graphical format are used for reports in this system. Figure 5.16 shows the flow chart of the FTMRC system.

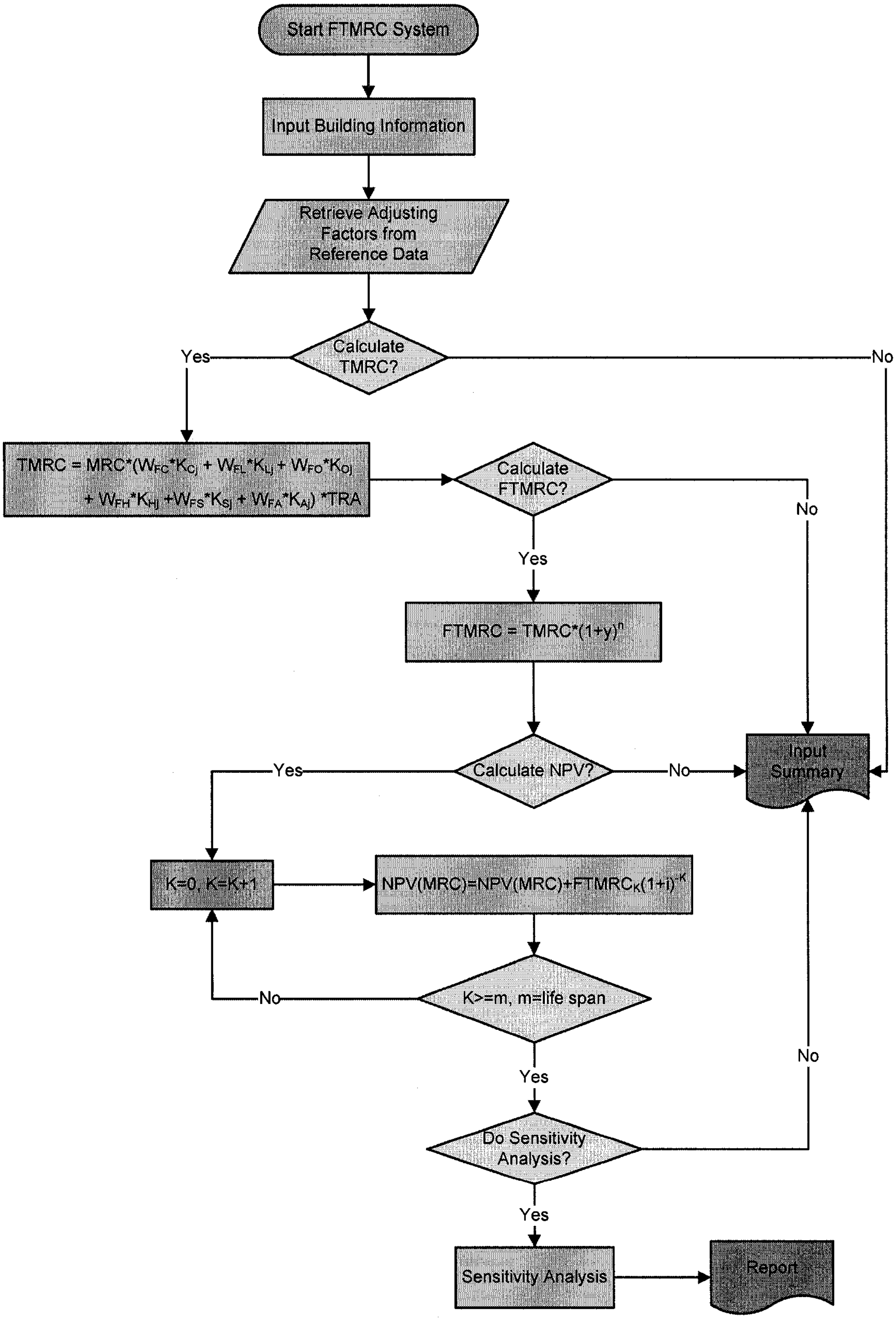


Figure 5. 16 Flow Chart of FTMRC System

5.4 Summary

In this Chapter, the implementation of the proposed FTMRC system is introduced. The function-oriented design method is employed for the system implementation. The prototype software is coded using Visual Basic Applications and operates in a Microsoft Windows@ environment. Eight components are comprised in the FTMRC system. These components include the following: user interfaces, input/output, reference data, data storage, evaluation, forecasting, analyzing, and reporting. Users can interact with the system by inputting data to the data storage and retrieval from the reference data. The evaluation, forecasting, analyzing functionalities can be carried out by utilizing the proposed models and stored data. The system can also provide both numerical reports and graphical reports.

Chapter 6

CASE STUDY AND VALIDATION

6.1 General

In order to validate the proposed M/R costs forecasting model, as well as the algorithm and functionalities of the proposed FTMRC system, a real case has been studied and presented in this chapter. A questionnaire survey was conducted to collect the necessary information about real cases. This numerical example attained by the survey method is used to validate the forecasting model and to demonstrate the utilization of the developed FTMRC system. The system has also been presented to practitioners from the industry.

6.2 Validation of Proposed Forecasting Model

6.2.1 Questionnaire Survey

There are always some questions that must be answered before forecasting the M/R costs of the office buildings. These questions are as follows:

1. Which city is the office building in?
2. What is the ownership of the office building?
3. Where is the office building located?
4. How many stories are there in the office building?
5. How old is the office building?

6. What is the size of the office building?
7. Which year do the clients want to forecast the M/R costs for?

In order to collect necessary information to validate the M/R costs forecasting model, a questionnaire survey was conducted. The form of the M/R costs of office buildings questionnaire survey is shown in Appendix 6.

6.2.2 Numerical Example Introduction

The numerical example is a real case named PROVIGO HEAD OFFICE which belongs to the LOBLAW Company. The detailed information in the real numerical example was obtained by using of "maintenance/repair costs of office buildings questionnaire survey" as shown in Appendix 7.

The case "PROVIGO HEAD OFFICE" is a privately owned office building. This building is located in a suburban area of Montreal. It has a gross floor footage of approximately 489,500 SQ. FT. with a vacancy rate of 5%. The building consists of five stories. The total M/R cost of CAD$1,909,000.00 was reported for this building in 2005 when it was five years old. To validate the proposed forecasting model, a set of variables have to be determined based on this information.

6.2.3 Variables Determination

The set of variables includes the weights of the influencing factors and the related adjusting factors, which can be determined by utilizing the tables in

Chapter 4. Table 4.2 provides the weights of the six influencing factors. Table 4.5 indicates that the age adjusting factor of PROVIGO HEAD OFFICE is 0.952 derived from the building age of five years. The gross square footage of PROVIGO HEAD OFFICE is in the range of 300,000-599,000 SQ.FT. which means the size adjusting factor of the building is 0.979 as found in Table 4.6. The height adjusting factor of PROVIGO HEAD OFFICE can be determined as 0.956 as found in Table 4.7 because the building has five stories. According to the fact that the building PROVIGO HEAD OFFICE is in private ownership and in a suburban location, its ownership and location adjusting factors are 0.679 and 1.020 respectively as found in Table 4.8 and Table 4.9. The city adjusting factor of PROVIGO HEAD OFFICE is 0.988 from Table 4.11 based on the fact that this building is in Montreal. Table 6.1 summarizes the determined variables of the real case for the M/R costs forecasting model validation.

Table 6. 1 Determined Variables for Case Study

DETERMINED VARIABLES FOR M/R COSTS FORECASTING MODEL VALIDATION						
WEIGHTS	W_{FC}	W_{FL}	W_{FO}	W_{FH}	W_{FS}	W_{FA}
	0.175	0.174	0.171	0.166	0.158	0.155
ADJUSTING FACTORS	K_{Cj}	K_{Lj}	K_{Oj}	K_{Hj}	K_{Sj}	K_{Aj}
	0.988	1.020	0.679	0.956	0.979	0.952

6.2.4 M/R Costs Forecasting Model Validation

MRC is considered as a baseline of the M/R costs of office buildings in Canada in 2001. The value of MRC is $4.32/sq.ft. according to the result of the simulation application as shown in Figure 3.6. The total rental area can be calculated with the information of the gross square footage and the vacancy rate of the building.

1. Evaluation of TMRC

The evaluation of the total M/R cost of PROVIGO HEAD OFFICE in 2001 is calculated by utilizing Equation (4.14) and by using the variables in Table 6.1, and the other information given above:

$$\begin{aligned}
\mathbf{TMRC} &= \mathbf{MRC^*(W_{FC}{}^*K_{Cj} + W_{FL}{}^*K_{Lj} + W_{FO}{}^*K_{Oj} + W_{FH}{}^*K_{Hj} + W_{FS}{}^*K_{Sj} + W_{FA}{}^*K_{Aj})} \\
&\quad \mathbf{{}^*TRA} \\
&= \mathbf{\$4.32/sq.ft.\ ^*\ (0.175^*0.988 + 0.174^*1.02 + 0.171^*0.679 + 0.166^*0.956} \\
&\quad \mathbf{+\ 0.158^*0.979 + 0.155^*0.952)\ ^*\ 489{,}500\ sq.ft.\ ^*\ (1 - 0.05)} \\
&= \mathbf{\$1{,}863{,}115.52}
\end{aligned}$$

2. Forecasting Model Validation

As described in section 4.5, the inflation rate is necessary for forecasting M/R costs. The forecasting year for this case study is 2005. According to Table 3.1, the average of inflation rates from 2001 to 2004 can be employed for the forecasting model validation. Table 6.2 shows the result of the inflation rate calculation.

Table 6. 2 Inflation Rate

Year	Inflation Rate (%)
2001	1.11
2002	3.84
2003	1.73
2004	2.28
Average	**2.24**

Therefore, the M/R cost of PROVIGO HEAD OFFICE for the year 2005 can be forecast as follows:

FTMRC = TMRC*(1+y)^n

= $1,863,115.52 * (1+2.24%)^4 = $2,035,743.92

3. Comparison the Accuracy of M/R Costs Forecasting Model

The actual encountered M/R cost of PROVIGO HEAD OFFICE for the year 2005 was reported as $1,090,000 by the questionnaire survey. The mean absolute percent error (MAPE) is used to evaluate the accuracy of the developed forecasting model by calculating the average of the absolute values of the difference between the forecast and the actual encountered values and then expresses the difference as a percentage of the actual encountered value as shown in the following:

MAPE (%) = (2,035,743.92 - 1,909,000)/ 1,909,000 *100%

= 6.64%

6.3 Validation of Developed FTMRC System

The process of validating the developed FTMRC system includes the test of the prototype regarding its code and functions, as well as the proposed forecasting model. The detailed process is described in the following subsections.

6.3.1 Data Input and Retrieval

In order to forecast the M/R costs of the PROVIGO HEAD OFFICE, the basic M/R cost, the total rental area, the weights of the influencing factors and related adjusting factors are needed. The weights of the influencing factors are known and already designed inside the system. The other variables can be obtained through the input/output component of the system. The process of the variables retrieval is illustrated in Figures 6.1 to 6.6. Figure 6.1 shows that the city adjusting factor is 0.988 because the PROVIGO HEAD OFFICE is in Montreal.

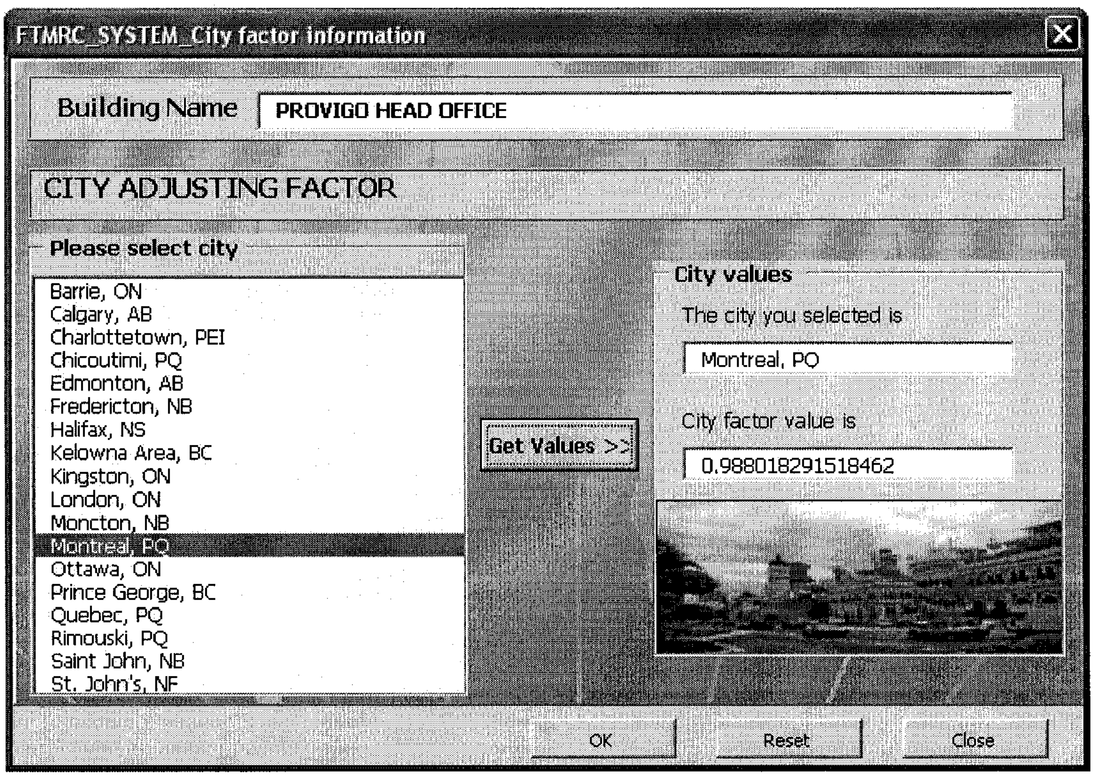


Figure 6. 1 City Factor

Figure 6.2 shows that the ownership adjusting factor is 0.679 and the location adjusting factor is 1.020 due to the private ownership and the suburban location of the building.

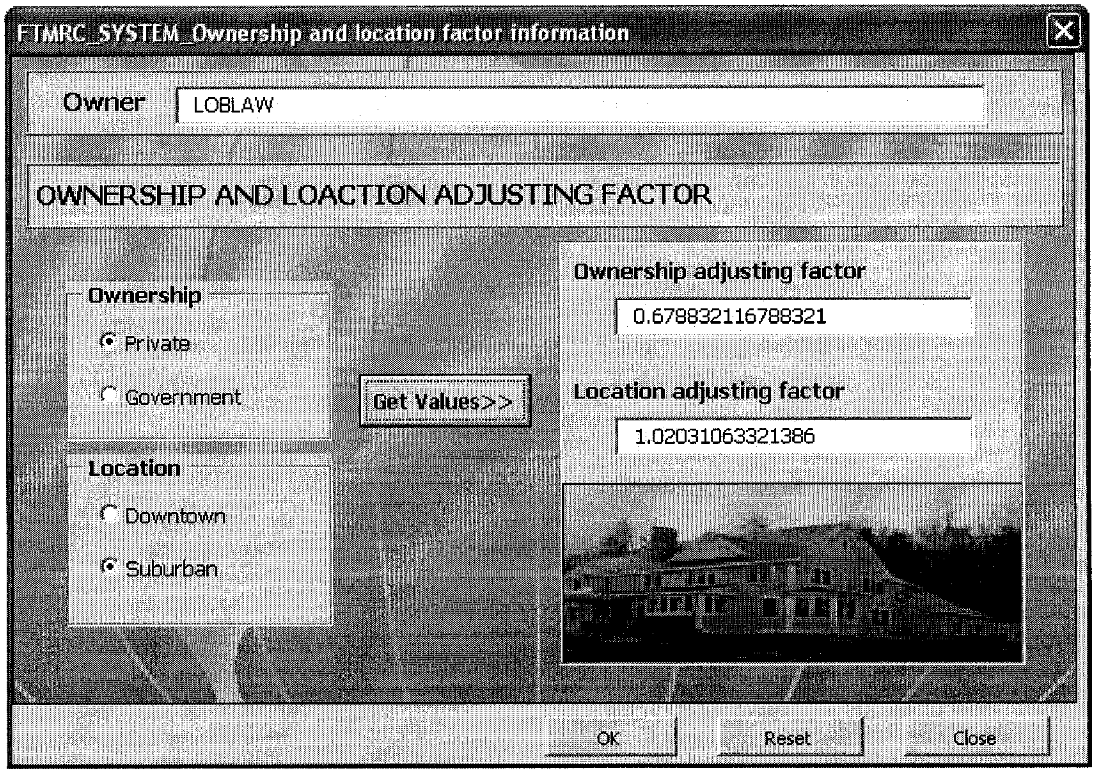


Figure 6. 2 Ownership and Location Factor

Figure 6.3 gives the height adjusting factor as 0.956 because the input height range of PROVIGO HEAD OFFICE is 5-9 stories. Figure 6.4 shows that the age adjusting factor of the building is 0.952 due to its age range of 0-9 years. Figure 6.5 presents the size adjusting factor as 0.979 due to the gross square footage of PROVIGO HEAD OFFICE is 489,500 SQ.FT. Figure 6.6 demonstrates the basic M/R cost based on 2001 data is $4.32/sq.ft. The vacancy rate of PROVIGO

HEAD OFFICE is 5%. Therefore the total rental area of the building, which is showed in the “InputSummary” window is as follows:

TRA = 489,500 sq.ft. * (1- 5%) = 465,025 sq.ft.

This figure also shows that the forecasting year is 2005 and the inflation rate is 2.24%.

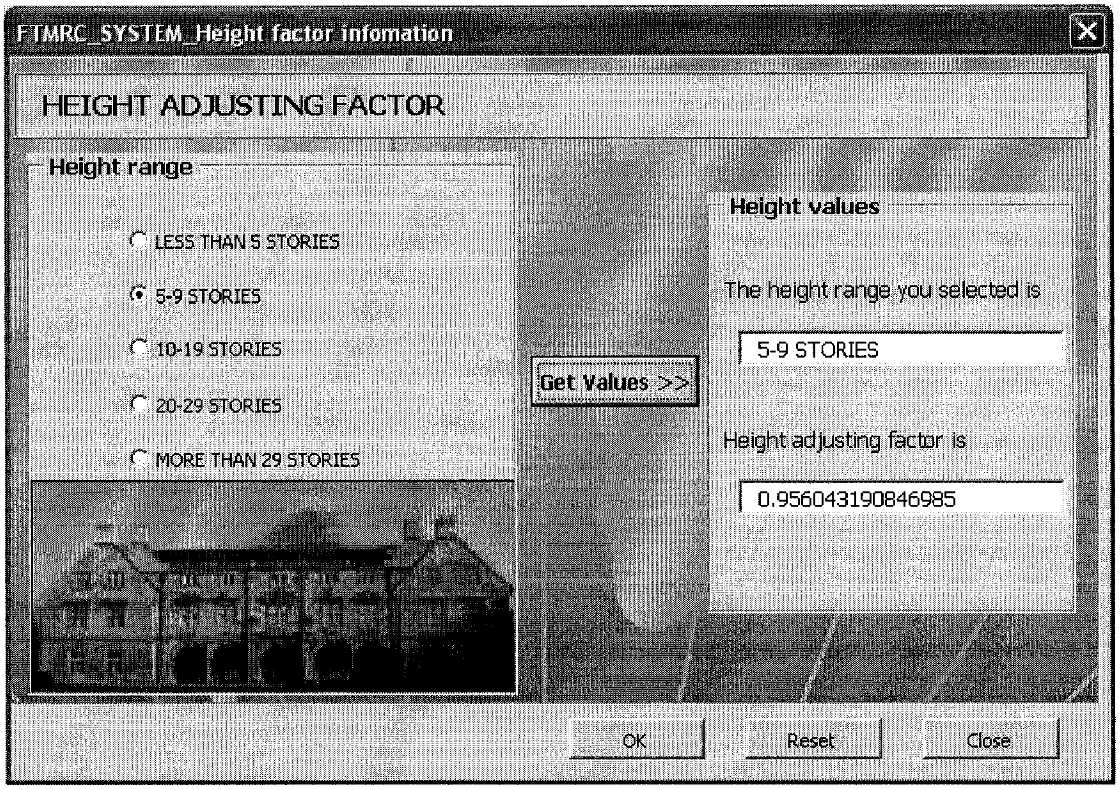


Figure 6. 3 Height Factor

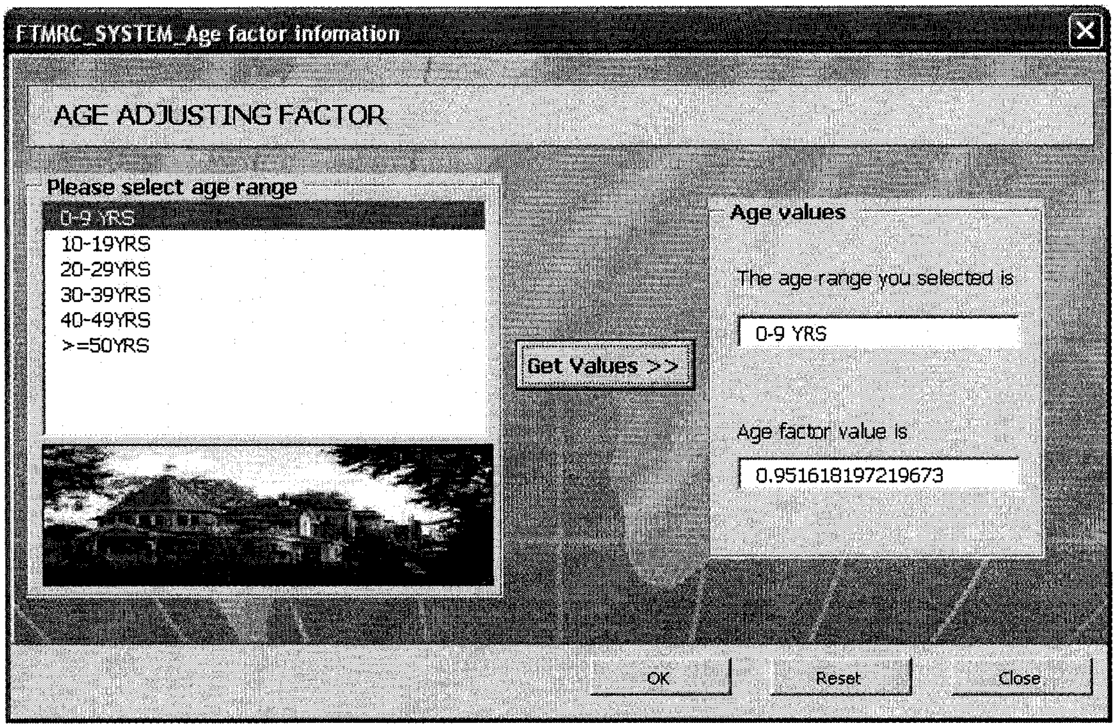


Figure 6. 4 Age Factor

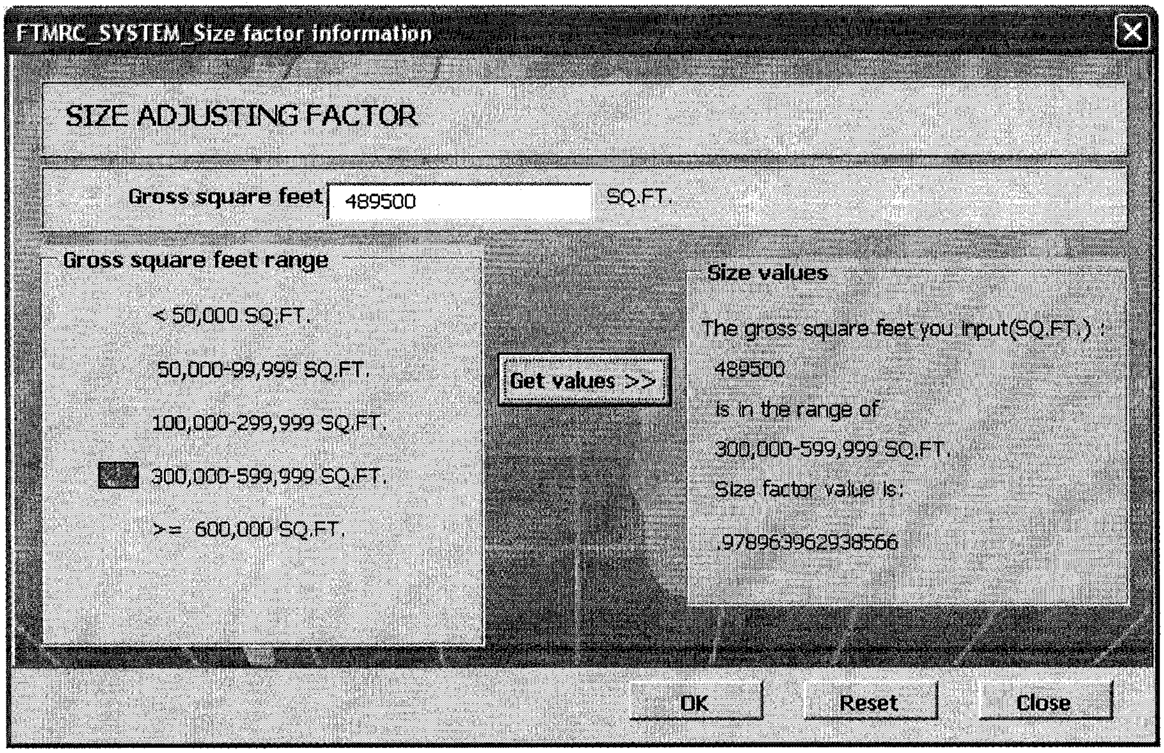


Figure 6. 5 Size Factor

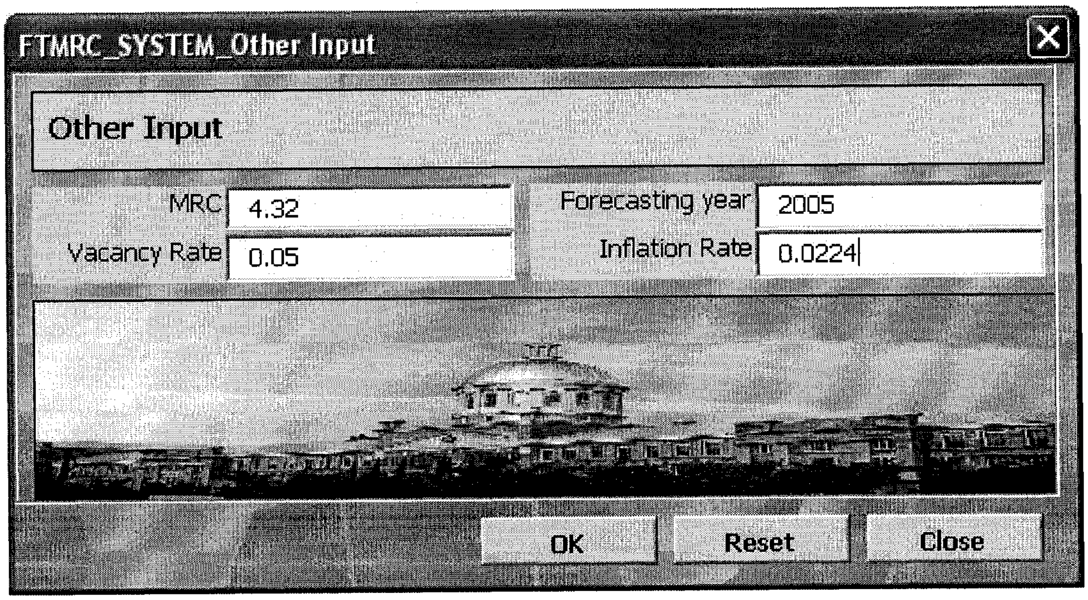


Figure 6. 6 Basic M/R cost

Figure 6.7 shows the other information in order to calculate the Net Present Value of the M/R cost of PROVIGO HEAD OFFICE over its analyzed life span. This information includes the following: the discount rate is 6%, the year the building started to operate is 2000, and the proposed life span is 30 years.

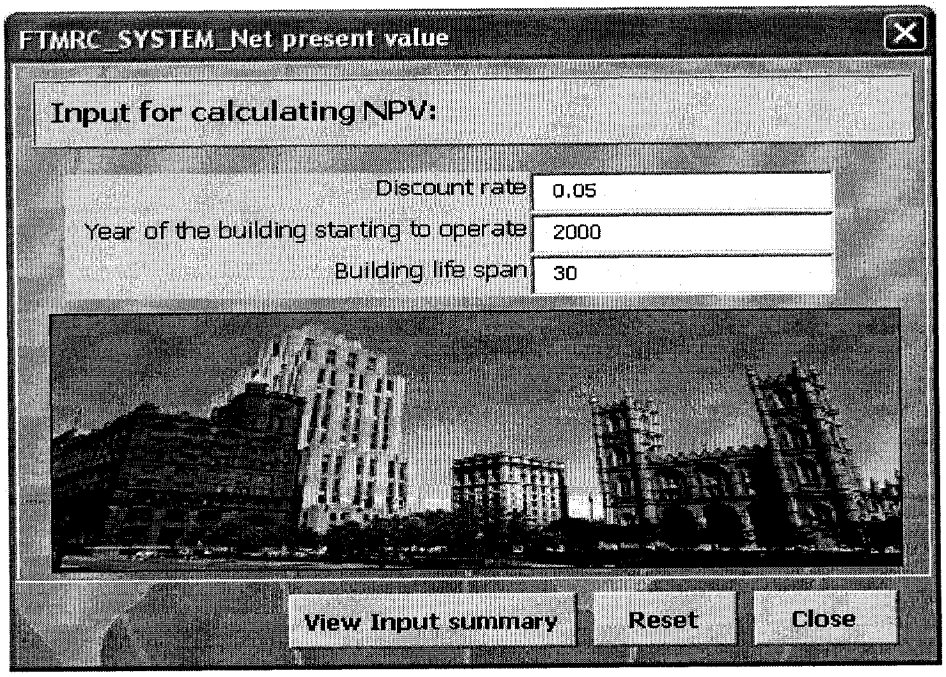


Figure 6. 7 Other Information

6.3.2 Validation of Input Summary Report

The developed system was employed to generate the Input Summary report with all the input information through the interfaces and the related retrievals. Figure 6.8 shows the Input summary of PROVIGO HEAD OFFICE. It includes the building information, the finical information for the economic analysis and the retrieved variables for further calculation.

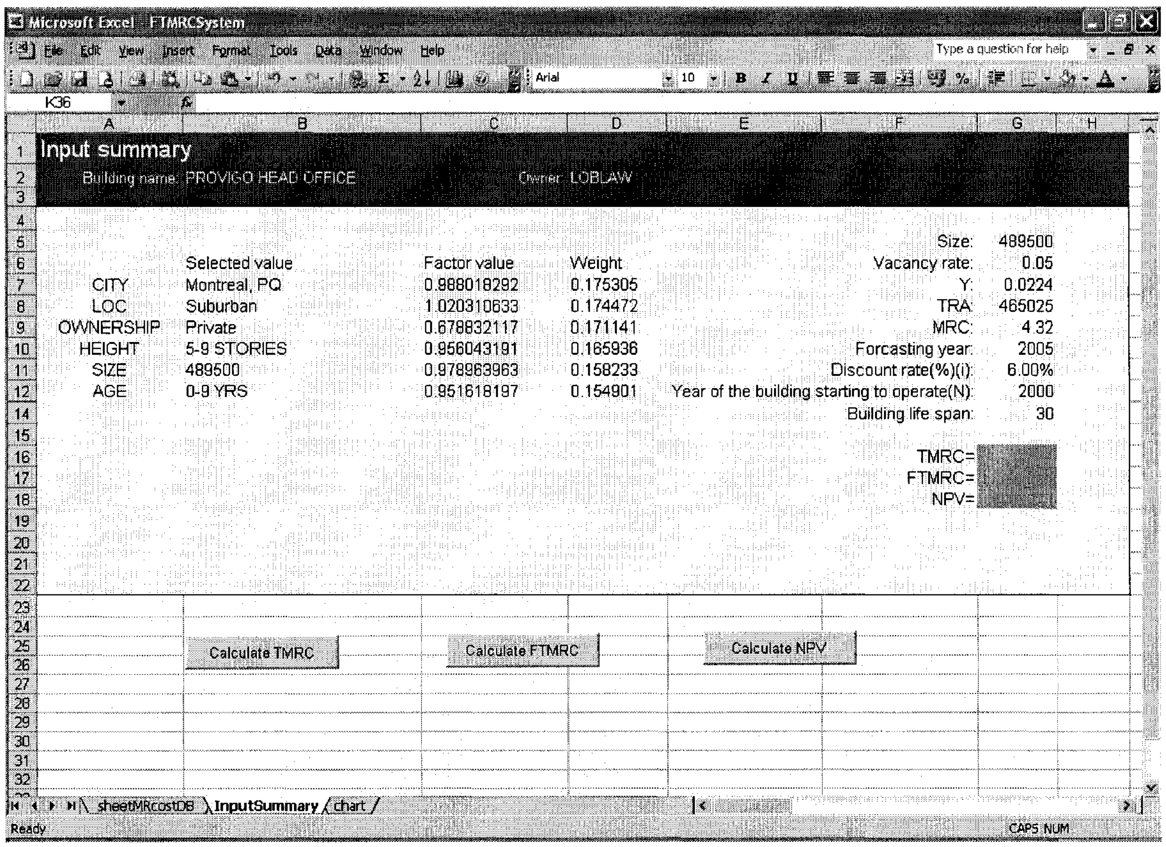


Figure 6. 8 Input Summary

6.3.3 Validation of Functionalities

The three functionalities can be carried out by clicking on the three buttons in the Input Summary window. If users want only to evaluate the total M/R costs of office buildings based on 2001, the result report can be obtained as shown in Figure 6.9 by clicking on the button "**Calculate TMRC**". After the user clicks on the **Calculate FTMRC** button, the report of the forecast total M/R costs for the certain year can be shown in Figure 6.10. Clicking on the **Calculate NPV** button can generate Figure 6.11, which shows the Net Present Value report with the total M/R costs of office buildings over their analyzed life span.

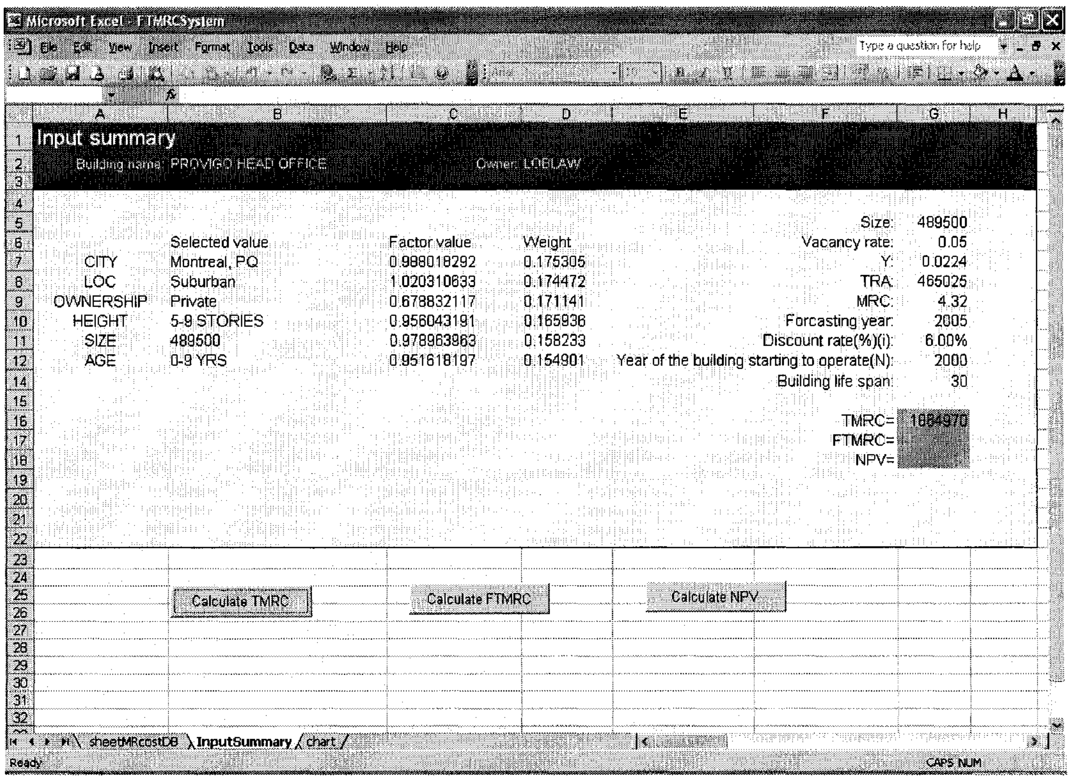


Figure 6. 9 TMRC Report

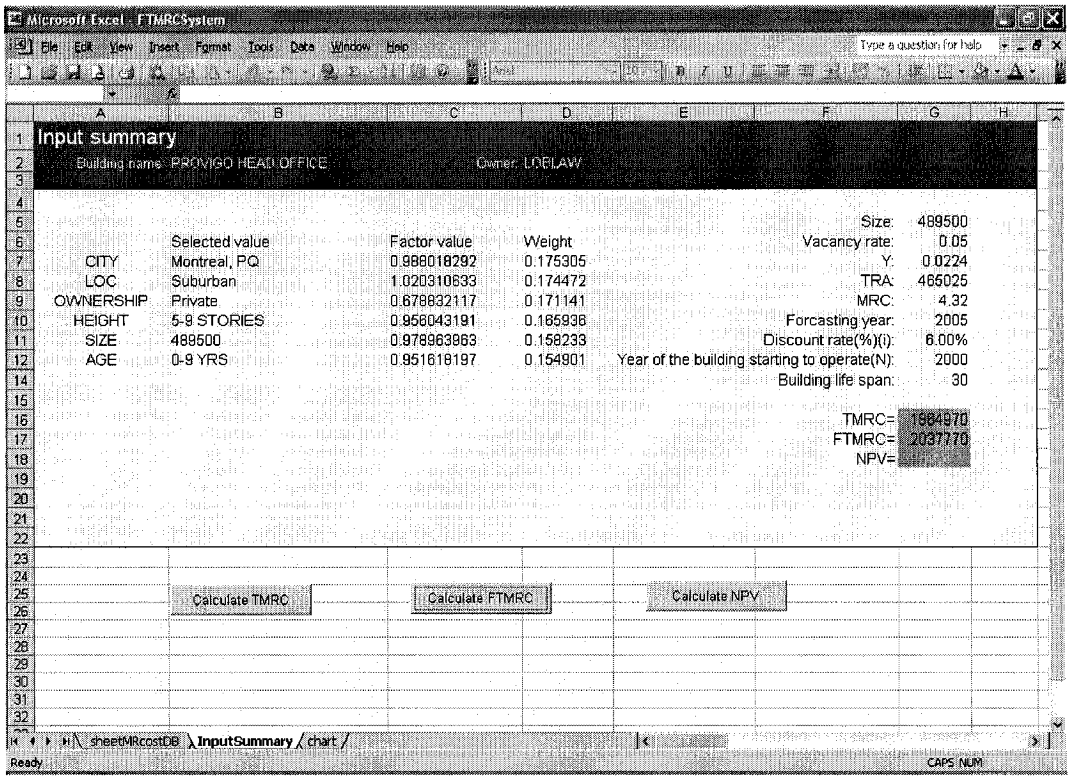


Figure 6. 10 FTMRC Report

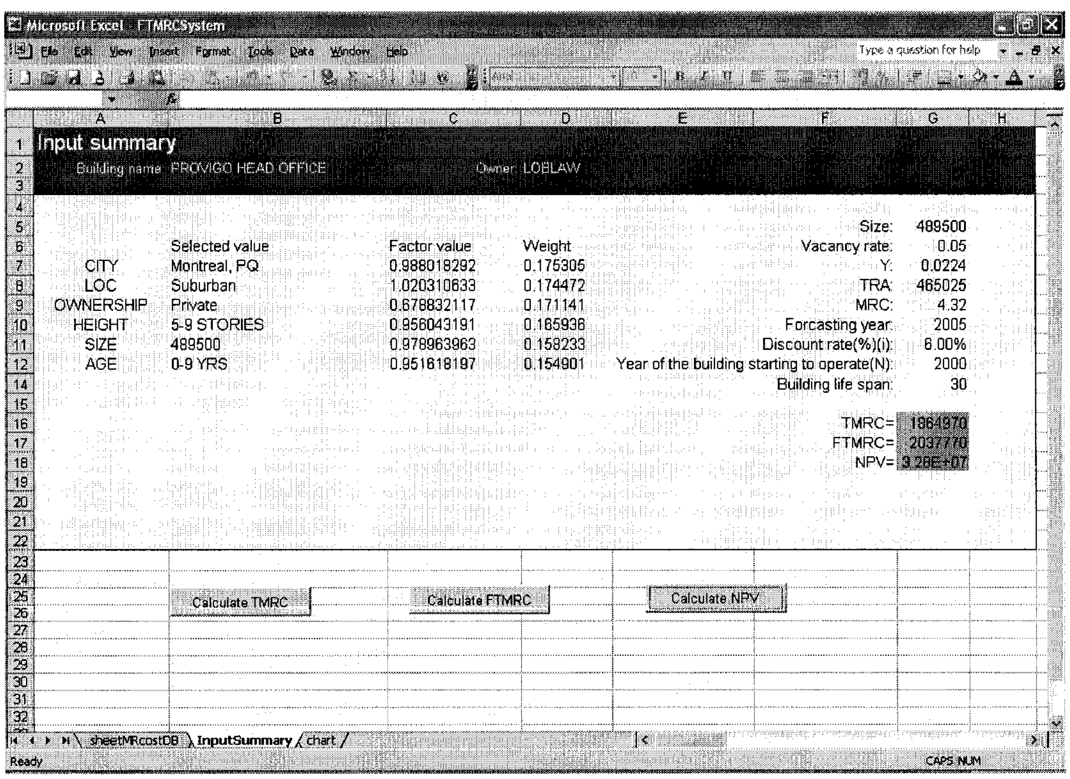
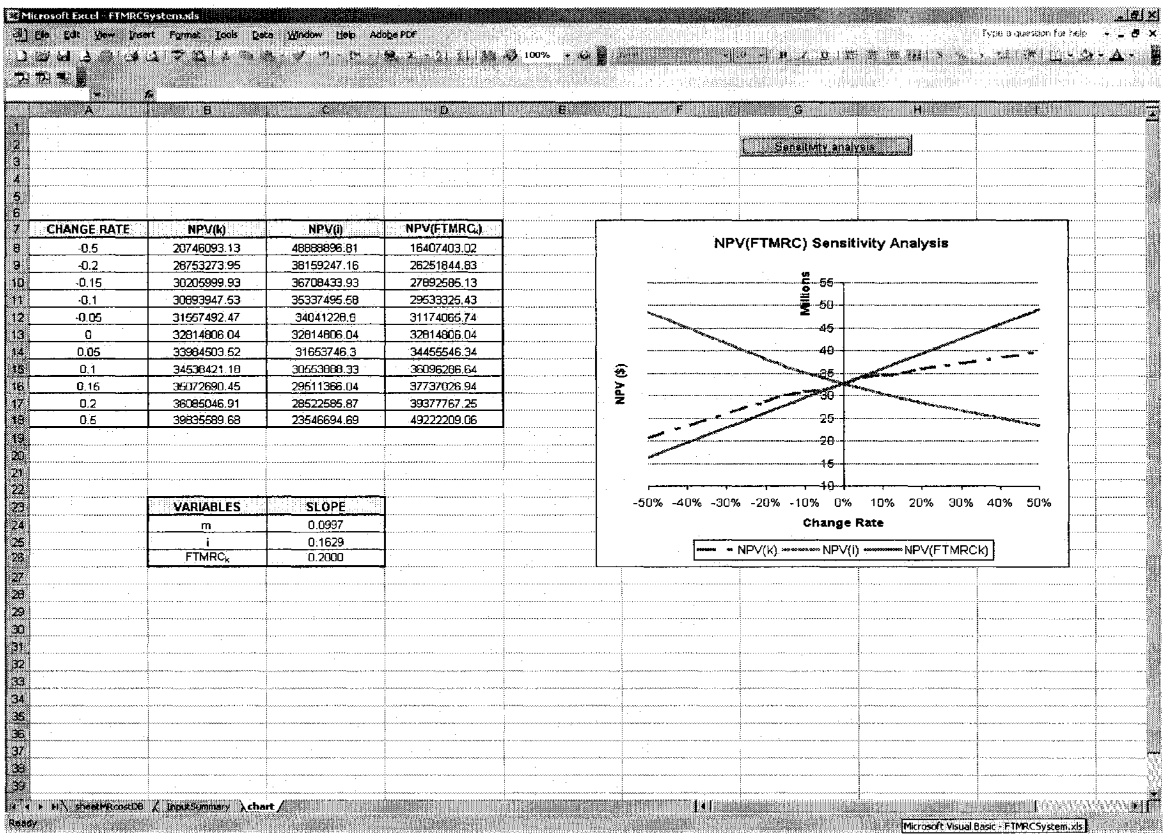


Figure 6. 11 NPV Report

6.3.4 Validation of Report

FTMRC system provides both a numerical report and a graphical report. Figures 6.9 to 6.11 show the numerical reports. The chart in Figure 6.12 shows the results of the sensitivity analysis for the Net Present Value of the M/R costs model as in Equation (5.1) by clicking on the **Sensitivity analysis** button. This chart shows the relationship between the change rates of the proposed analyzed variables and the NPV values. The value (X) axis gives the change rate with an interval unit of 0.10 in percentage format. The value (Y) axis gives the NPV values along with the appropriate values of the X axis.

There are three variables selected for the purposes of the sensitivity analysis in this research. These variables are independent variables that include the following: the analyzed life span m, the discount rate i and the forecasting total M/R costs $FTMRC_K$. Each variable is processed in turn changing its value to the certain rates, and the NPV value changes accordingly. The basic measure of sensitivity is the ratio of the NPV value changing rate over the variable changing rate. The more sensitive the variable, the greater the ratio. As shown in Figure 6.12, the line plot is generated according to the relations between the variables and their corresponding NPV values. The ratios are given as slopes of the lines. Therefore, the conclusion can be reached that the variable $FTMRC_K$ is the most sensitive because its slope is the greatest.



CHANGE RATE	NPV(k)	NPV(i)	NPV(FTMRC$_k$)
-0.5	20746093.13	48888896.81	16407403.02
-0.2	28753273.95	38159247.16	26251844.83
-0.15	30205999.93	36708433.93	27892585.13
-0.1	30893947.53	35337495.58	29533325.43
-0.05	31557492.47	34041228.6	31174065.74
0	32814806.04	32814806.04	32814806.04
0.05	33984503.52	31653746.3	34455546.34
0.1	34538421.18	30553888.33	36096286.64
0.15	35072690.45	29511366.04	37737026.94
0.2	36085046.91	28522585.87	39377767.25
0.5	39835589.68	23546694.69	49222209.06

VARIABLES	SLOPE
m	0.0997
i	0.1629
FTMRC$_k$	0.2000

Figure 6. 12 Sensitivity Analysis Report

6.4 Summary

In this Chapter, a numerical example from real industry is utilized to validate both the proposed M/R costs forecasting model and the developed FTMRC system, as well as to demonstrate the use of the developed prototype. The forecasting M/R cost of PROVIGO HEAD OFFICE calculated with the proposed model is compared with the actual M/R cost of this building. The result of the comparison has shown that the value generated by the proposed model is very accurate due to MAPE rate between the forecast and the actual encountered values is only 6.64%. The validation of the developed FTMRC system shows that this prototype implements all the proposed system tasks and provides users with an easy and efficient tool to have an overall view of their M/R costs and to forecast their future M/R expenditure. The FTMRC system also provides a sensitivity analysis to assist users to recognize the most important variables affecting the Net Present Value of M/R costs over the analyzed life span of office buildings.

Chapter 7

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

7.1 Summary

Building operation and maintenance costs play a key role in the total ownership costs of buildings over the lifetime of a building. Accurate forecasting of these costs can assist owners and asset managers to make sound investment decisions and sound budget allocations. However, the accurate costs of maintenance/repair are very difficult to determine due to the uncertain maintenance/repair activities and asset conditions over the life cycle of buildings. The present research has developed an M/R costs forecasting model and has also developed a FTMRC system to implement the proposed forecasting model.

Historic data from BOMA were analyzed. The proposed procedure of data processing involves data collection, analyzing, sorting, as well as data statistical processing. A simulation method was used to establish the probability distributions of M/R costs. These distributions are believed to provide more realistic ranges of M/R costs for office buildings. A set of results based on the data treatment express the M/R unit costs of office buildings based on different categories and different affecting factors. Six main factors influencing the total M/R costs and their associated elements have been defined. The Analytic

Hierarchy Process (AHP) method is used to determine the weights of these influencing factors and their associated elements. A set of equations is developed to calculate the weights based on the generated pairwise comparisons by the AHP method. Another set of equations is also developed to determine the adjusting factors along with each category. Afterwards, the M/R costs forecasting model has been developed by integrating all the influencing factors, M/R costs baseline (MRC), and total rental area of office buildings.

The proposed procedure will help owners and asset managers to forecast the future expenditures of their assets and to design the budget plan more effectively.

The function-oriented design method is employed for the system implementation. The prototype software is coded using Visual Basic Applications and operates in a Microsoft Windows® environment. The FTMRC system comprises eight components. These components include the following: user interfaces, input/output, reference data, data storage, evaluation, forecasting, analyzing and reporting. Users can interact with the system by inputting data to the data storage and can carry out retrieval from the reference data. The evaluation, forecasting, analyzing functionalities can be carried out by utilizing the proposed models and stored data. The system can also provide both numerical reports and graphical reports.

A numerical example from the real industry is utilized in the present research to validate both the proposed M/R costs forecasting model and the developed

FTMRC system, as well as to demonstrate the use of the developed prototype. The forecasting M/R cost of PROVIGO HEAD OFFICE calculated by using the proposed model is compared with the actual M/R cost of this building. The result of the comparison has shown that the value generated by the proposed model is very close to the real value because the mean absolute percent error rate is only 6.64%. The validation of the developed FTMRC system shows that this prototype implemented all the proposed system tasks and provides users with an easy and efficient tool that allows them to obtain an overall view of their M/R costs and to forecast their future M/R expenditure. The FTMRC system also provides a sensitivity analysis to assist users to recognize the most important variables affecting the Net Present Value of the M/R costs over the analyzed life span of office buildings.

7.2 Contributions

The present research establishes a model to evaluate and to forecast the total M/R costs of office buildings. The main contributions of this research are summarized as follows:

1. The development of a data processing procedure to categorize and analyze the collected data from BOMA ***EER.*** Eight data categories are organized by sorting a large amount of collected data.

2. The employment of the stochastic simulation method to figure out the realistic value of the M/R costs of office buildings. Distribution assumptions have been defined for the elements of the M/R costs respectively. The M/R costs of each category are obtained by utilizing simulation software.

3. The establishment of a hierarchy structure to determine the factors and the relative elements influencing the total M/R costs.

4. The employment of the Analytical Hierarchy Process (AHP) method and the development of formulae to determine the weights of the influencing factors and the related adjusting factors.

5. The development of a forecasting model to help owners and facility managers to evaluate and forecast the M/R costs of office buildings and to manage their budget so far as the M/R costs of office buildings are concerned.

6. The development and implementation of the FTMRC system based on the function-oriented design method and all the reference data referred to above. The system provides three functionalities to implement the M/R costs evaluation, forecasting and Net Present Value calculation. It also provides both numerical and graphical reports.

7. The validation of the proposed forecasting model and the developed FTMRC system by conducting a real case study.

7.3 Recommendations for Future Work

A proposed M/R costs forecasting model and a developed FTMRC system have been presented in the present study. In order to improve this model and the system, the following recommendations are made for future work:

1. All the coefficients generated in this model are based on the reported data in 2001. More historical data in years other than in 2001 should be analyzed to expand the proposed model to dynamic application.

2. Explore methods to determine the most appropriate distribution assumptions for simulation applications.

3. Explore the method used to forecast the inflation rate i.

4. More real cases are necessary for the testing and validation of the proposed M/R costs forecasting model and the developed system in the present research.

5. Expand the algorithm utilized for developing M/R costs forecasting model in the present research to develop models of other costs of ownership costs occurred throughout the life cycle of office buildings.

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APPENDIX 1

Simulation Report

Crystal Ball Report
Simulation started on 3/20/2006 at 21:06:26
Simulation stopped on 3/20/2006 at 21:06:53

Run preferences:	
Number of trials run	10,000
Extreme speed	
Monte Carlo	
Random seed	
Run statistics:	
Total running time (sec)	605.77
Trials/second (average)	17
Random numbers per sec	3,137
Crystal Ball data:	
Assumptions	190
Correlations	0
Correlated groups	0
Decision variables	0
Forecasts	6
** Frozen items **	13

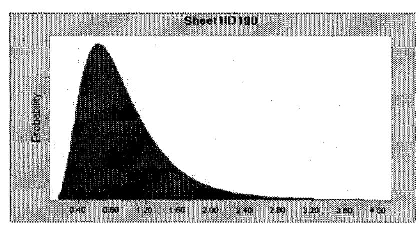
Assumptions

Worksheet: [VBDatabase_1.xls]Sheet1

Assumption: D190 — **Cell: D190**

Lognormal distribution with parameters:

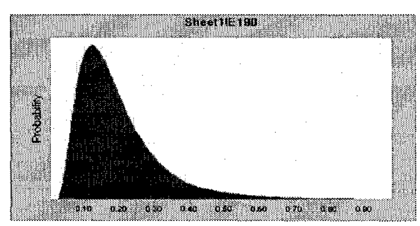
Mean	0.95
Std. Dev.	0.52



Assumption: E190 — **Cell: E190**

Lognormal distribution with parameters:

Mean	0.20
Std. Dev.	0.12

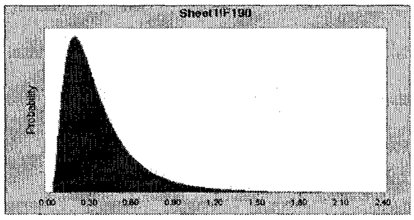


Assumption: F190

Lognormal distribution with parameters:

Mean	0.37
Std. Dev.	0.28

Cell: F190

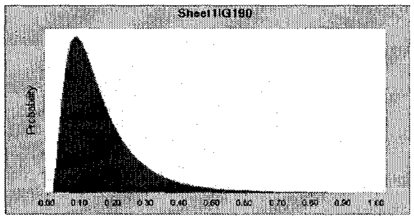


Assumption: G190

Lognormal distribution with parameters:

Mean	0.16
Std. Dev.	0.12

Cell: G190

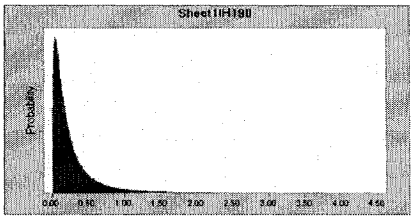


Assumption: H190

Lognormal distribution with parameters:

Mean	0.30
Std. Dev.	0.43

Cell: H190

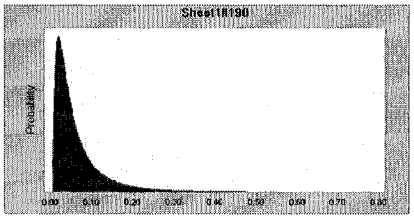


Assumption: I190

Lognormal distribution with parameters:

Mean	0.07
Std. Dev.	0.08

Cell: I190

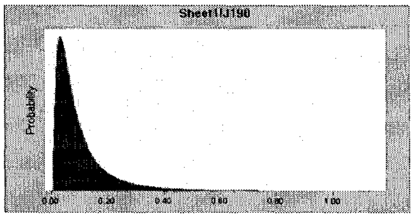


Assumption: J190

Lognormal distribution with parameters:

Mean	0.11
Std. Dev.	0.12

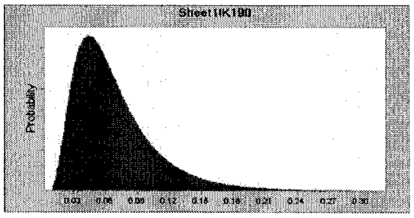
Cell: J190



Assumption: K190 **Cell: K190**

Lognormal distribution with parameters:

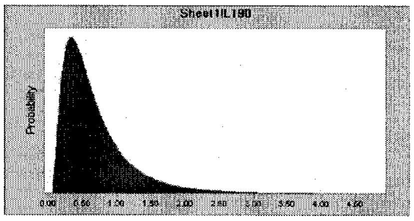
Mean	0.07
Std. Dev.	0.04



Assumption: L190 **Cell: L190**

Lognormal distribution with parameters:

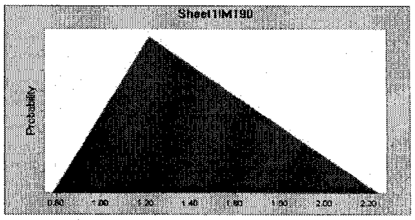
Mean	0.70
Std. Dev.	0.56



Assumption: M190 **Cell: M190**

Triangular distribution with parameters:

Minimum	0.78
Likeliest	1.21
Maximum	2.24



Forecasts

Worksheet: [VBDatabase_1.xls]Sheet1

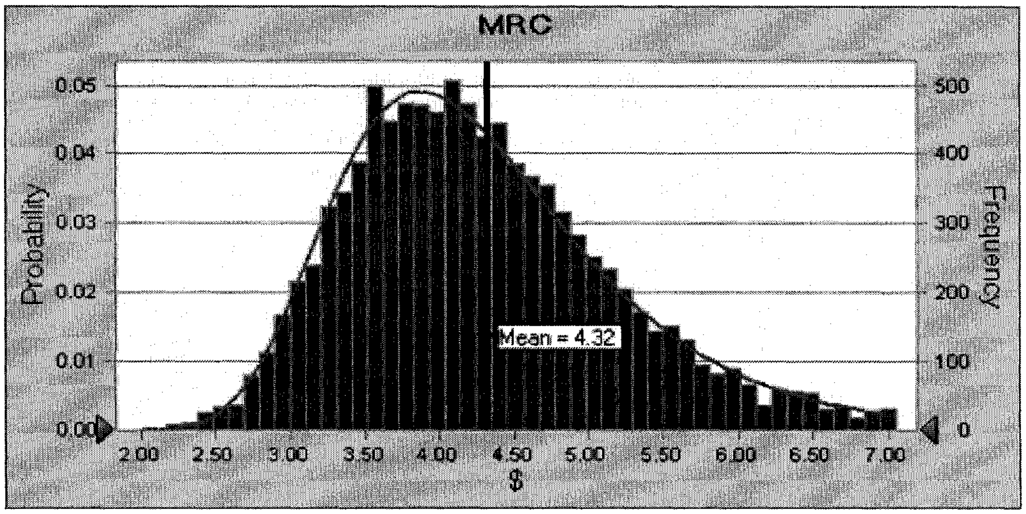
Forecast: MRC **Cell: N190**

Summary:

Entire range is from 1.96 to 11.86

Base case is 4.13

After 10,000 trials, the std. error of the mean is 0.01



Statistics:	Forecast values
Trials	10,000
Mean	4.32
Median	4.18
Mode	---
Standard Deviation	0.98
Variance	0.95
Skewness	1.15
Kurtosis	5.94
Coeff. of Variability	0.22620
Minimum	1.96
Maximum	11.86
Range Width	9.89
Mean Std. Error	0.01
Percentiles:	**Forecast values**
0%	1.96
10%	3.23
20%	3.52
30%	3.75
40%	3.96
50%	4.18
60%	4.41
70%	4.69
80%	5.02
90%	5.56
100%	11.86

APPENDIX 2 Questionnaire Survey Form

MAINTENANCE/REPAIR COSTS OF OFFICE BUILDINGS QUESTIONNAIRE SURVEY

INFORMATION OF OFFICE BUILDINGS		
BUILDING NAME:		
OWNER:		
ADDRESS:		
LOCATION:	1. DOWNTOWN	2. SUBURBAN
OWNERSHIP:	1. GOVERNMENT	2. PRIVATE
HEIGHT (STORIES):		
CITY:		
AGE (YEARS):		
GROSS FLOOR AREA (SQUARE FEET):		
VACANCY RATE (%):		
TOTAL MAINTENANCE/REPAIR COST (CAD$):		
YEAR OF THE ABOVE M/R COST REPORTED:		

Please complete this form and return to:

Yiqun Liu
Department of Building, Civil and Environmental Engineering
Concordia University
1515 Sainte-Catherine St W.
Montréal, Québec, Canada
H3G 2W1

APPENDIX 3 Case Information

MAINTENANCE/REPAIR COSTS OF OFFICE BUILDINGS QUESTIONNAIRE SURVEY

INFORMATION OF OFFICE BUILDINGS		
BUILDING NAME: PROVIGO HEAD OFFICE		
OWNER: Loblaw		
ADDRESS: 400 ave. SAINTE-CROIX, MTL		
LOCATION:	1. DOWNTOWN	(2.) SUBURBAN
OWNERSHIP:	1. GOVERNMENT	(2.) PRIVATE
HEIGHT (STORIES): 5 STORIES		
CITY: MONTREAL		
AGE (YEARS): 5		
GROSS FLOOR AREA (SQUARE FEET): 489,500 sq ft.		
TOTAL MAINTENANCE/REPAIR COST (CAD$): 1,909,000.00		
YEAR OF THE ABOVE M/R COST REPORTED: 2005		

VACANCY RATE: ± 5%

Please complete this form and return to:

Yiqun Liu
Department of Building, Civil and Environmental Engineering
Concordia University
1515 Sainte-Catherine St W.
Montréal, Québec, Canada
H3G 2W1