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**The American University in Cairo
School of Science and Engineering
Construction and Architectural Engineering Department**

**A RISK MITIGATION FRAMEWORK
FOR
CONSTRUCTION / ASSET MANAGEMENT
OF REAL ESTATE AND INFRASTRUCTURE PROJECTS**

A Dissertation Submitted to the School of Science and Engineering
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy in Engineering
With Specialization in
Construction Engineering

BY

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May 2014

ABSTRACT
The American University in Cairo
A RISK MITIGATION FRAMEWORK
FOR
CONSTRUCTION / ASSET MANAGEMENT
OF REAL ESTATE AND INFRASTRUCTURE PROJECTS
AHMED M. FAYAD

The increasing demand on residential, office, retail, and services buildings as well as hotels and recreation has been encouraging investors from both private and public sectors to develop new communities and cities to meet the mixed demand in one location. These projects are huge in size, include several diversified functions, and are usually implemented over many years. The real estate projects' master schedules are usually initiated at an early stage of development. The decision to start investing in infrastructure systems, that can ultimately serve fully occupied community or city, is usually taken during the early development stage. This applies to all services such as water, electricity, sewage, telecom, natural gas, roads, urban landscape and cooling and heating. Following the feasibility phase and its generated implementation schedule, the construction of the infrastructure system starts together with a number of real estate projects of different portfolios (retail, residential, commercial,...etc.). The development of the remaining real estate projects continues parallel to customer occupancy of the completed projects.

The occurrence of unforeseen risk events, post completing the construction of infrastructure system, may force decision makers to react by relaxing the implementation of the remaining unconstructed projects within their developed communities. This occurs through postponing the unconstructed project and keeping the original feasibility-based sequence of projects unchanged. Decision makers may also change the sequence of implementing their projects where they may prioritize either certain portfolio or location zone above the other, depending on changes in the market demand conditions. The change may adversely impact the original planned profit in the original feasibility. The profit may be generated

from either real estate portfolios and/or their serving Infrastructure system. The negative impact may occur due to possible delayed occupancy of the completed real estate projects which in turn reduces the services demand. This finally results in underutilization of the early implemented Infrastructure system.

This research aims at developing a dynamic decision support prototype system to quantify impacts of unforeseen risks on the profitability of real estate projects as well as its infrastructure system in the cases of changing projects' implementation schedules. It is also aimed to support decision makers with scheduled portfolio mix that maximizes their Expected Gross Profit (EGP) of real estate projects and their infrastructure system. The provided schedules can be either based on location zone or portfolio type to meet certain marketing conditions or even to respect certain relations between neighbor projects' implementation constraints.

In order to achieve the research objectives, a Risk Impact Mitigation (RIM) decision support system is developed. RIM consists mainly of four models, Real Estate Scheduling Optimization Model RESOM, Sustainable Landscape Optimization Model SLOM, District Cooling Optimization Model DCOM and Water Simulation Optimization Model WSOM. Integrated with the three Infrastructure specialized models SLOM, DCOM, WSOM, RESOM provides EGP values for individual Infrastructure systems. The three infrastructure models provide the demand profile that relate to a RESOM generated implementation schedule. RESOM then uses these profiles for calculating the profits using the projects' capital expenditure and financial expenses. The three models included in this research (SLOM, DCOM and WSOM) relate to the urban landscape, district cooling and water systems respectively.

RIM is applied on a large scale real estate development in Egypt. The development was subjected to difficult political and financial circumstances that were not forecasted while preparing original feasibility studies. RIM is validated using a questionnaire process. The questionnaire is distributed to 31 experts of different academic and professional background. RIM's models provided expected results for different real life cases tested by experts as part of the validation process. The validation process indicated that RIM's results are

consistent, in compliance with expected results and is extremely useful and novel in supporting real estate decision makers in mitigating risk impacts on their profits. The validation process also indicated promising benefits and potential need for developed commercial version for future application within the industry.

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ACKNOWLEDGEMENT

If the effort that one takes to achieve a milestone in life can be compared with a load, this Ph.D. study is among the heaviest loads I have ever carried. Along the way, a number of people had supported this achievement. I would like to dedicate this section to those who had given me the support I needed.

First, I would like to thank my committee chair, Dr. Ossama Hosny who not only led me into the Ph.D. study, but also supported and mentored me through. His mentorship significantly influenced the study. His support granted me opportunities to gain invaluable experience for my future in the academic world.

My thanks extend to the committee members; Dr. Samer Ezeldin, Dr. Khaled Nassar, Dr. Emad Elbeltagi, Dr. Mohamed El Mikawi for their time, efforts and advice. Their advice was invaluable to the achievement of the study.

I am fortunate that I have many good friends who made my life filled with warmth, happiness, and good memories. Among others, I am very fortunate that I have been friends with; Dr. Mohamed Abu-Zeid, Dr. Ahmed Elhakeem, Dr. Elisabeth Yoder, Dr. Mohamed Tantawy, Mr. Kareem Zahran and Mr. Soliman Abu-Samra. I would like to extend my gratitude to Al-Futtaim Group Real Estate (AFGRE) team and consultants, at Cairo Festival City project, Andre Steyn and my colleagues, who have been supportive and cooperative in feeding valuable data and information during the study. My thanks are also extended to Al-Alfi Foundation for the continued support.

This accomplishment would not have been possible without support from my family. First of all, I would like to extend loving appreciation to my wife, Nahla El-Ghayaty, for her patience and support to make sure that my health and our family's well-being were well taken care of. My appreciation also to my son Mohamed and lovely daughters Fatma, Zeinab and Rokaya Fayad. I would like to extend my highest gratitude to the soles of my parents and brothers Fayad: Wafaa, Alaa and Amal Fayad.

Finally to my students: The highest fortune in my life is being your instructor.

The long journey was over. I am fortunate that I had an opportunity to choose this route. I am glad that I took it. I am glad that I made it through and that the above-mentioned persons have touched my life.

CHAPTER 1. INTRODUCTION

1.1 General

The economy of the Real Estate development and its serving infrastructure projects are at risk. The increasing demand on residential, office, retail, and services buildings as well as hotels and recreation has been encouraging investors from both private and public sectors to develop new communities and edge cities. The Egyptian population for example has doubled in 34 years to reach 86.1 million capita in 2014. The annual growth rate for the period between 1996 and 2012 was 2.25% (Central Agency for Public Mobilization and Statistics, 2014). The United Nations estimated greater Cairo as one of 15 new megacities (over 10 million inhabitants) with 20.25 million capita in 2011 (Central Agency for Public Mobilization and Statistics, 2014). Around 95% of the population inhabits the Nile valley which constitutes 4% of the Egyptian territories (Soliman and Sharaf Eldin, 2010). As a result, urban informal expansion has been gradually consuming the limited agricultural land. The natural increase of population was also attributed to a heavy inflow of rural migrants. The migration towards the greater Cairo region has been mainly due to the employment opportunities and the major proportion of services it provides. In the early years of the 1900s, Egypt has introduced privately developed areas at the edge of the old Cairo area, e.g. Heliopolis and Nasr City. Due to their attractiveness, they were targeted for residency during the first half of the century. However, they lost their attracting elements in the second half of the twentieth century as a result of accumulating residency overload.

Beside the man/space problem, Egypt with its limited resources; has also been challenged by several consecutive events over the twentieth century. The frustrated Middle Eastern region and the limited resources are examples of the challenging circumstances Egypt has faced. This continued until the Middle Eastern peace process began in the late 1970s. Over and above, the environmental pollution and increasing rate of crimes have both accumulated additional challenges to the country (Soliman and Sharaf Eldin, 2010). In addition, recent water shortages and civil unrest are counting additional challenges to the country. Under these circumstances, the consecutive governments in Egypt have been

unable to make sufficient funds available for providing sufficient homes and renewing the deteriorating infrastructure systems to meet the increasing demands. This has led in turn to overloading the old cities, the deteriorating infrastructure and the transportation systems.

Egypt has begun addressing the increasing challenges through initiating two waves of real estate development in the 1980s. The objective was to expand its urbanized areas through introducing new communities near the old cities. A first wave of new satellite communities was initiated around the older expanding cities. Other new communities were also developed to provide a mix of industrial/residential functions such as Sadat City, 10th of Ramadan, Borg Al Arab and October City. The private sector was further allowed in the 1990s to develop a second wave of “gated” communities. Greater Cairo has seen a number of privately developed communities such as Al-Rehab, Dreamland and many others.

1.2 Delayed Occupancy of Newly Established Cities in Egypt

The cyclic risks facing the real estate industry has also affected the occupancy profile of the newly developed cities in Egypt. Soliman and Sharf Eldin (2010) referred to the dissatisfaction of inhabitant requirements as a main reason for the slow occupancy. However, several risk events such as financial recessions have also resulted in deviations from the planned occupancy profile. Table 1.1 includes the planned population target compared with the actual population in the new communities in the 1980s up to 2006 where the last Egyptian census has taken place. The table shows that the populations in eight developed cities have taken 20 years before reaching 25% or less of their target. Two cities, the 10th of Ramadan and Noberia could not reach 40% of their target within the same period while only two cities reached 72% and 66% of their target in the 20 years period in 15 May and 6 October Cities respectively.

Table 1-1: Planned Versus Actual Population in the Egyptian New Cities

(Ibrahim, 2006)^(*) & (Soliman and Sharaf Eldin, 2010)^(**)

New City	Base year (*)	Target population in year 2000 (*)	Actual Population (1986) (**)	Actual Population (1996) (**)	Actual Population (2006) (*)	Actual Population (2006) compared with the base-year % (*)
New Cairo (Al-Rehab)	1996	150,000 (2015)	-	-	25,000	25%
Bader	1983	420,000	-	-	60,000	14%
15 May	1979	250,000	24,106	-	180,000	72%
El-Shorouk	1988	500,000	-	-	60,000	12%
El-Salam	1979	500,000	19,077	366,317	-	-
Burj Elarab	1979	500,000	-	7,055	-	-
New Demiatte	1985	350,000	70	6,517	95,000	27%

New City	Base year (*)	Target population in year 2000 (*)	Actual Population (1986) (**)	Actual Population (1996) (**)	Actual Population (2006)	Actual Population (2006) compared with the base-year % (*)
10 Ramadan	1979	500,000	8,509	47,839	195,000	39%
El-Ebour	1982	600,000	1,037	1,991	85,000	14%
Sadat	1978	1,000,000	669	19,209	125,000	12%
Noberia	1986	30,000	25,754	25,924	11,000	36%
6 October	1979	750,000	528	35,477	500,000	67%
New Bani Suief	1988	120,000	-	202	20,000	17%
New Menia	1986	156,000	-	68	6,000	4%

1.3 Problem Statement

Although huge investments were pumped in to support the optimistic vision of developing new urban areas, the occupancy profile of the residents has been far below the planned targets. The first wave, for example, has taken more than a decade to attract its residents. Similar to the first wave occupancy profile, the private real estate developments have also faced delayed occupancy due to unforeseen risk circumstances. The risks facing real estate vary from business and management to financial or politically related actions (Etter and Schmedemann, 1995).

The lifecycle of real estate projects is usually composed of two consecutive or sometimes overlapping stages; the development and post-development stages. The feasibility study of projects is usually developed at the beginning of the development stage. Decision makers usually take the go/no go decision at the end of that stage. The development stage contains also the design, value engineering as well as procurement and construction implementation activities. The implementation starts usually with developing the serving infrastructure system together with a limited number of real estate projects. The selection of project sequence depends mainly on detailed market and financial analysis. The early stage feasibility analysis considers the zoning requirements by regulatory authorities as constraints. The occupancy of completed projects usually starts upon completing their construction. However, man can recognize the overlap period that is usually called the Taking Over period, in the large scale real estate developments that contain several individual projects of different portfolio types (commercial, residential, retail...etc.). The completion date of each individual project determines the starting date of its end users' occupancy. In the real world, construction actual implanted programs may deviate from the feasibility-based as a sequence of the occurrence of risk events. This in turn delays the occupancy of units by customers. This is shown in Figure 1.1 which illustrates delayed occupancy in cases of delayed construction due to unforeseen risk events. Interrupting construction schedules creates interruptions for the prepared financial analysis of early prepared feasibility studies. The interruption may extend to deviate the Expected Gross Profits (EGP) of the infrastructure system, if the

system is implemented prior to the risk events. This is due to the actually delayed occupancy and services consumption and hence affected Cash Flows. The nature of real estate Cash Flow and Expected Gross Profits reflects a dynamic process rather than a static one. The sales/rental process moves dynamically from one status to the other over time. In response to different sources of unforeseen risk events, any delay and deviation in the occupancy profile, a deviation is created in the Cash Flow of the infrastructure projects. As a result, the gap between planned versus risk impacted Cash Flow profile of real estate projects increases. The same profiles may also reflect the demand on infrastructure services in both cases (pre- and post-risk events). Figure 1.1 shows changes in the work progress as a result of occurrence of risk event and its impact during implementing the projects.

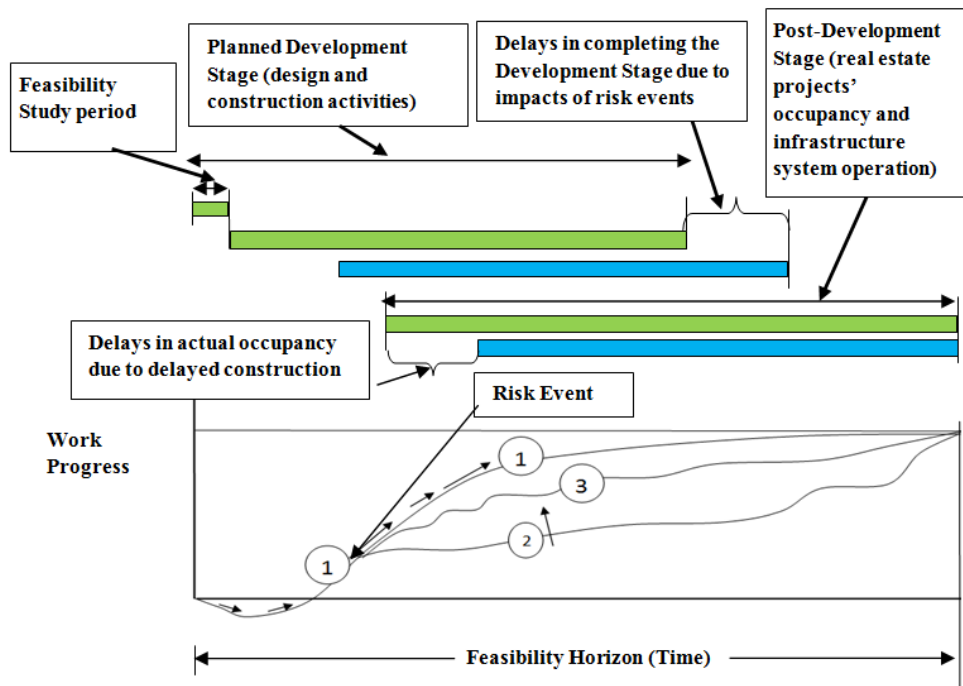


Figure 1-1: Expected Risk Impact on Real Estate and Infrastructure Projects Progress

The work progress is sensitive to impacts caused by the occurrence of unforeseen risks. The application of delayed (or relaxed) scenarios of the planned execution schedules of projects, in response to risk events, may lower the Cash Flow profile and hence reduce the Expected Gross Profit (EGP) of constructed infrastructure system. These projects are usually constructed at early stage of development. The losses are represented by the area between curves 1 and 2 in the Figure. This is due to reduced service's demand profile and consequently the less

profits it causes, compared with the original feasibility-based case. The infrastructure systems include the electrical power supply, heating and cooling, building management, telecommunication, natural gas, potable water and sewer, urban landscaping and irrigation water, roads and hardscape, street lighting and furniture, solid waste, security and housekeeping systems.

The logic used for preparing construction schedules may change and hence may require updated forecast of changes impact on infrastructure system's profitability. It is difficult to do so without linking updates in construction logic and sequence to the customer occupancy and hence with infrastructure Cash In and out. The link is extremely important in forecasting possible changes in the expected gross profit in response to changes in the market condition and/or in loan/equity availability.

1.4 Research Motivation

This research is therefore motivated by the need for real estate infrastructure risk quantification decision support system that is dynamic and integrated to construction scheduling and consumption profile tools. The proposed system should be able to quantitatively forecast possible impacts of changing projects' implementation schedules on their occupancy profile and hence to infrastructure system demand and profitability. Determining the changing in services demand is useful in estimating possible impacts on the real estate and infrastructure system's Cash-In and Cash-Out as well as its expected gross profits. Through the application of this approach, real estate decision makers will be able to select certain construction schedules for implementing their unconstructed projects in such a way that a minimum hindrance is caused to the expected gross profits of their constructed infrastructure system and the real estate projects as well. The approach is useful for application at early development stage while preparing the feasibility studies of infrastructure projects and forecasting their Expected Gross Profits. It is also useful in supporting decision makers during the construction of projects in response to risk events.

1.5 Research Objectives

The main objective of this research is to support decision makers in mitigating the effect of unforeseen risks on their real estate and infrastructure projects. The detailed objectives are as follows:

1. Investigate the capabilities of existing real estate and Infrastructure Decision Support System DSS
2. Check the availability of systems that dynamically link project management tools to infrastructure demand and utilization
3. Introduce a decision support system that supports real estate decision makers in forecasting and minimizing the impacts of changing the sequence and logic of their real estate projects on the profits of these projects in addition to the profits of the serving infrastructure system.
4. Verify and validate the applicability, accuracy and consistency of the DSS results.

1.6 Research Methodology

In order to achieve the aforementioned objectives, the research methodology is followed:

1. Conducting an intensive literature review to investigate the available construction scheduling tools, their shortcomings and then identify possible improvements.
2. Conducting an intensive literature review to investigate available scheduling approaches that links projects' implementation schedules to infrastructure demand profiles and economy.
3. Developing a Decision Support System that is in line with the proposed research approach. This includes database for different infrastructure systems' parameters such as consumption profiles, capital and operating costs and frequency,..etc. It includes also real estate parameters such as portfolio types, prices, marketing strategy, financial input,... etc.

4. Developing an integrated Decision Support System DSS that is able to generate implementation schedules. The DSS is dynamically interactive and can provide the Expected Gross Profit EGP for generated implementation schedules. This may require using Excel-based optimization engines with applied Artificial Intelligence optimization method.
5. Verifying the results of the developed DSS through double checking the results calculation process and using live cases for this objective.
6. Validating the DSS novelty, consistency and accuracy. This is done through trials and questionnaire.

Figure 1.2 presents a summary chart that includes the methodology for achieving each of the research objectives.

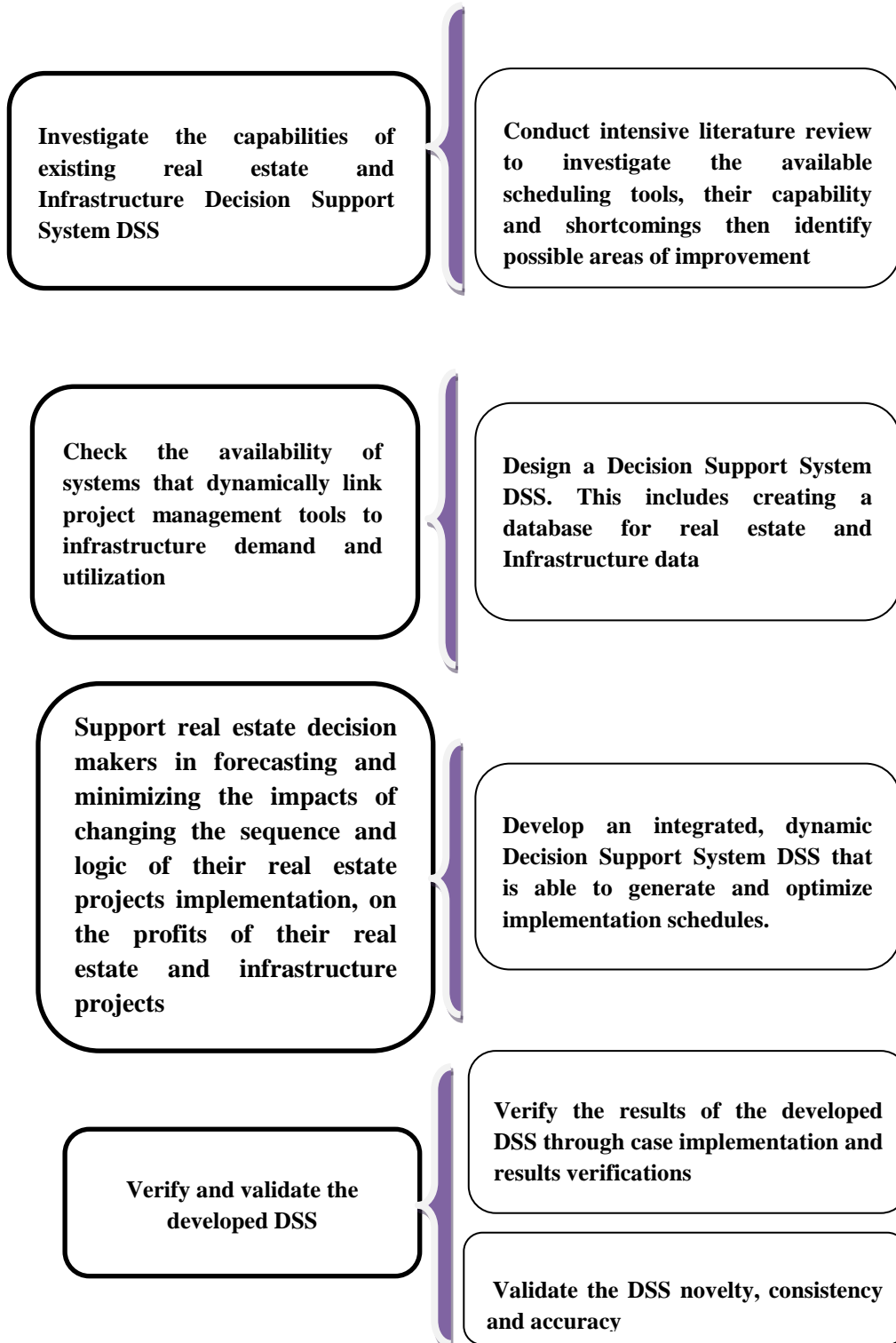


Figure 1-2: The Research Objectives and Methodology

1.7 The Research Scope

Three Infrastructure systems are considered in this research; namely the water system, cooling system and the urban landscape system. The selection is made in relation to the importance of the water and its sustainability. Water systems are usually developed to serve different customers. It provides potable water to customers and irrigation water for urban landscape needs. Although both systems are separated for hygiene purposes, however designers may select to partially share service buildings or electrical components to save the costs of both systems. The water loops of both systems remain closed for the said hygiene dimension. Beside the water consumption for cooling purposes, cooling systems also consume energy. This in turn dictates decision makers to focus on applying sustainable and cost saving infrastructure systems. In addition, the landscape system is also important as the selection of plant types is affecting irrigation water volumes and costs. This in turn impacts the Cash-Out of the system.

1.8 Thesis Organization

This dissertation includes five chapters as follows:

Chapter 1 Introduction: Chapter 1 presents the problem statement, the research motivation, the research objectives and methodology.

Chapter 2 Literature Review: Chapter 2 covers the literature review of the research. It includes description of real estate risk types and impacts, the effects of poor planning real estate lifecycle stages, models and tools for construction scheduling and planning. It then touches the problem of delayed occupancy of newly established communities. In addition, the chapter discusses the Infrastructure system and subsystems, e.g. district cooling, water and urban landscape. It then presents the use of Genetic Algorithm in optimizing construction planning and scheduling.

Chapter 3 The Proposed Framework:

Chapter 3 includes the Decision Support System DSS framework process flow chart. It further includes the equations describing the models' calculation

process. It also includes summary description of the work flow in the form of an integrated flow chart.

Chapter 4 Implementation and Case Study:

Chapter 4 includes a case study application with the purpose of testing the framework's verification and validation. In addition, the Chapter includes verification and validation approach.

Chapter 5 Conclusion and Recommendation for Future Research:

Chapter 5 contains the research conclusion, limitations and recommendations. Chapter 5 is then followed by the References List and the Appendices.

CHAPTER 2. LITERATURE REVIEW

This chapter includes a revision on the history, State-of-the-Art and different definitions and topics relevant to real estate development and its serving infrastructure system.

2.1 Introduction

This Life Cycle Costing LCC concept was developed to support asset managers' decision making. The LCC concept is based on systematic assessment of the life cycle costs of assets contained in a considered system. The initial capital expenditure is usually defined and is often a key factor when making the choice of assets. The selection is usually made from a number of alternatives. Owners, users and managers usually make their selection using certain considerations such as the financial, durability criteria. The initial capital cost of an asset may or may not be of high value if compared with the overall LCC of that asset. Therefore, the asset's life cycle that needs to be considered in making the right choice for asset investment.

An asset's LCC may vary significantly for alternative solutions for a given operational need. The LCC breakdown is an essential tool for proper decision making during different stages of asset's lifecycle. For example, it supports identifying the asset's future resource requirements, assess the asset's investment evaluation, decide between sources of supply, account reporting of resources used, improving system design through analyzing input trends such as manpower and utilities over the expected life cycle, optimize operational and maintenance support through deeper understanding of asset's data over its expected life cycle and finally assess point in time when the asset reaches the end of its economic life and if renewal is required. The life cycle costing process can take different formats from simple time/costing tables to more complicated or computerized models. The objective of these models is usually to generate scenarios based on assumptions in regards to future cost drivers.

2.2 The Goal of Finance

The goal of a company working in a free market economy should aim to maximize its operations value beside several other goals. Building market share, developing brand name recognition, introducing new exiting products and services and promoting employee and community support are examples of other goals a company may achieve. However, the ultimate goal of a company is to create a maximum level of enduring enterprise value which can be achieved through maximizing the Expected Gross Profit, managing the liquidity and solvency In addition, taking proper account of financial and operating risks. Since Risk is defined as “the uncertainty or variability surrounding a future event” (Banks, 2011), finance is concerned with groups of fluctuating variables and dynamic actions, or decisions. These decisions are mainly focusing on (future risks). The financial planning is the second phase in the financial process. This phase follows the financial planning and reporting/analysis phase and prepares for its following financial decision phase. The financial planning phase is of extreme importance since it forms the basis for decisions that affect firms’ financial position. The financial process continues over the firm’s lifecycle due to accumulating series of risk events. The financial process that should lead to achieving firm’s financial goals is summarized in Figure 2.1 (Banks, 2011).

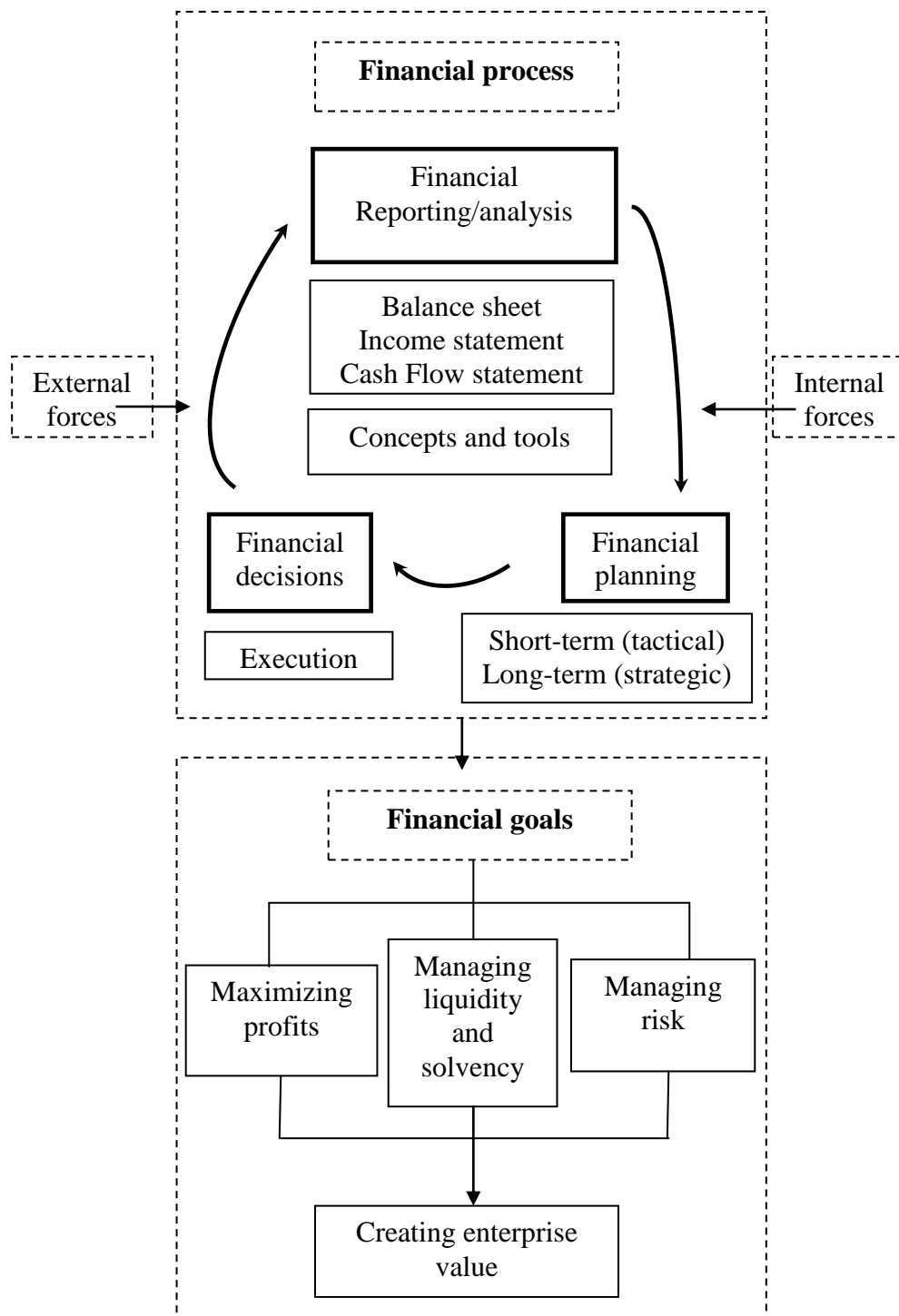


Figure 2-1: The complete financial picture
(Banks, 2011)

The financial planning phase helps the firms to define the actions needed on short and long term to meet their goals. The planning phase for example supports

the short term management decisions such as managing the working capital, liquidity, rebalancing financial/operating risks and funding management. The financial planning is also helpful in supporting long term or strategic decisions, such as:

- Capital investment
- Capital structure
- Mergers and Acquisitions
- Tax planning
- Dividend policy
- Risk management

The later item is managed through creating consistent strategic approaches for managing firm's financial, legal and operations. Short and long term decisions in a certain company have to be meaningful and flexible enough to adapt the changing circumstances.

2.3 Real Estate Development

Real estate development usually demands extensive long term investments. One of the primary characteristics of real estate is the presentation of entrepreneurs with numerous opportunities to generate extraordinary return (Pyhrr, 1989). During the pre-construction stage, developers must carefully assess possible development scenarios in order to fulfill certain objectives, such as product marketability, physical sustainability, financial feasibility and conformity to social and environmental space requirements. Previous research studies focused on preparing and assessing real estate projects at the pre-construction stage rather than developing pro-active concepts in monitoring the deviations of the risks during the construction phase.

2.3.1 Real Estate Risk Types

Banks (2011) classified the factors affecting companies as external and internal forces. The external risk includes macro-economic factors, directly or indirectly affecting the companies. Examples are national economic growth and productivity, employment, inflation, interest rates, currency rates, competitive pressures, regulatory restrictions, market demand and supply, consumer confidence,..etc. The external forces are usually beyond the organizations' control, however, the organizations have to adapt their conditions according to this type of risks. On the other side, the internal forces or risks are also important in shaping the organizations' path towards success. These risks may include among others the financial position, access to cash, ability to respond to changing prices due to fluctuations in supply and demand and the quality of their leadership. The organizations should continuously improve their weaknesses in regards to these internal factors since the control of these factors is within their control. Due to these risks, the financial process is dynamic. Companies should therefore adapt their financial processes and goals to achieve their success. The financial full picture is illustrated in Figure 2.1.

Brooks and Tsolacos (2010) described the applications for which real estate forecasting is made. They listed a number of reasons for a number of concerned groups such as:

- 1- Real estate investors: the forecast is useful when deciding which real estate projects are more valuable.
- 2- Real estate consultancies: the forecast assists this group in planning their long term business.
- 3- Real estate developers: the forecast is useful in defining scenario analysis when dealing with long term real estate investments.

Among several risk types that challenge real estate projects, certain types are affecting the progress of developing the projects as originally planned. Etter and Schmedemann (1995) collected the risk types which challenges real estate projects as shown in Table 2.1.

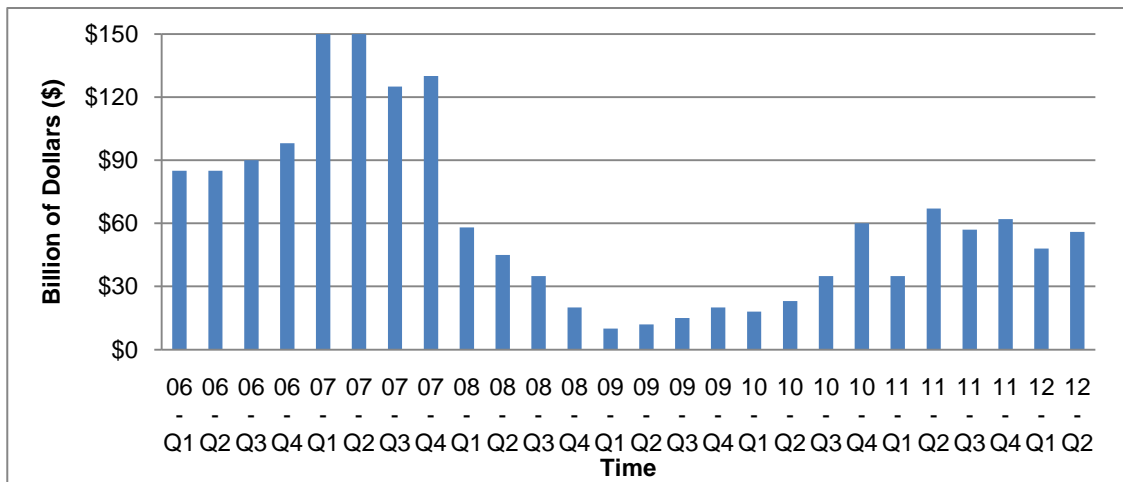
Table 2-1: Real Estate Investment Risks (Etter and Schmedemann, 1995)

Risks Type	Description	Main characteristics of real estate projects
1- Business	The property will fail to generate sufficient cash flow.	Physical Immobility and Long Economic Life
2- Management	The property manager will fail to respond properly to changes in the business environment and, therefore, fail to earn a satisfactory return.	Physical Immobility and Long Economic Life
3- Financial	The property will have inadequate income to meet debt service requirements.	Physical Immobility, Long Economic Life and Large Economic Size
4- Political	A government action adversely affects the property or the investor.	Physical Immobility and Long Economic Life
5- Inflation	Cash benefits received in the future will have less purchasing power than an equal benefit received today	Large Economic Size
6- Liquidity	A property cannot be sold quickly without loss or large selling expenses.	Physical Immobility and Large Economic Life
7- Interest rate	The property's value will decrease because of increased interest rate.	Long Economic Life and Large Economic Size

2.3.2 Real Estate Development and Risk Impacts

In the US, the real estate industry dropped when the nation's economy has suffered from the largest bankruptcy of big organizations in its history in 2008 and early 2009. A number of mega organizations in different sectors, including the real estate sector, have collapsed. The pre-bankruptcy assets were valued at 1405 Billion US dollars (New Generation Research, 2013). The analysis during the same period, just prior to the collapse, indicated a dramatic increase in real estate rental prices reflecting an uprising upturn phase where strong investors' sales demand has driven up the prices. The monthly sales volume of the large real estate

commercial properties has increased for example from 80 to 90 Billion US Dollars during its upturn phase in year 2006 to around 150 Billion US Dollars in year 2007 as shown in Figure 2.2. The monthly sales have then dropped in response to the financial recession in early 2008 to less than 60 Billion US Dollars commencing a downturn phase. The monthly sales volume has further dropped and reached the 10 Billion US Dollars level in early 2009. A new real estate upturn cycle was then born in early 2010 (Emerging Trends, 2013). The cyclic nature of real estate projects is presented in Figure 2.2.



**Figure 2-2: Historical sales of large commercial properties in the US
(Emerging Trends, 2013)**

The cyclic trend in the US real estate commercial properties business is an example of a typical cyclic trend in the real estate business. The cycle is divided into three consecutive phases as shown in Figure 2.3. The cycle usually starts with emerging demand on real estate units. This phase continues to grow to reach its maturity followed by its downturn where the demand drops and market prices face instability. Another cycle starts again by the end of the downturn phase.

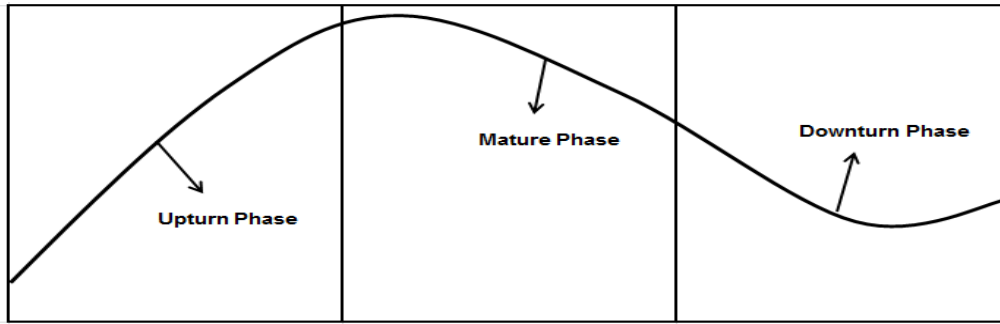


Figure 2-3: Real Estate Cycle
(Hewlett, 1999)

General finance and investment theories were developed and used in the real estate field in order to support the real estate financing sector. Tawari et al (2010) for example explained how the Modern Portfolio Theory (MPT) considers the investors' trade off risk and expected return from their investments. It enables the investor to diversify away from the risk attached to holding the assets. This can be achieved through lowering the correlation between the assets in a real estate portfolio (Tiwari and Michael, 2010). Tiwari and Michael (2010) introduced ways to demonstrate risk impacts and the status of real estate cycles in the cities. The so called property clock for example was introduced as shown in Figure 2.4 to demonstrate the real estate phase to which the development cycle in a number of European cities belongs to at a certain point in time.

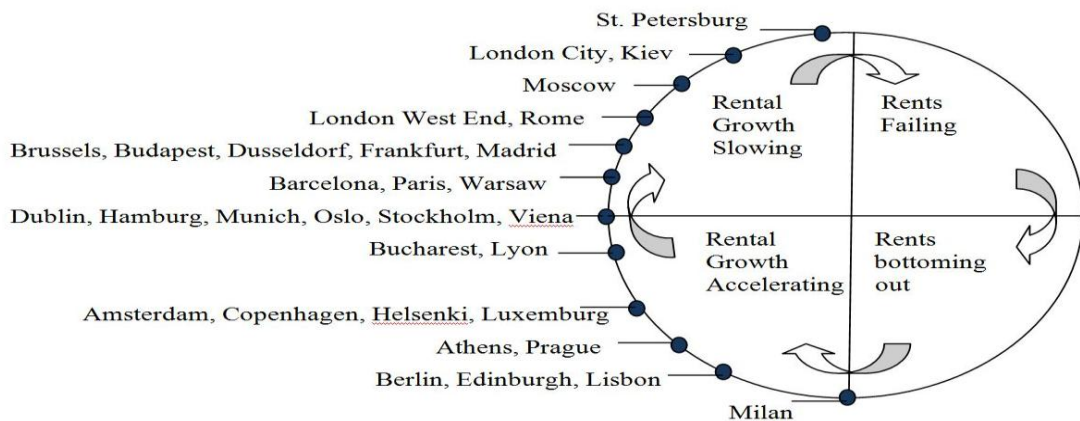


Figure 2-4: The property clock
(Tiwari and Michael, 2010)

2.3.3 Quantitative Risk Analysis

The Project Risk Management Handbook has included the Risk Management Process Flowchart. It describes proper processes which support the decision makers in preparing risk response plans (PMI, 2003). These plans are usually updated periodically to consider arising risk events over time.

The quantitative risk analysis is usually addressed whenever value analysis is required to quantify the risk impact and probability. The risk quantification is necessary before initiating the risk response plan, monitoring and control (steps 4 and 5 in Figure 2.5). Since the risk quantification has been applied for the construction duration of projects, several software programs were developed to support quantifying risk impacts and their probability.

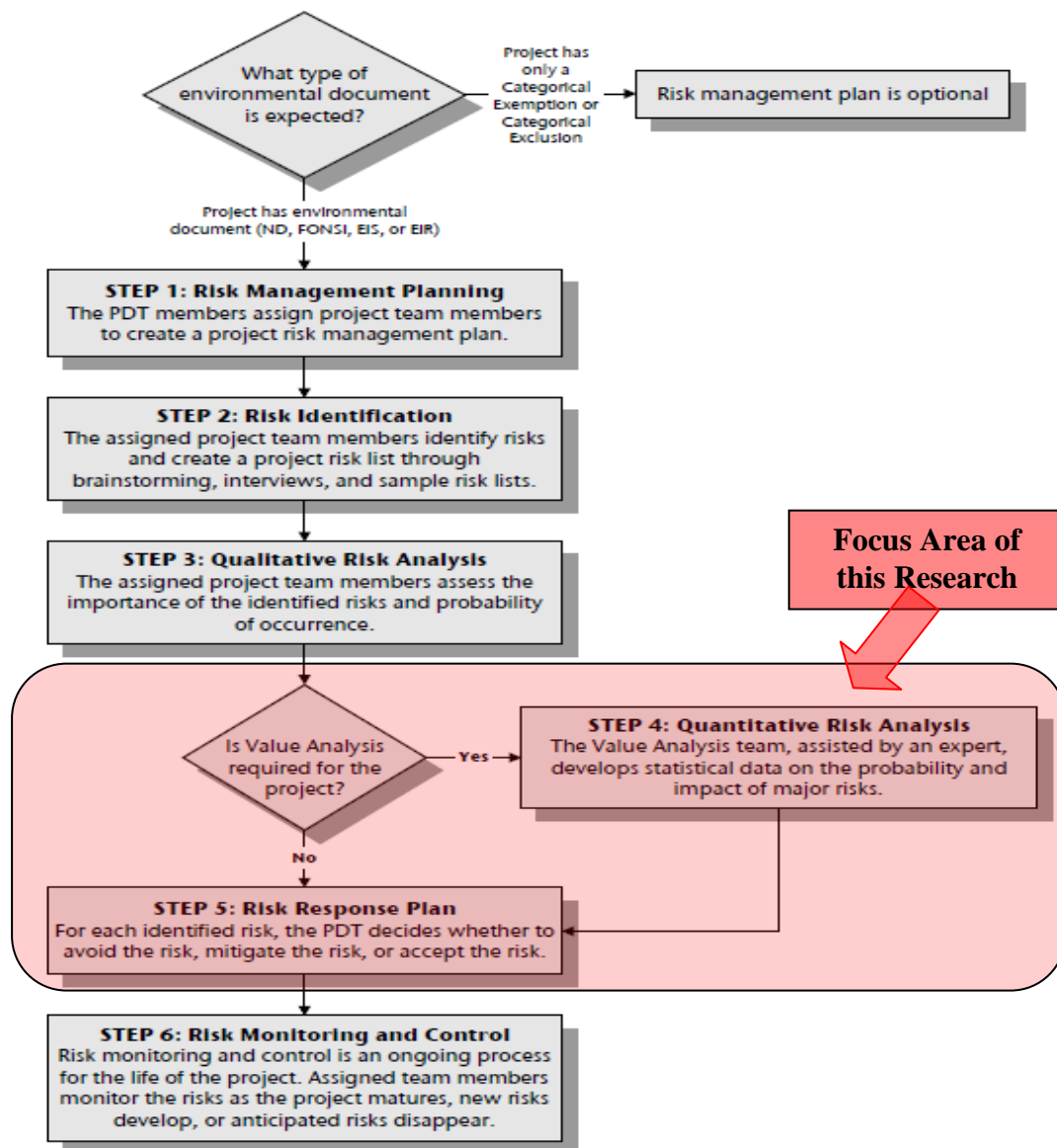


Figure 2-5: Risk Management Process Flowchart

(PMI, 2003)

2.3.4 Effects of Poor Planning

The real estate industry has been facing economic cycles of ups and downs leading in many cases to major bankruptcy. In the US for example, 42% of the real estate firms has failed to continue surviving after their fourth year of operation. The percentage increases further for older companies due to different factors. The incompetence that includes lack of planning accounts for approximately 46% of the total recorded pitfalls as shown in Figure 2.6 (Statistics Brain, 2012).

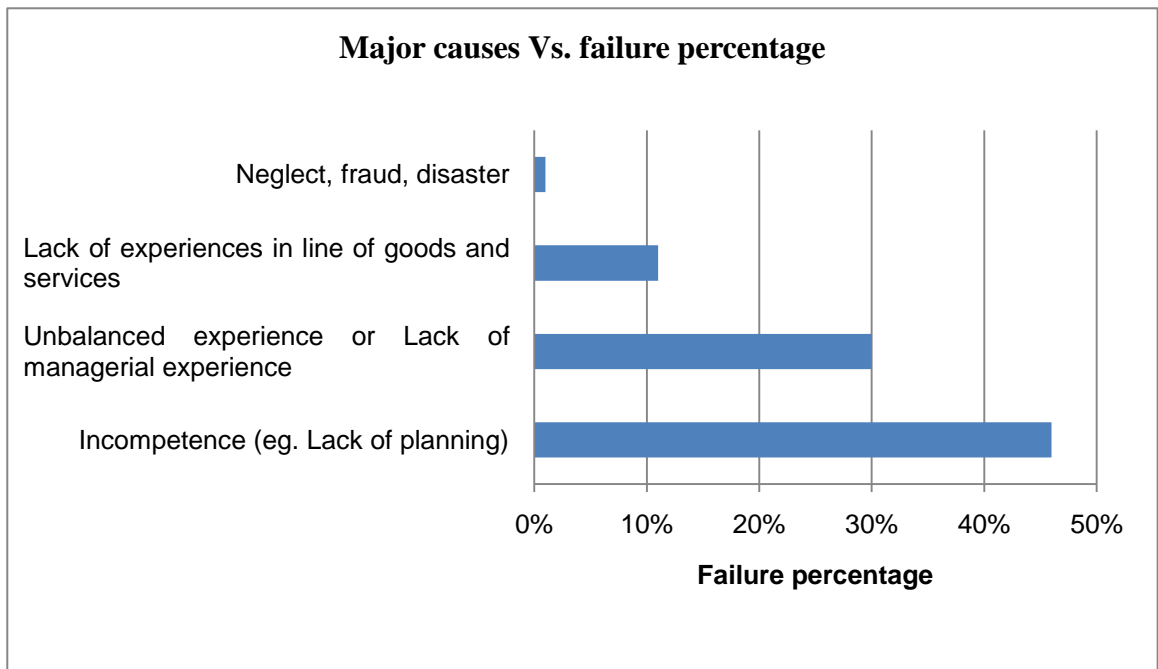


Figure 2-6: The percentage of failing companies in the US
(Statistics Brain, 2012)

Statistics Brain (2012) also mentioned that the companies of real estate business was listed as the highest worst rate among the failing companies as shown in Figure 2.7. The percentage of the real estate failing companies continued its increase and reached 70% for the ten year old companies.

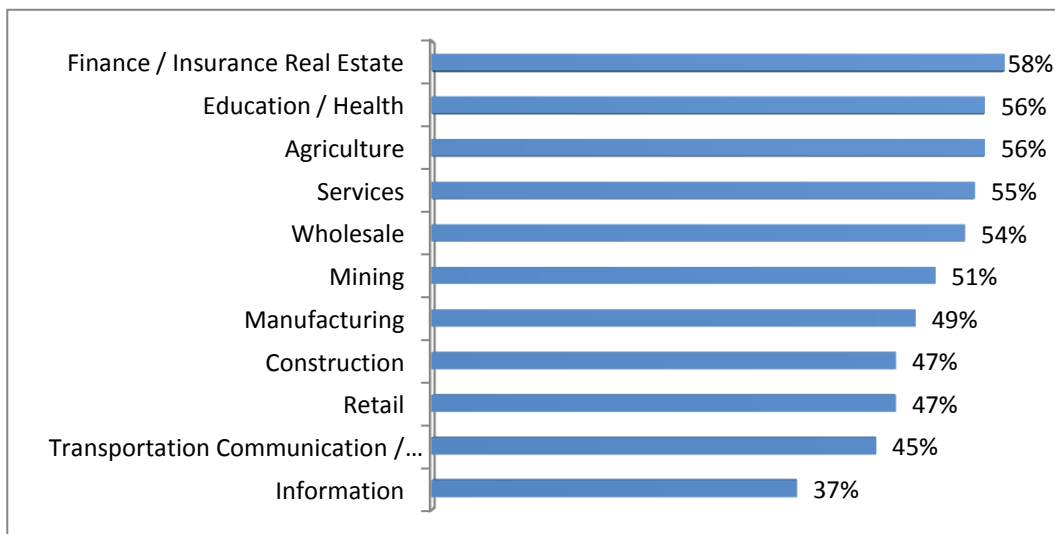


Figure 2-7: Statistics showing the percentage of companies still operating after four years (Statistics Brain, 2012)

2.4 Real Estate Lifecycle Stages

The general concepts of processes have been well published. Leelarasamee (2005) identified different sources who divided the development process into five phases; planning, initiation, feasibility, commitment, construction and management and operation. It is noted that the number and title of development phases differ from one source to the other. The development process is usually composed of phases that are chronologically ordered as shown in Table 2.2.

Table 2-2: Stages of Real Estate lifecycle (Leelarasamee, 2005)

Development Stage	Pre-Development	Project initialization
		Schematic Study
	Document Development	Preliminary Study
		Final Documents
	Project Production	Construction/ Rehabilitation
		Marketing/ Leasing and Sale
Holding Period	Post-Development	Property Management
		Asset Management

The integration between all the stages is usually considered only at the time of preparing feasibility studies, i.e. during the Pre-Development stage, for strategic planning purposes. The planning and scheduling activities are then used during each later stage separately for monitoring and controlling purposes. However, the impacts of major unforeseen risk events during any of the later stages of development may not be taken proactively by the available Decision Support Systems DSS.

Graaskamp and Sharkawy (1971) introduced timeline representation of the relation between real estate development activities and their participants. The Graaskamp-Sharkawy's Multidisciplinary Planning Model (MDPM) introduced the interfaces within multidisciplinary real estate development framework (Graaskamp and Sharkawy, 1971). Leelarasamee (2005) reproduced the MDPM

as shown in Figure 2.8. For feasibility preparation purposes, Leelarasamee (2005) assumed four main development stages; Predevelopment, Document Development, Project Production and Post Development as shown in Table 2.2. These stages are subdivided further into eight chronological phase (Leelarasamee, 2005). Further to his classification, Leelarasamee (2005) developed a Decision Support System for the Pre-Development Stage when real estate projects feasibility is usually prepared. He considered the financial, physical requirements while producing the facility program.

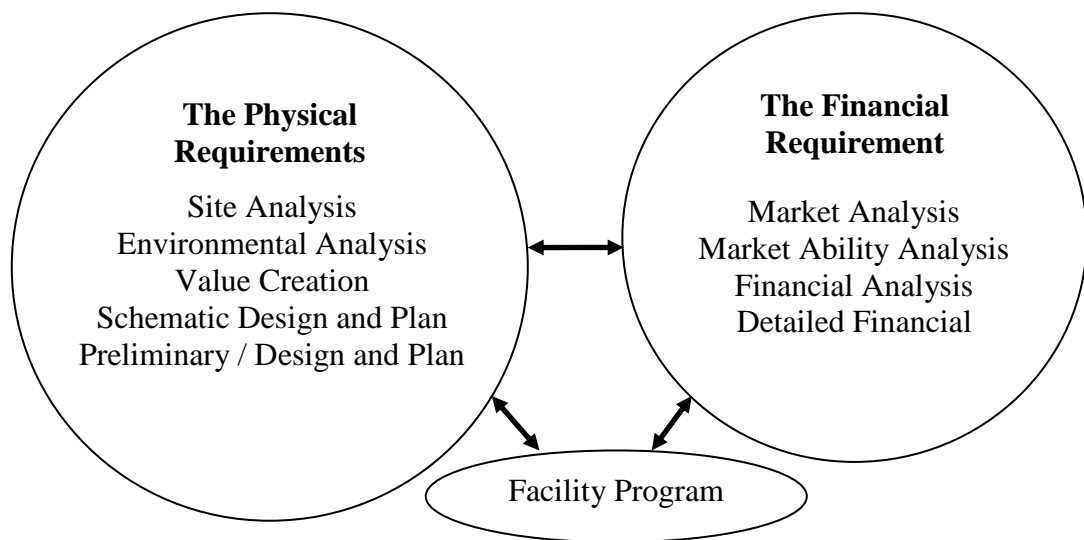


Figure 2-8: Feasibility preparation process

(Leelarasamee, 2005)

While dealing with the real estate development process, real estate researchers focused on the Pre-development stage of the Multidisciplinary Development Planning Model (MDPM). Delisle and Sa-Aadu (1994) developed the model and included numerous elements that should be addressed while preparing a feasibility study for new projects. Although different inputs are affecting the Go/No Go decision, based on real estate projects feasibility, the model is considered as a static tool that is based on a snapshot taken at an early stage of the project development (Delisle and Sa-Aadu, 1994). The process is shown in Figure 2.9.

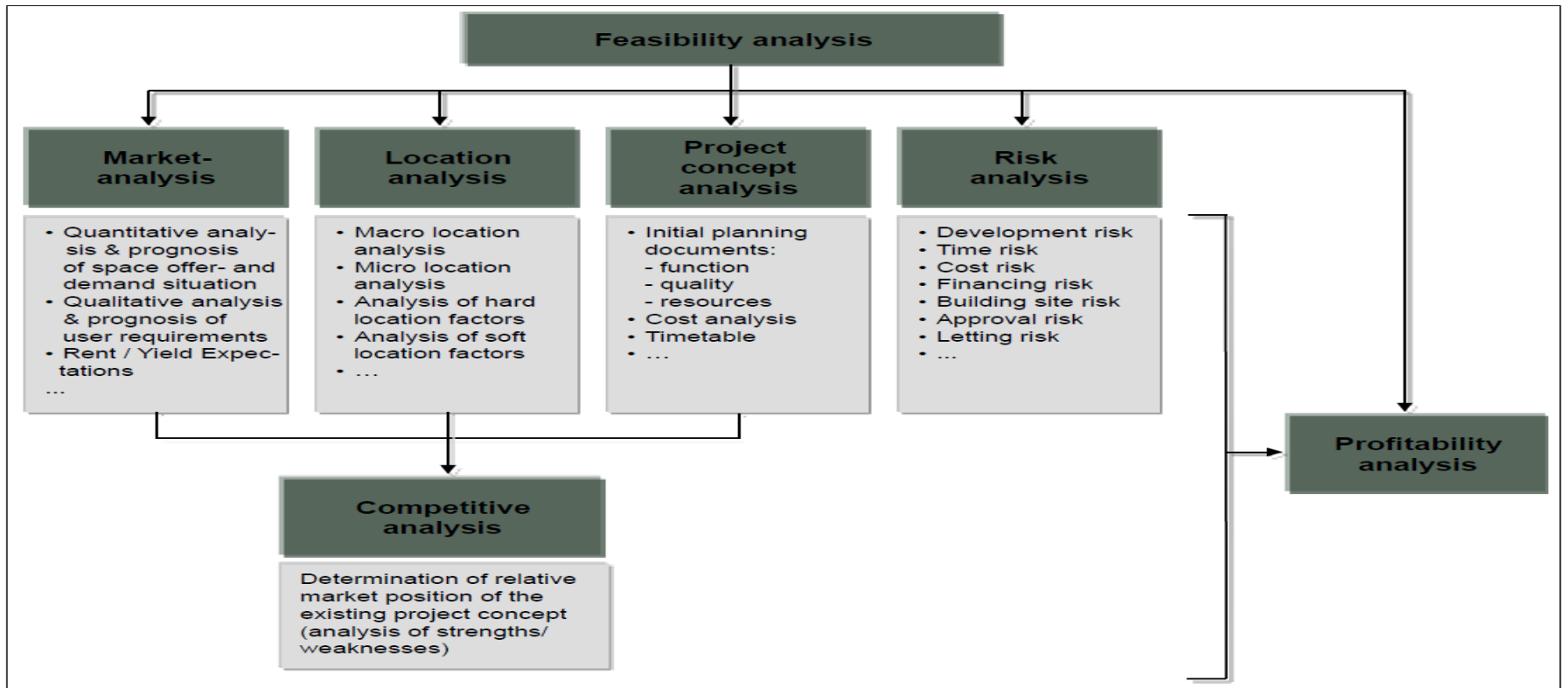


Figure 2-9: Structure of feasibility analysis (Wiegelmann, 2012)

Sharpe has suggested that asset performance could be related to an index of business performance (Leelarasamee, 2005). This was the basis for the Capital Asset Pricing Model (CAPM) and the Capital Market Line (CML) (Tiwari and Michael, 2010). The purpose of these theories is to assist the investors in minimizing their risk impact on their future real estate sales while selecting their portfolios. It supports the investor's decision makers in defining which real estate portfolio(s) have a minimum financial risk for their investment. These approaches are valuable when preparing the feasibility studies at the early stage of real estate development.

The above models are useful while preparing projects' feasibility studies at early Pre-Development Stage. However it does not provide the dynamic ability for decision makers to support their decisions in response to unforeseen risk events during the later stages. The demand and supply are the main factors used by the financials to forecast real estate market trends. Numerous causes of business cycles cause fluctuations to the real estate market demand. Examples of these causes are wars and international conflicts, introducing new industries, changing interest rates and inflation, recession cycles and the psychological frame of mind of business people and consumers (Mckenzie and Betts, 2006). Additional challenging factors are facing the real estate projects such as large transportation costs, government regulations, and the overall illiquidity of real estate (Wiedemer et al, 2012).

2.4.1 Construction Scheduling and Planning

Beside the Capital Asset Pricing Model (CAPM) and the Capital Market Line (CML) theories, that were developed to assist investors, during the Pre-Development phase of the Development Stage, in selecting their future portfolios with minimum risk impact on their investment, numerous project management tools were developed to serve different academic and professional construction control and monitoring purposes during the later construction phases of the Development Stage. A summary of these tools is listed in Appendix 1 (Wikipedia, 2012).

In addition, different optimization tools were developed to support real estate decision makers in prioritizing their projects. These tools fall under two main research areas, namely scheduling and portfolio selection. These models utilize simple ranking, based on certain evaluation criteria. Under portfolio selection (selecting projects for implementation), there has been much research based on finding the criteria then selecting and prioritizing projects according to these criteria (Elkashif et al, 2005), (Hosny et al, 2007). Hosny et al (2007) categorized potable water public utility projects into six categories: uncompleted projects, politically enforced projects,

maintenance projects, replacement projects, auxiliary projects and ordinary new projects. Projects are prioritized for implementation according to those categories.

As for the commercial construction planning software, a number of 139 planning software was found for planning and project management software (see Appendix 1) (Wikipedia, 2012). Their capability changes from one to the other. The main focus of all available software packages is the capital expenditure through construction scheduling, monitoring and control. There is no planning package available that links the construction scheduling activities and durations to the rest of the assets lifecycle cost and durations that includes the operating and maintenance costs beside the capital expenditure. Therefore, the link does not exist to show impacts of risks during an asset’s construction on its operating expenditure over the remaining lifecycle time.

2.4.2 Lifecycle Integrated Planning Approach

Fayad et al (2012) highlighted that during construction, unforeseen risks may accumulate. The magnitude of the accumulating risk impacts increases by time resulting in series of cyclic ups and downs rather than representing a constant profile in the work progress that indicates the cash flow profile as shown in Figure 1.1. The construction schedules for the early stage projects, infrastructure projects and early stage Real Estate Projects (or the REPs), are expected to follow the original feasibility-based schedule with minor adjustments as represented by curve 1 in Figure 2.10 (Fayad et al 2012).

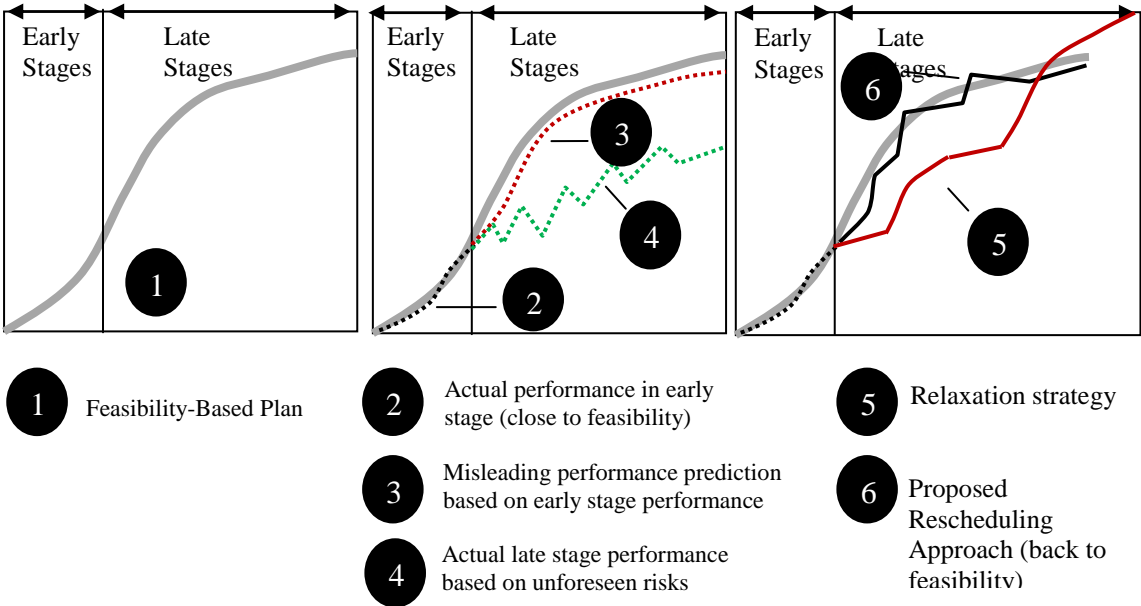


Figure 2-10: Problem illustration and proposed solution approach

(Fayad et al, 2012)

However, the later stages Cash Flow profile, for the period post completing the early stage projects and during implementing the remaining (REPs), is expected to deviate from the original feasibility due to the increasing risk events by time. This is due to the fact that at a sensitive point in time when unforeseen risk event occurs, the decision makers usually react by relaxing the implementation of their un-started late stage projects. This is represented by curves 2 and 3 in the Figure.

The impact of repetitive risk events accumulates due to the applied relaxing strategy. The relaxing strategy increases the gap between the original feasibility-based and the actual Cash Flow profiles and consequently in the Expected Gross Profit EGP. This is represented by curve number 4 in the Figure.

As seen above, the relaxing strategy does not only affect the Cash Flow and Expected Gross Profits of real estate projects, but it does also extend to cause less occupancy and services demand profiles. The reduction in the services demand profile reduces in turn the services demand profile compared with the original feasibility-based master schedules. The reduced demand on services may lead to a critical situation where originally planned profits are not met due to failure to cover the capital as well as the operating expenditures. This is represented by curve 5 in Figure 2.10. Therefore, it is important to introduce new strategies that are different from the current relaxation strategies. The new approach should be based on maintaining the projects actual Cash Flow profile as close as possible to the original feasibility-based assumed trend while responding to the individual risk events as represented by curve 6 in the Figure.

Since most of the infrastructure systems are usually constructed at early stage of development, the delayed occupancy profile directly affects their economies. Developing new cities and large scale real estate communities of mixed use purposes usually requires a huge investment. This investment is usually distributed over lengthy construction periods. The overlap between construction activities and commencing partial occupancy of the newly built units is a phenomenon of these projects. The overlap usually takes several years and may extend to decades depending on the community size (Fayad et al, 2012).

2.5 The Infrastructure System

Hudson et al (1998) listed eight reasons for the deterioration of infrastructure systems. The deterioration leads to accumulated problems that may extend for decades. The reasons are:

- 1- The underinvestment in public works programs.

- 2- Lack of good management systems for infrastructure.
- 3- Failure to recognize the importance to the future economy of maintaining a sound physical infrastructure.
- 4- Cutbacks slashing public works budgets.
- 5- Failure to replace the infrastructure as fast as it wears out.
- 6- Failure to realize that lack of physical infrastructure seriously impacts the level and types of services government can provide to their citizens.
- 7- Tendency by national state, and local officials to defer the maintenance of public infrastructure.
- 8- Increased costs to taxpayers to repair and rebuild the obsolescent public infrastructure.

Hudson et al (1998) also highlighted the importance of adaptation of Infrastructure Management Systems (IMS) and educating the human resources for its applications in order for better management of the infrastructure systems. This should improve their lifecycle costs. They have also highlighted that usually public officials and private interests are concerned primarily with initial costs although a low capital expenditure today can result in excessive future costs for a particular alternative.

Ecorys & Delft (2005) defined different infrastructure expenditures according to the way they enhance the functionality and/or lifetime of infrastructure (asset approach). According to the asset related expenditures, the classification is made as follows:

- 1- Investment expenditures: this includes expenditures on: a) new infrastructure with a specified functionality and lifetime or, b) expansion of existing infrastructure with respect to functionality and/or lifetime.
- 2- Renewal (or replacement) expenditures: this includes expenditures on replacing existing infrastructure, prolonging the lifetime without adding new functionalities.
- 3- Maintenance expenditures: this includes expenditures for maintaining the functionality of existing infrastructure within its original lifetime.
- 4- Operational expenditures: expenditures not relating to enhancing or maintaining lifetime and/or functionality of infrastructure.

The classification is illustrated in Figure 2.11.

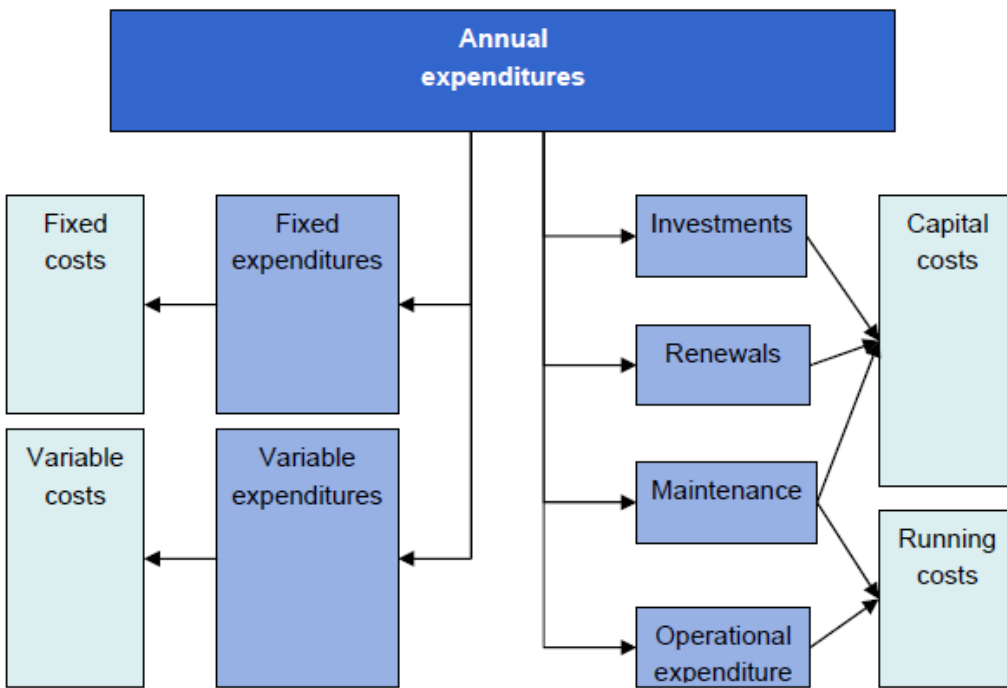


Figure 2-11: Components of the total infrastructure costs
(Ecorys & Delft, 2005)

The report also included other classification approach that is based on usage related approach. This approach classifies the expenditure in fixed and variable. Different from the variable expenditure, the fixed expenditure remains unchanged with the change of the demand on an infrastructure system output. According to Ecorys & Delft (2005), three approaches are available for distinguishing fixed and variable components in the maintenance and operating expenditures; these are:

- 1- The econometric approach: the total expenditure is considered a dependent variable in the infrastructure output. The variable is determined from analysis of time series of data.
- 2- The engineering approach: the total expenditure is disaggregated into subcategories. The analysis is then made for each of these subcategories to provide the share of the expenditure. These two methods proved deficiencies due to the lack of technical experts while the second results in huge analysis effort that is needed to deal with unlimited number of system components.
- 3- Cost allocation approach: This approach mixes both of the above methods and relies on expert opinion in defining the percentage of expenditures for both the fixed and variable components.

The running cost can also be considered as a percentage of the investment cost according to expert opinions and analysis of historical data collected for other similar systems. This type of data input assists in long term planning of infrastructure lifecycle cost and profit calculations.

2.5.1 Maintenance Expenditure

Hudson et al (1998) referred to different types of maintenance for which several sources have defined terms such as routine maintenance, corrective maintenance, preventive maintenance, proactive maintenance and reactive maintenance, hard-time replacement, on-condition assessment, condition monitoring, servicing task, rework task (repair, overhaul, rebuild), replacement task, and time-directed (versus condition-directed) activities. The term routine maintenance applies also to the time-based maintenance (Hudson et al, 1998). He defined the maintenance as “that set of activities required keeping the condition of each component, system, infrastructure asset, or facility functioning as it was originally designed and constructed to function”.

2.5.2 Renewal Expenditure (Rehabilitation)

Hudson et al (1998) defined the Infrastructure Rehabilitation as “the act or process of making a compatible use for a property through repair, alterations, and additions, while preserving those portions or features that convey its historical, cultural, or architectural values”. The boundary line between maintenance and rehabilitation is often policy and rule-dependent. However, rehabilitation is seen as the action of restoring something to a former condition or status while maintenance is seen as continuous retention of something “in an existing state”. The infrastructure management Maintenance Management Systems MMS which considers the operation required for maintenance during the assets lifecycle. It is important to consider reconstruction of a facility at the end of its lifecycle.

The action’s selection whether its maintenance, rehabilitation or reconstruction, depends mainly on the overall lifecycle cost so that the level of service is maintained at a minimum acceptable level of Service. The definition of these concepts is important when dealing with the management of infrastructure assets over their lifecycle for different disciplines (e.g. water system, district cooling system...etc.).

2.6 The Infrastructure Subsystems:

The Infrastructure system contains usually a combination of different subsystems. These subsystems are aimed to provide certain service to end users at satisfactory level of service. The principle and components of a number of Infrastructure systems are illustrated here after. This includes the district cooling, potable water and urban landscape and irrigation water subsystems. These systems are selected due to the relative importance of the water conservation and sustainability topics.

2.6.1 District Cooling

Similar to the Sun Belt area in the US (the southern hot states) and different from Western European countries with their colder weather, the demand on cooling in the Middle East is increasing exponentially. The Arab Gulf states, the UAE, KSA, Qatar followed by Egypt have seen a jumping increase in the cooling demand. The increase was mainly due to the change in the usage pattern and is relating to the global warming change phenomena. In the years 1970s, the air-conditioning technologies were developed for commercial use to cool small unit spaces. Recently, cooling technologies have increased the cooling capabilities to reach thousands of tons refrigerants per cooling unit, or chiller. Different cooling concepts were introduced to provide cooling water to the end users. Cooling can be generated and distributed through cooled water from distributed chiller plants in the building to feed the building units. It can also be generated in a different location and then the cooled media (water) is transported in pipes to a network feeding a number of buildings. To imagine the effectiveness of using water as coolant media, the transfer of cooled water through a 2” pipe is more efficient than coolant air through a 42” duct. Different energy sources may be used to operate the developed chillers and equipment (electrical power, natural gas, etc.). The energy type selection usually follows feasibility studies. These studies define which approach and components are the best for achieving less lifecycle cost, easier maintenance and operating technologies, minimum CO₂ emissions, less water consumption, better operating efficiency and hence less end user charges (Fayad et al, 2012).

The idea of centralizing all cooling chillers in one location represents the district cooling, has been a technically and financially sound approach and has been emerging in many countries. Several computer simulation programs have been developed to support cooling plant designers in estimating the cooling needs and demand that could be required in the future depending on many factors. These programs are able to predict the cooling demand profile that changes from hour to hour depending on the outside temperature as well as the building purposes (commercial, retail, residential,..etc.). The profile is useful when preparing cooling projects feasibility and in planning the plants operating schedules. The same cooling concept applies also for the heating systems. In both systems, and in order to make the demand future estimates more reliable, designers reduce the total loads of all buildings at peak hours by a certain factor to obtain a “diversified” load. The factor reflects the assumption that not all the buildings of mixed types would be fully occupied at the same time. The factor is important in avoiding oversized plants and underutilization. Therefore, the plants are designed to produce cooling or heating that matches the highest

diversified load demand. The feasibility of remote centralized district cooling technology has, therefore, supported its selection above other cooling systems. The use of the centralized district cooling approach has now been proven for years (Fayad et al, 2012).

Fayad et al (2013) explained the principle and main components of typical central district cooling plant system. The system includes different mechanical and electrical equipment. This equipment is installed in one building called the district cooling plant or the DCP. The cooled water, produced from the DCP is transported to the served buildings via dual water networks in both directions, cooled water supply network in the direction from the DCP to the buildings and water return network back from the buildings to the DCP. Both networks are contained in an insulated closed pipeline loop. The DCP usually includes the following main equipment:

- 1- Chillers: this main equipment cools the water and includes main items: the evaporator, condenser, drive motor, compressor, power switchgear and microprocessor. The chiller's main function is to transfer the heat from loop 2 to loop 3 as indicated in Figure 2.12.
- 2- Cooling tower: cools down the condenser by transferring the heat to the surrounding air.
- 3- Secondary chilled water pumps: These pumps transfer the cooled water the cooled water from the chillers to the supply line of closed pipeline network between the DCP and the ETS, or the heat exchanger rooms near to the consumer buildings.
- 4- Primary Water Pump: Suction side of these pumps connected to the Return Line of underground network, and outlet side is pumping that returned water to the chiller for cooling down the water temperature.
- 5- Condenser Water Pumps: These pumps transfer the hot water surrounding the condenser to the cooling tower through an open network, and return it after cooling it to cool down the condenser.

Beside the mechanical components, a typical DCP may contain: electrical switch gears, transformers, chemical treatment system and side stream filtration. Some plants may use more than energy source such as natural gas beside the electrical power for power reliability and cost efficiency purposes.

A typical central district cooling system includes three different closed loops that transfer the heat generated inside the consumer buildings up to the cooling towers in the DCP that is located away from the consuming buildings as illustrated in Figure 2.12. The first loop transfers the heat

from inside the consumer buildings (or the Real Estate Projects (REP)) to their own External Thermal System rooms (or the ETS rooms). The heat transfers from the first loop at the consumer building side (called the primary side) to the second loop (between the consumer buildings and the district cooling plant). The length of this second loop may extend to several kilometers depending on the community layout. The second closed loop starts from the ETS rooms and transfers the heat through return water to the chillers' evaporators inside the DCP with approximate temperature of about 13 degrees centigrade.

The evaporators cool the water down up to about 4 degrees centigrade and re-circulate it back to cool down the second loop back to the ETS for heat exchange. A third loop starts at the chillers' condensers part that absorbs the heat from the evaporators and transfer it to the cooling tower via the third loop inside the DCP. The warm water in turn cools down inside the cooling towers which exchange the heat to the outside air. The cooled water circulates back continuously to the chillers' condensers via the closed third loop. The operation is schematically illustrated in Figure 2.12 and Figure 2.13.

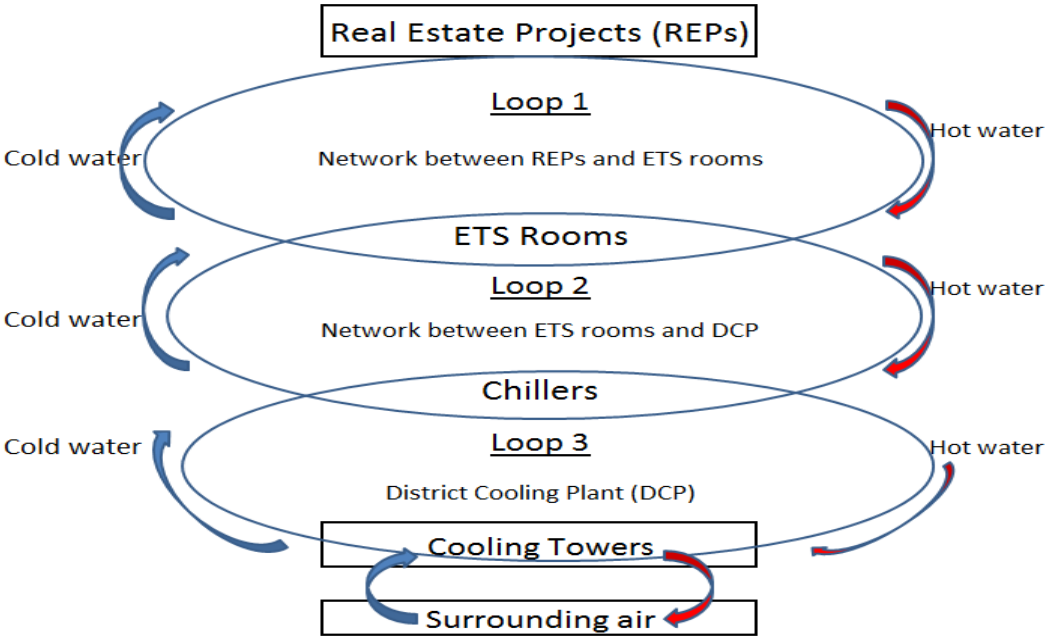


Figure 2-12: District cooling system

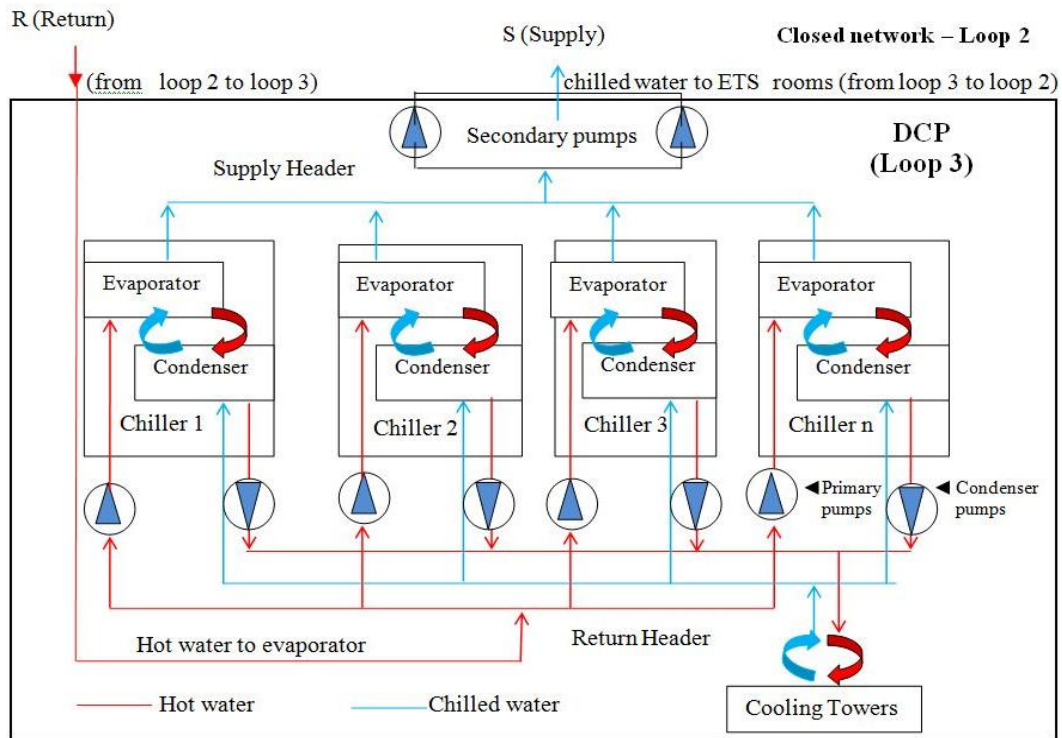


Figure 2-13: Water Flow and Heat Exchange in Central Cooling system

The heat exchange between loops 2 and 3

Several researchers have developed models for optimizing cooling plant equipment selection from lifecycle cost prospective. However, the impact of later risks challenging real estate projects during their construction could affect the economies of cooling or heating plants after their construction in early stages of development. The deviation in the later actual demand from the cooling/heating plants original feasibility-based demand could lead to a case where the operating costs become uncovered. It is important to study how to improve the efficiency of the plants maintenance schedules. This is in order to reduce their equipment operating costs which affects in turn the lifecycle cost and hence the charged fees to the end users. Previous literatures have included models for generation and conversion systems optimization and network structure optimization prior to construction. Chow et al (2004) developed a genetic algorithm to select the optimal composition, in terms of use of buildings, for a city quarter or an urban area by considering building typologies and demand profile types.

The optimization of District Heating and Cooling systems operation was introduced by Sakawa et al (2002). The Genetic Algorithms was used to solve mixed integer linear programming

(MILP) models. The goal of the optimization was to decide which engines, heaters and chillers should be used, at which load and at which point in time. Fichters et al (2001) and Sundberg and Henning (2002) and Rolfsman (2004) accounted for the cost advantage of larger plants, i.e. for the size components of cost functions that increase specific costs of smaller plants. The models' objective was to find the best sizes of conversion technologies in order to satisfy a given heat demand which is usually applicable during the feasibility stage of development projects. Chinese (2008) and Kim et al (2009) developed models for the optimization of district heating and cooling network using MILP modeling with the objective function to minimize the investment and operational cost and optimal amount of network transmission. Sideman developed MILP model for optimizing district cooling in new regions as well as new extensions of existing facilities (Sod07). Kim et al (2009) developed similar model with an optimization problem that is formulated as a MILP problem where the objective is to minimize the overall operating cost as well as prediction of future operation guidelines of district heating systems.

The above literature indicates the existing models can be used to provide a static snapshot of the future situation, which can be applied in the Pre-development stage. However, these models are not able to support decision makers in quantifying impacts on rescheduling the implementation of their remaining unconstructed projects on the economies of constructed district cooling system. The need is obvious for models that dynamically follow the changing demand due to changed implementation schedules, and then provide updated demand profile, optimized operating schedules that minimizes the cooling system lifecycle cost.

2.6.2 Potable Water

Several models have been developed by researchers to plan and manage water main networks as well as water supply systems. The models have not considered future risks facing the implementation of large scale real estate projects and their impact on the originally prepared feasibility of the projects as well as on the feasibility of its serving infrastructure systems.

Kleinerand and Rajani (2001) provided a comprehensive overview of a large body of work carried out in the statistical models in the past years. These models had the objective of quantifying the structural deterioration of water mains by analyzing historical performance data. Kleiner and Rajani (2001) focused on the physically-based models. Sinha and McKim (2007) developed a probabilistic-based integrated pipeline management system. The system can support strategic decision making in regards to pipeline lifecycle maintenance and rehabilitation of projects. The model applies a non-homogeneous (time-related) Markovian prediction method to forecast pipeline

deterioration and hence prioritize the maintenance and rehabilitation projects over the lifecycle. Al-Barqawi and Zayed (2008) developed a model for condition assessment and prediction of water mains performance using Analytic Hierarchy Process (AHP) and Artificial Neural Network (ANN). Gustafson (2007) developed a performance model for cast iron and ductile iron mains that is transformed into a predictive model. The predictive model is then used to determine the economic thresholds for rehabilitation or replacement of pipeline individual segments. The budget is periodically prioritized to meet rehabilitation/replacement criteria. Osman and Bainbridge (2001) presented a comparison and analysis of the transition state models by using a single data set for cast and ductile iron pipes in Canada. The objective was to compare the models in forecasting pipe breaks and strategic planning of repair.

On the other hand, other researchers have addressed infrastructure water systems. Ansell and Archibald (2004) proposed a general stochastic dynamic programming model allows for the effect of repair and preventive maintenance on the operating age of the system as well as the effect of replacement on the characteristics of the system. Their model is used to establish the form of the optimal repair, replacement and preventive maintenance policy. Black et al (2005) developed another model utilizing a semi-Markov process to predict time-related maintenance of items. Banjevic and Jardine (2006) developed a Markovian model to estimate the failure time through a probabilistic approach. The stochastic model included internal and external maintenance processes for the hazard function so that the cost per unit time is minimized. Durango-Cohen and Madant (2008) presented an adaptive optimization model for finding joint inspection point and maintenance policies for infrastructure facilities. The model simultaneously relaxes the assumption of a fixed inspection schedule and accounts for uncertainties both in the choice or specification of a performance model to represent deterioration and in the process of measuring facility condition. Ahmed and Kamaruddin (2012) presented an overview of the Time-based maintenance (TBM) and Condition-based Model (CBM) techniques with emphasis on how these techniques work toward maintenance decision making. They concluded that CBM application appears more realistic compared to TBM. This is based on the fact that 99% of equipment failures are preceded by certain signs, conditions, or indications that such a failure was going to occur.

The continuous success in supplying potable water at acceptable quality level has been a challenging topic facing municipalities as well as water supply companies. The water supply system, similar to the industrial sector, is composed of different components such as treating facilities, elevated tanks or pump stations that are usually connected to pressurized distribution networks. As seen here above, several researchers have been developing water systems

deterioration and optimization models using different deterministic and/or stochastic tools and models for different objectives.

2.6.3 Urban Landscape and Irrigation Water

The urban landscape is usually introduced to the developed communities for beautification, noise and dust mitigation and prevention purposes. A number of literatures have classified the urban landscape plants into groups. Hosny (2012) grouped the plant types in 7 groups and included several parameters for the classified plant groups; namely:

- a) Palms: this group includes 27 types of palm trees.
- b) Like-Palms (Ornamental like-palms): this group includes 7 types of Like-Palm trees.
- c) Trees: this group includes 102 types of trees. This group includes both evergreen and deciduous types.
- d) Shrubs: this group includes 48 types of shrubs which are either evergreen or deciduous.
- e) Climbers: this group includes 16 types of climbers which is either of evergreen or deciduous types.
- f) Ground covers: this group includes 27 types of ground covers which is either evergreen or annual ground covers.
- g) Ornamental Grass: this group includes 5 types. The Ornamental grass is of evergreen types.
- h) Grass: the grass type is an evergreen type.
- i) Succulents: this group includes 44 types of evergreen types.

The main key for success in providing a rich landscape design is the selection of more types and groups. However, other factors are also important in determining which plant mix is to be selected in the design. Examples are the irrigation quantities, feeding elements quantities, life time expectancy, certainly the construction cost of the selected plants. The type of irrigation, the soil and underground water, the availability of irrigation water and weather conditions are also important limiting factors in the cost as well as the plant selection.

Although several researchers addressed different landscape topics from different points of view, yet the management of urban landscape design issues still require more attention especially

in areas relating the plant types to their irrigating water consumption as well as their operating expenditure. Pettit and Wu (2008) suggested that “Real world resource managers and policy makers want tools that provide information about the potential impacts of management actions on a number of landscape services and that provide such information in a format that will facilitate efficient decision making.”

Roberts et al (2010) introduced an Evolutionary Multi-objective Optimization methodology for generating estimates of the Pareto optimal set of designs for an evolving landscape in the rural urban fringe of a major metropolitan area. Although the method is able to provide optimum designs from an ecological point of view, it has not considered the lifecycle cost optimization of the output landscape design.

Jienan (2009) discussed the landscape design for three cases in China. The study has discussed three dimensions that should be considered while designing landscape, namely:

- 1) Similarity in design and lack of own characteristics while designing residential landscape,
- 2) Lack of functions in the design of residential area, and
- 3) Energy consumption and lack of conservation techniques, e.g. solar and wind energy. The study has not addressed methods for designing landscape where lifecycle cost is considered.

Brunckhorst and Reeve (2006) described three principles of priority importance in identifying regional boundaries for resource governance. They included that resource management regions should reflect the area of most interest to local resident communities as one of their principles. They also included that administrative region within which natural resource management occurs should contain a relatively homogeneous set of landscapes with similar climate, ecological and geophysical characteristics. However little or no literature has addressed the urban landscape design in such a way that maintains the sustainability of available resources, e.g. irrigation water or lifecycle operation and maintenance cost.

Little research focused on minimizing the urban landscape lifecycle cost and the impact on the end users who usually finance such costs. Some researchers focused on the socio-ecological dimension of the problem, Fitzsimons and Cherry (2008) reviewed three conceptual frameworks used to identify indicators and guidance for integrated assessment of socio-ecological processes. The environmental indicators are used to assist in fulfilling legislative requirements for reporting on the state and condition of the environment along with its natural resources. They highlighted the need to develop a suite of indicator products to enable trend analysis between collection years and

allow comparison across the region under consideration. Romero et al (2010) documented the importance of irrigation on urban landscape plants and the importance of determining irrigation water requirements on irrigation water savings. There is no optimization applied in this research while it focused only on determining the actual irrigation water needs for plants' lives.

Previous research did not considered optimizing plants design mix and its impact on lifecycle cost where operation expenditure may dramatically exceed the capital expenditure. Moreover, the impact on lifecycle irrigation water consumption was not considered.

Designing sustainable and cost effective landscape is a very challenging topic. In large scale mixed use real estate projects and gated communities, the lifecycle cost of urban landscape projects represents a major component that consumes difficult-to-track running costs. As a type of cost to be transferred to residents or end users, proper cost estimate, cost optimization and cost analysis need to be conducted to ensure a competitive edge for real estate projects in their market. It is not an easy task for urban landscape architects to select their plants types for the projects they design and consider several requirements at the same time. The shape of their landscape plants design should be rich, sustainable, and attractive over its life and consume less irrigation water. The design should also be of less capital and operating costs, i.e. less lifecycle cost. Presenting the selected plants types to decision makers, whose landscape knowledge and background is limited, is an additional requirement.

Moreover, plant selection should be performed in a dynamic way since the lifetime of plants differ from plants' group to the other. This provides the option of selecting different plant types when it's required to replace the deteriorated plants by new ones. The periodic selection of plants is important in the sense that it supports urban landscape architects in selecting their plant types as well as meeting a number of additional requirements. A little research has focused on minimizing the urban landscape lifecycle cost and the impact on the end users who usually finances such costs.

As for the visualizing techniques, Mansergh et al (2008) examined the use and potential of various visualization tools as part of the emerging debate about biodiversity and adaptation to climate change in south-eastern Australia. (Pettit et al. 2008) provided an example prototype virtual world with the goal of increasing the understanding of landscape processes and the data and modeling tools available to catchment managers and planners for making more sustainable land use decisions for regional planning purposes that includes agricultural natural landscape. The above

solutions has not provided tools for comparing different design mixes of plantation or irrigating water consumption and its relation to lifecycle cost.

There are a number of packages that were developed to select plant mixes. The available packages provide basic landscape databases that are usable in certain regions of certain climate/soil conditions. These packages include several parameters for different landscape plant types. The available packages enable landscape designers to select certain plants in their designs as well as drawings' capability. However, the available packages do not provide optimization capability neither from cost nor from water consumption perspectives. The Research University of Florida developed software package for choosing suitable trees for urban and suburban sites: site evaluation and species selection (UOF, 2013).

The University of Minnesota, Department of Horticultural Science, developed "SULIS" software for selecting Plant Elements. The goal of the software is to provide sustainable landscape information to the public and to the horticulture/landscape industry. By utilizing SULIS concepts, homeowners, business owners and related industry personnel are able to create outdoor spaces that are functional, maintainable, environmentally sound, and cost effective and aesthetically pleasing (UOMinn, 2014). CAD Pro landscape design software was developed by CADPRO for quick seeing the dramatic transformation of undeveloped spaces (CADPro, 2014). In addition, SmartDraw developed a real time landscaping software that is useful for easy design, planning and drawing of urban landscape. An extensive plant encyclopedia and plenty of template assist in building home's landscape elements. There are few design tools missing, and it does not import as many file types as one would like (SmartDraw, 2014). In addition, the Ohio State University, Department of Horticulture and Crop Science, developed software for static selection of plant type (OSU, 2014).

The available applications usually include plant information database from which academicians, site engineers and architects may select their plant types. Although the databases include various technical information, they are static and do not provide optimization option for selecting plant mixes from different groups to match certain objective, such as minimizing the mix's lifecycle cost or minimizing its lifecycle water consumption. Examples of these packages are summarized in Table 2.3 below.

Table 2-3: Available landscape selection tools

Developer	Features	Optimization
Research University of Florida	choosing suitable trees for urban and suburban sites: site evaluation and species selection	No
University of Minnesota Department of Horticultural Science	Plant Elements of Design – A plant Selection Program The goal of the SULIS is to provide sustainable landscape information to the public and to the horticulture/landscape industry. By utilizing SULIS concepts, homeowners, business owners and related industry personnel is able to create outdoor spaces that are functional, maintainable, environmentally sound, cost effective and aesthetically pleasing	No
CADPro	CADPro landscape design software can quickly get seeing the dramatic transformation of undeveloped spaces	No
SmartDraw Real Time landscaping	Landscape Software for Easy Design & Planning of Landscapes Drawing capability An extensive plant encyclopedia and plenty of templates assists in building home’s outline. There are a few design tools missing, and it does not import as many file types.	No
Ohio State University Department of Horticulture and Crop Science	Static selection of plant types	No

2.7 Optimization Applications:

A fuzzy multi-criteria decision-making model was developed to support decision-makers in the selection of the optimum combination of potable water projects to be implemented under limited budget constraints (Hosny et al, 2011) and (Hosny et al, 2013). For schedule optimization much research to optimize schedules has been conducted with various objectives such as minimizing the total cost, the project duration or monthly finance (Hosny and Nassar, 2013), (Hegazy and Elhakeem, 2011) and (Elazouni and Metwally, 2007).

Several models were also developed to optimize the scheduling process in other industries, e.g. in the transportation and manufacturing sectors. Zegordi et al (2009) developed a model for the integration of production and transportation scheduling in a two-stage supply chain environment. The model applied a mix of integer programming and Genetic Algorithm GA and has the objective of minimizing the total tardiness and total deviations of suppliers' assigned workloads. Termos et al (2011) developed a GA model for railway scheduling problem. The objective was to develop a timetable that would optimize train operations. Andre et al (2012) developed optimization model for minimizing investment costs on an gas transportation network by finding the optimal location of pipeline segments to be reinforced and their optimal sizes (among a discrete commercial list of diameters) under the constraint of satisfaction of demands with pressure enough for all users. Wang (2010) introduced a two-stage real estate development project portfolio selection and scheduling decision-making system that can select groups of projects by maximizing their Expected Gross Profit and minimizing risk. He has also considered minimizing the value of cumulative net Cash Flow and minimizing the value of breakeven time of cumulated net Cash Flow to assist developers' decision makers to implement optimal capital resource allocation. However, the model has not considered the infrastructure projects that are usually implemented at early stages of development and prior to risks occurrence. Leelarasamee (2005) claims that though decision-making systems are proven to be useful, they ignore several risks. Dzung and Lee (2007) developed a model that used GA in the optimization of the development of resort projects. GA has been implemented through a model which is used to develop an optimized

schedule for the amenities of the resort considering both the costs, Cash Flow and Expected Gross Profits' NPV, which was taken as an objective function to be maximized. This model integrates simulation and GA for obtaining such development schedule.

2.7.1 The Genetic Algorithm GA Concept:

The Genetic algorithm (GA) concept is mainly based on the survival of the fittest derived from the biological systems (Elbeltagi and Tantawy, 2005). Each solution of a given problem is represented as a string called chromosome where each chromosome consists of several genes. These genes represent the variables for the optimization problem. The GA procedure starts by creating a population of chromosomes (solutions). During the creation of the initial population, the genes in the chromosomes are set randomly within variables allowable values. The procedure evaluates these chromosomes by measuring their fitness against an objective function. To simulate the natural process of the survival of the fittest, the chromosomes allow exchanging their genes through mutation and crossover to generate new chromosomes for new generations. Any new chromosome is evaluated and replaces a weaker member in the initial population to allow the population to evolve and have better chances to produce better solutions. This process continues till a best fit (near optimum) solution is generated. There are four main parameters which affect the performance of the GA: the number of generations, population size, mutation rate and crossover rate. A larger population size and a larger number of generations help in getting an optimum solution but increase the time needed for processing.

A solution to the time-Cash Flow problem is simply a specific combination of possible construction start dates for all the entire projects in real estate development. Only projects, that have not started, take part in the optimization process. In the GA, the solutions are represented as chromosomes by assigning each box (gene) in the chromosome string to a project's starting date. There are as many genes in the chromosome as there are projects. The sequence of the project's starting date in the chromosome is constrained by the starting and ending dates of the group to which a project belongs to. These pre-defined dates are considered as hard constraints during the optimization process. In other words,

the gene value of the box corresponds to the starting date of the corresponding project. Each solution, therefore, defines a certain set of gene values for its chromosome.

The optimization process starts with the initialization of a population. A random feasible solutions (starting dates) is generated. Each individual solution is evaluated based on its fitness in regards to the criteria; that is the maximum lifecycle Expected Gross Profit. The calculation module in the model then calculates the ending date by adding the given project duration to the generated starting date. It also calculates the corresponding Cash-In and Cash-Out that follows the demand on the infrastructure system. Two genetic operators are used in Recombination; these are crossover and mutation (Que, 2002).

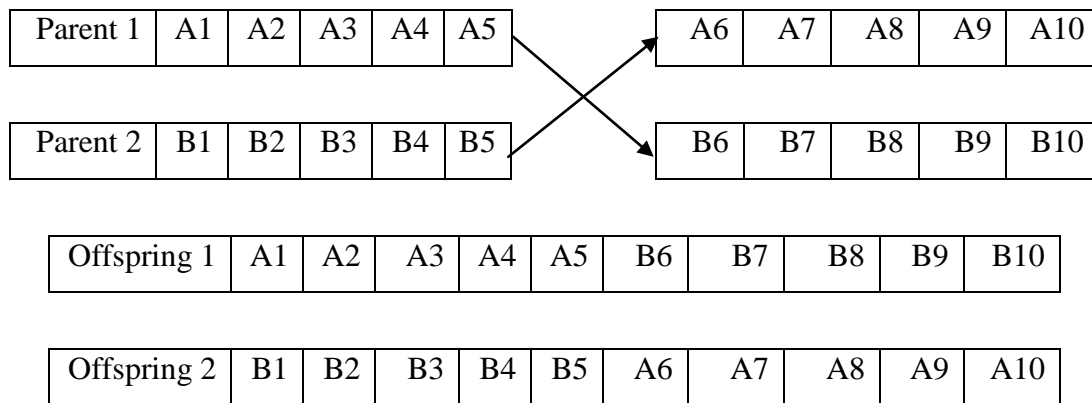


Figure 2-14: Crossover process (Que, 2002)

The recombination is principally effected by an operator called crossover. The crossover is performed by randomly selecting two members from the population and exchanging their chromosomal information. Single-point crossover involves exchange of a part of each chromosome in a pair across a randomly chosen point. Figure 2.14 illustrates that two strings parents 1 and 2 are randomly selected and broken at a random point at gene 5. After the exchange of genetic material, two new strings (offspring 1 and 2) are generated. It is stated that the power of GAs arises from crossover, where a randomized exchange of genetic material is executed with a possibility that “good” solutions can generate “better” ones. Although crossover is principally thought of as a mechanism that improves the quality of solutions, it is also possible that crossover will disrupt a good schema already present in the solution.

Another genetic operator used in recombination is mutation. Mutation involves changing the genes' values across a chromosome at random. The principal use of mutation is to improve genetic diversity by introducing unexplored or restoring lost genetic material to prevent the GA from getting trapped into a local optimum and prematurely converging to suboptimal solutions.

The new solutions are used to replace existing members of the population. The population undergoes evaluation, selection, recombination, and replacement until the terminating condition is met. The number of generations is normally set as the terminating condition. Once the number of generations specified is reached, the GA determines the best solution in the current population in accordance with the set criteria. The best solution, the one with the lowest fitness value, has the best combination of possible durations for the activities. This combination has a valid project completion date and has the lowest project cost. A flowchart of the approach is shown in Figure 2.15. Note that the best solution determined by the GA is not necessarily the overall optimal solution, since there is at present no means to determine if and when the overall optimal solution is obtained. Also note that alternative solutions exist in the final population that may be more desirable when other considerations are factored in.

2.7.1.1 Evaluation process:

The evaluation process is based on the fitness score. The initial schedule fitness score is calculated based on the Expected Gross Profit.

2.7.1.2 Selection process:

The selection process is selecting the two chromosome strings (parents) in the initial schedule (projects' start date) as well as the breaking point (gene) for a certain project start date. In this process, two chromosome strings are chosen for exchange and two new strings; new construction schedules are generated (offsprings).

2.7.1.3 Re-combination process:

The recombination process involves the selection of the contribution of cross over and mutation in the optimization engine. As discussed above, the cross over main drawback is the possibility of getting trapped into a local optimum and

thus, mutation is used to prevent this trap and converge the solution into a sub-optimal one.

2.7.1.4 Replacement process:

The replacement process takes place after a second evaluation process for the generated offsprings, for the generated construction schedules. The generated offsprings are evaluated and compared with the parents (the initial schedule). If the fitness score of any of the offsprings is lower than any of the parents, then the replacement process will take place by replacing the offspring by the weak parent or the weak schedule (that is having a lower Expected Gross Profit). If not, the optimization engine will continue until meeting a pre-defined number of generations. The above processes flow chart is summarized in Figure 2.15.

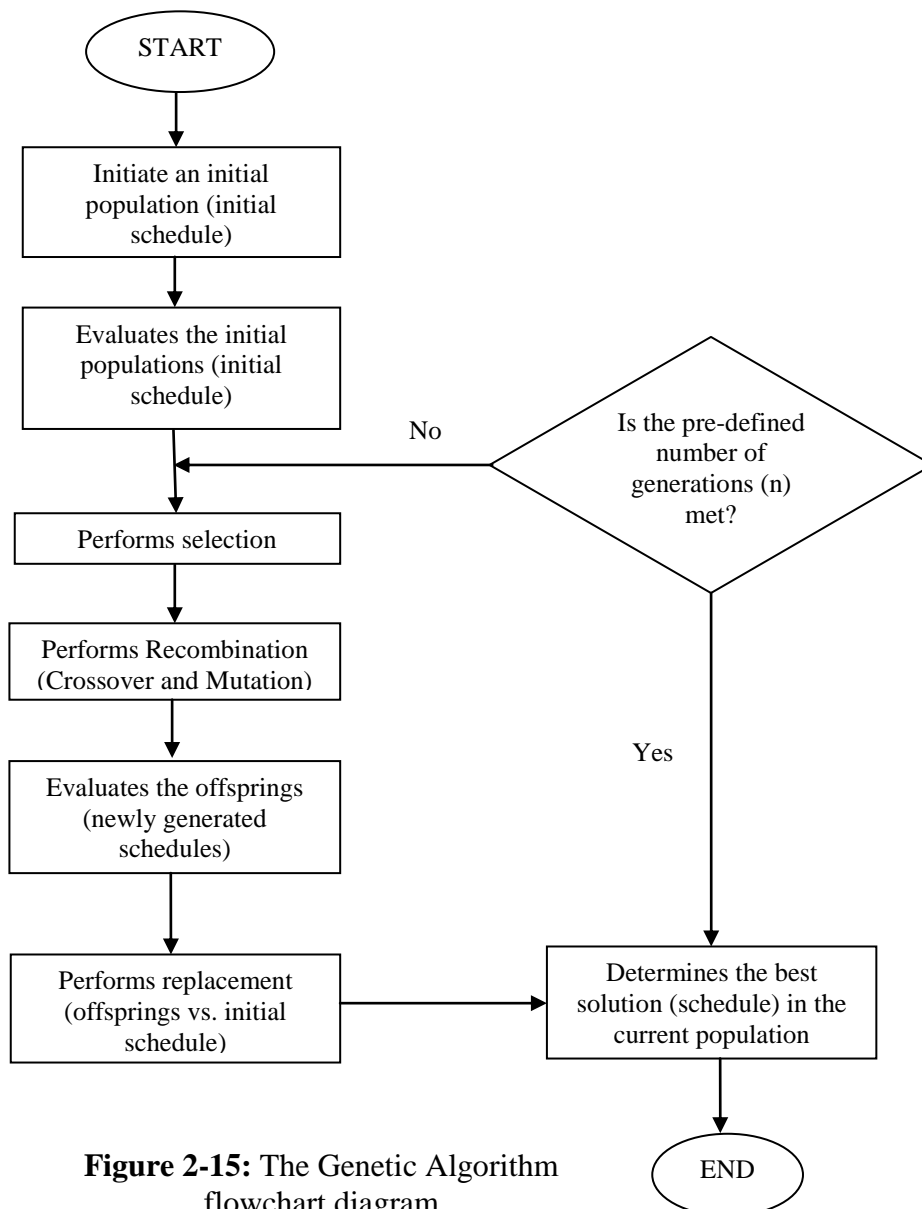


Figure 2-15: The Genetic Algorithm flowchart diagram

2.8 Concluding Remarks

In this chapter, previous literature, that covered different aspects relating to real estate development and infrastructure systems, was discussed. The risks impacting the different development stages of real estate and infrastructure development projects have been addressed by many researchers. Although the studies have covered different aspects from different prospective, the isolation between the real estate construction stage and the utilization or occupancy stage was one of the drawbacks as follows:

- 1- There are different DSS that support decision makers in estimating the expected profits of their real estate and infrastructure projects. However, these tools are only used during the Pre-development stage of real estate projects. At later implementation stages, too many project management and construction management tools were developed to support different stakeholders engaged during the construction process. These have included resources as well as time and cost management. However, there is lack of DSS that can be continuously used to quantify the impacts of changing projects' implementation schedules on their profits.
- 2- Several tools have also supported real estate buildings and infrastructure asset management and maintenance policies over its lifecycle after construction completion. However, there is lack of optimization DSS that combines the implantation schedules to the financial impacts when changing these schedules. The impact of delaying construction schedules on the economies of lengthy construction as well as on its serving infrastructure systems is not being dynamically forecasted, especially in cases of accumulating risk events during construction.
- 3- Through improving the efficiency of infrastructure systems, remarkable savings can be made for the operating expenditure. The efficiency of their operations can be further improved if their economies are linked to the impacts of risk events. The available city management tools do not provide dynamic link that reflect the impacts of changing projects' implementation schedules to the end

users' occupancy and their demand and consequently to the overall operating costs of serving Infrastructure system and its efficiency.

CHAPTER 3. THE PROPOSED FRAMEWORK

The main objective of this research is to develop a Decision Support System DSS to minimize, at any time, the impacts of future unforeseen risks on completed infrastructure systems. This is through minimizing the impact on the profits generated from both real estate as well as Infrastructure projects.

This chapter includes different models that form together an integrated Decision Support System to fulfill the research objectives. The models are dynamically linked together and are finally able to determine optimized starting and end implementation or construction dates of entire projects included in large scale real estate development. This determination respects a number of conditions, such as maximizing both real estate as well as infrastructure projects' profits. It also minimizes the operating expenditure of different infrastructure systems which in turn mitigates risk impacts on real estate long term investments.

3.1 Research Progress

In order to achieve the research objectives, the research passed through a number of concurrent activities, these are:

- 1- Literature review and expert interviews: This included investigating the available Decision Support Systems DSS that support decision makers at different development phases. The DSS are usually used at certain points in time to serve specific static objectives, such as during the early feasibility phase, during the development and construction phase or during the operation phase. The output is to define shortcomings and identify potential improvement and concrete research objectives and methodology.
- 2- Database development: the research problem belongs to interdisciplinary research that involves real estate scheduling, finance as well as a variety of infrastructure systems asset management topics such as urban landscape and irrigation water, water systems and district cooling systems. Therefore, the researcher developed a number of databases for these different disciplines. This included for example data relating to real estate marketing strategy,

capital and operating expenditures for real estate and their infrastructure projects.

- 3- DSS framework design and development: the researcher then commenced programming the DSS frameworks' models. The models are developed using the EXEL[®] software as the research media and EVOLVER[™] V.5.5 add-in for solving the Artificial Intelligence AI optimization problems.
- 4- Model Verification: upon developing the individual infrastructure models, the researcher applied the framework on an Egyptian case study of large scale real estate development. The case faced local civil unrest during its development stage in January 2011. This risk event is considered as an external force or risk that caused interruption to the development case which represents similar large scale projects having lengthy construction periods. The results of the models are verified through real cases given by experts belonging to the different disciplines of the research.
- 5- Validation process: Moreover, the research applied validation process through questionnaire technique. Through the questionnaire, experts' opinions are collected in regards to the framework's novelty, reliability, consistency and accuracy.

3.2 The System Architecture

As mentioned above, a DSS framework is developed in order to fulfill the research objectives; that is the **Risk Impact Mitigation framework (RIM)**. RIM includes a number of dynamic integrating models. The architecture of RIM framework is shown in Figure 3.1. The Figure illustrates the traditional input for preparing real estate master plan, portfolio mix and implementation schedule during the real estate development stage. The traditional input items are shown in the box on the left hand side of Figure 3.1. The traditional input includes the market ability and demand analysis, the site analysis and its zoning, utilities and edge effect, the environmental analysis that includes the sustainability and edge effect as well as the financial input (e.g. the cost capital components, the equity-debt plan and timeline). Although there are several input parameters for the decision maker, the decision is usually taken based on the expected financial projections.

RIM is designed in a way that the traditional input is kept unchanged as an input to RIM's DSS. However, RIM is designed to integrate the economies of real estate and infrastructure projects and link it dynamically to the services demand generated from certain implementation and occupancy schedules. This is shown in Figure 3.1 through the integration between the rescheduling model, Real Estate Scheduling Optimization Model, RESOM, and the infrastructure specialized models included in the box on the right hand side of the Figure. RESOM is used to optimize the implementation schedule of the entire unconstructed projects through changing their starting dates and durations as shown in the middle box of the same Figure 3.1.

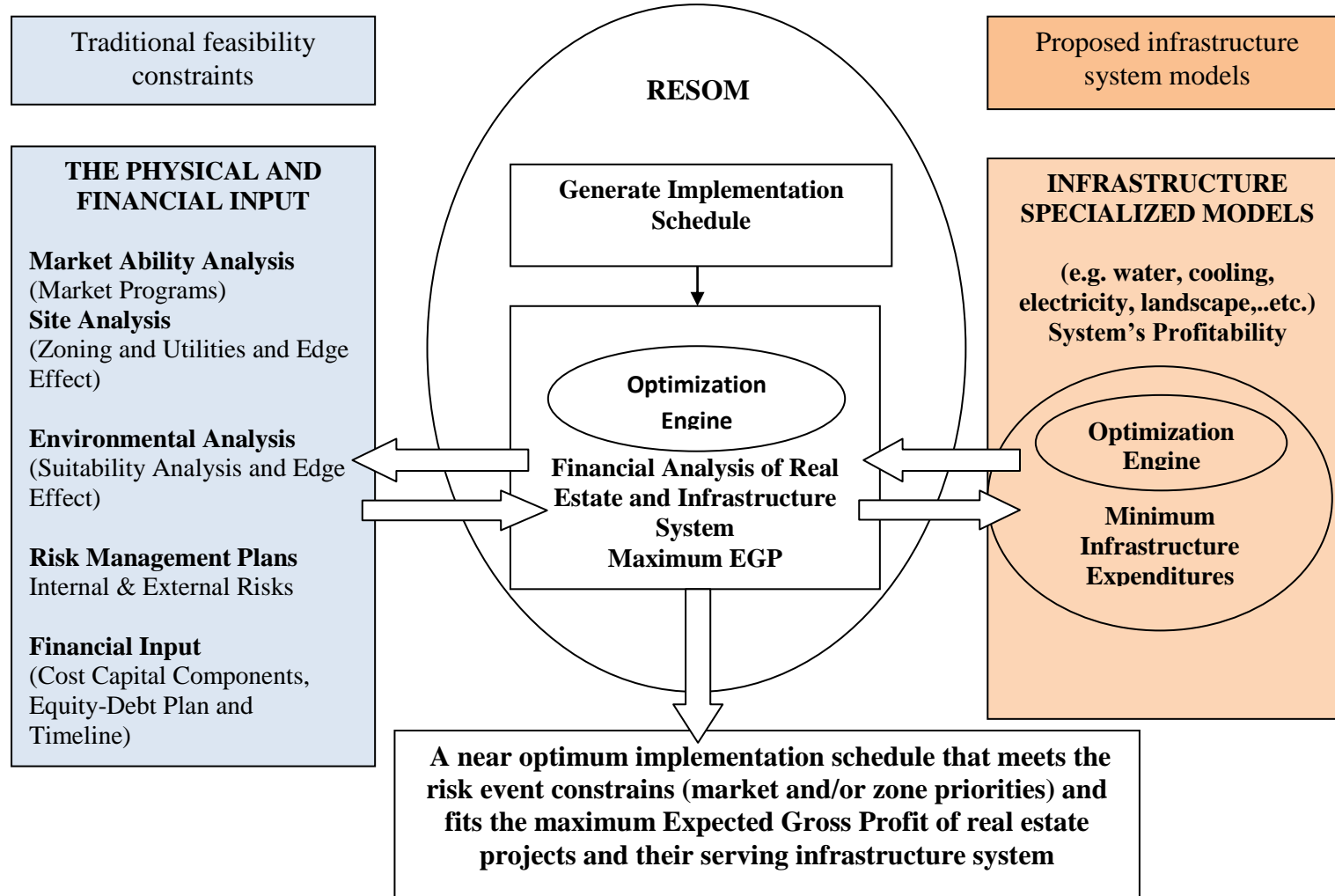


Figure 3-1: RIM's Proposed Approach – Real Estate Feasibility Study Process Flow

In order to include the economies of the Infrastructure subsystems, RIM includes Real Estate Scheduling Optimization Model (**RESOM**) in addition to a number of infrastructure specialized models. The developed specialized models are the District Cooling Optimization Model (**DCOM**), the Sustainable Landscape Optimization Model (**SLOM**) and the Water Simulation Optimization Model (**WSOM**).

RESOM uses the output of the other infrastructure models (DCOM and WSOM) in the form of demand profile of services (cooling and potable water). RESOM then provides further financial calculations with Cash Flow profiles and the Expected Gross Profit that corresponds to implementation scheduling cases. Through an optimization process, RESOM provides a near optimum implementation schedule that fits maximum Expected Gross Profit for infrastructure systems as well as real estate projects.

In addition, providing infrastructure system's demand profiles, the infrastructure specialized models; also improve the systems' operating cost while calculating the system's expenses. The interaction between RIM's entire models is shown in Figure 3.2. DCOM uses the cooling demand that follows construction schedule as an output from RESOM. The water model, WSOM, uses the potable water profile provided by RESOM in addition to the landscape irrigation water profile obtained from SLOM. RIM's framework flow chart is illustrated in Figure 3.3. The Figure demonstrates the relations between the different Infrastructure's specialized models included in RIM. These models are the District Cooling Optimization Model (DCOM), the Water Scheduling Optimization Model (WSOM) and the Sustainable Landscape Optimization Model (SLOM). The objective of DCOM and WSOM is to minimize the maintenance expenditure of district cooling and potable water systems with slightly different approaches. DCOM is based on optimizing the operating and maintenance schedules of central district cooling plants. These schedules change as a sequence of changing the construction schedules obtained from RESOM which in turn is updated following the occurrence of unforeseen risk events. Similarly, the asset management model, the stochastic WSOM provides optimized city management tool where repair,

rehabilitation policies are determined so that a minimum acceptable level of service is achieved with a minimum maintenance expenditure of water systems.

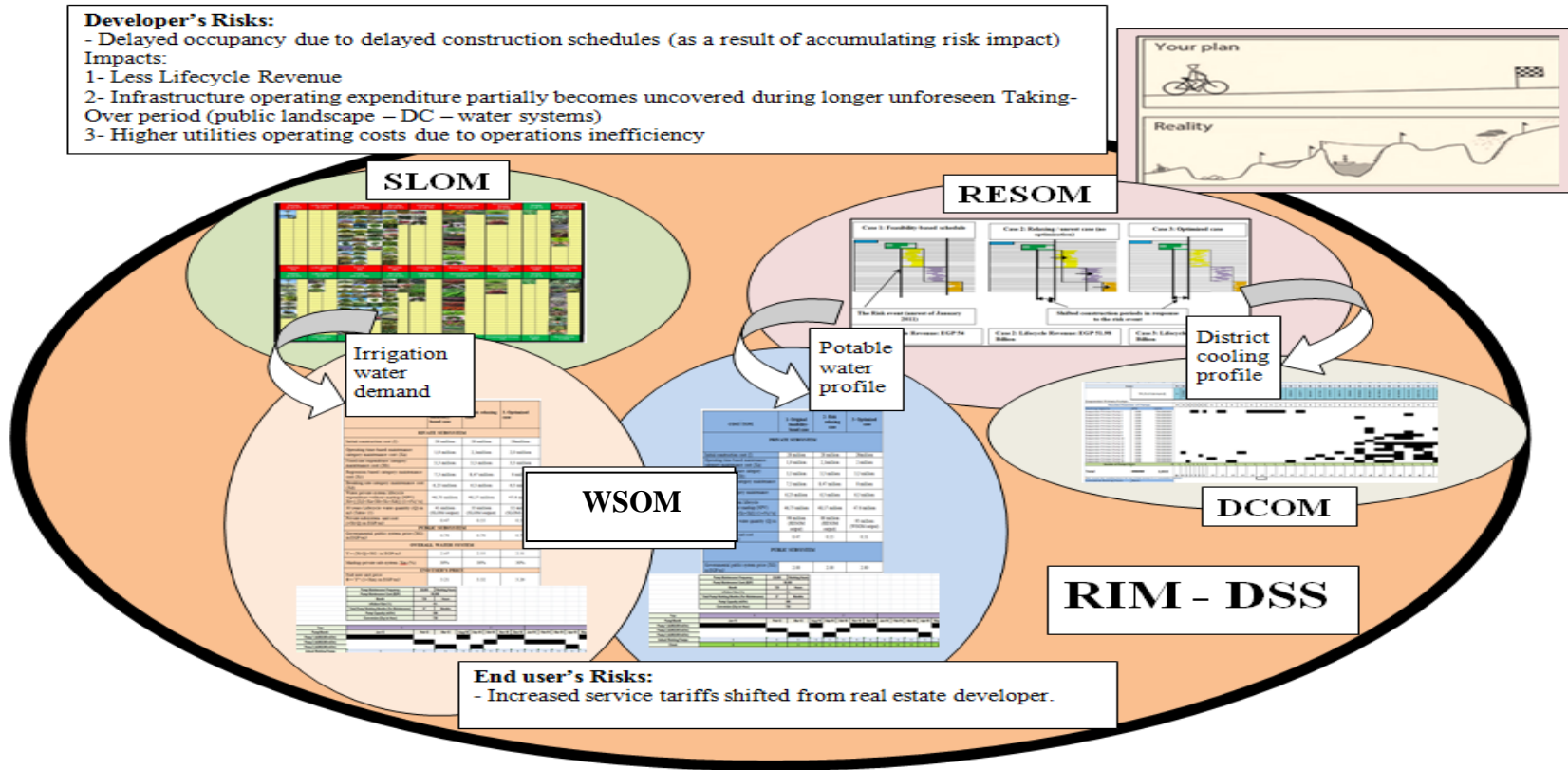


Figure 3-2: RIM – DSS components and stakeholders

An additional landscape plants selection model; Sustainable Landscape Optimization Model (SLOM) is developed to assist urban landscape architects in determining the best design mix that can be used to produce the final urban landscape design. The process flow chart of RESOM and its interaction with Infrastructure specialized SLOM, WSOM and DCOM models is illustrated in Figure 3.3.

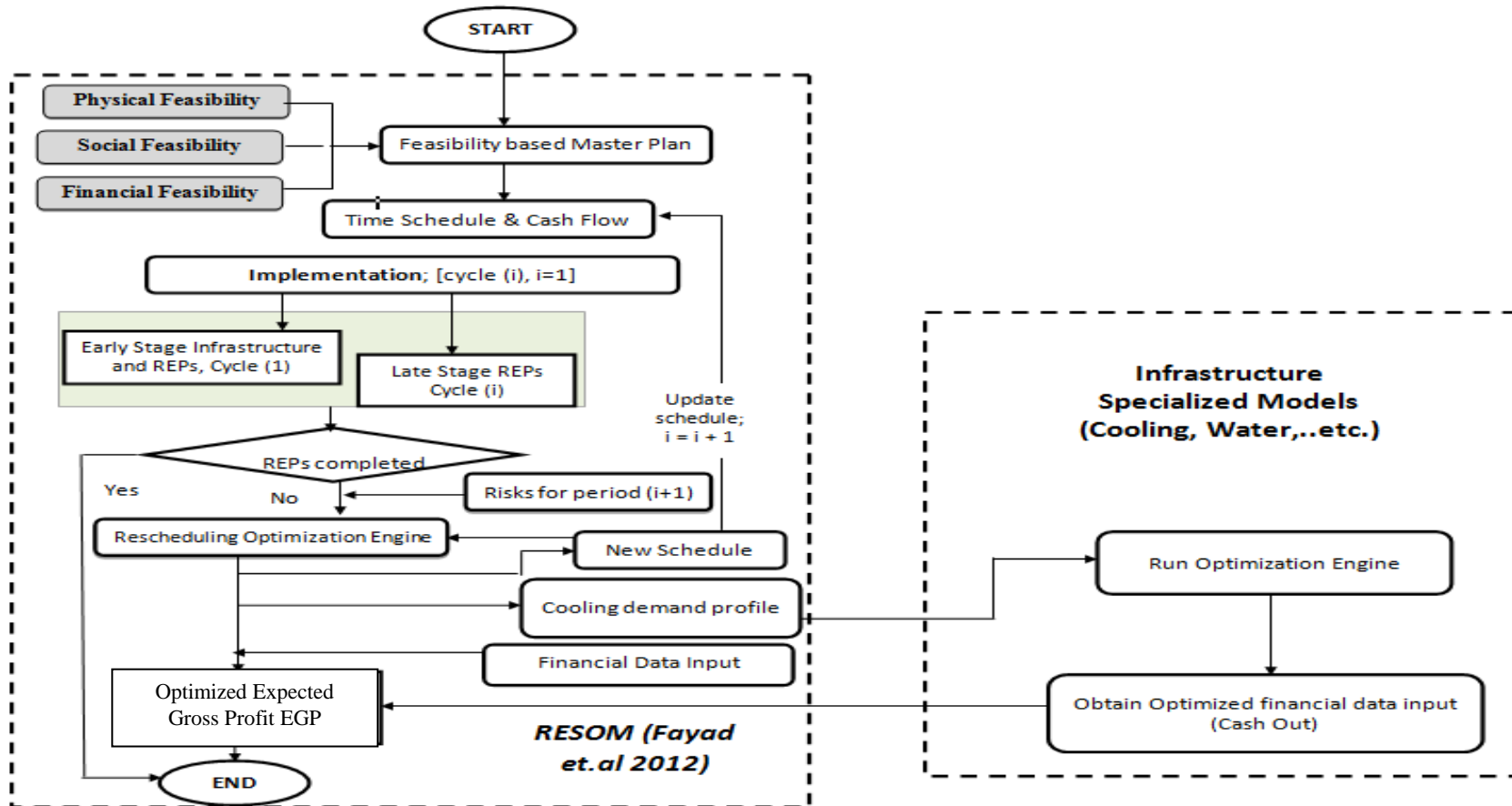


Figure 3-3: RESOM process flow chart and interaction with Infrastructure specialized mode

Through periodic running of RIM, the decision makers become able to keep their profits maximized through continuous rescheduling of the implementation of their remaining (unconstructed) projects. The decision makers become also able to increase their savings through optimizing the operating expenditure of the infrastructure systems over their lifecycle.

The application of RIM can therefore narrow the gap between Expected Gross Profit of infrastructure systems (e.g. in cases of risk events occurrence) compared with original feasibility Expected Gross Profit. The income Cash-In for infrastructure systems is represented by the (receipt) or generated income against the service provided to customers and its Cash-Out is represented by its (expenses) construction and operating cost over its feasibility horizon. These figures are obtained by considering proper financial feasibility analysis. The scheduling of real estate projects is either based on prioritizing certain locations above the others as shown in the development layout example shown in Figure 3.4. However, projects can also be scheduled by prioritizing certain portfolio types above others as shown in Figure 3.5. The schedules are usually based on a mix between both types depending on market demand input as well as regulatory pressures to develop certain zone prior to developing others.

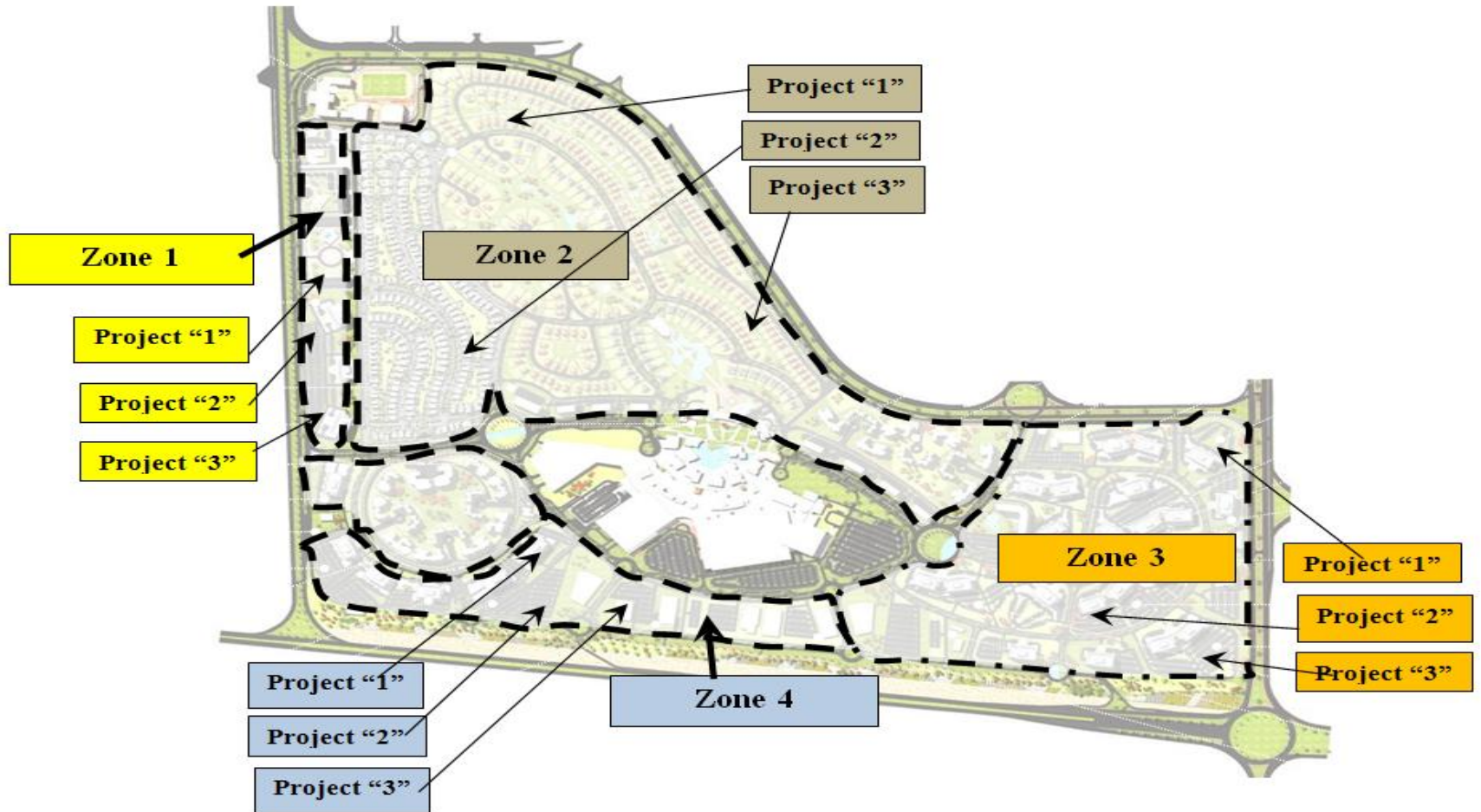


Figure 3-4 Real Estate Projects classifications in zones (sample project)

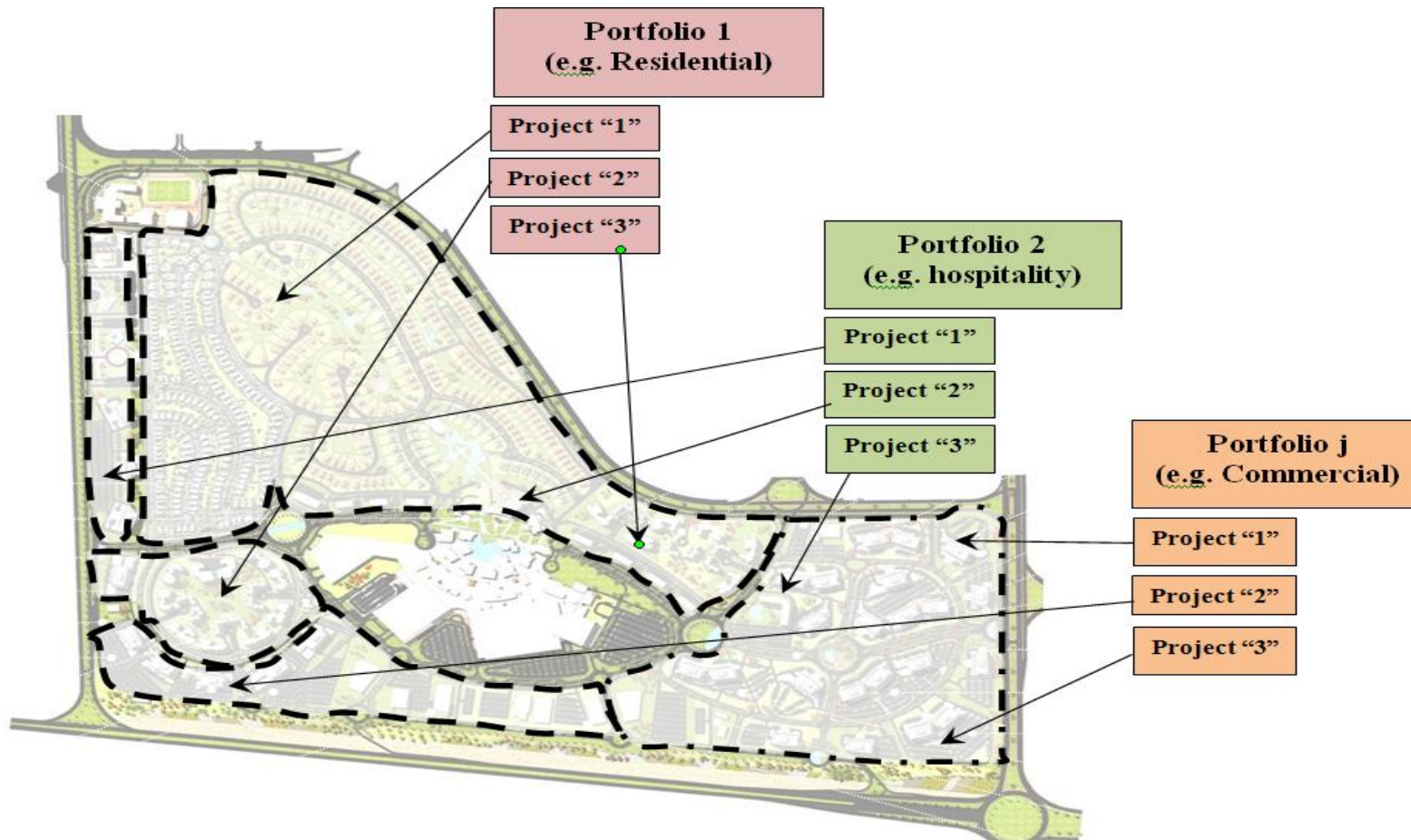


Figure 3-5: Real Estate Projects classifications in portfolios (sample project)

It is also possible that the implementation of projects follows certain sequence and logic that is determined during the feasibility stage as shown in Figure 3.6. However, risk events may require changing the pre-determined logic in order to match changes in the market demand. In other cases, regulatory authorities may put pressure on real estate developers to prioritize developing certain zones of their land above the others as mentioned earlier. These different options are shown in Figures 3.7 and 3.8. In both cases, the decision makers usually consider revisiting their original feasibility studies and update their expected profits based on updates made to their feasibility-based schedules. It is also important to quantify impacts on the pre-planned profits of infrastructure systems, which are usually constructed at early phase of the development stage.

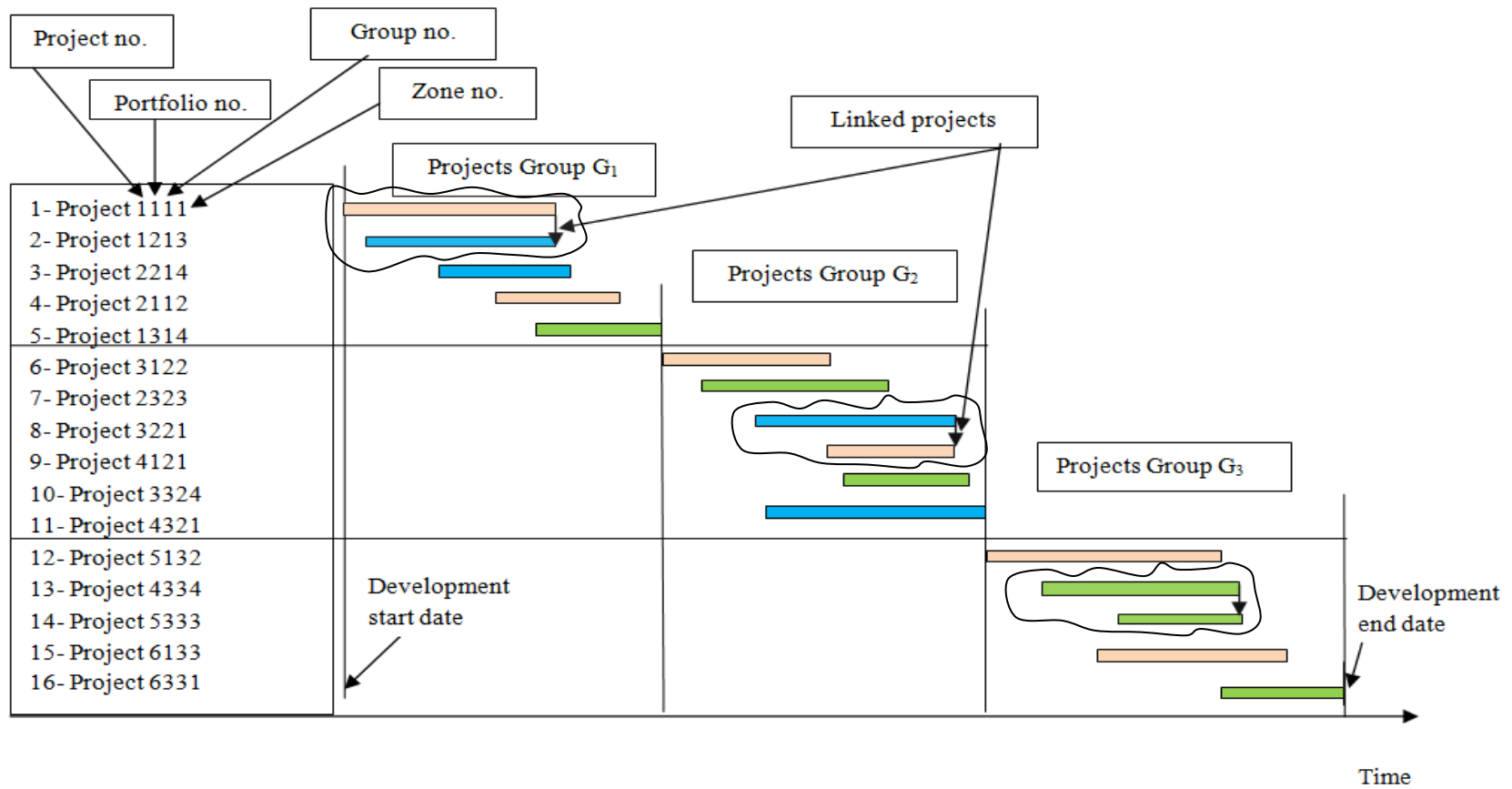


Figure 3-6: Implementation Schedule – mixed zones and portfolios – Example

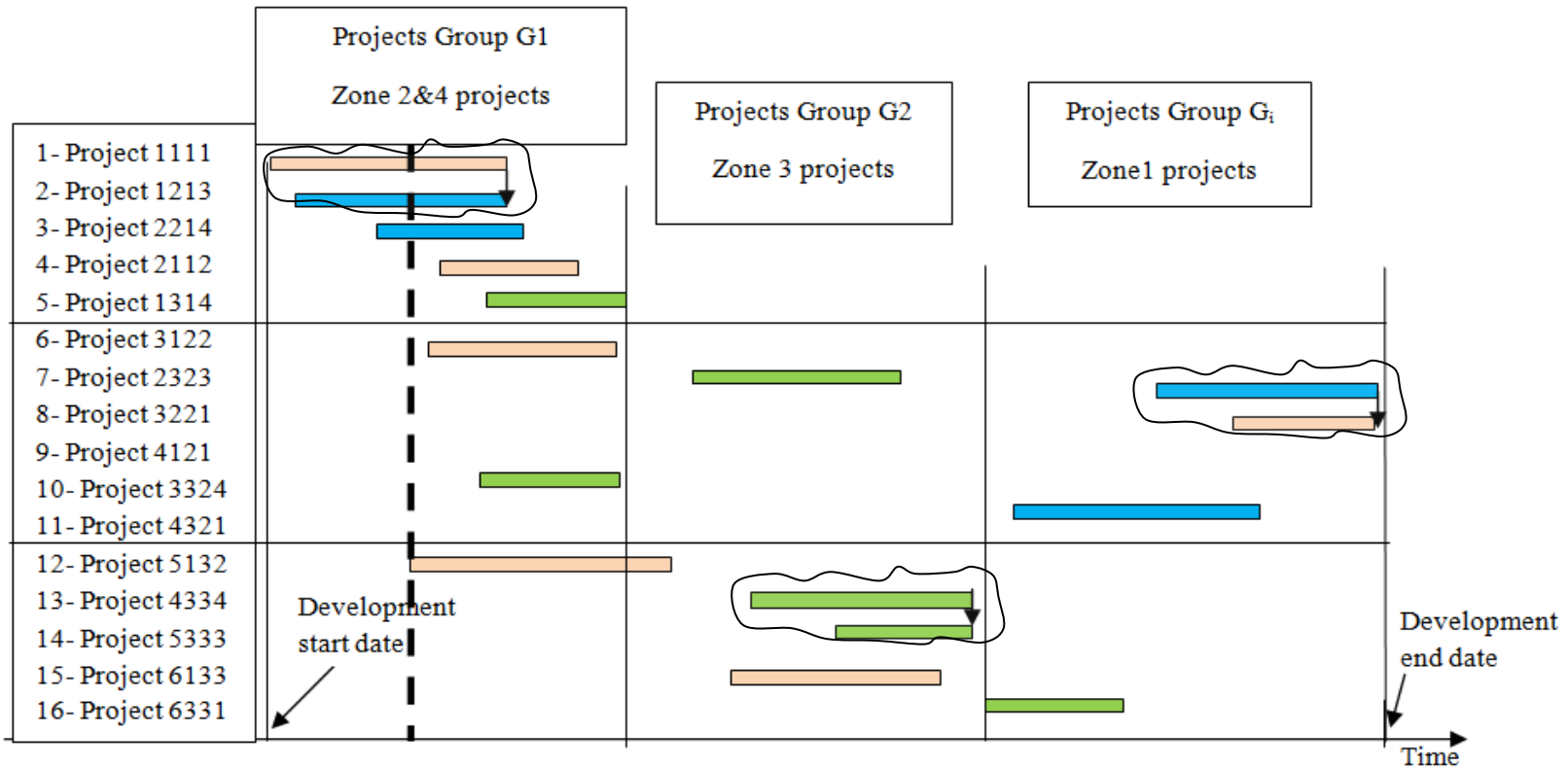


Figure 3-7: Risk Impacted Schedule – Zones-Based Rescheduling – Example

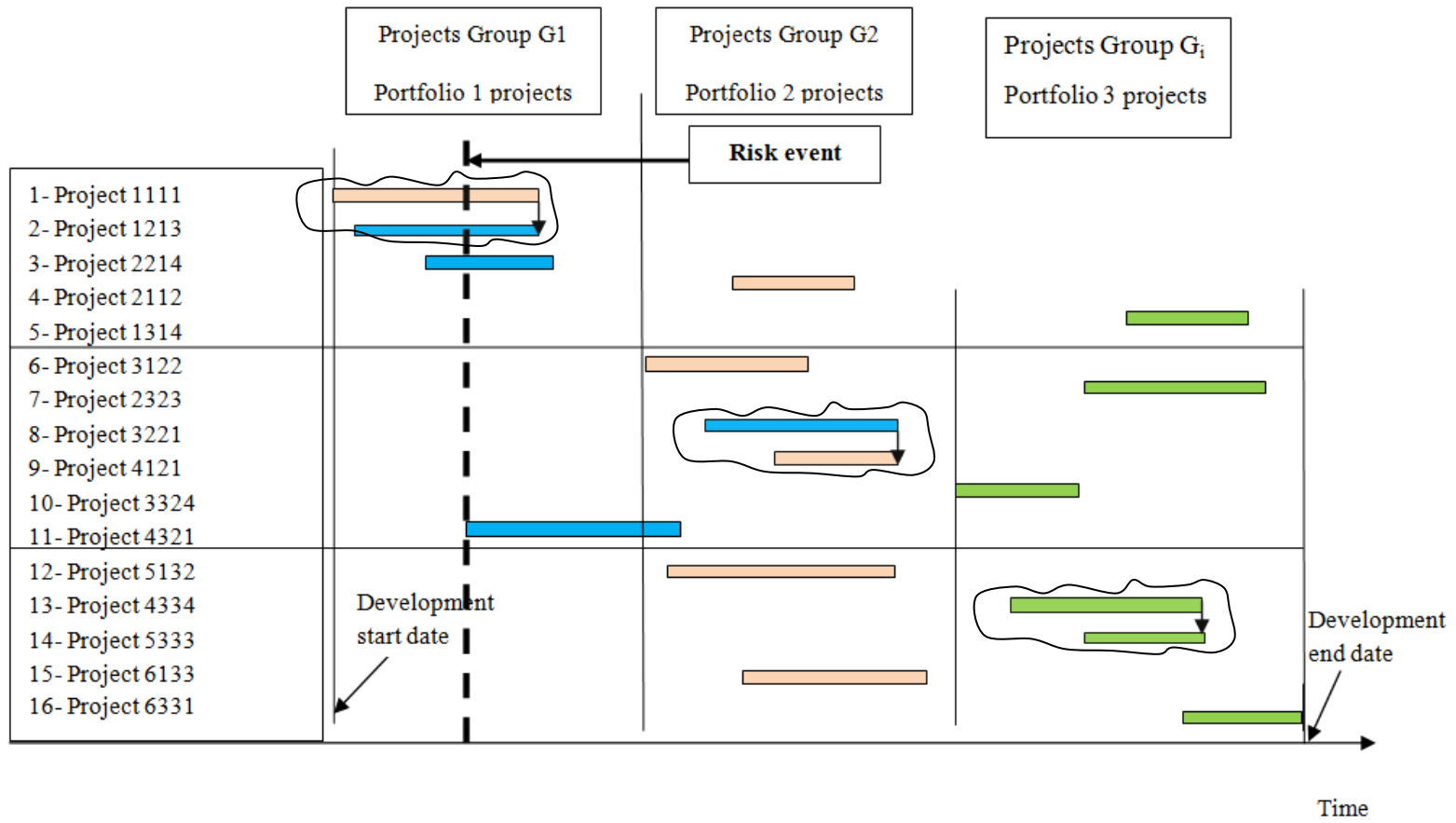


Figure 3-8: Risk Impacted Schedule – Portfolios-Based Rescheduling – Example

3.3 The Need for Optimization

Through the periodic application of the proposed approach, it provides alternating scheduling scenarios for executing the remaining projects. In order to understand how complex the model can be, imagine a 60 Real Estate Projects (REPs) are remaining at a certain period, where each has only three possible starting months (1, 2 or 3). The start for each project needs to be optimally determined. Possible scenarios are $(3)^{60}$ (i.e., 4.24E28), from which only few will represent balanced solutions. The real problem is even more challenging due to the fact that these projects are long term projects that can reach to 120 months (10 years). Such problems are combinatorial in nature where the increase in the number of projects will add to the complexity many folds. Accordingly exhaustive search cannot be used and there is a need for not only an optimization technique but for a non-traditional one. In this research, the Genetic Algorithm (GA) is used as solving technique for the optimization problems under consideration.

Since the objective of this research is to minimize the risk impacts of unforeseen risk events on the economies of real estate development projects that having lengthy construction periods. The equations are solved using the Artificial Intelligence AI approach using Genetic Algorithm GA approach to find the near optimum solutions of the Objective Functions in the mentioned models. However, future research may investigate the possibility of applying alternating solution approaches and relative advantages versus disadvantages among them.

For implementation purposes, advanced spreadsheet modeling was used. The model replaces the optimization mathematical formulation and links between the different variables. These are for example the starting month and durations of constructing the remaining projects at the risk event point in time in the RESOM model case. The objective in the RESOM case is set to maximize the lifecycle Cash Flow and Expected Gross Profits; constrained to be within a slight deviation from feasibility figures for the developed infrastructure.

3.4 Real Estate Scheduling Optimization Model (RESOM)

As shown in Figure 3.3, real estate feasibility-based master plans are usually created by considering three feasibility inputs: physical, social and financial (Etter and Schmedemann, 1995). The implementation plans, are usually divided into two main stages; these are the development and post-development stages. The development stage starts with preparing feasibility studies followed by design preparation and construction development. The implementation of infrastructure systems usually takes place at early phase of real estate projects having long construction periods. Upon projects completion, occupancy commences to start the second post-development stage of projects' lifecycle, which includes operation activities. Projects' master plans and their implementation schedules are developed at early phase of the development stage and are used to generate projects' Cash Flow and calculate their financial Cash Flows and profits while preparing the necessary feasibility studies.

The proposed RESOM provides a feasibility-based schedule as the base or bench-mark for assessing other implementation schedules generated by its optimization process. This is in order to demonstrate effects of changing schedules on the Cash Flow and generated profit. The optimization process output provides an implementation scheduling for remaining unconstructed Real Estate Projects (REPs) with an objective function of maximizing the infrastructure system's profit. Additional conditions can also be respected such as the time ranges within which the groups of REPs are to be implemented. This method is useful in tracking the profitability measures for both the real estate as well as their serving infrastructure system in response to unforeseen risk events during the implementation phase. The applicability of this method is also possible during early feasibility phases of developing real estate projects and their infrastructure system through forecasting certain risk events scenarios and use RIM framework to provide possible impacts on their expected profits.

RESOM can be used to provide optimized schedules with an objective function of maximizing projects' profits. RESOM may prioritize the implementation of certain real estate portfolios and/or zone locations above others. Large scale real estate development projects usually include mixed

portfolios (commercial office buildings and retail, residential apartments and villas, hospitality business and luxurious hotels,..etc.). Their plot area is usually clustered in a number of district zones inside the development master plan. The market demand and regulatory requirements (e.g. the percentage of projects to be implemented in phases) are considered as input information to RESOM. This information may include possible selling or renting a given percentage of the different portfolio projects over future consecutive phased plans. The implementation priorities may be given in the form of specific zone or location areas inside a real estate development as indicated in Figure 3.7. It may also be based on portfolio selection as indicated in Figure 3.8 above. RESOM provides a schedule for implementing the projects in a way that specific requirements as such are met from one side and that the Expected Gross Profit EGP, of the development real estate projects and their infrastructure system, is maximized.

3.4.1 RESOM Modules

RESOM consists of four main modules, as follows: (1) Database Module, (2) Schedule Generating Module, (3) Financial Module, and (4) Optimization Engine as shown in Figure 3.9 (Fayad et al, 2012). As shown in the Figure, the scheduling module uses the data input that is available in the database module that contains data of real estate projects that needs to be scheduled (area, function, ..etc.). The database imports the services consumption rate from infrastructure specialized models (e.g. water, cooling,..etc.) and use them to calculate the services demand profile based on construction completion and occupancy. RESOM also calculates infrastructure Cash-In. RESOM imports then the Cash-Out profile, calculated in the specialized infrastructure models, to provide the Cash Flow and NPV of the system's Expected Gross Profit. Finally, the optimization engine is responsible for achieving and respecting the problem objectives and constraints using a GA solver (EVOLVER).

3.4.1.1 Data Input to RESOM:

The Database Module includes the basic information of real estate projects (individual projects). The database covers three categories of information:

- (1) Basic information about the land area as well as data for the entire projects;
- (2) Projects' construction cost, and
- (3) Infrastructure services consumption rates.

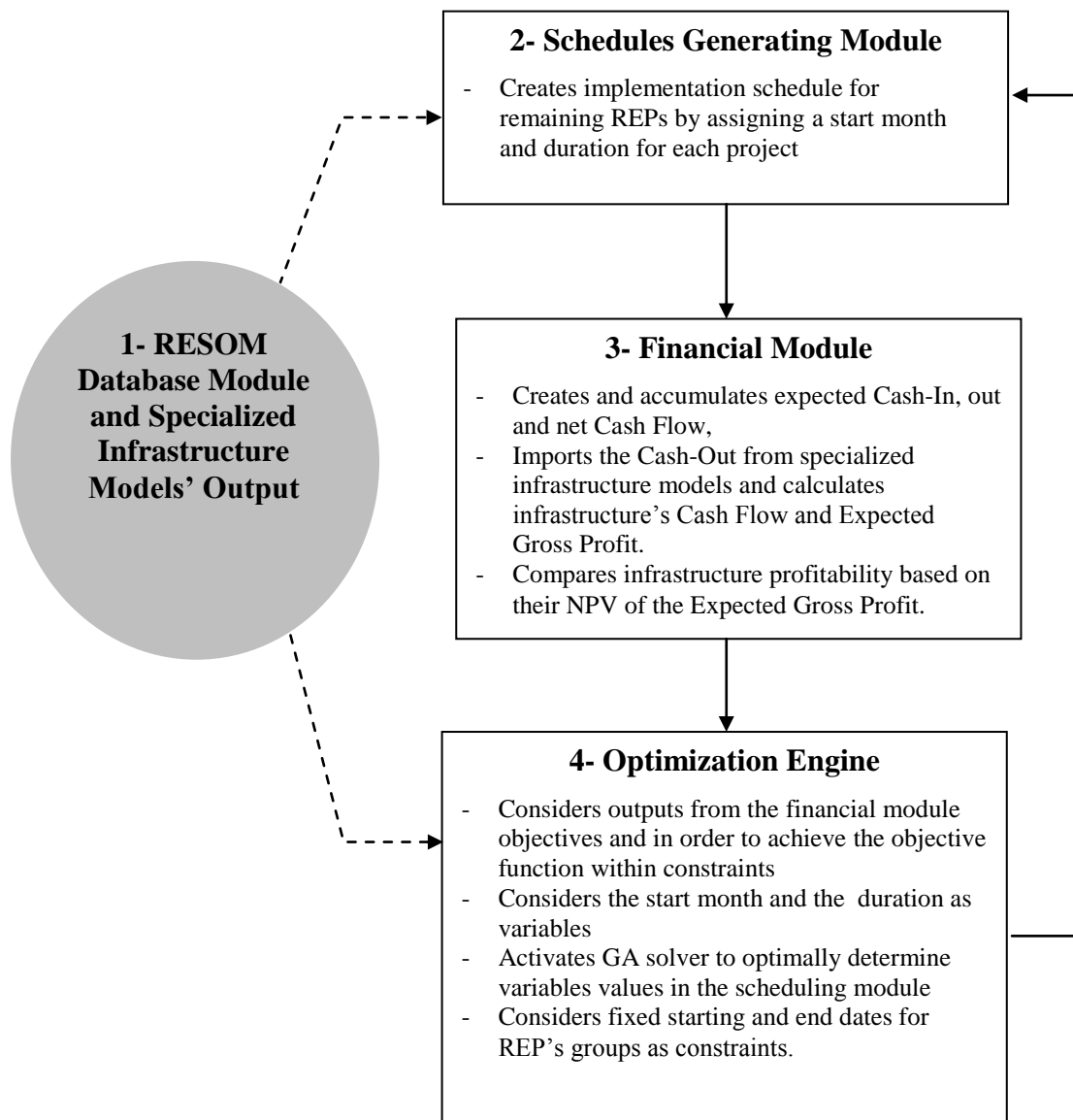


Figure 3-9: RESOM Framework Main Modules

RESOM input contains mainly the land area, Gross Built-up Area (GBA), location code on the master plan, and land use (residential, office buildings, retail, mixed use, hotel, public services,...etc.), the land cost, unit area selling price, the

interdependence relations between the different projects (e.g. retail projects serving certain commercial projects or hospitality, or health care centre that serves residential projects,..etc.) . These basic information is simply modeled using Excel as an extendable table as shown in Figure 3.14.

The second category (the monetary data) includes information regarding the land cost of infrastructure utilities and other financial information input (inflation rate, WACC percentage, Equity/Loan percentage,... etc.). The information helps calculating the infrastructure system's Cash-In, Cash Flow and Expected Gross Profits for certain construction schedule, and its occupancy profile, generated by the Scheduling Generating module. The monetary input parameters are shown in Figures 3.10, 3.11, 3.12 and 3.13. In addition, RESOM uses the output from the specialized infrastructure models (Cash-Out results obtained from SLOM, WSOM and DCOM) as explained in the following sections below.

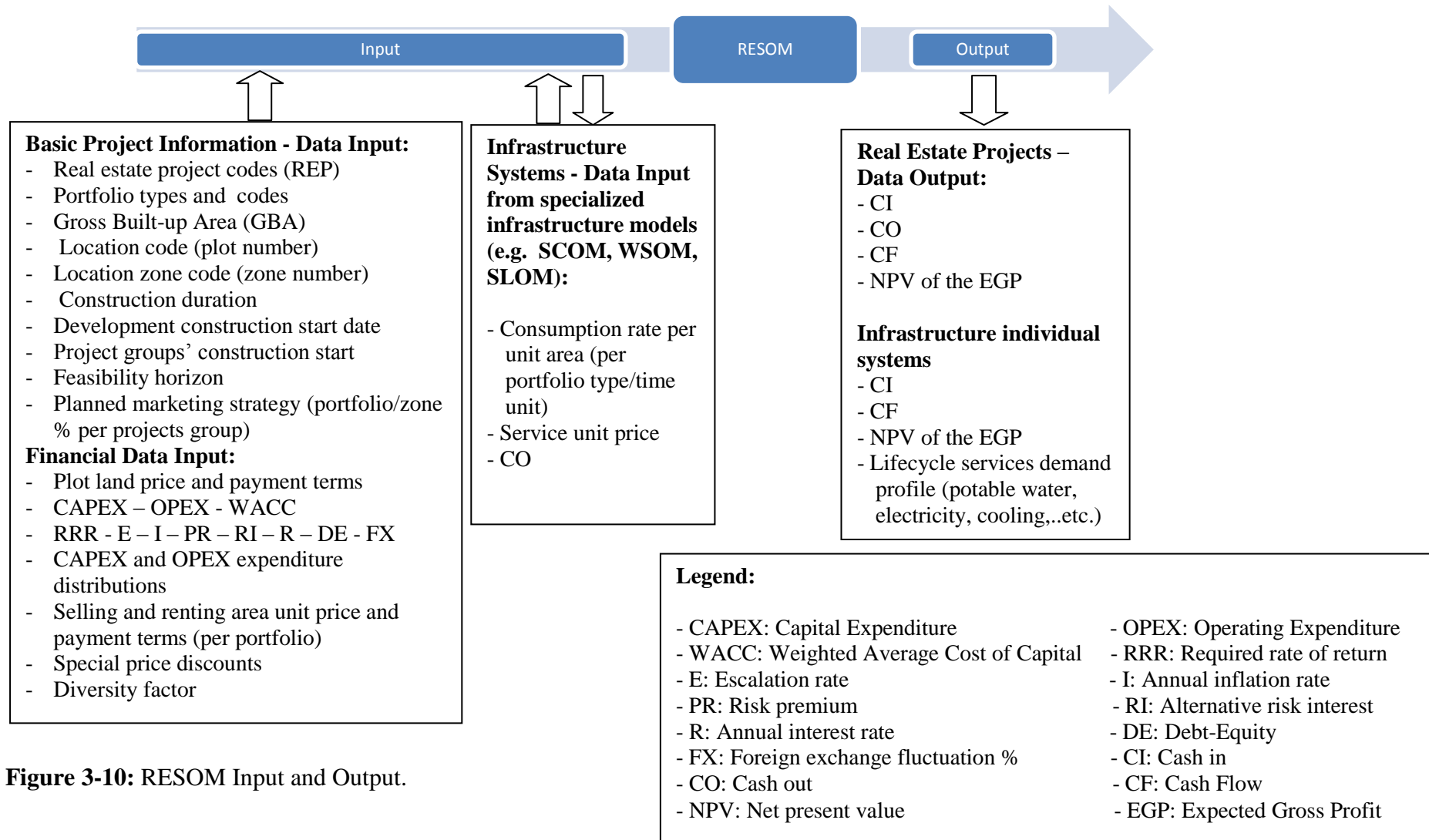


Figure 3-10: RESOM Input and Output.

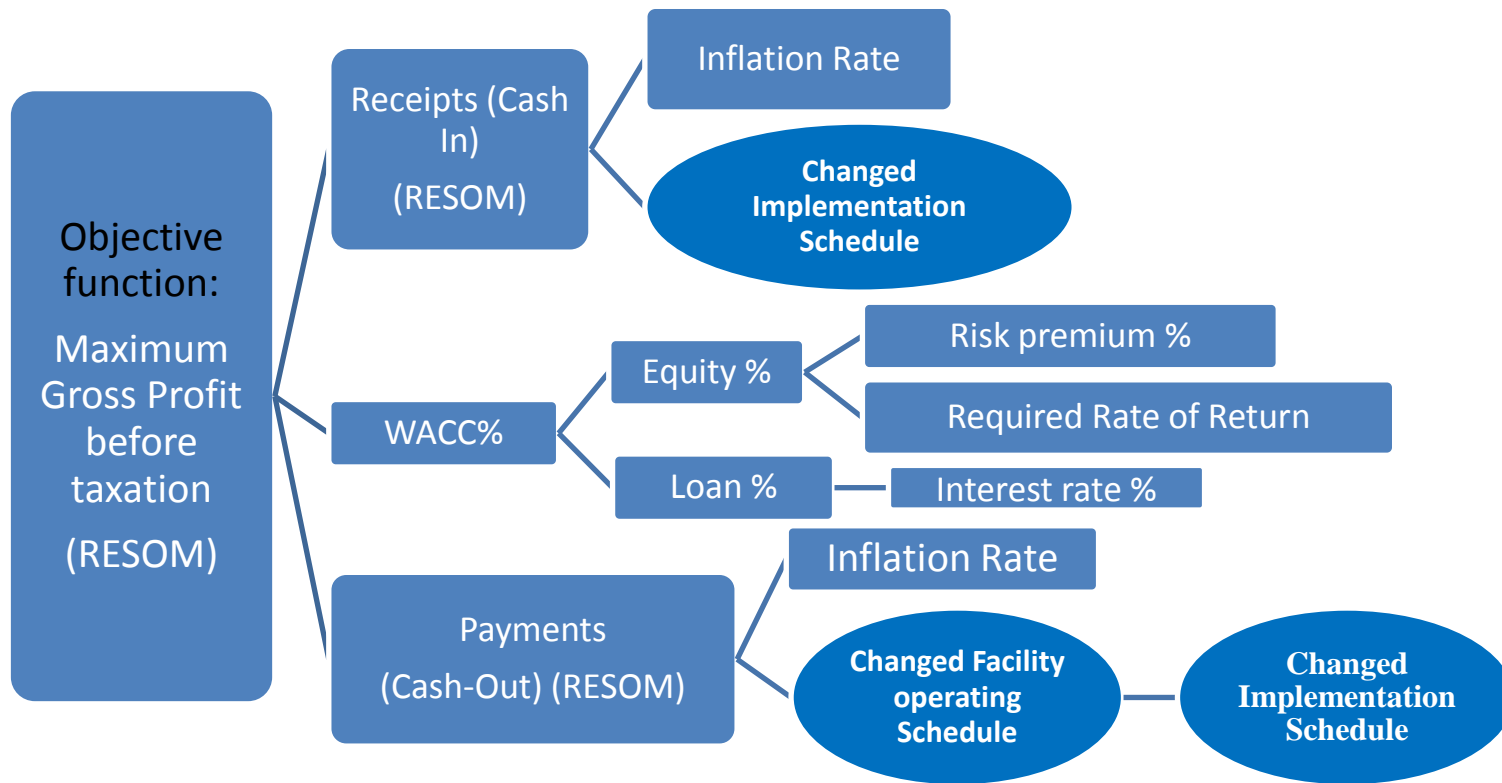


Figure 3-11: RESOM - WACC Input

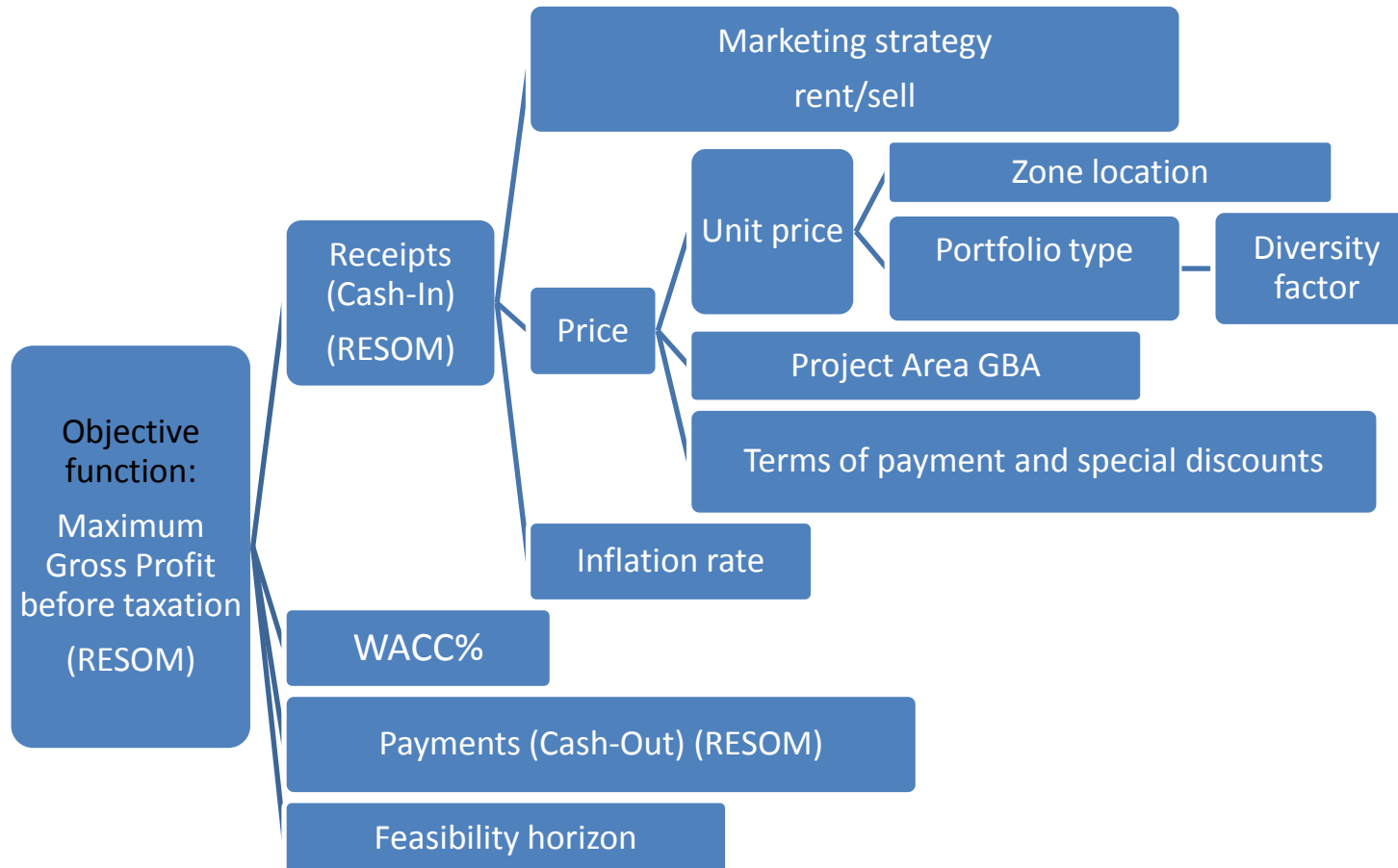


Figure 3-12: RESOM - Cash-In Parameters Input

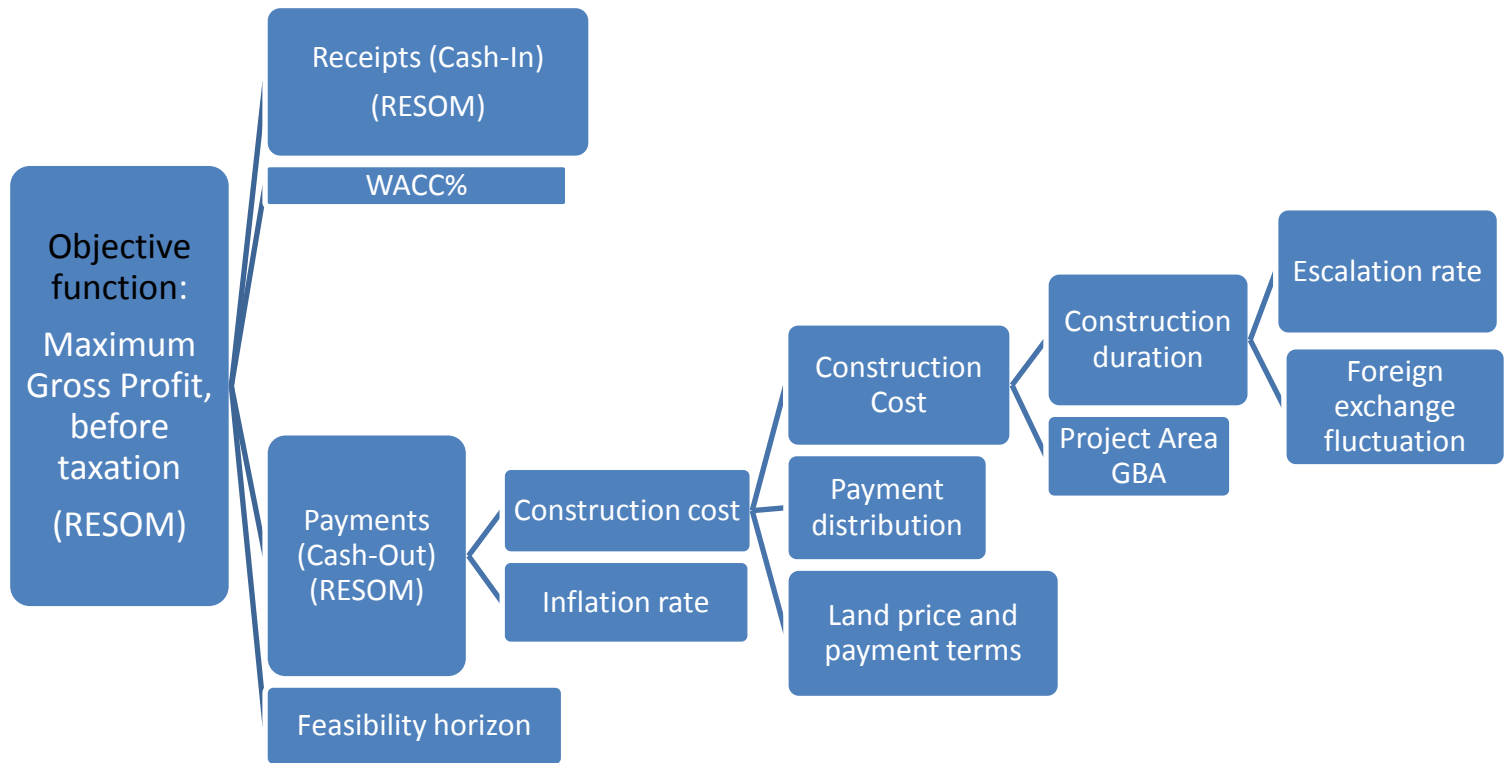


Figure 3-13: RESOM - Cash-Out Parameters Input

Project code

Gross Built-Up Area

Project Group code

Starting month, that counts from the development start date (generated by the Scheduling Module)

Group start and end dates (hard constraints)

#	Plot No.	Land use	GBU	REP Duration (D)	New Group Coding	Group max Duration (m)	X	Min. D REP	Max. D REP	Group	Group start construction	Group end construction	Group Duration	Group Beginning	Group End
REP 1	O3-0	Life Style	5,000	36	0	36	0	36	36	0	1/1/2005	31/12/2007	36	1/1/2005	31/12/2007
REP 2	09a	Education	22,662	36	0	36	0	36	36	0					
REP 3	10a01	Show rooms	23,017	36	0	36	0	36	36	0					
REP 4	10a02	Show rooms	23,017	36	0	36	0	36	36	0					
REP 5	O3	Life Style	62,283	36	1	48	48	36	36	1	1/1/2009	31/12/2012	48	1/1/2009	31/12/2013
REP 6	O7	Retail	222,130	48	1	48	48	48	48	1					
REP 7	14b01	Offices	23,998	24	1	48	60	24	24	1					
REP 8	10a05	Retail	11,213	36	1	48	48	36	36	1					
REP 9	14d06	Offices	20,528	24	1	48	60	24	24	1					
REP 10	12b04	Offices	15,883	24	1	48	48	24	24	1					
REP 11	14e01	Offices	20,897	24	1	48	48	24	24	1					
REP 12	Infra	Infrastructure	0	48	1	48	48	48	48	1					
REP 13	O3-1	Life Style	62,283	36	2	36	72	36	36	2	1/1/2011	31/12/2013	36	1/1/2013	31/12/2015
REP 14	11b01	Offices	18,014	24	2	36	82	24	36	2					
REP 15	11b02	Offices	18,014	24	2	36	80	24	36	2					
REP 16	14d01	Offices	6,009	24	2	36	85	18	36	2					
REP 17	14d02	Offices	6,009	24	2	36	84	18	36	2					
REP 18	14b05	Offices	23,016	24	2	36	79	24	36	2					
REP 19	10a07	Retail	3,558	24	2	36	80	24	36	2					
REP 20	14d03	Offices	9,013	18	2	36	76	18	36	2					
REP 21	14d04	Offices	17,427	24	2	36	73	24	36	2					
REP 22	04b07	Offices	5,246	18	2	36	80	18	36	2					
REP 23	04b08	Offices	4,370	18	2	36	80	18	36	2					
REP 24	13b01	Hotel	5,128	24	2	36	75	24	36	2					
REP 25	04b06	recreation	473	18	2	36	88	18	36	2					
REP 26	O3-2	Life Style	62,283	36	2	36	72	36	36	2					
REP 27	O3	Life Style	62,283	36	2	36	72	36	36	2					

DATA INPUT

Figure 3-14: Database Module (Basic Information)

The third category is the infrastructure basic information is as follows:

3.4.1.1.1 Cooling Demand:

First, a technical district cooling simulation model was used by experts to define the demand depending on several factors, including the land use of each building (residential, retail, offices etc.), its orientation, external wall thickness and insulation, glass types and thickness as well as the daily temperature profile and the season. The monthly cooling demand is then extracted from the simulation infrastructure specialized models and tabulated as part of RESOM Database Input as shown in Figure 3.15.

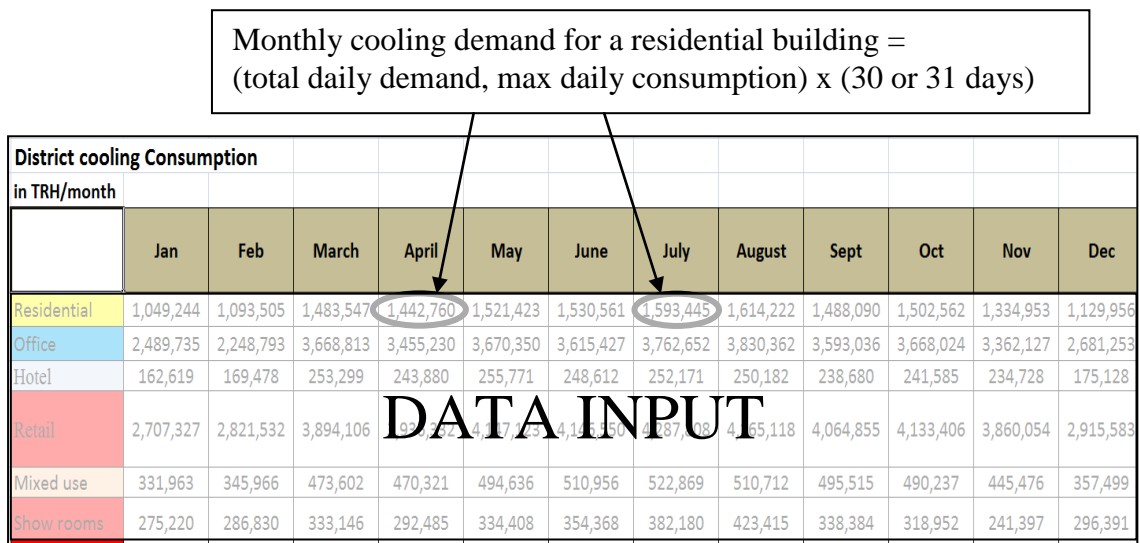


Figure 3-15: Database Module (example of district cooling demand data)

3.4.1.1.2 Potable water demand:

The potable water consumption rates are country-related and depends on building type (residential, retail, office buildings etc.), as shown in Figure 3.16.

	consumption (m3/m2 GBA/day)
Villas	0.00065
Residential	0.018
Office	0.0035
Hotel	0.0149
Retail	0.0042
Mixed use	0.0106
Show rooms	0.0019
Education	0.0025
civic	0.0208
patrol station	50

DATA INPUT

Different water consumption dependent on project type

Figure 3-16: Database Module (example of potable water demand data)

3.4.1.1.3 Sewer demand:

The demand is calculated as percentage of the potable water demand.

3.4.1.1.4 Electrical power demand:

The basis for calculating the electrical power demand is in accordance with the country related standards. The data is tabulated as shown in Figure 3.17. Since the electrical power supply system is not considered in this research as part of RIM, the electrical consumption data is only used for generic modeling purposes. Therefore, it requires further verification before usage in future research studies.

Electrical Power	
	consumption (KWHR/day)
Villas	1.0
Residential	2.0
Office	3.0
Hotel	4.0
Retail	5.0
Mixed use	6.0
Show rooms	7.0

DATA INPUT

Figure 3-17: Database Module (example of electrical power supply data)

3.4.1.2 Scheduling Module:

The Scheduling module is a generic schedule model which is responsible for producing a set of schedules for projects' implementations, rentals and selling in addition to infrastructure utilization by each project. It is based on logic sequence network which is the basis to schedule the traditional construction projects. The values of the projects' start date variable, X_i , represents the process variables as stated above and shown in Figure 3.18. The changes in the scheduling logic or the sequence of implementing Real Estate Projects REPs will change the Cash Flow as well as the NPV of Expected Gross Profit accordingly. The NPV of the Expected Gross Profit is thus linked to both values of the X_i and D_i .

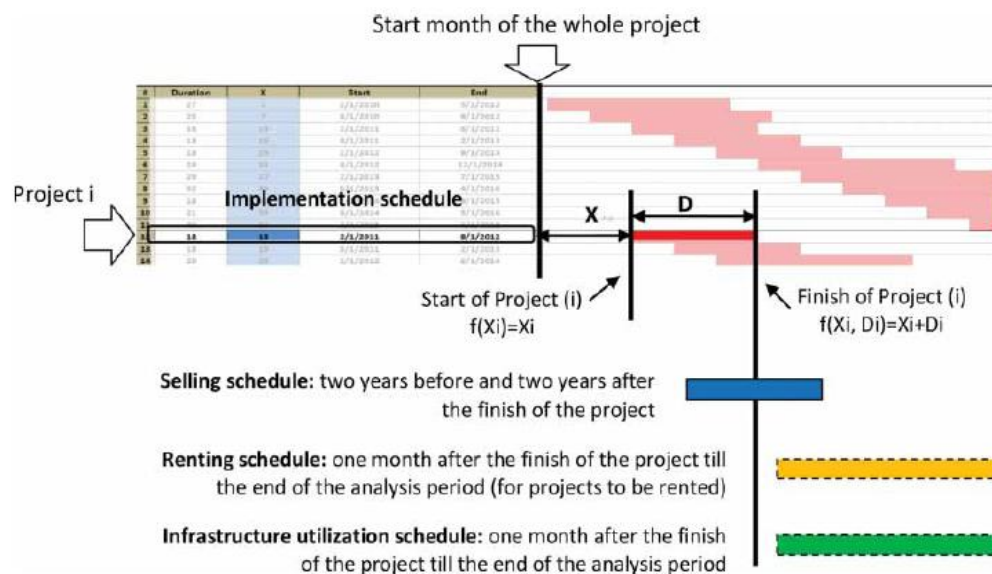


Figure 3-18: RESOM Variables (projects' starting dates X and durations D)

The scheduling module uses an intelligent binary representation in its spreadsheet modeling, to determine the bars using zero and one where one is used corresponding to scheduling times (e.g., under the grey bars as shown in Table 3.1) and zero otherwise. The Excel conditional feature, zero cells will appear transparent while the one's cells backgrounds will appear in a color (grey for example) to show the intelligent bar, or the project duration schedule. For example if a project (i) is having $X_i=5$ (starting in month 5) and $D_i=3$ (construction duration of 3 months). Table 3.5 shows the presentation of these durations.

Table 3-1: Project construction starting date and duration.

Month no.	1	2	3	4	5	6	7	9	10	11	12	13 development end date
Project i	0	0	0	0	1	1	1	0	0	0	0	0	0

This feature enables accumulating further display of expenditure, income, infrastructure utilization,.... etc. on monthly bases.

3.4.1.3 Financial Module:

If a large scale real estate development (e.g. city) contains a number of individual projects of different types (k), (e.g., commercial, retail, hospitality,...etc.). Accordingly, the projects can be denoted as (p_{rk}) where (r) represents the building number of certain type (k). At the end of the process, the financial module provides the Cash-In, net Cash Flow and NPV of the Expected Gross Profit of infrastructure utilization. These functions are functions of real estate projects construction start and end dates (X_i and D_i respectively). Any change in the starting month of each project X_i will lead to a change in the mentioned generated Cash Flow and Expected Gross Profit for the infrastructure systems. In this research, the objective function of the optimization problem is to maximize the Net Present Value (NPV) of the Expected Gross Profit (EGP). This can be obtained by changing the set of X_i and D_i for each project. Beside the NPV of the Expected Gross Profit, the model may provide other financial measures such as the Internal Rate of Return or the Pay Back Period, which can also be used as an Objective Function for financial comparison and assessment purposes. The effect of Loan/Equity percentage, inflation rate and opportunity cost are considered in the risk impact calculation process. The Cash-In of infrastructure systems calculation process depends mainly on the occupancy dates of the real estate projects upon their construction completion. The Cash-Out is calculated using the specialized infrastructure models (DCOM, SLOM and WSOM) that are dynamically linked to the financial module of RESOM. The Cash-Out includes the infrastructure construction cost as well as its operating cost that are calculated

over its feasibility horizon using proper escalation, inflation and opportunity cost percentages and equations.

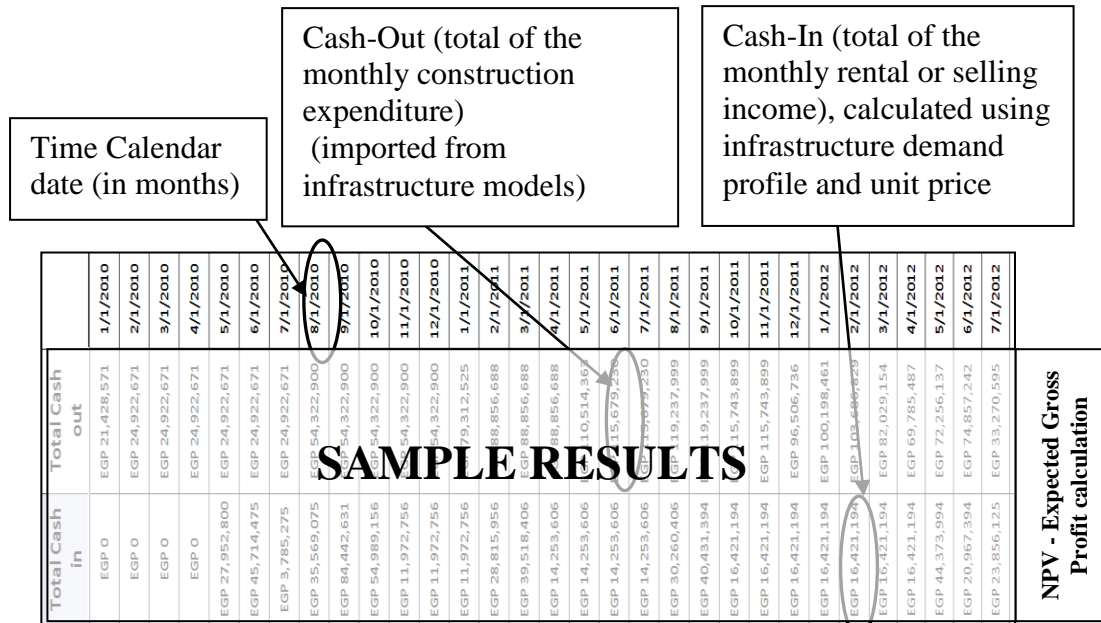


Figure 3-19: Financial Module Feasibility Horizon →

The Cash-In calculation depends on the renting and selling schedules. Once a project is scheduled for construction, its renting or selling schedule can be determined and used to determine the expected Cash-In according to the pre-specified marketing strategy as shown in Figure 3.19. Finally, the Expected Gross Profit is calculated for both infrastructure as well as real estate projects as shown in Figure 3.20 and 3.21.

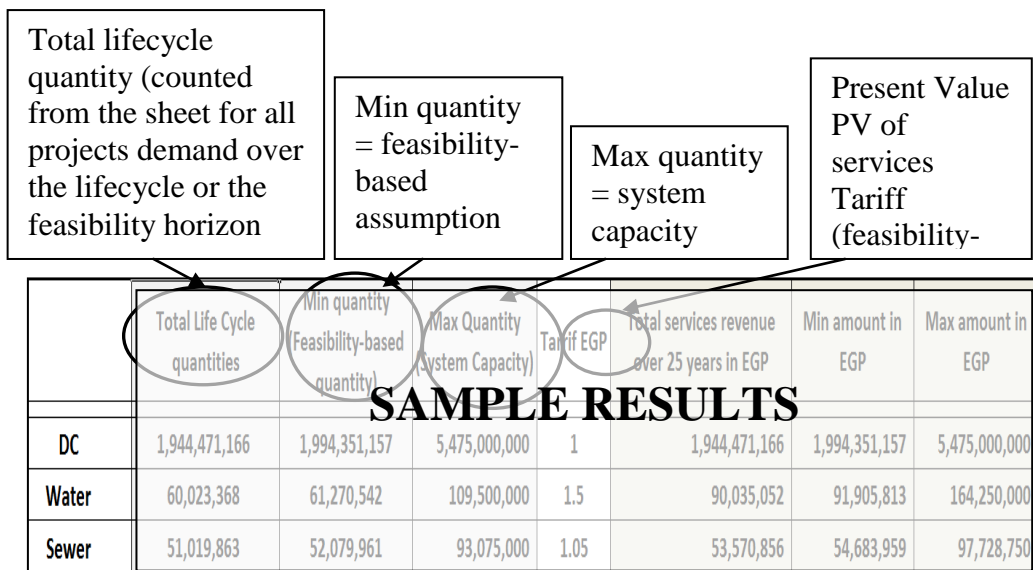


Figure 3-20: Expected Gross Profit calculations by RESOM

Financial Module				
NPV	Cash Flow	Total Cash in	Total Cash out	
	-EGP 3,345,100	EGP 0	EGP 3,345,100	1/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	2/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	3/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	4/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	5/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	6/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	7/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	8/1/2005
	-EGP 3,345,100	EGP 0	EGP 3,345,100	9/1/2005
	-EGP 7,805,233	EGP 0	EGP 7,805,233	10/1/2005
	-EGP 7,805,233	EGP 0	EGP 7,805,233	11/1/2005
	-EGP 7,805,233	EGP 0	EGP 7,805,233	12/1/2005
	-EGP 4,805,233	EGP 4,805,000	EGP 7,805,233	1/1/2006
	-EGP 2,898,983	EGP 2,898,500	EGP 7,805,233	2/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	3/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	4/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	5/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	6/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	7/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	8/1/2006
	-EGP 7,398,983	EGP 406,250	EGP 7,805,233	9/1/2006
NPV	EGP 11,206,279 ← NPV of the EGP			

Figure 3-21: Cash Flow and NPV of the Expected Gross Profit in the original case (RESOM Output).

The infrastructure demand and monthly demands are calculated using the infrastructure utilization schedule. It is assumed that the consumption starts a short period (s) after the delivery of the unit to the end user (Figures 3.22 and 3.23).

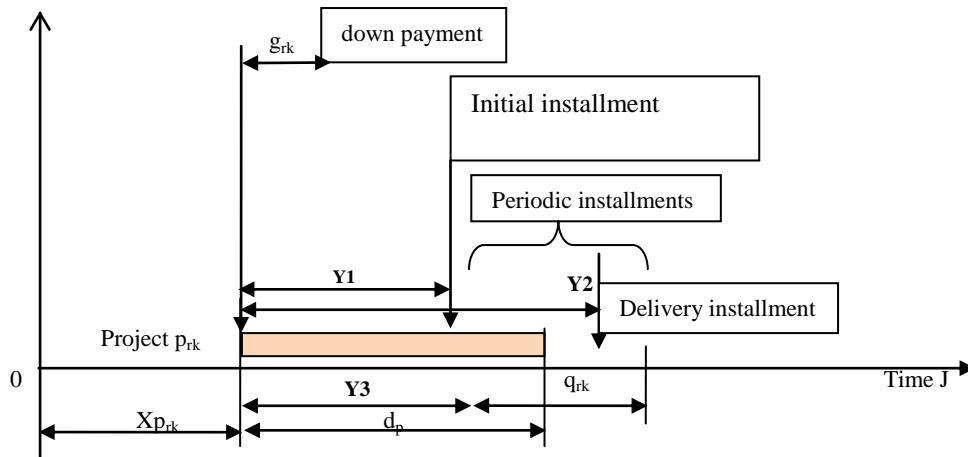


Figure 3-22: Receipt distribution – Selling case

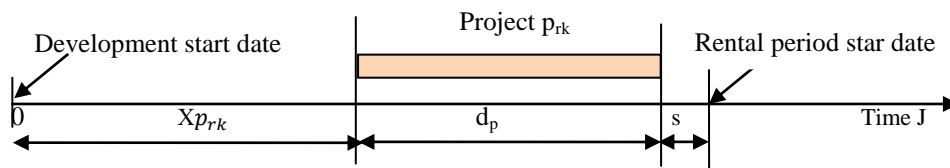


Figure 3-23: Receipt Distribution – Renting case

3.4.1.4 Optimization Engine:

The three aforementioned modules form one dynamic platform model at which many inputs are dynamically linked to the outputs. This model is capable to conduct several analyses, sensitivity and scheduling optimization. The optimization represents one of the main research focuses; the last module is an optimization engine which functions on top of the developed model. EVOLVERTM V.5.5 add-in for Excel[®] is used, which suits the complexity of the problem in hand. The final results interface is shown in Figures 3.24 and 3.25.

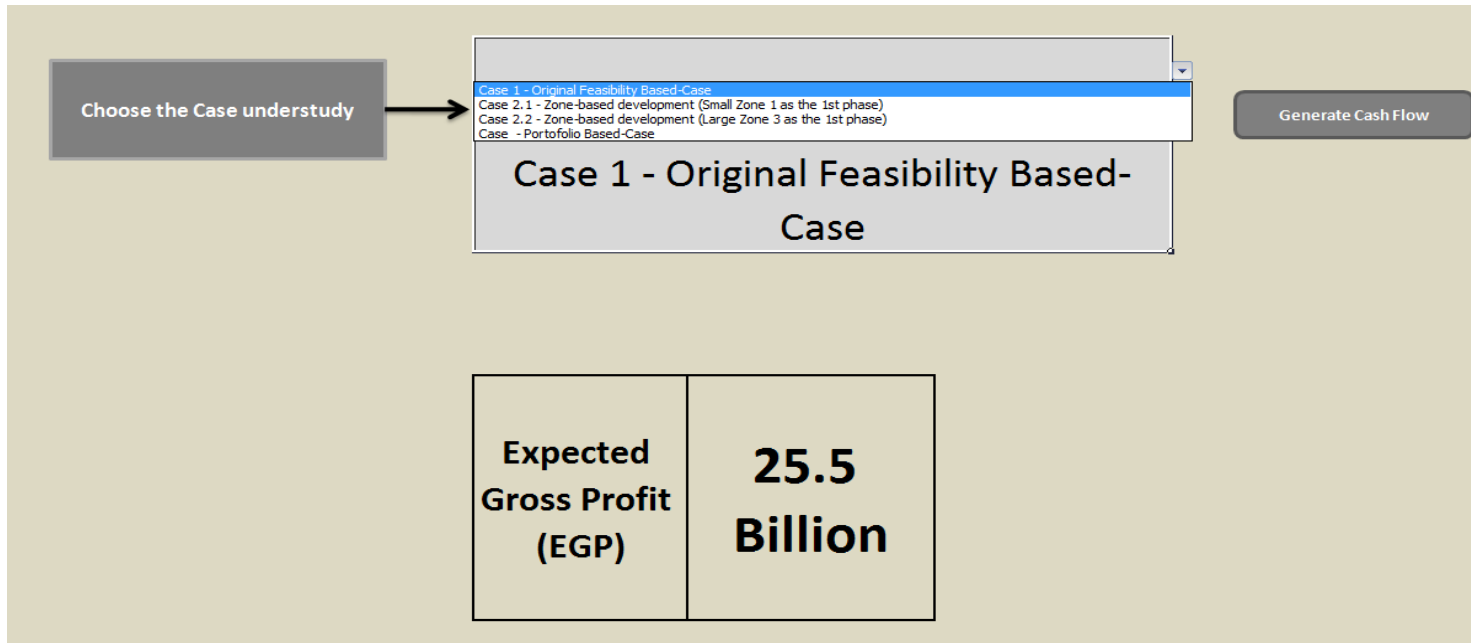


Figure 3-24: User Interface - RESOM model

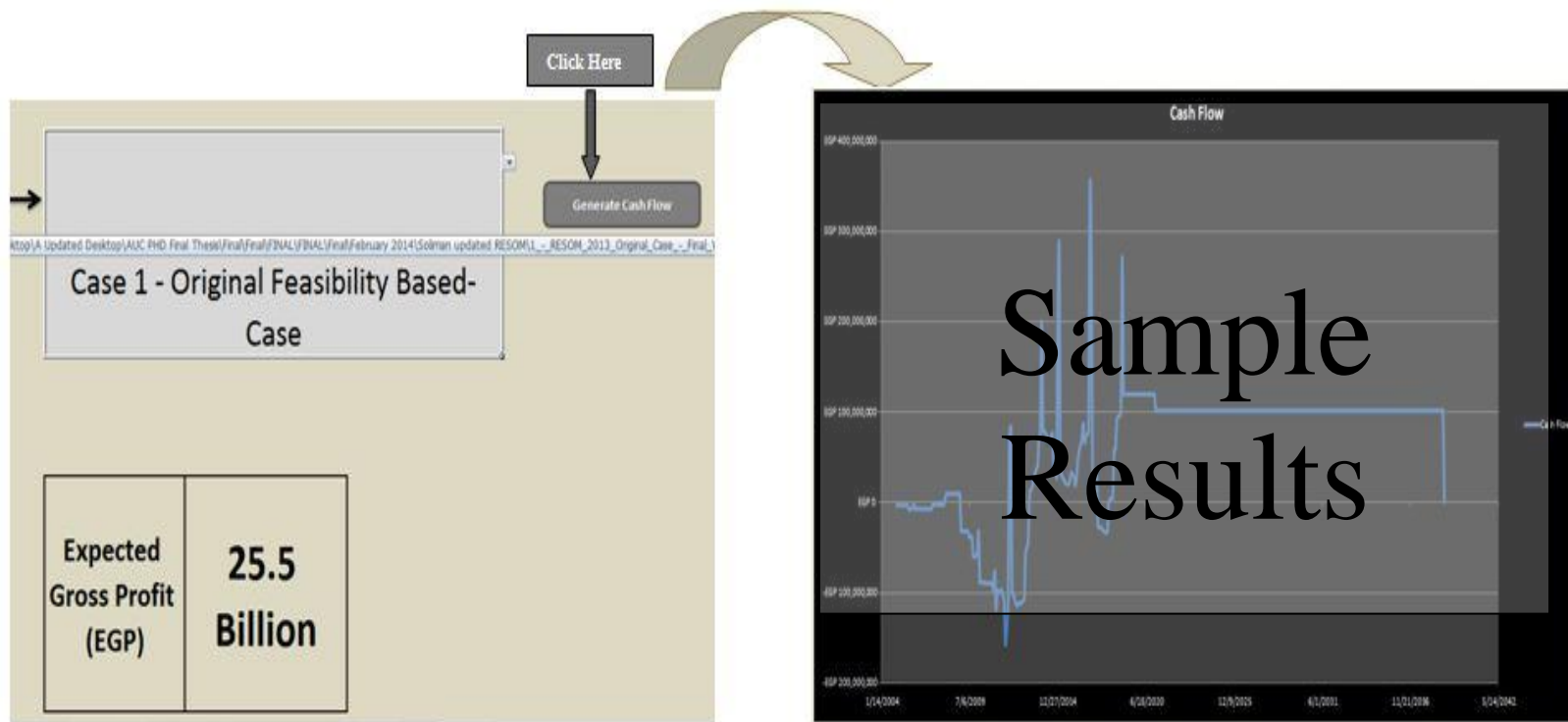


Figure 3-25: Automated Generation for the Cash flow diagram

3.4.1.4.1 Real Estate Projects NPV Calculation:

If the net present value of the NPV for the expected gross profit (EGP) can be calculated using the cash flow inflated formula (Collier, 2003). This leads to the following formula:

$$NPV = \sum_0^t \left(\frac{N_t - O_t}{(1+i)^t} \right) \quad \text{Equation 1}$$

Where;

N_t = Income at time t

O_t = Expenses at time t

$$i_i\% \begin{cases} \text{WACC\%} & \text{if } (N_i - O_i) \geq 0 \\ \text{Inflation\%} & \text{if } (N_i - O_i) < 0 \end{cases}$$

Where;

NPV = Present Value (PV) of the Cash Flows discounted at i_i

i_i % = Inflation rate

WACC% = Weighted Average Cost of Capital %

T = Feasibility Horizon (e.g. 50 years)

The WACC% is calculated using the following formula (Collier, 2003):

$$WACC = \frac{E}{V} * Re + \frac{D}{V} * Rd * (1 - Tc)$$

Where;

Re = cost of equity

Rd = cost of debt

E = market value of the firm's equity

D = market value of the firm's debt

V = E + D

E/V = percentage of financing that is equity

D/V = percentage of financing that is debt

Tc = corporate tax rate

In order to calculate the term (RI), as indicated by the area between curves (1) and (2) in Figure 1.1. If the Risk Impact (RI) on real estate project or a given infrastructure system, the RI formulation can be derived as follows:

$$RI = \{NPV_{\text{original feasibility case}} - NPV_{\text{optimized risk impacted case}}\} \quad \text{Equation 2}$$

and;

$$RI \% = \{NPV_{\text{original feasibility case}} - NPV_{\text{optimized risk impacted case}}\} / \{NPV_{\text{original feasibility case}}\} \quad \text{Equation 3}$$

The NPV values are obtained by using Equation 1 above. The equation is a linear integer programming problem.

3.4.1.4.1.1 Real Estate Projects' Cash-Out calculation

The construction expenditure may follow certain distribution. It depends mainly on the type of the project and whether the budget is front loaded (e.g. spending more money ahead to finance huge amounts of earth works) or back loaded (e.g. purchasing electromechanical or finishing works at the end phase of construction). Planners may select the Normal Distribution, Trapezoidal Distribution or any other distribution that may suit their construction case.

Developing large scale real estate projects usually include a number of project groups. The starting and ending date of the whole real estate development or of its groups can either put as fixed or hard constraints in RIM's models. The starting and ending dates of each project or of a building included in a project, are flexible and considered as soft constraints that should be within their group's starting and ending dates. This principle is illustrated in Figure 3.26.

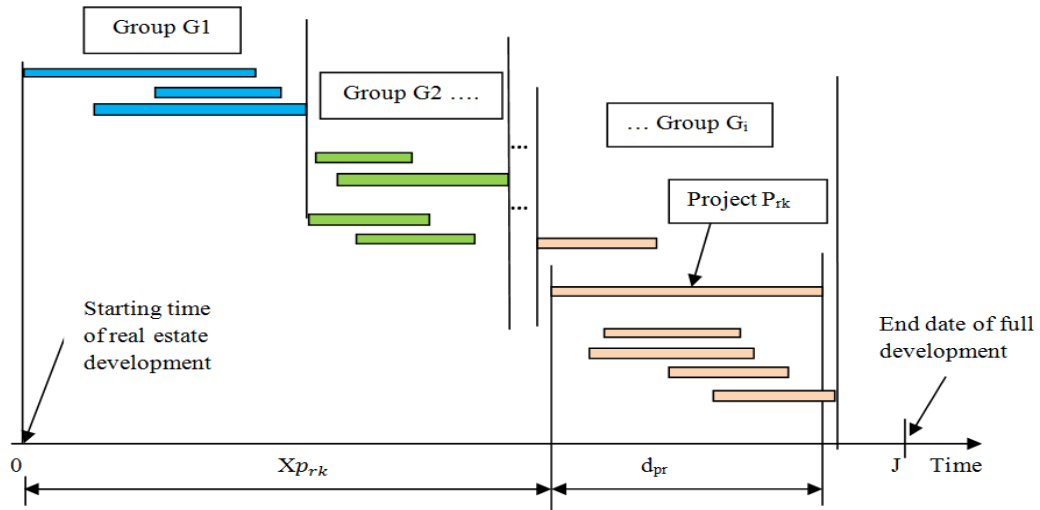


Figure 3-26: Construction of projects and their groups.

The construction of any building r within project p of type k starts after time duration X_{p_rk} that counts from the starting date of the whole development.

3.4.1.4.1.2 Real Estate Projects' Cash-In Calculation

On the other hand, the Cash-In calculation considers two cases of marketing strategy; namely selling and renting. The marketing strategy whether to sell or rent a building number r depends mainly on the type k of project number p .

The general formulation of the Cash-In is therefore:

$$N_{t_j} = Np_{rkt_j} = f(\text{Area, unit price, project type})$$

Selling case:

The selling conditions are given to the Scheduling Module as input so that the Cash-In is calculated for the real estate projects. These conditions include installments' values and time.

Rental case

Similar to the selling case, the rental case and time of renting, for those portfolios rented to the customers, is given to the scheduling module in order for the financial module to calculate the real estate projects' Cash-Out as shown in Figure 3.27.

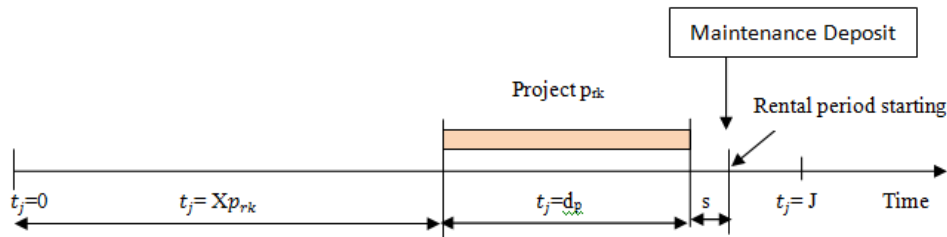


Figure 3-27: Cash-Out distribution inputs

3.4.1.5 Variables:

RESOM generates values for Xp_{rk} as shown in Figure 3.27, under Cash-Out calculation. The model gives values to the variables that are within a given range of the start and end date of the project's group G_i as shown in the Figure.

3.4.1.5.1 Infrastructure System Expected Gross Profit (EGP) Calculations:

RESOM calculates the Expected Gross Profit using the NPV of infrastructure net Cash Flow. The net Cash Flow is generated from subtracting the Cash-Out (generated from specialized infrastructure models) from the Cash-In (generated from RESOM). The Cash-In and Cash-Out calculations are according to the following:

The Objective Function is to maximize the summation of the NPV of infrastructure profit's Expected Gross Profit similar to Equation 3.

3.4.1.5.1.1 Cash-In Calculation

The construction cost is an input to the RESOM model and may follow any proper distribution. It depends mainly on the type of infrastructure project and whether the budget is front loaded (e.g. in cases of spending more money ahead to finance huge amounts of earth works) or back loaded (e.g. in cases of purchasing electromechanical or finishing works at the end phase of construction).

Developing large scale real estate projects usually include a number of project groups. The starting and ending dates of the overall real estate development are usually fixed as hard constraints by local authorities, the financial capability and/or market conditions and forecast. The starting and ending dates of each project or a building included in a project, are considered flexible as

soft constraints and are allocated to change within their group's fixed starting and ending dates.

The construction of any building r within project p of type k starts after time duration X_{prk} that counts from the starting date of the whole development (as shown in Figure 3.27). RESOM then calculates the services demand for each time unit (e.g. a month). The calculated demand is based on the selected values of X_i and D_i as well as the consumption rates and prices, obtained from the specialized infrastructure models (DCOM, SLOM and WSOM).

Based on the produced demand profile, which is calculated from RESOM, the specialized infrastructure models provides the Cash-Out profile calculations. RESOM then uses the Cash-Out as an input to calculate the Cash Flow as well as the Expected Gross Profit of the infrastructure system using the Cash-In calculated earlier by RESOM. RESOM then provides a near optimum implementation schedule that minimizes the NPV of the infrastructure Expected Gross Profit.

3.4.1.5.1.2 Cash-Out Calculations:

The developed framework, RIM, is capable to support decision makers in assessing the feasibility of infrastructure systems serving real estate projects under risk. As discussed above, RESOM is developed to provide NPV of Expected Gross Profit for infrastructure system. In order to calculate the Expected Gross Profit, the Cash-In is first calculated by RESOM. The Cash-In is a function of the service unit charge and the demand profile. Although RESOM can calculate the Cash-In, RESOM is integrated with specialized infrastructure models which provide services consumption rates and infrastructure system's Cash-Out. RESOM then provides the Cash Flow and Expected Gross Profit calculations. Three models are developed as specialized infrastructure systems. However, the same concept applies to any other infrastructure system. The developed models are developed for:

- Urban landscape system.
- Water system (potable water and/or irrigation system), and
- Cooling system,

The selection of these systems is due to possible water shortage in the future and the importance of the sustainability dimension of the water resource. The models do not only focus on providing the Cash-Out of infrastructure projects, but also optimize the efficiency of the system's operation cost which is part of its Cash-Out calculation process. The models are discussed in detail in the following sections.

3.5 Sustainable Landscape Optimization Model (SLOM)

Recent social and economic changes have motivated people to move their housing and working activities towards newly developed mixed-use gated communities. Establishing and maintaining urban landscape at these communities is an important attraction factor. During the early construction stage of projects, landscape architects and real estate developers are both concerned with own interests. Landscape architects are usually concerned with selecting plants types in a way that their design beauty is reflected while the real estate developers are more concerned about capital expenditure. Other factors such as the irrigation water consumption, maintenance costs may not be considered during the early construction stage of real estate projects. These factors are usually more important to city managers who manage the operations during the lengthy construction which is overlapped with the real estate units' occupancy.

Upon the occupancy process of real estate projects, city managers and end users are faced with landscape plants components that may require more finance to cover the maintenance and irrigation costs over the remaining project lifecycle. This situation may create frustration between the developers or city managers and the end users who may refuse to finance an exaggerated costly landscape system. This may require the introduction of an updated landscape plants mix design that requires less lifecycle cost and water consumption.

Based on the above realities, the author developed a Sustainable Landscape Optimization Model or SLOM that is aimed to provide the city managers with the irrigation water demand corresponding to the landscape plant mix design (Fayad et al 2013). Moreover, the model supports architects and real

estate developers in selecting a near optimum landscape plants mix design that provides both low lifecycle cost and irrigation water consumption.

3.5.1 SLOM Process Flow

The main process of the proposed model is shown in Figure 3.28. The landscape design plants component is usually produced by considering two main input streams; these are the architects' and the developers' points of view. SLOM considers the operation and maintenance cost or irrigation water demand for plants while selecting the plants types. It provides an optimized solution that compares different costs and water consumption of all possible plants design mixes over their lives and recommends a best mix design for which the lifecycle cost and irrigation water consumption are both minimized. As shown in the Figure, the irrigation water profile is used as input to WSOM Model to optimize the operation of the irrigation water system, similar to the optimization operation of the potable water system that is based on the demand profile. The potable water profile is obtained as output from RESOM Model.

3.5.2 SLOM Modules and Spreadsheet Modeling

The main modules of the Sustainable Landscape Optimization Model SLOM functions through:

- (1) Database Module which contains the data that relates to plant groups,
- (2) Landscape Plant Selection Module which generates possible plant mixes for the urban landscape design,
- (3) Financial Module which calculates the lifecycle water consumption and cost selected design mix
- (4) Optimization Engine which is used to provide the plant mix of the minimum lifecycle water consumption or expenditure, and
- (5) Chess Carpet Diagram, CCD that enables the non-expert users visualizing images of the proposed landscape plant mix. Figure 3.29 illustrates the different modules of SLOM.

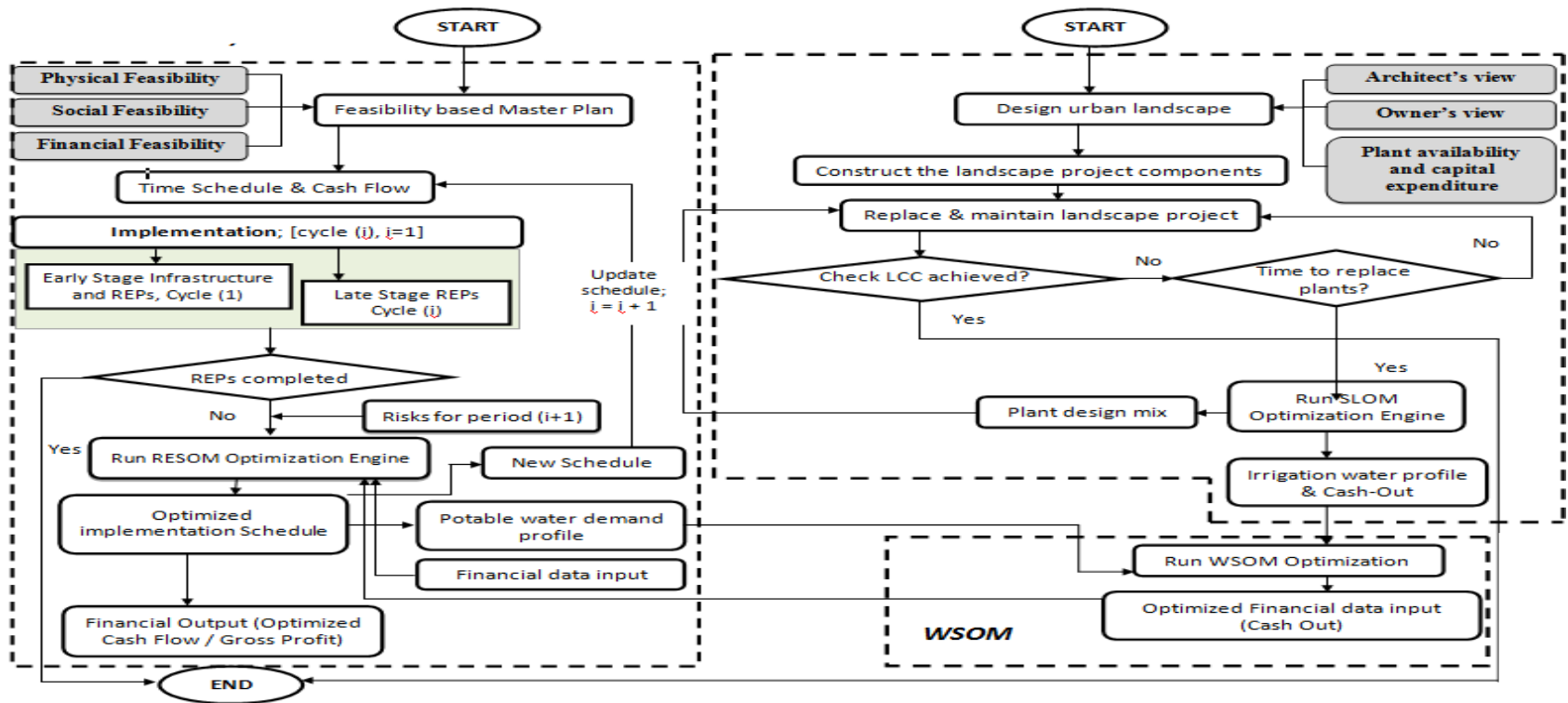


Figure 3-28: The interaction between RESOM & SLOM and WSOM

(Fayad, 1012), (Fayad, 2013)

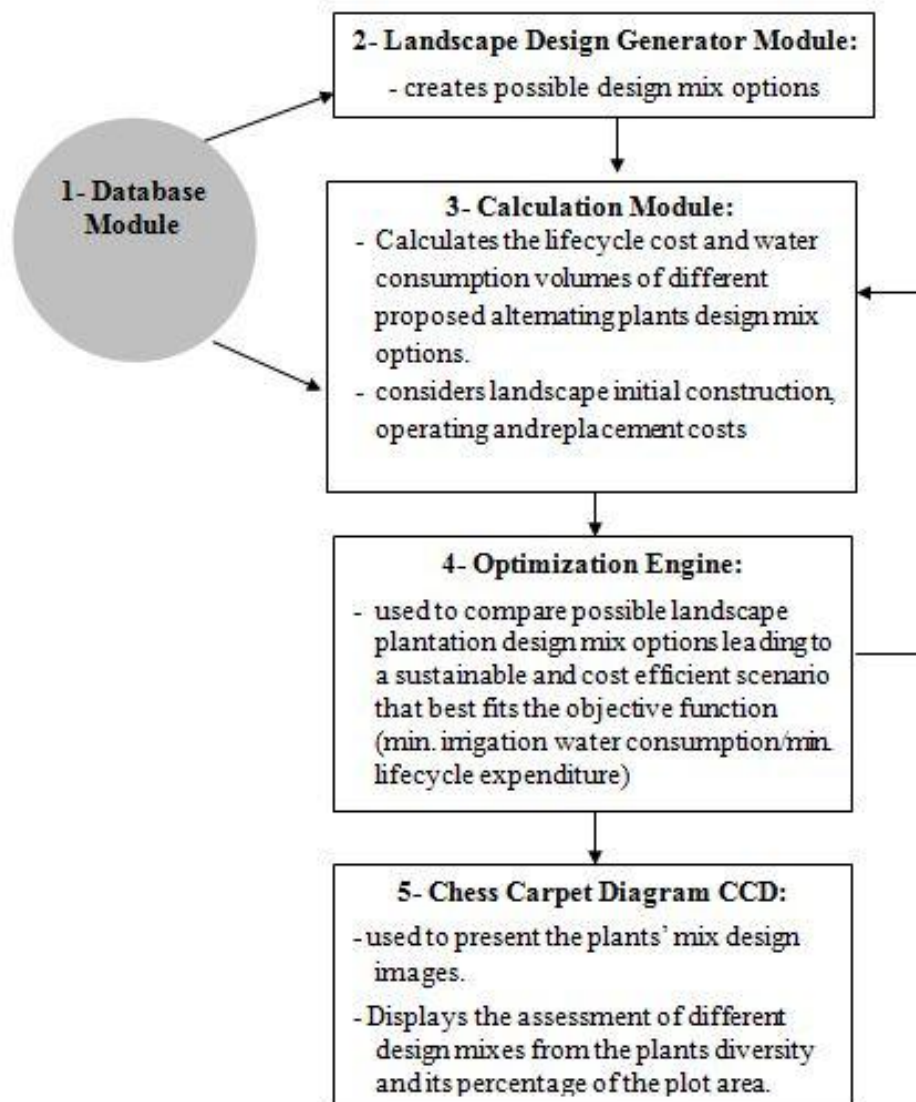


Figure 3-29: SLOM Main Modules

SLOM selects plant mix design that satisfies different requirements. In addition the architectural requirement, the mix design should fulfill the following requirements:

- 1- Owner's budget: the model may respect budget constraints while selecting the plants mix.
- 2- Water consumption: the model may select plants mix that fits minimum lifecycle water consumption.

- 3- A minimum given percentage range of each plant groups represented in certain plant mix and a given percentage range of plant types in their group.

The different modules of SLOM are structured in Figure 3.29. The data input and output of SLOM is shown in Figure 3.30. Through its periodic running, SLOM provides a plant mix design that fits certain objective such as minimum lifecycle costs and/or minimum water consumption for the remaining life time of the project. The modules are:

3.5.2.1 Database Module

The database module contains the plants listing under groups that include the scientific name of each plant, their purchasing, planting and maintenance cost. It also includes several information relating to soil type and suitable conditions and plant resistance to salt, drought and underground water. The database contains all plant types, their main groups and their images as shown in Figure 3.31. It also includes the construction date and other technical data such as the plant's height, spread and caliber. The expected life time is also included which is useful for defining the point in time at which plants have to be replaced. The Database includes further information on the sweet sand, manor quantity and prices. It also includes additional plant information such as its salt tolerance, draught tolerance and the plant's tolerance to high ground level. It also includes information on the plant lifecycle (or the expected life time) in years. The Database includes specific type of irrigation whether drip or sprinkler. It uses the codes P, IP or B to indicate Possible, Impossible or Better usage of both irrigation options respectively. The Database also includes the water demand consumption of each plant in different seasons of different weather conditions as shown in Figure 3.30. In addition, it includes project's data such as its landscaped area as well as the overall project Gross Built-up area GBA.

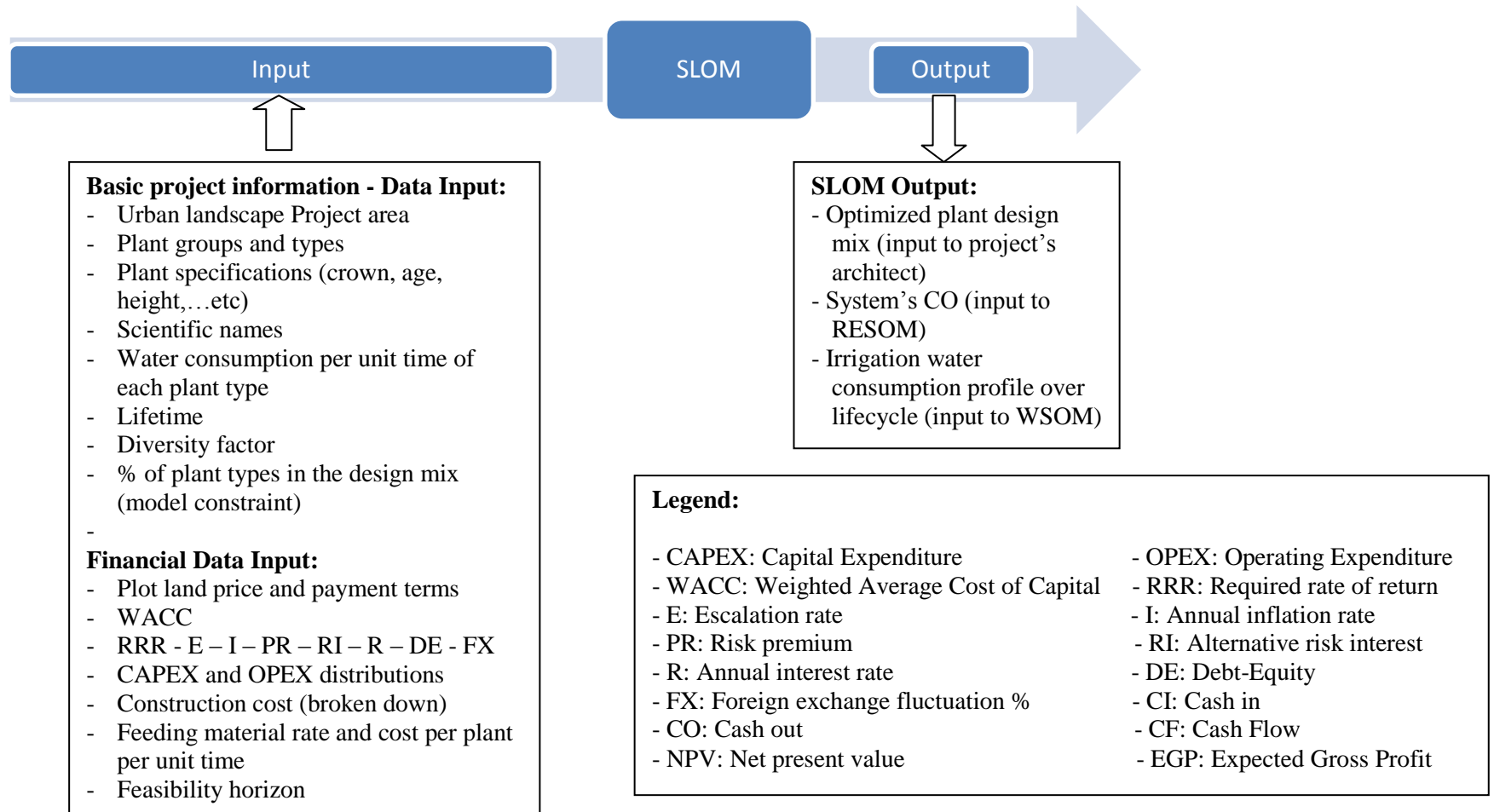


Figure 3-30: SLOM – Data Input and Output






Figure 3.31 and 3.32 present samples of the database input data, e.g. different costs of each plant contained in each group, the percentage range in the design mix (architect's requirements). As for the financial data, the Database module includes two types of data:

- CAPEX: the data required to calculate project's capital expenditure costs or the Capital Expenditure (CAPEX) breakdown, e.g. the costs associated with plant supply, transportation, installation, maintenance and risk and profit.
- OPEX: the data that are used to calculate the operation expenditure referred to as OPEX, which includes the consumption rate of feeding elements over the plant lifecycle. These elements are for example water, Nitrogen, Potassium, Phosphor, minor elements and insecticides.

Plant basic information;
scientific name, photo,
family code)

Plant specification at
construction time

Planting cost elements (CAPEX);
plant unit cost breakdown

Pic 1	General				Specifications						Planting Cost						
	ID #	Family	Palms	Data Code	Height	Units	Spread	Units	Caliber	Unit	Supplying Price (EGP)	Transporation (EGP)	Installation (EGP)	Risk factor (EGP)	Maintenance (EGP)	Profit (EGP)	Unit Cost (EGP)
	1	Arecacea	Phoenix dactylifera	F.P.	3-4M	Meter	4	Meter	0.75-1M	Meter	650	65	97.5	19.5	45.5	97.5	975
	2	Arecacea	Hyphaene thebaica	F.P.	3-4M	Meter	4	Meter	0.75-1M	Meter	950	95	142.5	28.5	66.5	142.5	1425
	3	Arecacea	Roystonea regia	O.P.	3-4M	Meter	4	Meter	0.75-1M	Meter	1200	120	180	36	84	180	1800
	4	Arecacea	ragrus romanzoffianu	O.P.	3-4M	Meter	4	Meter	0.75-1M	Meter	1500	150	225	45	105	225	2250
	5	Arecacea	Phoenix canariensis	O.P.	3-4M	Meter	4	Meter	0.75-1M	Meter	2500	250	375	75	175	375	3750

Sample Data

Soil	Soil Properties		Soil Cost		Environemtal Properties		
	Sweet sand (m3)	Manur (m3)	Sweet sand unit cost (EGP)	Manur unit cost (EGP)	Salt tolerance	Drought tolerance	Tolerant trees to high ground water level
sweet sand (1.8m*1.8m*1.8m) + 15 - 20% manur	4.6656	1.1664	139.97	46.66	1	1	1
	4.6656	1.1664	139.97	46.66	1	1	0
	4.6656	1.1664	139.97	46.66	0	0	0
	4.6656	1.1664	139.97	46.66	0	0	0
	4.6656	1.1664	139.97	46.66	0	0	0
	4.6656	1.1664	139.97	46.66	0	0	0
	4.6656	1.1664	139.97	46.66	0	0	0
	4.6656	1.1664	139.97	46.66	0	0	0

Continued: plant unit
cost breakdown
(CAPEX)

Figure 3-31: SLOM Database - Data Input

Age	Irrigation Network		Water duty			
Life Cycle (Years)	Drip irrigation	Sprinkler irrigation	Spring and Summer Consumption	unit	Autumn and Winter Consumption	unit
30	P	IP	100	Liter/unit/day	80	Liter/unit/day

Sample Data

yearly materials & insecticides for Palms maintenance						
Nitrogen by grams per one plant per 6 summer months	Nitrogen price (EGP)	Potassium by grams per one plant per 6 summer months	Potassium price (EGP)	Phosphor by grams per one plant per 6 winter months	Phosphor price (EGP)	Minor elements by grams per one plant
250	3.6	150	3.33	200	1.08	50

yearly materials & insecticides for Palms maintenance							
Potassium price (EGP)	Phosphor by grams per one plant per 6 winter months	Phosphor price (EGP)	Minor elements by grams per one plant per 3 months	Minor elements price (EGP)	Insecticides by L.E per one plant 2 months	Total cost for yearly materials & insecticides for planting maintenance	Units
3.33	200	1.08	50	0.54	18	26.55	EGP

Figure 3-32: SLOM Database for calculating the landscape operating cost






3.5.2.2 Landscape Design Generator Module

The landscape planting variety module creates possible plantation mix of plants. The Module proposes certain percentage of each group in the landscape plants design mix that respects a percentage range given by the project's architect and depends mainly on the project type and location. The Module proposes further percentages for certain plants that are included in each of the groups. It transfers the plant's crown diameter into an area that is part of the overall project available area.

3.5.2.3 Calculation Module

The Calculation Module enables calculating the lifecycle cost LCC which is the sum of both the capital expenditure CAPEX and operating expenditure OPEX costs for plants' design mix proposed by the Landscape Design Generator Module. The Module produces the Net Present Value NPV of the Cash Flow for certain plant mix considering the annual inflation rate. Accordingly, the module calculates the water consumption as well as the OPEX per square meter of the gross built-up. This indicates how much an end user should pay for his own sold or rented area.

SLOM provides then both the cost and water consumption for any selected plant design mix by multiplying the decision binary matrix by the matrix under consideration. This is shown in Figure 3.33 where generated plant types are indicated by the module using the Binary system (0 and 1). The 1 and 0 digits are used to indicate whether a plant is selected or not selected in the generated plant mix respectively.

Photo	ID #	Family	Group: Palms	Data Code	Percentage Design (%)	chosen (0/1)
	1	Areceaceae	<i>Phoenix dactylifera</i>	F.P.	0.34%	1
	2	Areceaceae	<i>Hyphaene thebaica</i>	F.P.	0.00%	0
	3	Areceaceae	<i>Roystonea regia</i>	O.P.	0.00%	0
	4	Areceaceae	<i>Syagrus romanzoffianum</i>	O.P.	0.00%	0
						

Sample Data







*0-1 binary system to indicate the selected plant types

Figure 3-33: Binary representation in SLOM model

The model calculates the operating costs OPEX for all selected plants in each year of the lifecycle. The OPEX includes the replacement costs as well depending on the lifetime of each plant. The lifetime changes from a plant to another. The age of some plants may be limited to 2 years; others may reach 7 or 30 years. SLOM repeats counting the CAPEX costs as soon as the lifetime of the selected plant is ended. Example of SLOM's OPEX calculation is illustrated in Figure 3.34.

The selected plants marked in yellow

Water consumption and calculated lifecycle costs and

Pic 1	Ref	ID #	Family	Plants	Replacement Cost (EGP)	Spring & Summer Water Consumption	Autumn & Winter Water Consumption	Total yearly water consumption	Units	Total Water Consumption Cost (EGP)
	18	216	Verbenaceae	<i>Verbena hybrida</i>	158,996.10	18,534.24	12,288.64	30,822.88	m ³	107,263.62
	19	217	Lamiaceae	<i>Ocimum basilicum</i>	315,993.77	87,301.81	24,731.98	62,033.79	m ³	215,877.57
	20	218	Lamiaceae	<i>Rosmarinus officinalis</i>	660,497.85	76,994.51	51,049.18	128,043.69	m ³	445,592.02
	21	219	Lamiaceae	<i>Salvia farinacea</i>	0.00	0.00	0.00	0.00	m ³	0.00
	22	220	Lamiaceae	<i>Salvia splendens</i>	0.00	0.00	0.00	0.00	m ³	0.00
	23	221	Geraniaceae	<i>Pelargonium odoratissimum</i>	127,418.23	14,853.20	9,848.02	24,701.22	m ³	85,960.23

Sample Data

Figure 3-34: OPEX calculation sheet in the SLOM model.

3.5.2.4 Optimization Engine

The Optimization Engine produces a proposed plants' mix design within the required design percentage range (model constraints) so that the landscape system's Cash-Out is minimized. The Cash-Out is fed to RESOM for further calculation of the Cash Flow and system's NPV Expected Gross Profit. The variables are the percentages of landscape plant types in the overall mix design. The constraints are the percentages ranges of each plants group in the landscape mix design (e.g. palms or trees). The objective function of the optimization process may achieve plant mix that minimizes either the Cash-Out or the irrigation water consumption. The Genetic Algorithm optimization is used by applying the GA solver using the EVOLVER™ V.5.5 add-in for Excel®.

3.5.2.5 Chess Carpet Diagram CCD

SLOM model is used to display the selected plants of each mix option. The images of the selected plant types from each group are displayed in a developed chess carpet shape diagram, called Chess Carpet Diagram or CCD as shown in Figure 3.35. Each design mix is displayed between two upper and lower rows. Each row contains information of each group, e.g. the total number of the plant types contained in the same group. Each group in the upper or lower row is colored in one of three colors indicating the assessment of the group. The upper side colors indicated the deviation degree of the selected number of plants from the architect recommended range. The colors of the bottom side groups reflect how the area percentage covered by each group to the overall area is deviated from the architect recommendation. The green color, for example, reflects a limited deviation of certain allowable range (say 10%), the orange for example can be used to reflect a wider range (say from 10% to 25%) while the red for example may be used to reflect a much wider deviation (that is for example more than 25%). The three colors green, orange and red refer to Excellent; Fair and Poor evaluation of the design mixes respectively. In addition the plants' photos are stored in a separate folder that is linked to the CCD included in the SLOM by using Macro's commands that is linked by using the same ID number of each plant in SLOM model. The model presents the plants pictures as a code. The code

is indicated at the same field that contains all calculations for the same plant type. This developed method enables importing the selected plant picture accurately from the picture folder to the CCD.

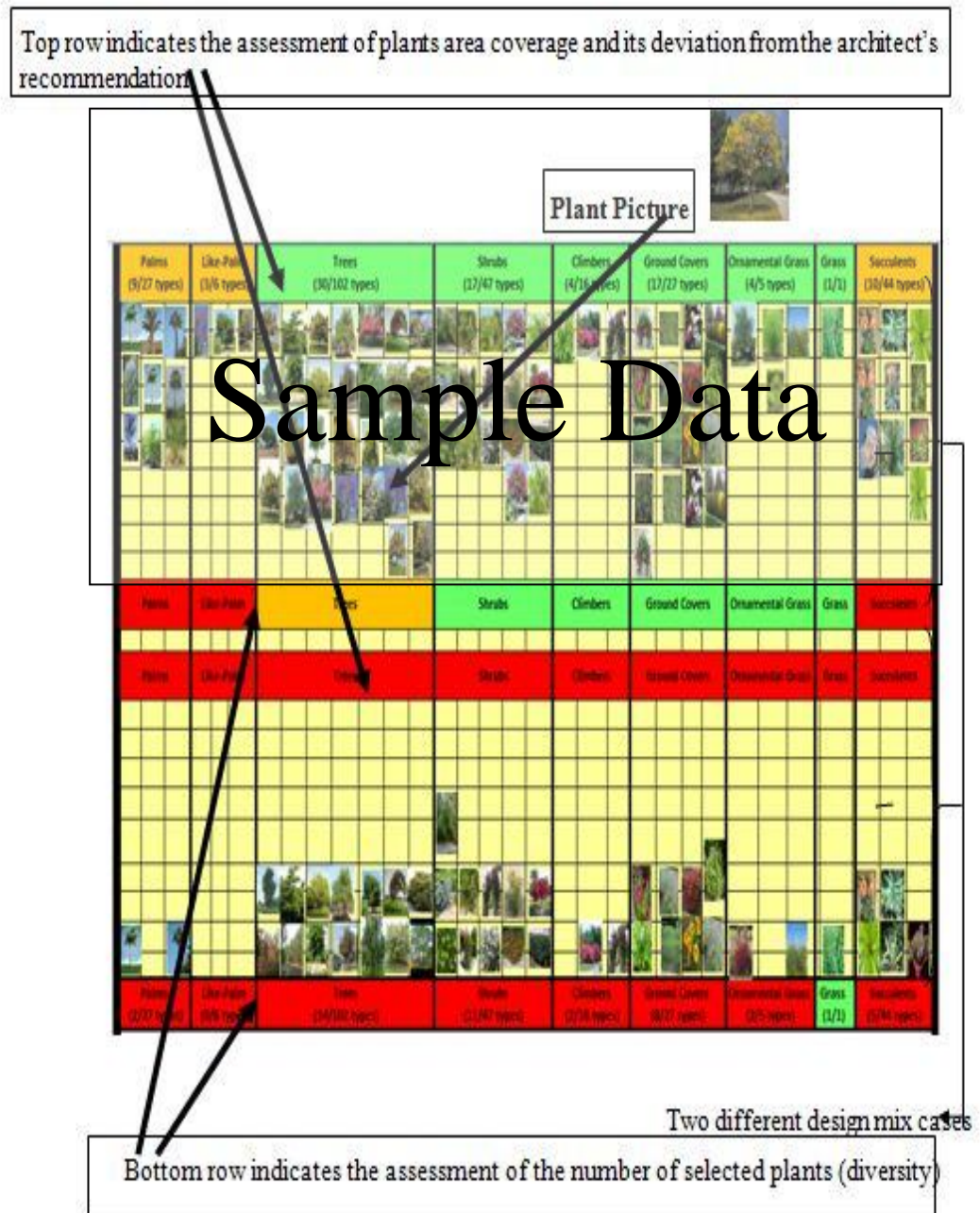


Figure 3-35: Example of a double-case Chess Carpet Diagram (CCD) layout

3.5.3 Irrigation Water Profile Output

As mentioned above, the model provides a monthly irrigation water demand based upon the plant selection and the season. The irrigation water profile is obtained from SLOM. The profile is then fed to WSOM, the water management system model, in order to produce the operating/maintenance schedule of the system electromechanical components (e.g. pumps) so that the irrigation water system (OPEX) is minimized.

The Landscape plant lifecycle cost is the summation of its construction cost (selling cost at the nursery, transportation to site, soil preparation and installation, warranty for certain period after installation). Additionally, plants consume feeding material and irrigation water over their life time. The lifetime differs from a plant to another. Some plants may live for example for two to twenty years then replaced by new plants. The lifetime of other plant types may extend to decades. The model also considers a loss factor that is applied to the plants lifecycle cost to represent its resistance to the living circumstances. The percentage differs from a plant to another depending on its nature and resistance.

The plants lifecycle cost is the inflated summation of the construction costs. Table 3.2 illustrates the cost breakdown items of the capital and operation expenditures (CAPEX and OPEX).

Table 3-2: Cash-Out cost breakdown calculation (SLOM model)

Cost Type	Cost Breakdown
Capital Expenditure - CAPEX	Supply cost
	Transportation cost
	Installation cost
	Risk Factor
	Maintenance cost
	Overheads and profits
	Sweet sand cost
	Manor cost
Operating Expenditure OPEX	Irrigation water cost
	Nitrogen element cost
	Potassium cost
	Phosphor cost
	Minor elements cost
	Insecticides cost
	Replacement cost

3.6 Water Simulation Optimization Model (WSOM)

The potable water system usually requires special care and handling due to the importance of the hygiene and health dimensions. Like other infrastructure systems, the potable system is challenged by several deteriorating factors, such as aging, demand unexpected overload and others. On the other hand, the water supply required to cover the urban landscape needs may exceed the supply covering the potable water for a given community. However the standards of the irrigating water quality are not restricted like the potable water standards that should be of minimum hygiene and health requirements. Real estate developers have been targeting sources for irrigation water that differ from those used to feed potable water systems for cost saving purposes. Recycled water or treasury raw water may be sourced to cover the irrigation. Real Estate developers may also combine both distribution systems in shared buildings for cost saving purposes. Although both systems may share certain facilities, however each system should

physically be separated from the other due to the hygienic reasons. Both systems may use for example the same pump station building but would not share the pumps, pipelines or their electromechanical sets. WSOM is then useful as it can use RESOM output to produce an optimized full lifetime asset management plan and its related minimum Cash-Out calculations. In this research, the Water Simulation Optimization Model WSOM is developed to provide asset lifecycle for separate potable water, irrigation water, or for a combined potable and irrigation system. Through using RESOM output (potable water profile and lifecycle quantities) and SLOM output (irrigation water profile and lifecycle quantities), WSOM can provide optimized lifecycle asset management plan for each separate water system, or for a combined water system. It is then possible to provide the Cash-Out calculation, which includes the construction and operation cost added together. WSOM calculation output (Cash-Out) is then used by RESOM to provide the water system's Cash Flow and NPV Expected Gross Profit. The process flow chart is indicated in Figure 3.36.

In accordance with the cost allocation approach for calculating the system's lifecycle cost (Ecorys & Delft, 2005), WSOM classifies the components into four categories. These categories are:

- 1- Fixed rate expenditure category maintenance cost:** This category includes the civil works items,
- 2. Regression based category maintenance cost:** This category includes the electrical components,
- 3. Breaking rate category:** this category includes the plant pipes, and
- 4. Operating time-based maintenance category:** this category includes the electrochemical items, which require operating time-related preventive maintenance.

In the case of applying WSOM for a combined potable/irrigation water system, WSOM provides the maintenance policy for each category of the system and considers the separate categories for each of them. The classification is shown in Table 3.3. The calculation of the last category follows an optimization module to provide a best operating schedule of the components included in this category. It uses the demand profile of the irrigation system that is output of SLOM model

while it uses the demand profile of the potable water that is input of RESOM model. WSOM provides at the end the system's Cash-Out that is used as an input to RESOM for Cash Flow and NPV Expected Gross Profit of the water system.

Table 3-3: WSOM integrated model – combined facilities

(Potable water and irrigation water)

	Potable water system	Irrigation water system
Civil works items (shared by both systems)	A percentage of the Cash-Out is allocated to each of the systems in case of combined water system	
Electrical components (shared by both systems)		
Pipes (breaking failure rate module)	Own pipe network	Own pipe network
Electrochemical components	Own components	Own components
	RESOM output (3 cases)	SLOM output (3 cases)

3.6.1 Potable Water

During construction, unforeseen risks may dictate the real estate developers to relax the construction schedules from their original feasibility. This action may indeed mitigate risk impacts but actually reduces the demand on the potable water compared with the estimated feasibility-based demand of early development stage. However, this may affect the economies of the potable water system due to the resulting system underutilization. This is due to the less occupancy and hence the less potable water demand. Consequently, real estate private sector developers may not become able to continue financing the operating expenditure necessary to keep the system's level of service at a minimum acceptable level. As seen above, RESOM can provide the potable water demand profile. It can change the demand profile dynamically as the development entire projects construction durations and their occupancy dates change.

3.6.2 Irrigation Water

The irrigation water demand depends mainly on the plant mix selected in the landscape design. As seen earlier, SLOM process provides the irrigation water profile over long lifecycle periods. Any change in the irrigation water demand, due to changing plant mix by time, is in turn considered while planning the lifecycle maintenance policy of the system. It is possible through periodic updates in the irrigation water profile to update the maintenance policy for the overall water system using WSOM.

3.6.3 WSOM Main Process

WSOM provides a full management system for the remaining pipeline, structural, electrical and architectural components. It provides a best maintenance policy scenario that produces a minimum lifecycle cost. It also produces an optimum operating/maintenance schedule for those items requiring periodic time-related maintenance (e.g. pumps).

The main process of WSOM main modules are shown in Figure 3.36. As shown in the Figure, WSOM model consists of five main modules, these are 1) the Database Module, 2) the RESOM/SLOM Model output, 3) the Deterioration Module, 4) the Financial Module, and 5) the Optimization Engine.

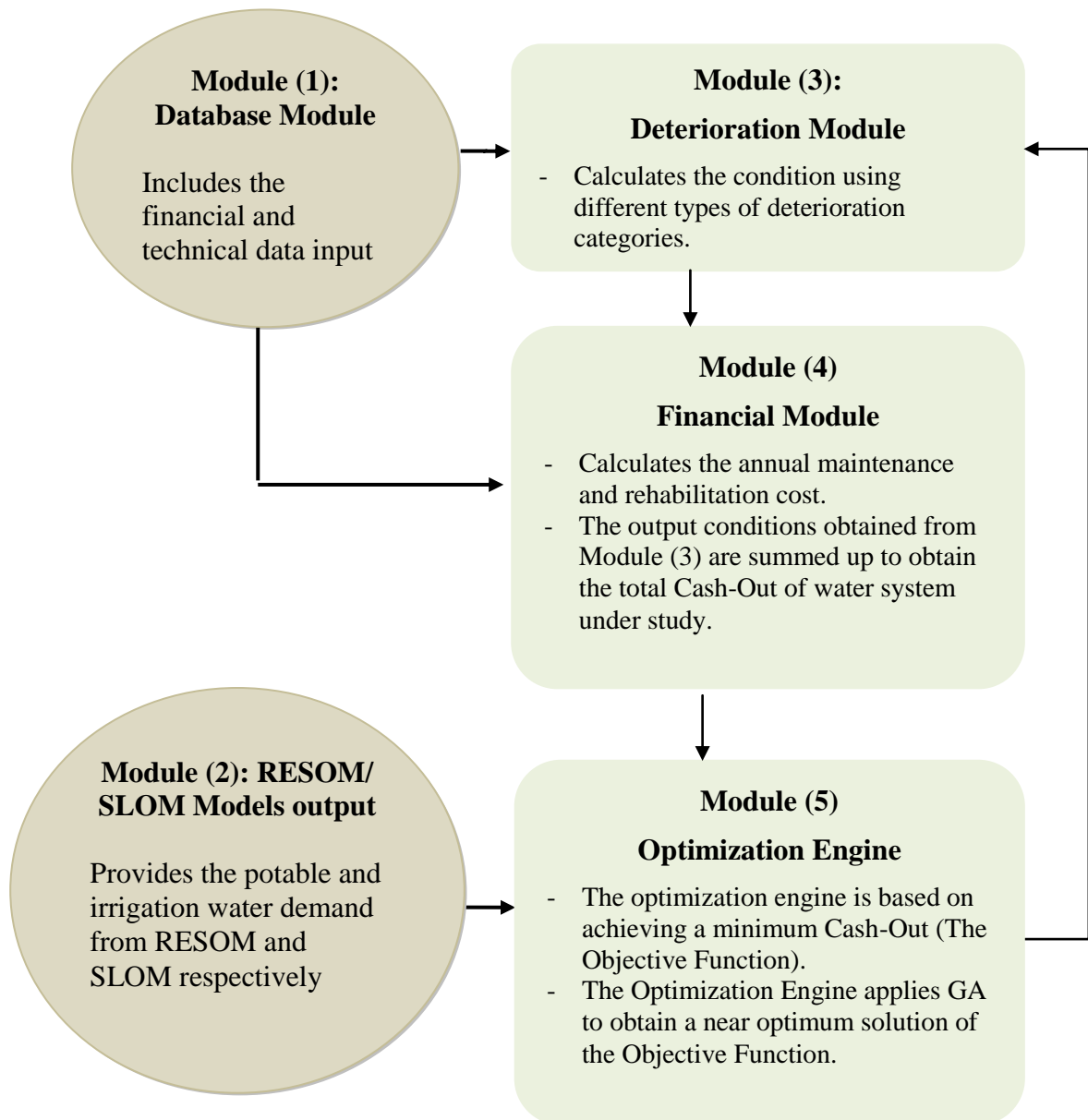


Figure 3-36: Proposed Water System Optimization Model (WSOM modules)

3.6.3.1 Database Module

The database module in WSOM includes the basic information used by other model modules to calculate WSOM outputs. The database includes the technical and financial data of water system components. This includes the

mechanical, civil, architectural and electrical items of pump rooms, tanks, pipe network...etc. The information is modeled using spreadsheet as an extendable table aiding the other modules extracting their input from the database automatically. The components are categorized into two types:

- (1) Basic information describing the item, its useful life, engineering discipline and exact physical location.
- (2) Monetary information that includes the initial construction cost, and preventative maintenance cost of the items.

Figure 3.37 shows the data input and output of WSOM. The data included in the Database Module are partially shown in Figure 3.38.

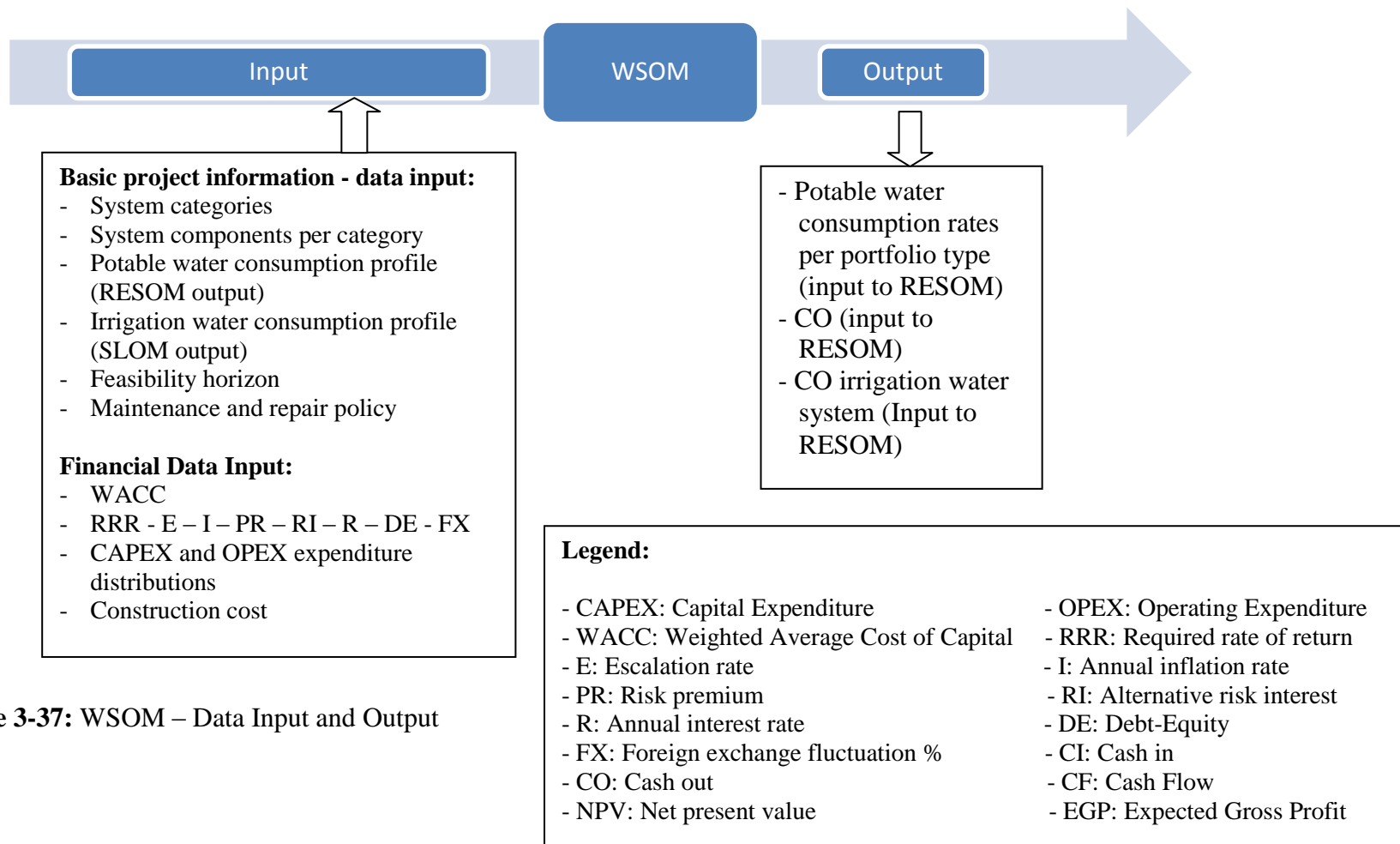


Figure 3-37: WSOM – Data Input and Output

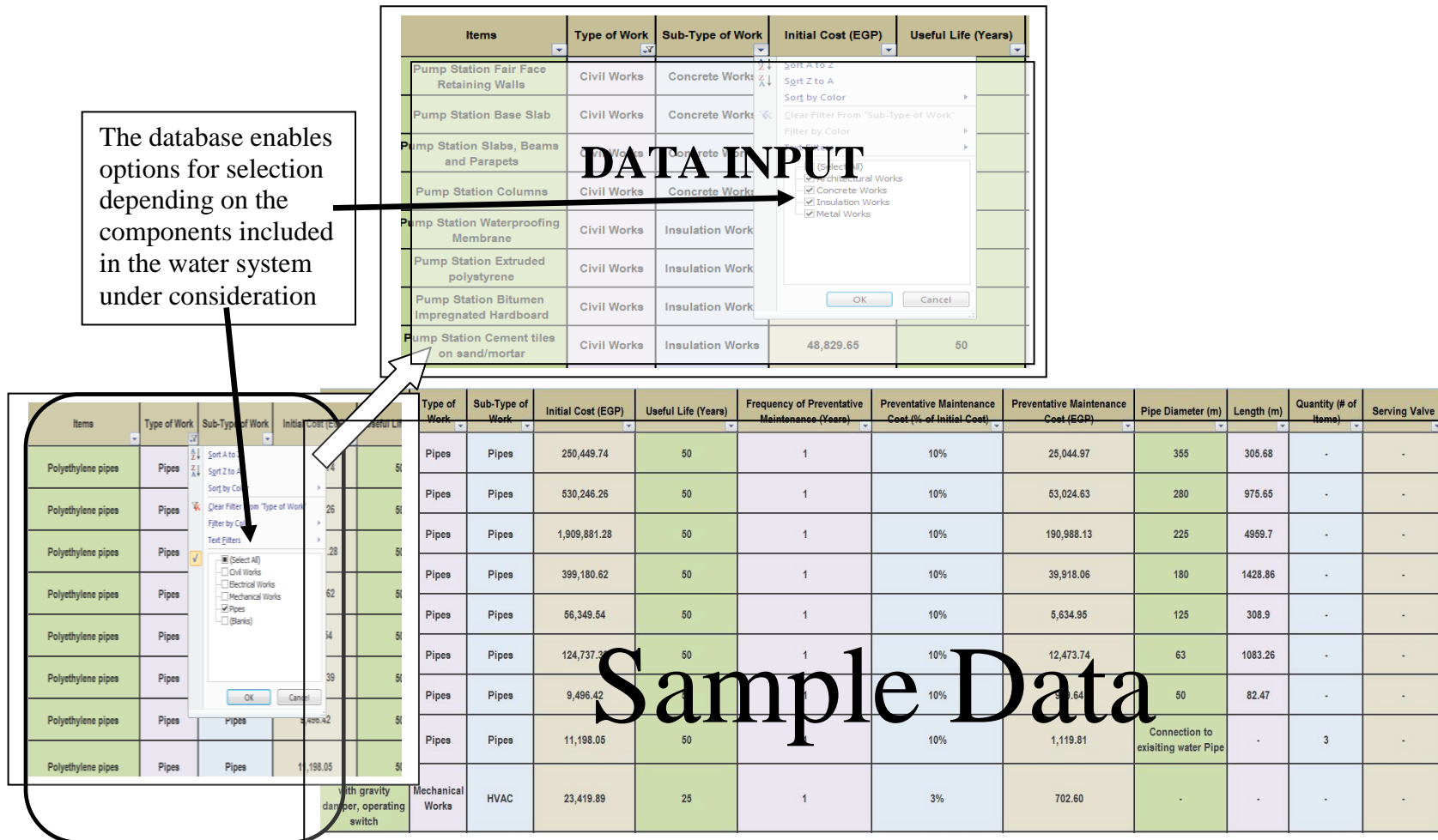


Figure 3-38: WSOM Database Module

3.6.3.1.1 RESOM / SLOM Models Output (Input to WSOM)

As explained above, RESOM model output is used to provide the potable water consumption profile over projects' life (Fayad et al, 2012). The monthly and total water consumptions are then used as inputs to WSOM model.

Figure 3.39 shows RESOM's output that is the input to WSOM. Similar to the potable water, the updated irrigation water profile is fed from SLOM model output as shown in Figure 3.40 (Fayad et al, 2013).

Potable water quantities for each project (RESOM output)

#	end of constr.	operation start	W. consum.	12/1/2014	1/1/2015	2/1/2015	3/1/2015	4/1/2015	5/1/2015	6/1/2015	7/1/2015	8/1/2015	9/1/2015	10/1/2015	11/1/2015	12/1/2015	1/1/2016
REP 1	1/1/2008	2/1/2008	100	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961	99.56838961
REP 2	1/1/2008	2/1/2008	1744	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905	1743.515905
REP 3	1/1/2008	2/1/2008	1359	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133	1358.647133
REP 4	1/1/2008	2/1/2008	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 5	1/1/2012	2/1/2012	1240	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624	1240.278624
REP 6	1/1/2013	2/1/2013	28112	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189	28111.65189
REP 7	1/1/2012	2/1/2012	2541	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592	2540.613592
REP 8	1/1/2012	2/1/2012	1419	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697	1419.060697
REP 9	1/1/2012	2/1/2012	2173	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597	2173.252597
REP 10	1/1/2011	2/1/2011	1681	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028	1681.497028
REP 11	1/1/2011	2/1/2011	2212	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786	2212.317786
REP 12	1/1/2013	2/1/2013	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 13	1/1/2016	2/1/2016	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 14	11/1/2015	12/1/2015	1610	0	0	0	0	0	0	0	0	0	0	0	0	1609.612845	1609.612845
REP 15	9/1/2015	10/1/2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 16	8/1/2015	9/1/2015	707	0	0	0	0	0	0	0	0	0	706.9846473	706.9846473	706.9846473	706.9846473	706.9846473
REP 17	7/1/2015	8/1/2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 18	8/1/2015	9/1/2015	2486	0	0	0	0	0	0	0	0	0	2486.409318	2486.409318	2486.409318	2486.409318	2486.409318
REP 19	9/1/2015	10/1/2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 20	11/1/2014	12/1/2014	954	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781	954.1857781
REP 21	2/1/2015	3/1/2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
REP 22	3/1/2015	4/1/2015	555	0	0	0	0	555.3820694	555.3820694	555.3820694	555.3820694	555.3820694	555.3820694	555.3820694	555.3820694	555.3820694	555.3820694
REP 23	3/1/2015	4/1/2015	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

DATA OUTPUT

Figure 3-39: RESOM output (Potable Water Profile - Input to WSOM)

WSOM calculates the annual water consumption over the plants lifecycle (e.g. 30 years) and sums the consumption up to obtain the lifecycle irrigation water profile for selected plant mix (input to WSOM irrigation part)

							Total Life Cycle Costs (LCC)	
Year #							OPEX (EGP)	CAPEX + OPEX (EGP)
30								
Replacement Cost (EGP)	Spring & Summer Water Consumption	Autumn & Winter Water Consumption	Total yearly water consumption	Units	Total Water Consumption Cost (EGP)	OPEX (EGP)		
687,449.08	4,922.70	3,916.64	8,839.34	m ³	761,501.02	2,323,323.63		2,635,800.48
0.00	0.00	0.00	0.00	m ³	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	m ³	0.00	0.00	0.00	0.00

DATA OUTPUT

Figure 3-40: SLOM Data Output (Irrigation Water Profile - Input to WSOM)

3.6.3.2 Deterioration Module

This module provides the condition of the water supply system at any point in time of its lifecycle. The deterioration module predicts the condition based on a pre-defined deterioration rate. In this module, different deterioration-modeling tools for different item categories are applied to predict the conditions depending on the category to which an item belongs to. The Deterioration Module calculates the lifecycle cost of the water system. In order to do so, it classifies the system components into four main categories depending on its maintenance management approach, these are:

1. Operating time-based maintenance category: this category includes the items that require preventive periodic maintenance every certain operating time to be defined by equipment manufacturer (e.g. pumps).
2. Fixed rate expenditure category: this category includes the items for which lifecycle maintenance budgets are fixed as a percentage of its capital expenditure (e.g. civil works).
3. Regression-based deterioration category: the Maintenance costs are defined annually based on inspections and Annual Condition Index AIC which is based on condition/age relationship (e.g. Heat, Ventilation and Air Conditioning items HVAC).
4. Breaking Rate Category: the lifecycle cost calculation for this category is based on the Expected Annual Cost that follows the chosen repair policy over the item lifecycle.

The above mentioned categories are calculated in this module as follows:

3.6.3.2.1 Operating time-based maintenance category

3.6.3.2.1.1 Potable water

In order to achieve the best combination for the working pumps (as an example of time-related maintenance equipment categories) over their lifetime, the model changes the selection of the operating pumps over time unit (e.g. a week or a month) and optimizes the selection in way that the number of the

operating pump at any time is assured to provide the requested demand profile. This profile is obtained from RESOM. The model optimizes the selection of the operating pumps schedule that minimizes the operating expenditure. As the problem is dealing with uncertainty in terms of future water demand profile (RESOM output) which is function of future end users' occupancy that follows unforeseen risk impacted implementation schedules. Therefore, the Crystal Ball simulation technique is applied to simulate both the original feasibility based demand (the larger amounts) versus the risk-impacted demand (less amounts) of potable water consumption. The simulation may follow for example the Normal or other distribution that suits the cases under consideration. In case of applying the Normal distribution, the minimum monthly water demand represents the risk event-related profile while the maximum monthly demand values represent the original feasibility-based quantities as shown in Figure 3.41. Both the minimum and maximum values are originated as RESOM output as illustrated in Figure 3.42.

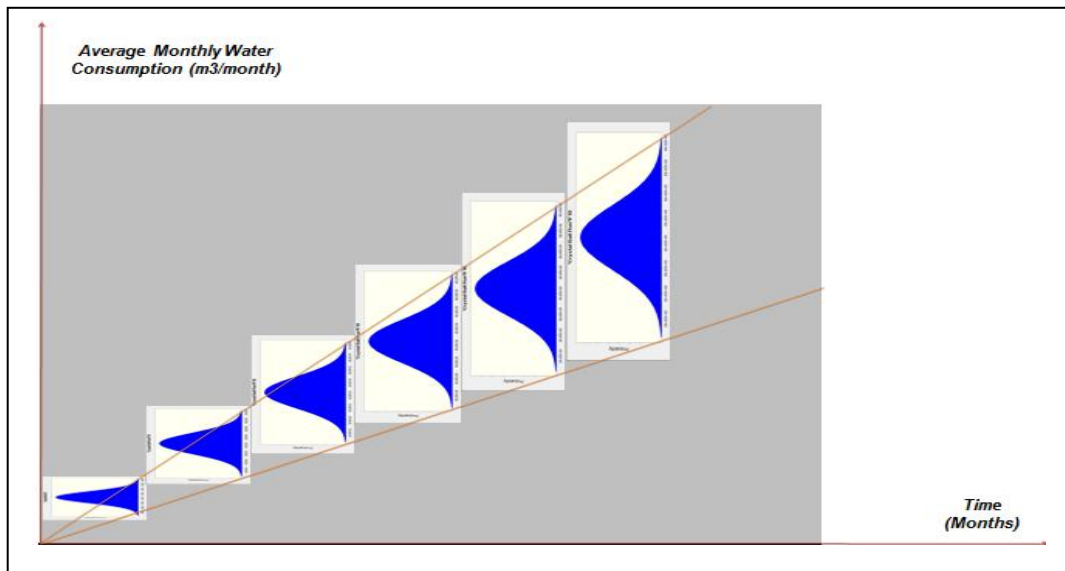


Figure 3-41: Simulation Based Modeling Description for potable water demand

3.6.3.2.1.2 Irrigation water:

Similar to the potable water, the irrigation water profile updates are obtained from SLOM model output. Through periodic application of SLOM, it is possible to change the plant mix and hence reduces the irrigation water demand shown in Figure 3.42.

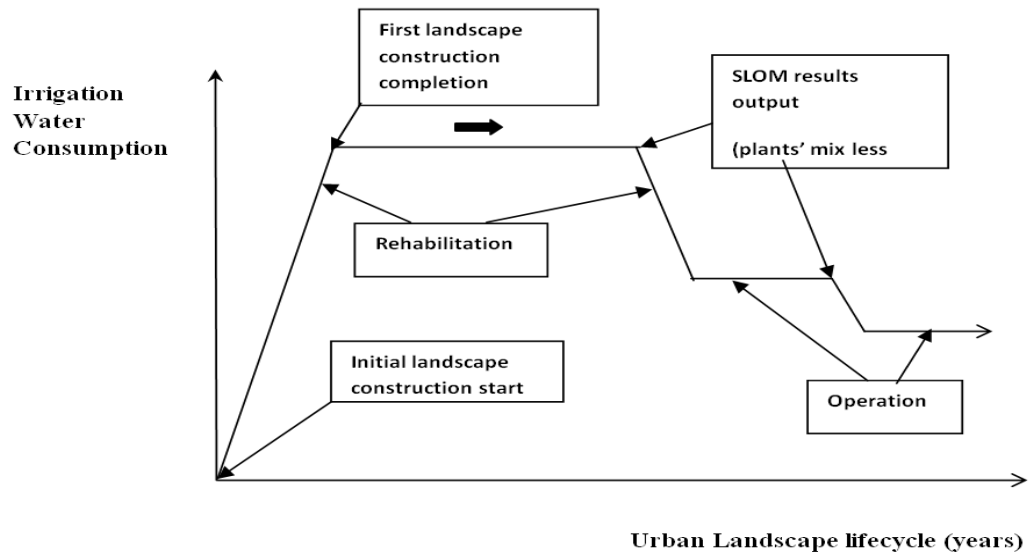


Figure 3-42: SLOM Implementation during Landscape Lifecycle, Impact on Irrigation water lifecycle demand

As explained above, this module provides operation/maintenance schedule of the equipment sets included in this category as shown in Figure 3.43 and 3.44.

30												
Jan-41	Feb-41	Mar-41	Apr-41	May-41	Jun-41	Jul-41	Aug-41	Sep-41	Oct-41	Nov-41	Dec-41	
												0
2	2	2	2	2	2	2	2	2	2	2	2	696
0	0	0	0	0	0	0	0	0	0	0	0	0
300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	300,000	98,110,204.50
612	612	612	612	612	612	612	612	612	612	612	612	
2	2	2	2	2	2	2	2	2	2	2	2	
0	0	0	0	0	0	0	0	0	0	0	0	678,000.00
0	0	0	0	0	0	0	0	0	0	0	0	8,000.00
0	0	0	0	0	0	0	0	0	0	0	0	668,000.00
												2,114,000.00
0	0	0	0	0	0	0	0	0	0	0	0	-
0	0	0	0	0	0	0	0	0	0	0	0	-
0	0	0	0	0	0	0	0	0	0	0	0	-
												0

Total Maintenance Costs (EGP)	Total Construction Costs (EGP)	Total Life Cycle Costs LCC - (EGP)
2,114,000.00	10,348,946.83	12,462,946.83

DATA OUTPUT

Lifecycle cost output for the time-maintenance category

Figure 3-44: Operating/Maintenance Schedule Output (WSOM calculation for the operating time-based category).

3.6.3.2.2 Fixed Rate Expenditure Category

This type of expenditure is allowed for those items having maintenance budget that is a percentage of its construction initial cost, such as the civil and architectural items. In some cases, this category may be shared between both the irrigation and potable equipment since both sets may be located in the same building for cost efficiency purposes. However both systems are totally separated for hygienic purposes. The sheets used for the calculation process is shown in Figure 3.45. The operating expenditure in this category is shared between both the potable and irrigation systems.

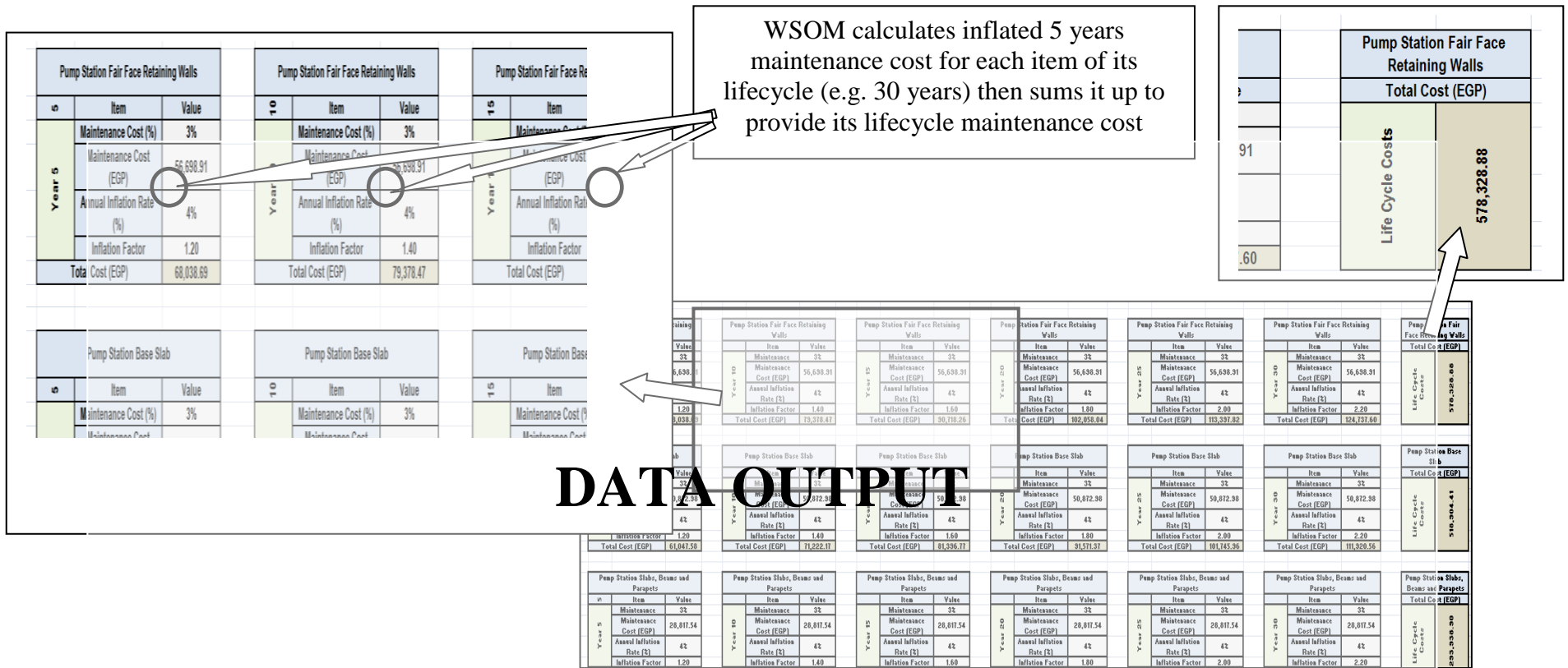
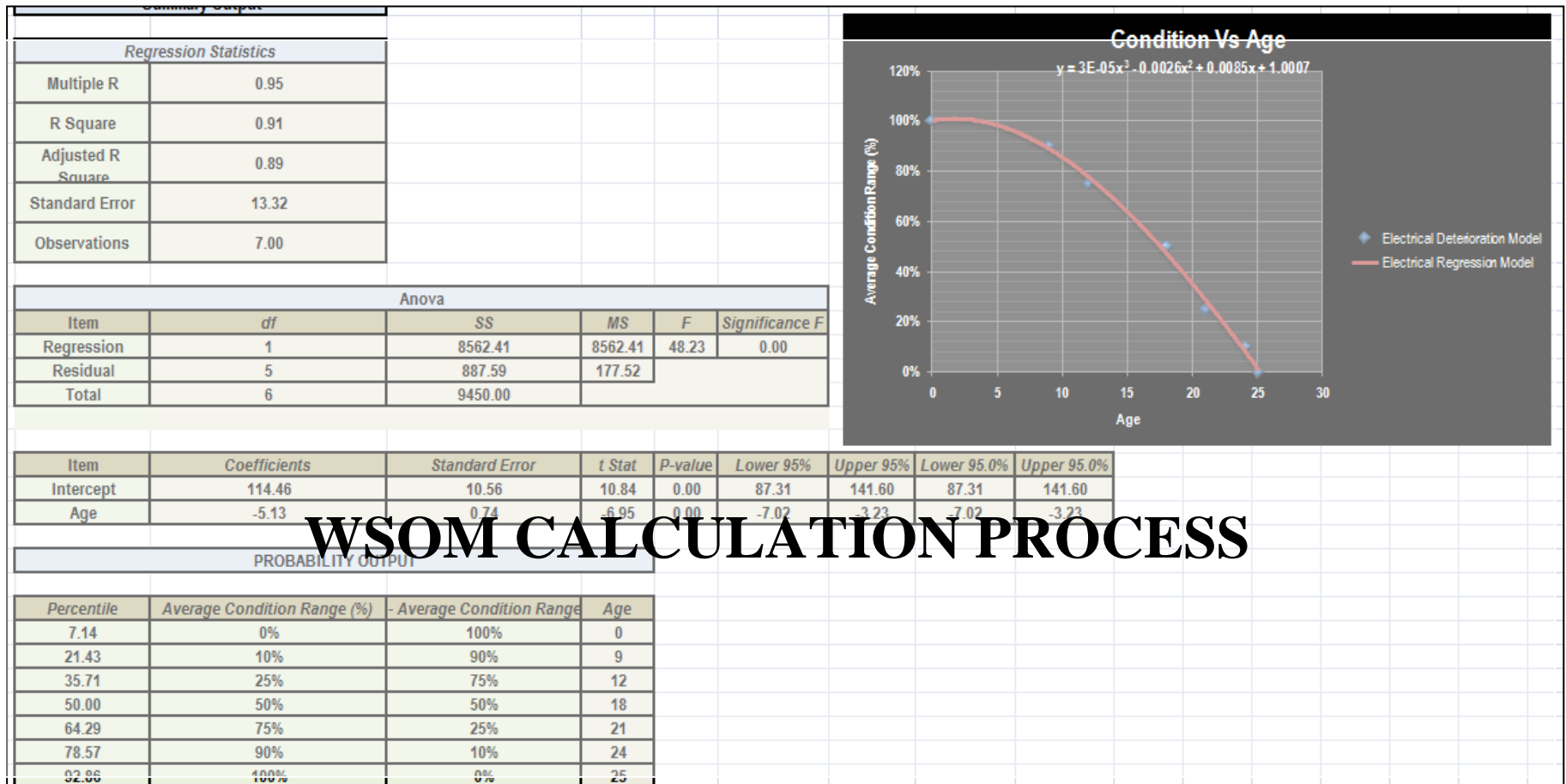


Figure 3-45: Cash-Out calculation for the Fixed-Rate expenditure category (WSOM Output)

3.6.3.2.3 Regression-based deterioration category

The regression modeling is applied in cases of the items that follow non-linear deterioration rates, such as electromechanical items, HVAC items and electrical items. The regression modeling uses the information in the database module that is originally collected from experts in the specialty. Upon calculating the condition/age annually, the regression model provides a graph that is plotted for the age and the condition and expresses their relationship in the form of an equation as indicated in Figure 3.46. The applied policy for maintenance represented by integer digits 0, 1 and 2. The ACI should be a certain limit (> 1.5 for example) to assure better condition and customer satisfaction.

The module thus provides each item's condition represented by the "Annual Condition Index" or the "ACI". The ACI is an integer on a "1" to "5" digital scale that indicates the item's annual condition. The digit "5" refers to an item whose condition is new or at an "Excellent" condition. The digit "1" refers to a "Failing" condition or 0% of its condition. The digits 2, 3 and 4 refers to "Good", "Fair" and "Poor" status respectively. The main output of this module is the term (ACI/LCC) where LCC is the Lifecycle cost. Details concerning the calculations of this module will be further explained in the remaining modules. This is shown in Figure 3.47 and 3.48. The calculation process is indicated in Figure 3.49. The final result is the summation of all costs for all items over the lifecycle (e.g. 30 years). The same principle of this category applies for both potable and irrigation systems.



WSOM CALCULATION PROCESS

Figure 3-46: Determination of the Actual Condition/Age relationship for the Regression-Based deterioration Category

Condition State	Range (%)
Excellent	90 -- 100
Good	75 -- 90
	60 -- 75
Fair	40 -- 60
Poor	25 -- 40
	10 -- 25
Failing	0 -- 10

Condition State	Average Condition Range (%)	Age (Years)
Excellent	100%	0
Good	90%	9
	75%	12
Fair	50%	18
Poor	25%	21
	10%	24
Failing	0%	25

Item	Initial Cost (EGP)
Axial exhaust fan with gravity damper, operating switch	23,419.89
Inline centrifugal exhaust fan with gravity damper, operating switch (one standby operated with temperature sensor)	118,900.08
Split type air conditioning unit	71,695.26
Galvanized steel duct with flexible connection Suspension Erection,	4,864.86

Decision Variables Abbreviations	Effect After applying this policy
0	Do Nothing Nothing happens
1	Rehabilitate (Reaches 90% of it's condition) Returns to 90% of its condition (Reaches age of 8 years)
2	Replace Replaced with a new one

Rehabilitation Cost (%)	3%
Increase in Rehabilitation Cost (%)	3%

WSOM CALCULATION PROCESS

Figure 3-47: Data Input for the Regression-based Deterioration Category

Axial exhaust fan with gravity damper, operating switch												
Year	Decision Variable	Applied Decision Policy	Age After Applying Decision Policy	Condition After Applying the Decision Policy	Condition State After Applying Decision Policy	Maintenance Cost (EGP)	Replacement Cost (EGP)	Rehabilitation Cost (EGP)	Total Annual Cost (EGP)	Cummulative Cost (EGP)	Annual ACI	(ACI/Annual Cost)*1000
1	0	Do Nothing	0	100%	Excellent	702.60	0.00	0.00	702.60	702.60	5.00	7.12
2	0	Do Nothing	1	100%	Excellent	730.70	0.00	0.00	730.70	1,433.30	5.00	6.84
3	0	Do Nothing	2	100%	Excellent	758.80	0.00	0.00	758.80	2,192.10	5.00	6.59

WSOM calculates the annual maintenance cost for each of the items included in the Regression-based deterioration category, then sums up all the costs to obtain the lifecycle maintenance cost for the category items

Axial exhaust fan with gravity damper, operating switch												
Year	Decision Variable	Applied Decision Policy	Age After Applying Decision	Condition After Applying the Decision Policy	Condition State After Applying Decision Policy	Maintenance Cost (EGP)	Replacement Cost (EGP)	Rehabilitation Cost (EGP)	Total Annual Cost (EGP)	Cummulative Cost (EGP)	Annual ACI	(ACI/Annual Cost)*1000
1	0	Do Nothing	0	100%	Excellent	702.60	0.00	0.00	702.60	702.60	5.00	7.12
2	0	Do Nothing	1	100%	Excellent	730.70	0.00	0.00	730.70	1,433.30	5.00	6.84
3	0	Do Nothing	2	100%	Excellent	758.80	0.00	0.00	758.80	2,192.10	5.00	6.59
4	0	Do Nothing	3	100%	Excellent	786.91	0.00	0.00	786.91	2,979.01	5.00	6.35
5	0	Do Nothing	4	100%	Excellent	815.01	0.00	0.00	815.01	3,794.02	4.99	6.10
6	0	Do Nothing	5	98%	Excellent	843.12	0.00	0.00	843.12	4,637.14	4.91	5.85
7	0	Do Nothing	6	96%	Excellent	871.22	0.00	0.00	871.22	5,508.36	4.82	5.54
8	0	Do Nothing	7	94%	Excellent	899.32	0.00	0.00	899.32	6,407.68	4.72	5.24
9	0	Do Nothing	8	92%	Excellent	927.43	0.00	0.00	927.43	7,335.11	4.59	4.95
10	0	Do Nothing	9	89%	Good	955.53	0.00	0.00	955.53	8,290.64	3.55	3.72
11	0	Do Nothing	10	86%	Good	983.64	0.00	0.00	983.64	9,274.28	3.42	3.48
12	0	Do Nothing	11	83%	Good	1,011.74	0.00	0.00	1,011.74	10,286.02	3.28	3.24
13	0	Do Nothing	12	80%	Good	1,039.85	0.00	0.00	1,039.85	11,325.86	3.12	3.00
14	0	Do Nothing	13	77%	Good	1,067.95	0.00	0.00	1,067.95	12,393.81	2.95	2.76
15	0	Do Nothing	14	73%	Good	1,096.05	0.00	0.00	1,096.05	13,489.86	2.77	2.53
16	0	Do Nothing	15	69%	Good	1,124.15	0.00	0.00	1,124.15	14,614.01	2.58	2.30
17	0	Do Nothing	16	64%	Fair	1,152.26	0.00	0.00	1,152.26	15,766.27	1.78	1.55
18	0	Do Nothing	17	59%	Fair	1,180.36	0.00	0.00	1,180.36	16,946.63	1.62	1.38
19	0	Do Nothing	18	53%	Fair	1,208.47	0.00	0.00	1,208.47	18,155.10	1.46	1.21
20	0	Do Nothing	19	47%	Fair	1,236.57	0.00	0.00	1,236.57	19,391.67	1.29	1.04
21	0	Do Nothing	20	41%	Poor	1,264.67	0.00	0.00	1,264.67	20,656.34	0.74	0.59
22	0	Do Nothing	21	35%	Poor	1,292.78	0.00	0.00	1,292.78	21,949.12	0.62	0.48
23	0	Do Nothing	22	29%	Poor	1,320.88	0.00	0.00	1,320.88	23,270.00	0.50	0.38
24	0	Do Nothing	23	23%	Poor	1,348.99	0.00	0.00	1,348.99	24,619.99	0.37	0.28
25	0	Do Nothing	24	17%	Poor	1,377.09	0.00	0.00	1,377.09	25,997.08	0.24	0.18
26	0	Do Nothing	25	11%	Failing	1,405.19	0.00	0.00	1,405.19	27,402.27	0.06	0.04
27	0	Do Nothing	26	-5%	Failing	1,433.30	0.00	0.00	1,433.30	28,834.57	-0.01	-0.01
28	0	Do Nothing	27	-11%	Failing	1,461.40	0.00	0.00	1,461.40	30,295.97	-0.07	-0.05
29	0	Do Nothing	28	-17%	Failing	1,489.51	0.00	0.00	1,489.51	31,785.47	-0.14	-0.09
30	0	Do Nothing	29	-21%	Failing	1,517.61	0.00	0.00	1,517.61	33,303.08	-0.21	-0.14
Total											73.94	82.40

Figure 3-48: WSOM calculation sheet for the Regression-based category

Total Electrical Works												
Year	Decision Variable	Applied Decision Policy	Age After Applying Decision Policy	Condition After Applying the Decision Policy	Condition State After Applying Decision Policy	Maintenance Cost (EGP)	Replacement Cost (EGP)	Rehabilitation Cost (EGP)	Total Annual Cost (EGP)	Cummulative Cost (EGP)	Annual ACI	(ACI/Annual Cost) * 1000,000
1	0	Do Nothing	0	100%	Excellent	105,824.12	0.00	0.00	105,824.12	105,824.12	5.00	47.25
2	0	Do Nothing	1	100%	Excellent	110,057.08	0.00	0.00	110,057.08	215,881.20	5.00	45.43

Year	Decision Variable	Applied Decision Policy	Age After Applying Decision Policy	Condition After Applying the Decision Policy	Condition State After Applying Decision Policy	Maintenance Cost (EGP)	Replacement Cost (EGP)	Rehabilitation Cost (EGP)	Total Annual Cost (EGP)	Cummulative Cost (EGP)	Annual ACI	(ACI/Annual Cost) * 1000,000
3	0	Do Nothing	2	100%	Excellent	114,319.88	0.00	0.00	114,319.88	330,199.38	5.00	43.79
4	0	Do Nothing	3	100%	Excellent	118,823.88	0.00	0.00	118,823.88	449,023.26	4.98	41.83
5	0	Do Nothing	4	100%	Excellent	123,388.97	0.00	0.00	123,388.97	572,412.23	4.96	40.03
6	0	Do Nothing	5	100%	Excellent	128,026.94	0.00	0.00	128,026.94	700,439.17	4.94	38.55
7	0	Do Nothing	6	100%	Excellent	132,748.88	0.00	0.00	132,748.88	833,188.05	4.92	37.31
8	0	Do Nothing	7	100%	Excellent	137,555.87	0.00	0.00	137,555.87	970,743.92	4.90	36.21
9	0	Do Nothing	8	100%	Excellent	142,448.92	0.00	0.00	142,448.92	1,113,192.84	4.88	35.23
10	0	Do Nothing	9	100%	Excellent	147,428.04	0.00	0.00	147,428.04	1,260,620.88	4.86	34.35
11	0	Do Nothing	10	100%	Excellent	152,493.24	0.00	0.00	152,493.24	1,413,114.12	4.84	33.55
12	0	Do Nothing	11	100%	Excellent	157,644.54	0.00	0.00	157,644.54	1,570,758.66	4.82	32.81
13	0	Do Nothing	12	100%	Excellent	162,881.94	0.00	0.00	162,881.94	1,733,640.60	4.80	32.13
14	0	Do Nothing	13	100%	Excellent	168,205.44	0.00	0.00	168,205.44	1,901,846.04	4.78	31.51
15	0	Do Nothing	14	100%	Excellent	173,615.04	0.00	0.00	173,615.04	2,075,461.08	4.76	30.93
16	0	Do Nothing	15	100%	Excellent	179,110.74	0.00	0.00	179,110.74	2,254,571.82	4.74	30.40
17	0	Do Nothing	16	100%	Excellent	184,692.54	0.00	0.00	184,692.54	2,439,264.36	4.72	29.91
18	0	Do Nothing	17	100%	Excellent	190,360.44	0.00	0.00	190,360.44	2,629,624.80	4.70	29.45
19	0	Do Nothing	18	100%	Excellent	196,114.44	0.00	0.00	196,114.44	2,825,739.24	4.68	29.03
20	0	Do Nothing	19	100%	Excellent	201,954.54	0.00	0.00	201,954.54	3,027,693.78	4.66	28.64
21	0	Do Nothing	20	100%	Excellent	207,880.74	0.00	0.00	207,880.74	3,235,574.52	4.64	28.28
22	0	Do Nothing	21	100%	Excellent	213,893.04	0.00	0.00	213,893.04	3,449,467.56	4.62	27.94
23	0	Do Nothing	22	100%	Excellent	219,991.44	0.00	0.00	219,991.44	3,669,461.00	4.60	27.61
24	0	Do Nothing	23	100%	Excellent	226,175.84	0.00	0.00	226,175.84	3,895,636.84	4.58	27.29
25	0	Do Nothing	24	100%	Excellent	232,446.24	0.00	0.00	232,446.24	4,128,083.08	4.56	26.98
26	0	Do Nothing	25	100%	Excellent	238,802.64	0.00	0.00	238,802.64	4,366,885.72	4.54	26.68
27	0	Do Nothing	26	100%	Excellent	245,245.04	0.00	0.00	245,245.04	4,612,130.76	4.52	26.39
28	0	Do Nothing	27	100%	Excellent	251,773.44	0.00	0.00	251,773.44	4,863,904.20	4.50	26.11
29	0	Do Nothing	28	100%	Excellent	258,387.84	0.00	0.00	258,387.84	5,132,292.04	4.48	25.84
30	0	Do Nothing	29	100%	Excellent	265,088.24	0.00	0.00	265,088.24	5,417,380.28	4.46	25.58
31	0	Do Nothing	30	100%	Excellent	271,874.64	0.00	0.00	271,874.64	5,719,254.92	4.44	25.33
32	0	Do Nothing	31	100%	Excellent	278,747.04	0.00	0.00	278,747.04	6,038,001.96	4.42	25.08
33	0	Do Nothing	32	100%	Excellent	285,705.44	0.00	0.00	285,705.44	6,373,707.40	4.40	24.84
34	0	Do Nothing	33	100%	Excellent	292,749.84	0.00	0.00	292,749.84	6,726,457.24	4.38	24.61
35	0	Do Nothing	34	100%	Excellent	299,880.24	0.00	0.00	299,880.24	7,096,337.48	4.36	24.38
36	0	Do Nothing	35	100%	Excellent	307,087.64	0.00	0.00	307,087.64	7,483,425.12	4.34	24.16
37	0	Do Nothing	36	100%	Excellent	314,372.04	0.00	0.00	314,372.04	7,887,797.16	4.32	23.94
38	0	Do Nothing	37	100%	Excellent	321,733.44	0.00	0.00	321,733.44	8,309,530.60	4.30	23.73
39	0	Do Nothing	38	100%	Excellent	329,171.84	0.00	0.00	329,171.84	8,748,702.44	4.28	23.53
40	0	Do Nothing	39	100%	Excellent	336,687.24	0.00	0.00	336,687.24	9,205,389.68	4.26	23.34

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29	0	Do Nothing	18	49%	Fair	224,347.13	0.00	0.00	224,347.13	8,245,815.13	1.46	6.50
30	0	Do Nothing	19	43%	Fair	228,580.09	0.00	0.00	228,580.09	8,474,395.23	1.29	5.64

WSOM provides the Cash-Out for the Regression Category

Figure 3-49: WSOM calculated lifecycle maintenance cost for the Regression-based category

3.6.3.2.4 Breaking Rate Category

This type is used for those items whose deterioration is represented by the breaking rate such as pipes. The breakage rate / age relation is developed to predict the average failure time for the pipes depending on the pipes material. The module relates the action to take whether repair or replacement depending on the number of failures that increases dramatically by time. The same principle of this category applies for both potable and irrigation systems.

An example of WSOM input for this category within the potable water system is shown in Figure 3.50. This input is considered as norm of the industry and is collected from experts in the field. The calculation process and the results sheets are illustrated in Figures 3.51, 3.52 and 3.53.

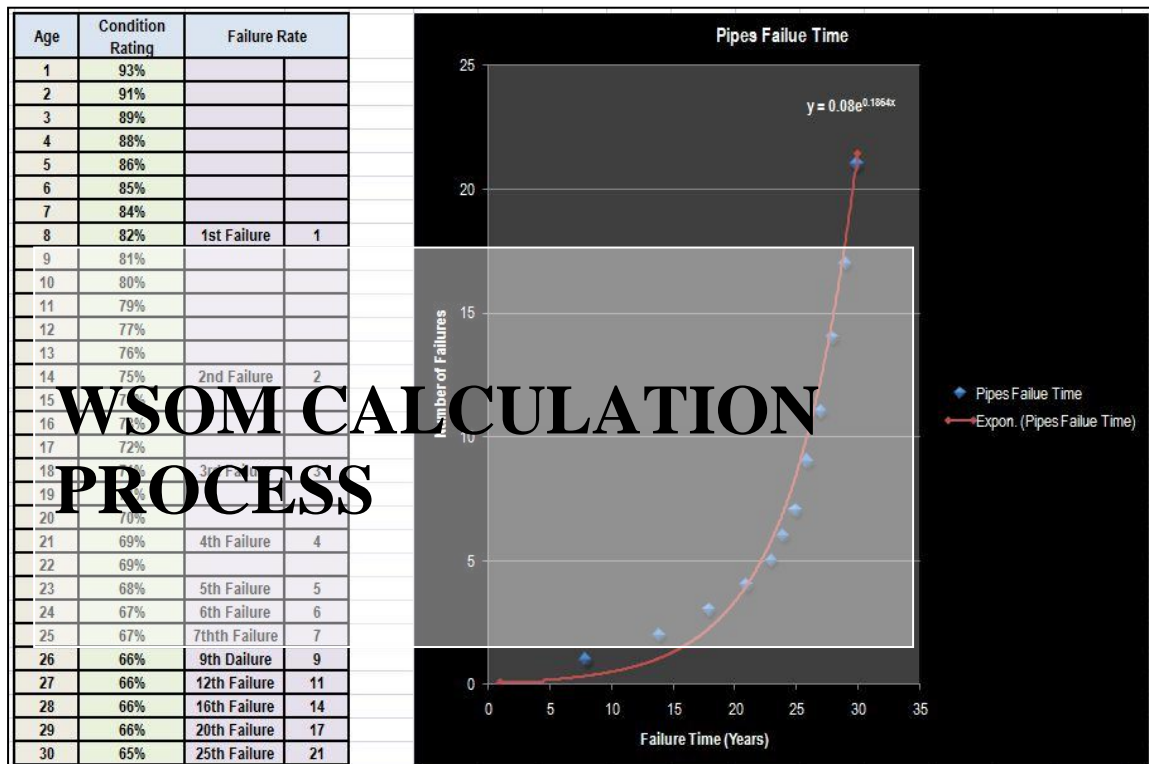


Figure 3-50: Breaking rate calculation (no. of failures versus failure time)

Pipe Type & Material	Pipe Diameter	Initial Cost (EGP)	Pipe Length (K.M)
Polyethylene pipes	355	250,449.74	0.31
Polyethylene pipes	280	530,246.26	0.98
Polyethylene pipes	225	1,803,891.28	4.86
Polyethylene pipes	180	598,189.92	1.43
Polyethylene pipes	125	36,733.58	0.31
Polyethylene pipes	63	124,731.39	1.08
Polyethylene pipes	50	9,496.42	0.08
Total Pipe-Line Pipes	Varies	3,280,341.24	9.14

Figure 3-51: Summary sheet of the input/output for the breaking rate category

Year	Failure Rate (Number of Failures)	Failure Repair Cost (EGP)	Cummulative Cost (EGP)	Total Failure Repair Costs (EGP)	Expected Annual Cost (EAC) for the Failure Repair Policy
1	0	0	0	6,974,005.48	232,466.85
2	0	0	0		
3	0	0	0		
4	0	0	0		
5	0	0	0		
6	0	0	0		
7	0	0	0		
8	0	0	0		
9	0	0	0		
10	0	0	0		
11	0	0	0		
12	0	0	0		
13	0	0	0		
14	1	255866.6168	255866.6168		
15	0	0	255866.6168		
16	0	0	255866.6168		
17	0	0	255866.6168		
18	1	282109.3468	537975.9636		
19	0	0	537975.9636		
20	1	295230.7117	833206.6753		
21	1	301791.3942	1134998.069		
22	0	0	1134998.069		
23	1	314912.7592	1449910.829		
24	2	642946.8833	2092857.712		
25	1	328034.1241	2420891.836		
26	2	669189.6132	3090081.449		
27	2	682310.9782	3772392.427		
28	2	695432.3432	4467824.771		
29	3	1062830.562	5530655.333		
30	4	1443350.146	6974005.479		

Figure 3-52: Calculation process for the breaking rate category

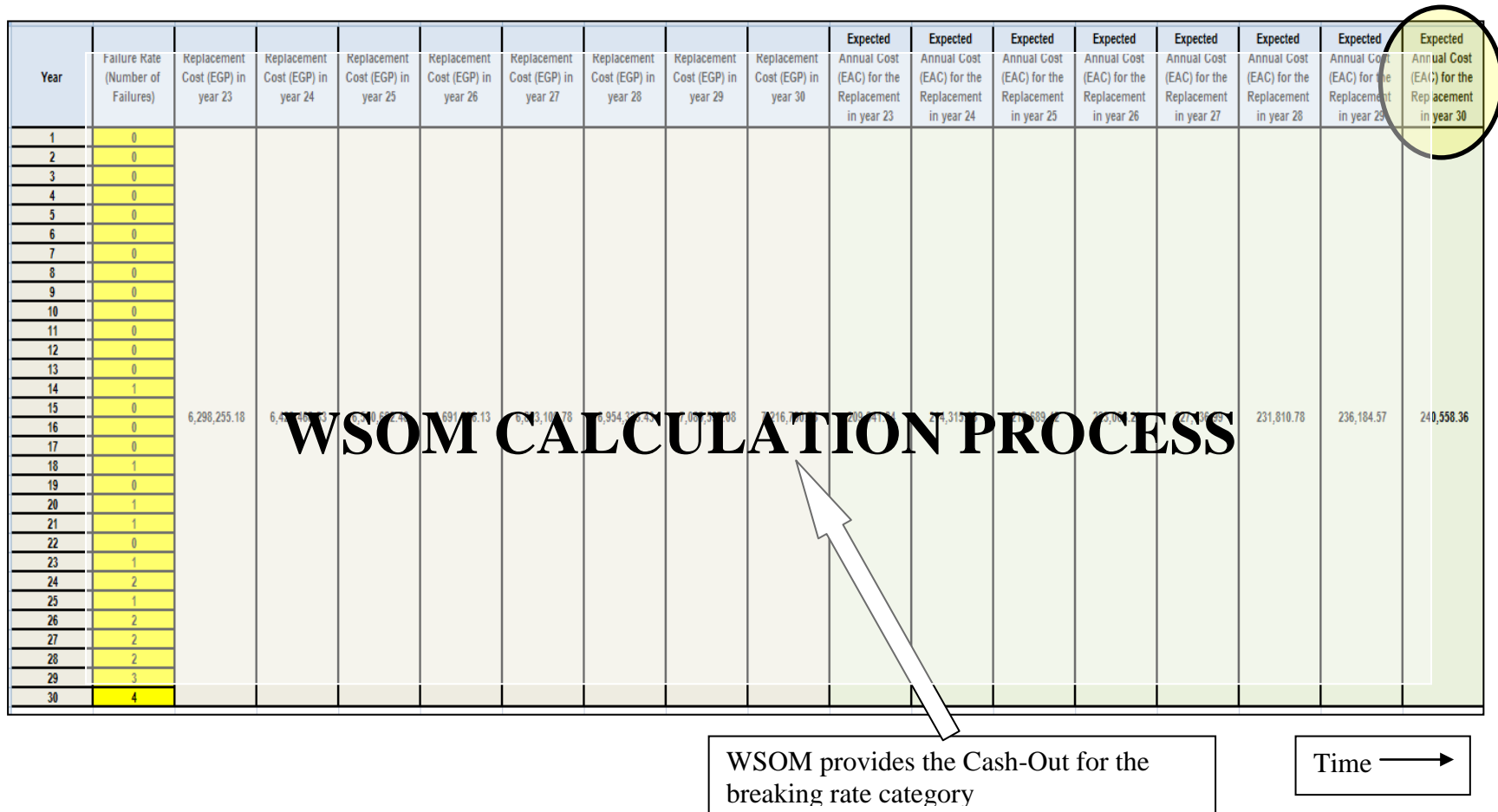


Figure 3-53: Summary Results for the Breaking Rate Category

3.6.3.3 Financial Module

At the end of the process, the financial module generates annual maintenance costs for each included item and then for both potable and the irrigation water supply systems together in case of combined water systems. The module uses the monetary information in the database module (construction cost, maintenance and rehabilitation cost) and the condition rate provided by the deterioration module. Depending on the deterioration category classification, the financial module calculates the Cash-Out that is then used by RESOM to calculate the NPV Expected Gross Profit of the system. In addition to calculating the system's construction cost, it calculates the operating cost and Cash-Out for each of the categories included in the water system as follows:

3.6.3.3.1 Operating time-based maintenance category

The Financial Module calculates the preventative maintenance costs for the items which relates to their number of operating hours. Certain cost is assigned for preventive maintenance as soon as the operating hours reach certain limit. Inflation rate percentage is considered and applied in the calculations.

The Financial module calculates the Cash-Out of the preventive maintenance cost (time-related maintenance category) for different generated operating/scheduling time scenario for the available item sets (pumps for example). The model represents the status of the operating items or components under this category whether operating or idle by applying the binary system to indicate 1 and 0 for operating / not operating respectively. This number is colored in black/white scale to indicate the operating/non-operating status. This is shown in Figure 3.54.

Year	1								8							
Pump/Month	Jan-12	Feb-12	Mar-12	Aug-18	Sep-18	Oct-18	Nov-18	Dec-18	Jan-19	Feb-19	Mar-19	Apr-19	May-19	Jun-19	Jul-19	Aug-19
Pump 1 (4,800,000 m3/hr)																
Pump 2 (4,800,000 m3/hr)																
Pump 3 (4,800,000 m3/hr)																
Actual Working Pumps	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Check	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Actual Consumption (m3/day)	12,932	12,932	12,932	190,000	190,000	190,000	190,000	190,000	190,000	190,000	217,000	217,000	217,000	217,000	217,000	217,000
Required Consumption (m3/hr)	306	306	306	306	306	306	306	306	306	306	306	306	306	306	306	306
Required Number of Working Pumps	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Maintenance Cost (EGP) of Pump 1	0	0	0	0	64,000	0	0	0	0	0	0	0	0	0	0	0
Maintenance Cost (EGP) of Pump 2	0	0	0	64,000	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance Cost (EGP) of Pump 3	0	0	0	0	0	64,000	0	0	0	0	0	0	0	0	0	0
Maintenance Constraint of Pump 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance Constraint of Pump 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Maintenance Constraint of Pump 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

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WSOM allocated preventive maintenance cost each certain running time of each item included in this category

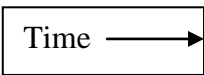


Figure 3-54: Financial module - Operating time-based category (optimized operating schedule and Cash-Out)

3.6.3.3.2 Fixed rate expenditure category

This module assumes the maintenance cost as a fixed percentage of the initial capital expenditure CAPEX that includes for example the civil works. Moreover, the deterioration of this category uses a fixed maintenance cost percentage and preventative maintenance frequency from the database module of the selected item. It allows the user to track the annually cost for each item in order to provide much more control for all the category items' lifecycle costs. The module calculates the costs for both the buildings and civil works that are shared between both the irrigation and potable water systems.

3.6.3.3.3 Regression-based deterioration category

As part of the financial module, the Cash-Out calculation of the regression-based deterioration items, in both the potable and irrigation water systems, is calculated. As discussed above, an equation is developed to represent the relation between the condition and age. Moreover, three cost types are considered in this module (Figure 3.55) as follows:

3.6.3.3.1 Maintenance cost

This cost covers the annual maintenance needed to ensure that the item's deterioration rate continues with its previous estimate. It represents a certain percentage of the initial cost which increases annually by an inflation rate (%).

3.6.3.3.2 Rehabilitation cost

This cost covers the rehabilitation needed to extend the service life time of the item. The rehabilitation cost is considered as a percentage of the initial cost and increases by time depending on the year under consideration; this is due to the non-linear deterioration of the item over time. In addition, an annual inflation rate (I %) is applied to the obtained cost.

3.6.3.3.3 Replacement (or reconstruction) cost

This cost covers the item replacement cost and includes its escalated initial cost with an inflation rate that is considered at the year of replacement.

The variables in the regression-based category are represented by three digital codes:

- *0 for a "Do nothing" action,*
- *1 for "Rehabilitate and reach 90% of the condition" action, and*
- *2 for "Replace" action.*

Year	Applied Decision Policy	Age After Applying Decision Policy	Condition State After Applying Decision Policy	Maintenance Cost (EGP)	Replacement Cost (EGP)	Rehabilitation Cost (EGP)	Total Annual Cost (EGP)	Cummulative Cost (EGP)
1	Do Nothing	0	Excellent	105,824.12	0.00	0.00	105,824.12	105,824.12
2	Do Nothing	1	Excellent	110,057.08	0.00	0.00	110,057.08	215,881.20
3	Do Nothing	2	Excellent	114,290.05	0.00	0.00	114,290.05	330,171.24
4	Do Nothing	3	Excellent	118,523.01	0.00	0.00	118,523.01	448,694.25
5	Do Nothing	4	Excellent	122,755.97	0.00	0.00	122,755.97	571,450.23
6	Do Nothing	5	Excellent	126,988.94	0.00	0.00	126,988.94	698,439.17
7	Do Nothing	6	Excellent	131,221.90	0.00	0.00	131,221.90	829,661.07
8	Do Nothing	7	Excellent	135,454.87	0.00	0.00	135,454.87	965,115.94
9	Do Nothing	8	Excellent	139,687.83	0.00	0.00	139,687.83	1,104,803.77
10	Do Nothing	9	Good	143,920.80	0.00	0.00	143,920.80	1,248,724.57
11	Do Nothing	10	Good	148,153.76	0.00	0.00	148,153.76	1,396,878.33
12	Do Nothing	11	Good	152,386.73	0.00	0.00	152,386.73	1,549,265.06
13	Do Nothing	12	Good	156,619.69	0.00	0.00	156,619.69	1,705,884.75
14	Do Nothing	13	Good	160,852.66	0.00	0.00	160,852.66	1,866,737.41
15	Do Nothing	14	Good	165,085.62	0.00	0.00	165,085.62	2,031,823.03
16	Do Nothing	15	Good	169,318.59	0.00	0.00	169,318.59	2,201,141.62
17	Do Nothing	16	Fair	173,551.55	0.00	0.00	173,551.55	2,374,693.17
18	Do Nothing	17	Fair	177,784.52	0.00	0.00	177,784.52	2,552,477.68
19	Do Nothing	18	Fair	182,017.48	0.00	0.00	182,017.48	2,734,495.16
20	Do Nothing	19	Fair	186,250.44	0.00	0.00	186,250.44	2,920,745.61
21	Do Nothing	20	Poor	190,483.41	0.00	0.00	190,483.41	3,111,229.02
22	Do Nothing	21	Poor	194,716.37	0.00	0.00	194,716.37	3,305,945.39
23	Do Nothing	22	Poor	198,949.34	0.00	0.00	198,949.34	3,504,894.73
24	Do Nothing	23	Poor	203,182.30	0.00	0.00	203,182.30	3,708,077.03
25	Do Nothing	24	Poor	207,415.27	0.00	0.00	207,415.27	3,915,492.30
26	Do Nothing	25	Failing	211,648.23	0.00	0.00	211,648.23	4,127,140.53
27	Do Nothing	26	Failing	215,881.20	0.00	0.00	215,881.20	4,343,021.73
28	Rehabilitate	8	Excellent	220,114.16	0.00	6,163,196.53	6,383,310.69	10,726,332.42
29	Do Nothing	9	Good	224,347.13	0.00	0.00	224,347.13	10,950,679.54
30	Do Nothing	10	Good	228,580.09	0.00	0.00	228,580.09	11,179,259.64

Figure 3-55: The Financial Module - Regression-based Deterioration Category

3.6.3.3.4 Breaking rate category

A separate financial module was applied for the breaking rate category items such as pipes in both the irrigation and potable water systems. As illustrated above, an equation was derived that represents the relation between the failure rate and the age. Moreover, there were several types of costs introduced to this module, namely:

3.6.3.3.4.1 Failure repair cost:

It is the costs of repairing any failure. The failure repair costs include a fixed cost for repairing the failure and the year under consideration. The annual inflation rate (%) is considered as well.

3.6.3.3.4.2 Replacement cost:

This cost covers the item replacement cost and includes its escalated initial cost with an inflation rate that is considered at the year of replacement.

The model is based on the concept of “Expected Annual Cost (EAC)”, which means that all the costs necessary to maintain a certain condition are spread over the useful lifetime. For the breaking rate category items, different policies

were applied and a detailed analysis was performed to obtain the annual cost of each alternative and decide which one to be applied. The different alternatives for this category are as follows:

1. Replace the item when the failure occurs.
2. Replace the whole category after a certain time, where the decision making tool recognizes as appropriate to meet the condition requirements.

This is shown in Figure 3.56.

Year	Failure Rate (Number of Failures)	Failure Repair Cost (EGP)	Cummulative Cost (EGP)	Total Failure Repair Costs (EGP)	Expected Annual Cost (EAC) for the Failure Repair Policy
1	0	0	0	6,974,005.48	232,466.85
2	0	0	0		
3	0	0	0		
4	0	0	0		
5	0	0	0		
6	0	0	0		
7	0	0	0		
8	0	0	0		
9	0	0	0		
10	0	0	0		
11	0	0	0		
12	0	0	0		
13	0	0	0		
14	1	255866.6168	255866.6168		
15	0	0	255866.6168		
16	0	0	255866.6168		
17	0	0	255866.6168		
18	1	32104.468	53797.083		
19	0	0	53797.083		
20	1	295230.7117	833206.6753		
21	1	30199.19	113919.865		
22	0	0	113919.865		
23	1	314912.7592	1449910.829		
24	2	642946.8833	2092857.712		
25	1	328034.1241	2420891.836		
26	2	669189.6132	3090081.449		
27	2	682310.9782	3772392.427		
28	2	695432.3432	4467824.771		
29	3	1062830.562	5530655.333		
30	4	1443350.146	6974005.479		

**WSOM CALCULATION
PROCESS**

N.B: The annual/regular maintenance activities take place in both alternatives.

Figure 3-56: The Financial module - Breaking Rate Category

3.6.3.4 Optimization Engine

The last module in WSOM is the optimization engine which functions on top of the developed model. EVOLVER™ V.5.5 add-in for Excel® is used. It suits the complexity of the problem in hand. The Genetic Algorithm optimization

engine searches for the optimized solution by comparing different rehabilitation policies corresponding to the total lifecycle cost and end users' satisfaction. Three separate optimization runs were developed for the regression-based category, breaking rate category and Operating time-based maintenance category respectively for both the water and irrigation systems.

3.6.4 External Public System

As stated above, the boundary line of the gated community is the connecting point of potable water in both the public and private systems. The main water system outside the gated community was constructed, operated and managed usually by a public company. It is a company responsible to provide potable or irrigation water and tie it in to private communities at the outside boundary. The second sub-system deals with the integrating sub-system until reaching the end user's premises. Both systems charges the end user against the service they provide through one bill from the private company which interfaces with the end users inside the community through the so called "City Management" entity. Although the public company charges are usually decided at national level, the privately operated sub-system is more flexible in terms of efficiency and control. Our research focuses on the second subsystem and its economies where it considered its lifecycle management aspects, its efficiency and how to optimize its costs.

3.7 District Cooling Optimization Model – DCOM

As highlighted earlier, DCOM is dynamically reactive to changes in the implementation schedules of projects which is in turn responsive to changes in the cooling demand profile.

3.7.1 DCOM Main Process

The resulting cooling demand profile from the RESOM model is an input to the proposed district cooling optimization DCOM model. The profile is then used to calculate the operation cost component of Cash-Out calculation. The data input and output is summarized in Figure 3.57. The model's process flow chart is

shown in Figure 3.58. Similar to RESOM, DCOM also consists of three main modules, these are:

- (1) Database Module,
- (2) Financial Module, and
- (3) Optimization Engine.

5) Optimization process that is similar to WSOM. Therefore, only the Operating-time based maintenance category is considered in the following section.

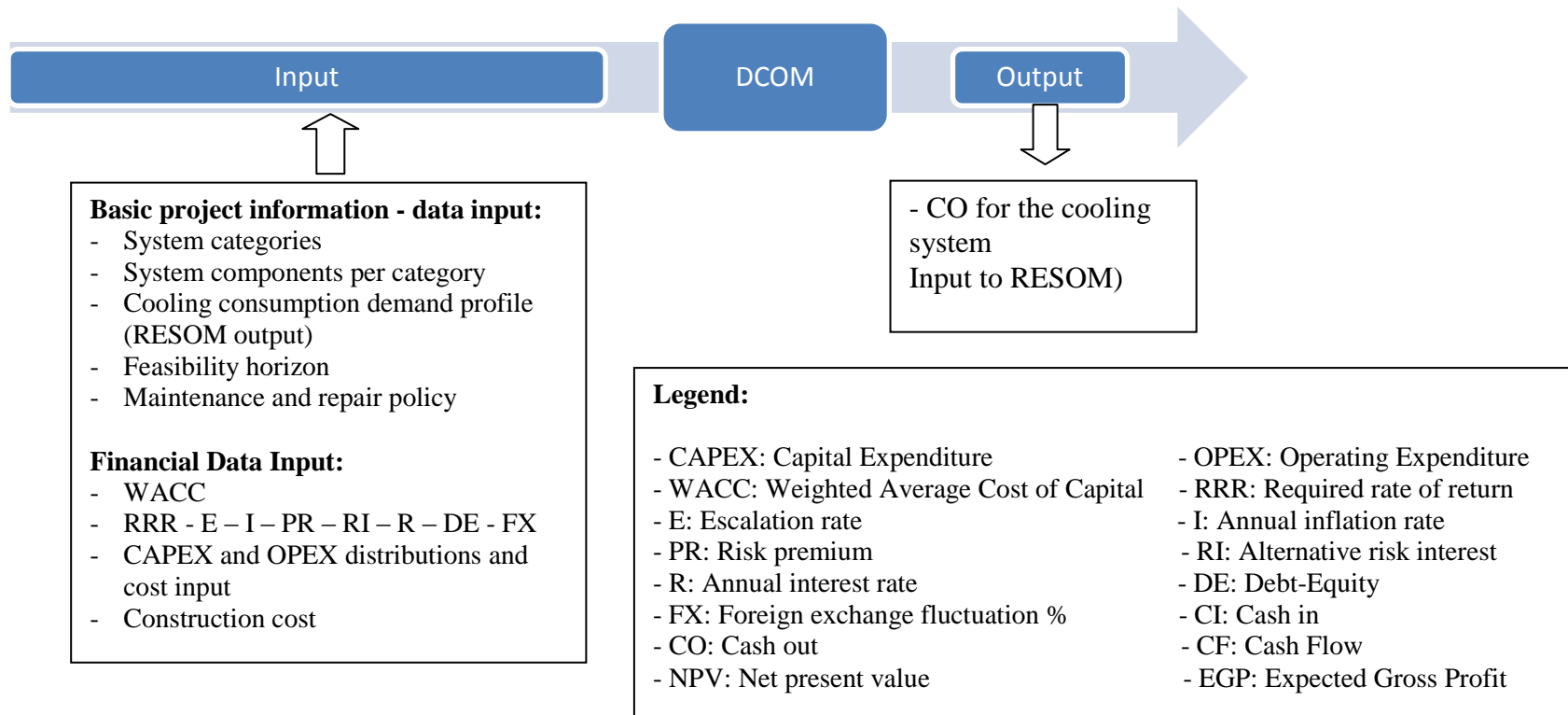


Figure 3-57: DCOM – Data Input and Output

3.7.1.1 Database Module

The database provides information regarding the cooling system components, their capacity and maximum flow rates of district cooling plant equipment (pumps, chillers,...etc), their CAPEX and OPEX breakdown. In order to harmonize the Operating Expenditure calculation, the system is categorized into four main categories as shown in Table 3.4.

Table 3-4: Cooling System Categories.

Category	Example
Fixed rate expenditure category maintenance cost	civil works items
Regression based category maintenance cost	Electrical components
Breaking rate category	Pipes
Operating time-based maintenance category	Electrochemical items

3.7.1.2 Financial Module

The Financial Module then calculates Cash-Out of the system. It includes the calculation of two main components; the construction and operation costs. The Cash-Out is then fed to RESOM for further calculations of the Cash-In, Cash Flow and the NPV of the system's Expected Gross Profit.

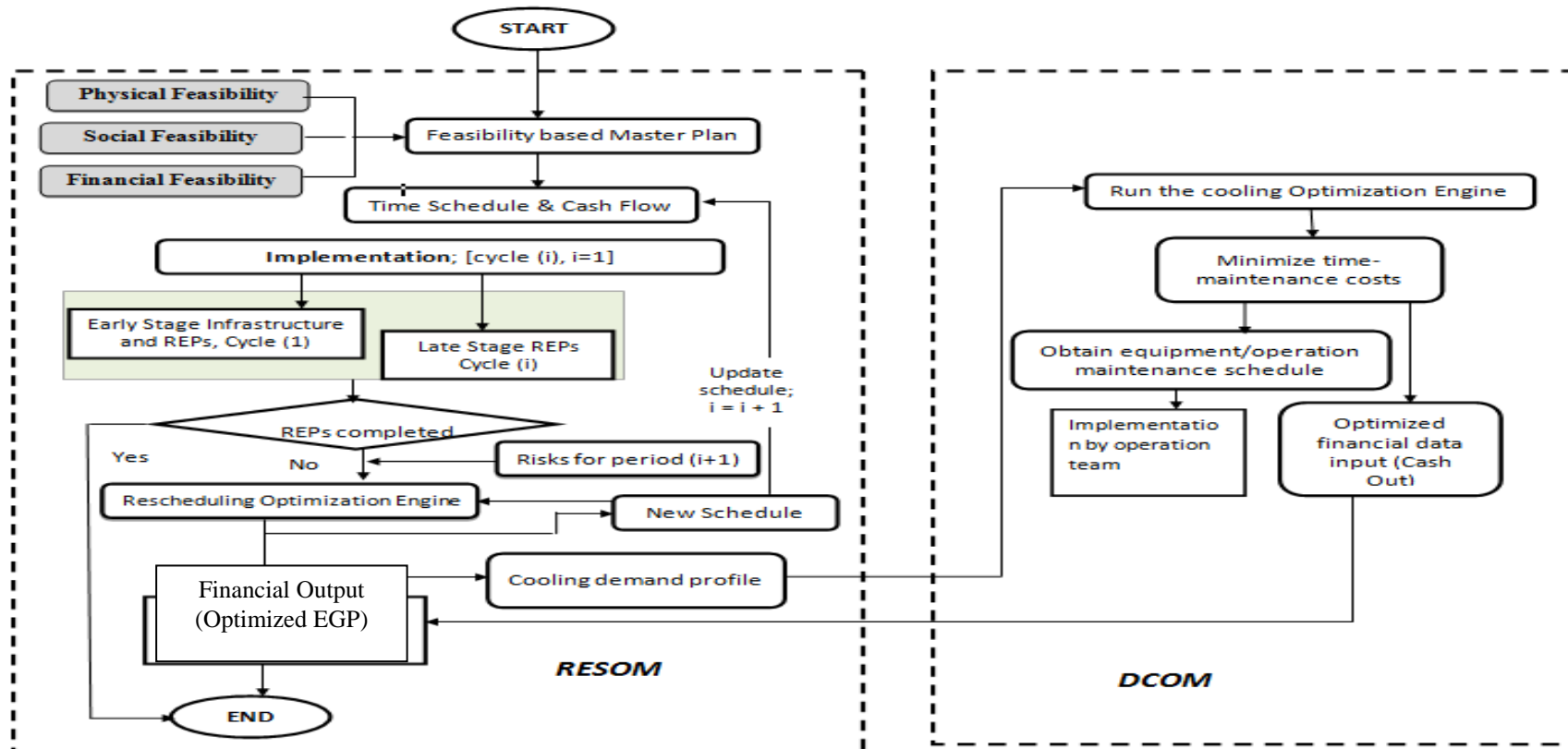


Figure 3-58: The interaction between RIM models – the Process Flow Chart for financial calculations of central cooling system (Fayad et al., 2012 and Fayad et al., 2013)

3.7.1.3 Optimization Engine

The engine optimizes the operating cost of the Operating time-based maintenance category. This is achieved through the efficient operation of the plant equipment to achieve minimum costs for maintaining the equipment under this category. The EVOLVER™ V.5.5 add-in for Excel® is used, which suits the complexity of the problem in hand. The model is run on two steps; first to achieve a scenario that fulfils the efficiency condition. This occurs by achieving the objective function, which is the difference between the actual number of operating equipment and the required operating number of the same equipment to meet the demand at certain time period. This difference should approach the zero value. If the difference is larger than zero, the actual number of operating pumps will exceed the calculated required number case which leads to operation inefficiency.

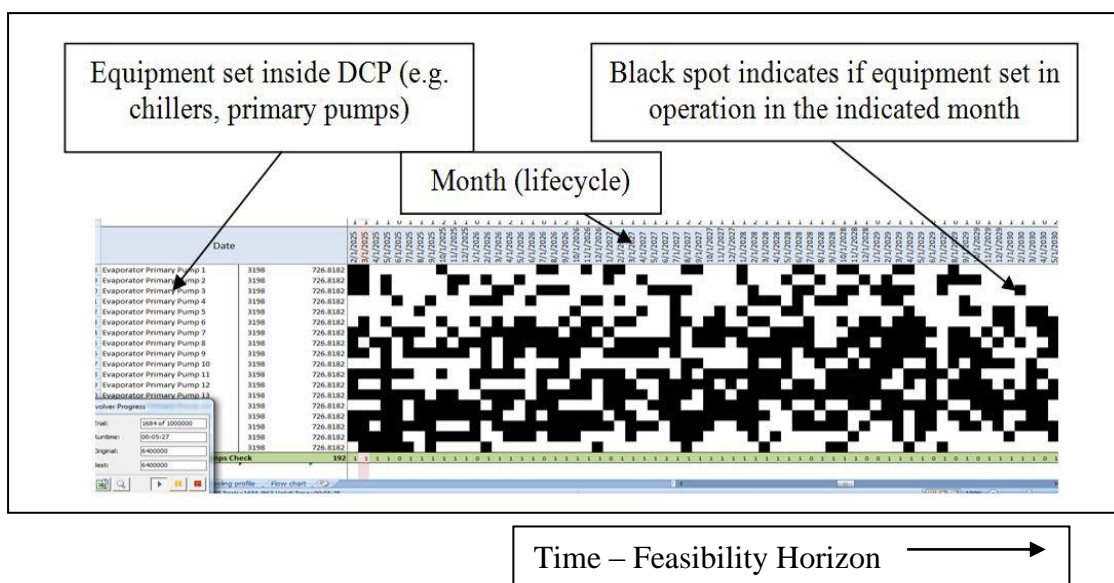


Figure 3-59: Operating schedule updates during DCOM run.

The DCOM model’s interaction with RESOM is illustrated in Figure 3.59. The optimized output operating schedule of DCOM is coded in black and white and produces the schedule shown in the shown Figure. The model’s output is shown in Figures 3.60, 3.61 and 3.62. The operation status is colored in black while the (0) digit that refers to the non-working status and is colored in white if it is under operation as shown in Figure 3.59.

The model further provides the minimum Cash-Out for this category after achieving the Objective Function. The Cash-Out of this category is added to the other Cash-Out of the three categories to provide the Cash-Out of the cooling system. RESOM then continues using this output to provide the Cash Flow and the cooling system's NPV of its Expected Gross Profit over its feasibility horizon.

Date		5/1/2017	6/1/2017	7/1/2017	8/1/2017	9/1/2017	10/1/2017	11/1/2017	12/1/2017	1/1/2018	2/1/2018	3/1/2018	4/1/2018	5/1/2018	6/1/2018	7/1/2018	8/1/2018	9/1/2018	10/1/2018	11/1/2018	12/1/2018	1/1/2019	2/1/2019	3/1/2019	4/1/2019	5/1/2019		
Cash Out Schedule																												
Evaporator Primary Pump 1	100,000													100,000														
Evaporator Primary Pump 2	100,000													100,000														
Evaporator Primary Pump 3	100,000													100,000														
Evaporator Primary Pump 4	100,000									100,000																		
Evaporator Primary Pump 5	100,000									100,000																		
Evaporator Primary Pump 6	100,000													100,000	100,000	100,000	100,000	100,000	100,000	100,000								
Evaporator Primary Pump 7	100,000																											
Evaporator Primary Pump 8	100,000																											
Evaporator Primary Pump 9	100,000																											
Evaporator Primary Pump 10	100,000																											
Evaporator Primary Pump 11	100,000																											
Evaporator Primary Pump 12	100,000																									100,000		
Evaporator Primary Pump 13	100,000	100,000																										
Evaporator Primary Pump 14	100,000																											
Evaporator Primary Pump 15	100,000																											
Evaporator Primary Pump 16	100,000																											
Evaporator Primary Pump 17	100,000																											
Evaporator Primary Pump 18	100,000																											
Total	Cash Out per month																											
Total LCC	1,700,000.00																											

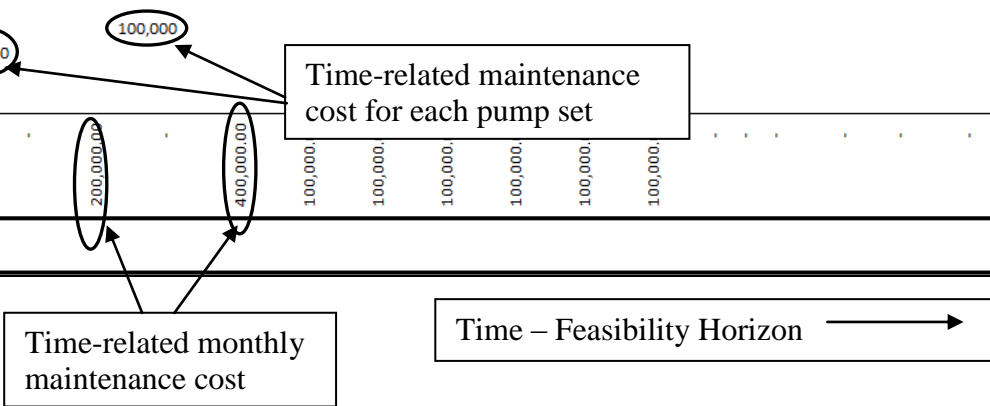


Figure 3-62: DCOM Output – Result Sample

3.8 RIM’s Objective Functions, Variables and Constraints

As discussed above, the RIM framework includes a number of integrating models, namely RESOM, DCOM, SLOM and WSOM. Table 3.5 summarizes the Objective Function, Variables and Constraints in each of these models. As highlighted above, the main target of RIM framework is to minimize the Residual Risk, denoted as “RI” in this study.

Table 3-5: The OF, Variables and constraints of RIM’s models.

Model	Objective Function (OF)	Variables	Constraints
RESOM	Maximize EGP value of real estate and infrastructure projects	Individual projects’ construction start date	- Projects interdependency - % of the portfolio or zone in the projects product mix (market demand and/or regulatory input) - Starting and end date of the group
SLOM	Minimize OPEX	Plant types and their percentage in urban landscape design	% of each plant group and % of each plant in the urban landscape design
DCOM		Operating and maintenance schedule of system mechanical components	Number of operating equipment per time unit (e.g. per week or month)
WSOM (potable water)			
WSOM (irrigation water)			

CHAPTER 4. IMPLEMENTATION AND CASE STUDY

This chapter contains a case study that is used to verify and validate RIM framework models. The development data of a three million square meter real estate development is used to implement RIM's models. The case is verified by recalculating the results obtained from the framework models to verify the models' accuracy and consistency. The models are then validated by using a questionnaire. A group of 31 experts answered the questionnaire. These experts belong to different professions in the construction academic field as well as real estate industry.

4.1 Model Implementation

RIM framework is developed with the purpose of supporting real estate decision makers in quantifying impacts of risk events during the implementation of their projects. In addition, the framework is able to provide strategies for mitigating the quantified impacts. Through periodic support of RIM's models, it is possible to optimize construction schedules that maximize lifecycle Cash Flow and Expected Gross Profits. It is also possible to quantify impacts of rescheduling the remaining projects on their lifecycle Cash Flow and Expected Gross Profits.

4.2 Case Study; Real Estate Development in Egypt

A three million square meters real estate development was selected to validate the proposed approach/model. The development is a visionary mixed use urban community located in new Cairo. The new development contains 69 different projects of a mixed portfolio such as retail, residential and commercial buildings. The total Gross Built-Up Area (GBA) of the overall project is 1.5 million square meter. The unit cost of the land is LE 500 per square meter, paid on 4 equal installments in January 1st, 2005, 2006, 2007 and 2008. Upon construction completion, the development will be home to over 13,000 residents in villas and apartments and a place to work for 50,000 office staff.

The project includes advanced and automatically controlled and operated infrastructure systems as follows:

- 30,000 tons refrigeration generated by a central district cooling plant (DCP). The DCP is connected to the ETS rooms near the served building projects through 16km pipeline network. The network is used to transport both the cooled water supply from the plant and the return water to the plant;
- 5000 m³ potable water underground storage tank, pumping facility and network;
- Urban landscape;
- 5000 m³ underground irrigation tank and landscape irrigation network;
- Natural gas system;
- Telecom networks;
- 66/22 electrical power substation, high and medium voltage power supply grid;
- 12,000 m³/day waste water treatment facility and sewerage network (future plan);
- Road network and street furniture.

The development master plan, shown in Figure 4.1, was developed at early stage in year 2004. It was approved by the authorities upon its compliance to local rules and regulations. The master plan included a number of construction groups. The construction schedule of every group was considered as hard constraints while preparing the master program. However, the construction dates of the projects inside each of the groups were considered as soft constraints that can change within its group's range of duration, i.e. the start and end dates of the group is respected while defining the start and end date of each project included in this group. In terms of zoning, the projects are classified according to their location on the master plan in to zones, namely the northern, eastern, southern and western zones as shown in Figure 4.2.

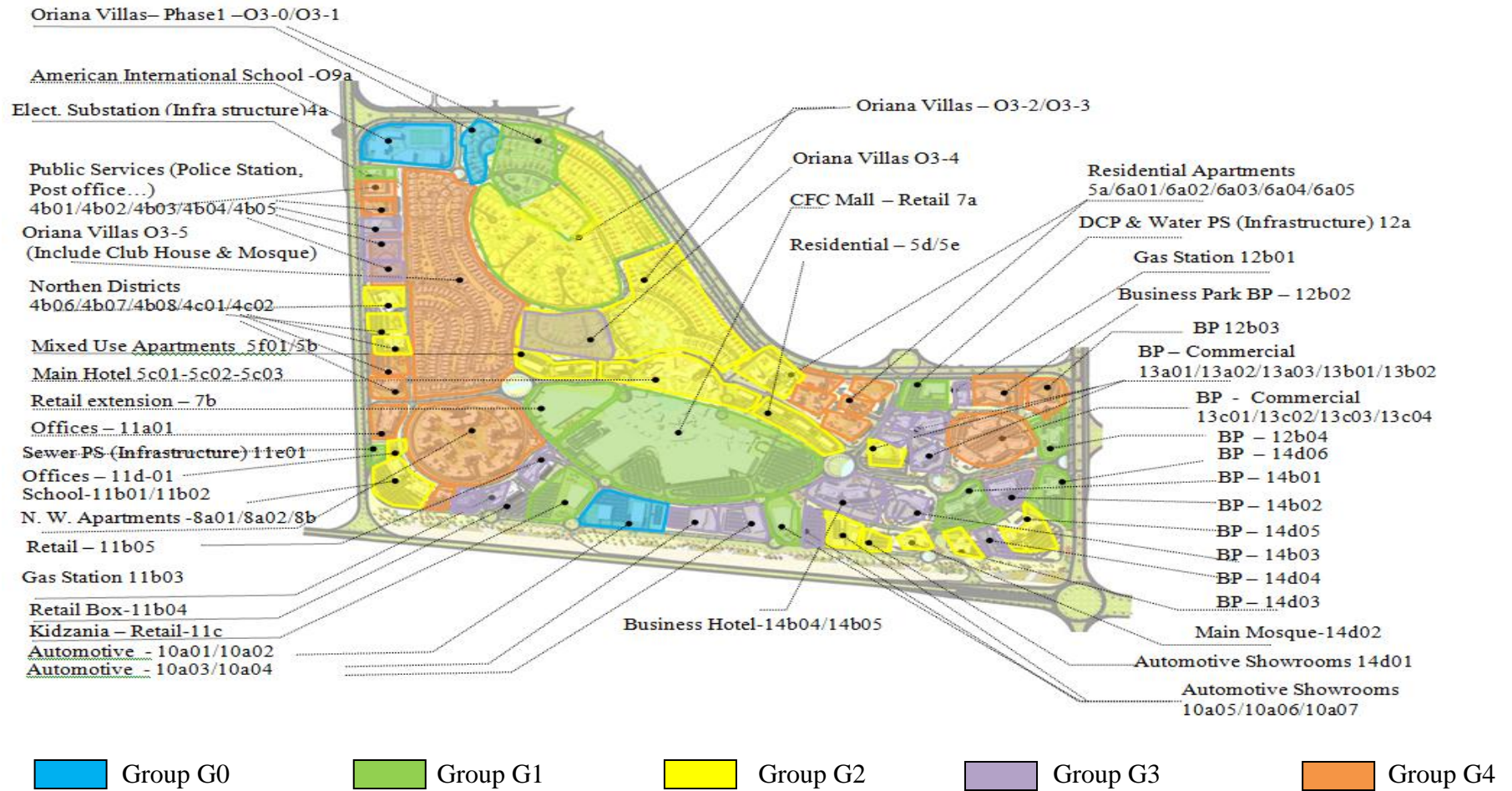


Figure 4-1: Real Estate development master plan and execution project groups

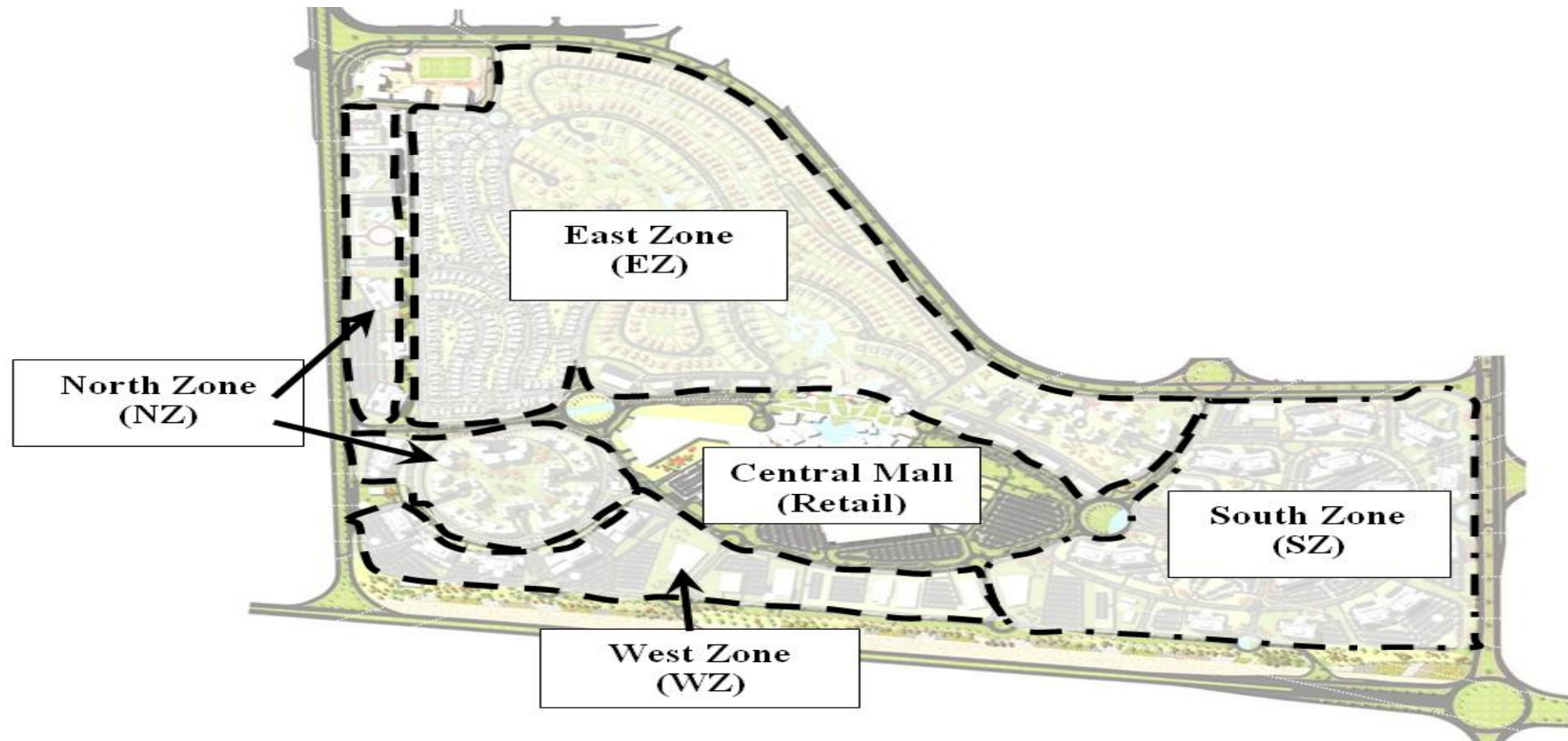


Figure 4-2: The Real Estate Project – Zone Classification

The construction started in year 2004 for a first wave of projects and started operation from year 2005 to 2007. This wave has included an educational facility, automotive show rooms and a number of residential villas. In relation to several challenges, the project was only able to recommence construction in January 2009. A summary of the project planned start and end dates are shown in Table 4.1. The data assumptions used in this case study are discussed in the following section.

4.2.1 RESOM Model

The basic projects' information of different project portfolios are fed to RESOM. The number of projects in this case study is 69 projects. These projects are included in a number of groups depending on the planned time for development. The starting and ending date of the whole real estate development are usually fixed as hard constraints by local authorities and the developer. Each group has also its own starting and ending date that are also considered as hard constraints. The starting and ending dates of each project or of a building included in a project, are changeable and considered as soft constraints that should be within their group's starting and ending dates. This is illustrated in Figure 4.3.

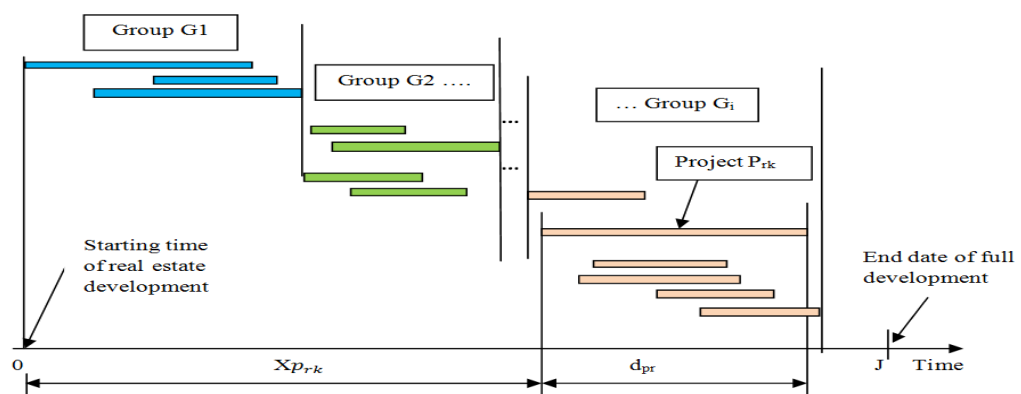


Figure 4-3: The construction durations of projects and their groups.

4.2.2 RESOM Application – Data Input

The data input of RESOM are as follows:

- Real estate project codes (REP).
- Portfolio types and codes.
- Gross Built-up Area (GBA).
- Location code (plot number).
- Location zone code (zone number).
- Construction duration.
- Development construction's start date.
- Project groups' construction start.
- Feasibility horizon.
- Planned marketing strategy (portfolio/zone % per projects group).
- Project's start date, which can also be generated by RESOM during the optimization process.

In addition, the Financial Data Input is as follows:

- Plot land price and payment terms
- CAPEX, OPEX and WACC% input and calculation equations.
- Financial input: $RRR - E - I - PR - RI - R - DE - FX$.
- CAPEX and OPEX expenditure distributions.
- Selling and renting area unit price and payment terms (per portfolio).
- Special price discounts.
- Conservative diversity factor.

The information given to RESOM includes for example the construction unit cost, the rent and selling prices as shown in Table 4.1. As shown in the Table, the development contains several building projects of different functions or portfolios (hospitality, residential, office buildings, show rooms, etc.). The Table includes the assumed construction cost and the selling or renting price per square meter.

Table 4-1: Data Assumptions - Case Study

	Construction cost	Rent	Sell
	EGP per m2	(EGP/m2/month)	(EGP/m2)
Residential	6000	0	12,000
Mixed use Retail	3000	120	0
Mixed use Residential	4000	0	12,000
Show rooms / Retail	3000	120	0
Offices	5000	120	0
Hotel	8000	100	0
Mosque	1000	0	0
Public services	1500	0	0
Health care	7000	1500	0
Recreation	4500	1500	0
Patrol station	2500	1500	0
Education	2500	150	0

The different cases of running RESOM model are summarized in Table 4.2. The original feasibility-based Case is referred to as Case number 1. In Cases 2.1 and 2.2, the project groups' classification of the risk impacted or relaxed cases is based on the zoning in both cases. The northern zone implementation is prioritized as Group G1 in Case 2.1 while Group 3 is prioritized in Case 2.2 instead. In Case 3, the grouping is based on the portfolio prioritization. The time span for projects' implementation in Case 3 reflects further relaxation of the groups' implementation schedule.

Table 4-2: Summary of RESOM Run Cases

Objective Function	Case 1 Feasibility-based case	Case 2 Risk event		Case 3 Risk event
		Zone prioritized case 2.1	Zone prioritized case 2.2	Portfolio prioritized case 3
Real Estate EGP	Without optimization	With optimization		
Infrastructure systems EGP (landscape, water, cooling systems)	Without optimization	With optimization		

RESOM model is applied to produce the lifecycle Cash Flow and Expected Gross Profit for real estate projects. Moreover, RESOM provides the same for the Infrastructure system through its link with the different Infrastructure models over a feasibility horizon of 30 years (from January 1st, 2009 up to December 31st, 2038). The produced demand quantities are fed to the DCOM to optimize the operation/maintenance cost over the same period and to optimize the maintenance schedule of the district cooling plant equipment. Moreover, the monthly potable water demand, produced by RESOM, and the irrigation water demand, obtained from the landscape model SLOM, are combined together the lifecycle Cash Out of combined water system by using WSOM.

The project groups planned start and end dates for the different cases are shown in Table 4.3. It is noted that Case 1 reflects the original feasibility implementation schedule prior to the risk event (the civil unrest of January 2011 in Egypt).

Table 4-3: The starting Dates and durations of the projects’ implementation groups – Case Study

	Group G1		Group G2 (incl. Infra projects)		Group G3		Group G4		Group G5		Group G6	
	Start/End Date	Duration (months)	Start/End Date	Duration (months)	Start/End Date	Duration (months)	Start/End Date	Duration (months)	Start/End Date	Duration (months)	Start/End Date	Duration (months)
Case 1 - Original Case	1/1/2005 - 31/12/2007	36	1/1/2009 - 31/12/2012	48	1/1/2011 - 31/12/2013	36	1/1/2014 - 31/12/2015	24	1/1/2016 - 31/12/2017	24	-	-
Case 2.1 – Prioritized zone 1	-	-	-	-	1/1/2011 - 31/12/2013	36	1/1/2014 - 31/12/2016	36	1/1/2017 - 31/12/2019	36	1/1/2020 - 31/12/2022	36
Case 2.2 - Prioritized zone 3	-	-	-	-	-	-	-	-	-	-	-	-
Case 3 - Relaxed Portfolios	-	-	-	-	1/1/2011 - 31/12/2015	60	1/1/2016 - 31/12/2020	60	1/1/2021 - 31/12/2025	60	-	-

Due to the occurrence of January 2011 unrest situation, the development in the local real estate market has slow down. The developer is therefore challenged by a situation where the construction of the entire infrastructure systems is approaching its completion while the demanding consumers would not exist as planned which enforces the decision maker to relax the implementation of unconstructed projects. The risk impacted therefore the Expected Gross Profit of the projects due to the relaxing decision of the originally planned feasibility-based implementation schedule (Case 1). The financial assumptions given to RESOM are summarized in Table 4.4.

Table 4-4: Financial Assumptions – Case Study

% Loan	60%	
% Equity	40%	
Annual Interest Rate (R)	13%	
Alternative Risk Interest (RI)	20%	
Risk Premium (RP)	2%	
Required Rate of Return (RRR)	22%	
Weighted Average Cost of Capital (WACC%)	Equation: $\{(Loan\%)*(Annual\ Interest\ Rate\%)\} + \{(Equity\%)*(Required\ Rate\ Return\%)\}$	16.6%
Annual Inflation Rate (I)	12%	
Escalation Rate (E)	3%	
Foreign Exchange Fluctuation (FX)	2%	

As shown in Table 4.5, the basic data for the entire 69 projects is included in RESOM database. The Gross Built-up Area GBA of each project and its type or its land use (lifestyle, educational, show rooms, retail,...etc.) are inserted into the database. The projects classification according to their type or portfolio is shown in Table 4.5.

Table 4-5: Projects classification – Case Study

Project Type (portfolio)	Number of Projects
Commercial (including commercial subcategories)	26
Education	2
Hospitality	4 (including 2 hotels)
Public Buildings	3
Residential (Apartment)	17
Residential (Villas)	5 zones
Retail	12
Total	69

Additional information such as the foot print area of each individual project, assumed cooling consumption and its diversity factor. The diversity factor indicates the percentage of each project that will be occupied and demand services, such as cooling, at certain point in time. Moreover, the database includes the land price, construction cost, marketing strategy (selling and renting terms of payment). In addition, the database includes also the project construction duration, project group coding and the fixed duration of each group as shown in

Table 4.3. The projects' duration is inputs to RESOM while the X value, or the project's start date, is considered variable in this case study.

The sheet also includes information regarding the start and end dates in the original feasibility-based construction schedule (Case 1) as well as in the risk impacted schedule with prioritized zones (Cases 2.1 and 2.2) versus the risk impacted case with prioritized portfolio percentages in different phasing groups (Case 3). These projects of these groups do not include the projects started prior to the risk event of February 1st 2011), this includes the group of projects planned to start in January 2011. The X value is allowed to change within the ranges included in Table 4.3. Figure 4.4 shows calculation sheet of RESOM. Table 4.6 includes the different constrains in the different cases. The term Phase in the Table refers to the term "Group" of projects. This means that Phase 1 projects is the same as Group 1 projects, Phase 2 is the same as Group 2,..etc.

#	Plot No.	Land use	GBA	REP Duration (D)	New Group Coding	Group max Duration (m)	X	Group	Group Beginning	Group End	Group Duration
REP 1	O3-0	Residential - Villas	5,000	36	0	36	0	0	1/1/2005	31/12/2007	36
REP 2	O9a	Education	22,662	36	0	36	0	0			
REP 3	10a01	Retail	23,017	36	0	36	0	0			
REP 4	10a02	Retail	23,017	36	0	36	0	0			
REP 5	O3-1	Residential - Villas	62,283	36	1	48	48	1	1/1/2009	31/12/2012	48
REP 6	O7	Retail	222,130	48	1	48	48	1			
REP 7	14b01	Commercial	23,998	24	1	48	60	1			
REP 8	10a05	Retail	11,213	36	1	48	48	1			
REP 9	14d06	Commercial	20,528	24	1	48	60	1			
REP 10	12b04	Commercial	15,883	24	1	48	48	1			
REP 11	14e01	Commercial	20,897	24	1	48	48	1			
REP 12	Infra	Infrastructure	0	48	1	48	48	1			
REP 13	O3-2	Residential - Villas	62,283	36	2	36	72	2			
REP 14	11b01	Education	15,204	24	2	36	82	2			

Figure 4-4: RESOM Database

#	Min Group Duration	Group Duration	Dur/4	Total cost	.42 Cost/month	.08 Cost/month	Start	End	period 1	period 2	period 3	period 4
REP 1	28	36	9	75,000,000.00	2,916,666.67	1,250,000.00	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008
REP 2			9	56,655,000.00	2,203,250.00	944,250.00	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008
REP 3			9	34,525,500.00	1,342,658.33	575,425.00	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008
REP 4			9	34,525,500.00	1,342,658.33	575,425.00	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008
REP 5	52	60	9	934,241,250.00	36,331,604.17	15,570,687.50	1/1/2009	1/1/2012	10/1/2009	7/1/2010	4/1/2011	1/1/2012
REP 6			12	666,390,000.00	19,436,375.00	8,329,875.00	1/1/2009	1/1/2013	1/1/2010	1/1/2011	1/1/2012	1/1/2013
REP 7			6	119,990,000.00	6,999,416.67	2,999,750.00	1/1/2010	1/1/2012	7/1/2010	1/1/2011	7/1/2011	1/1/2012
REP 8			9	33,639,000.00	1,308,183.33	560,650.00	1/1/2009	1/1/2012	10/1/2009	7/1/2010	4/1/2011	1/1/2012
REP 9			6	102,640,000.00	5,987,333.33	2,566,000.00	1/1/2010	1/1/2012	7/1/2010	1/1/2011	7/1/2011	1/1/2012
REP 10			6	79,415,000.00	4,632,541.67	1,985,375.00	1/1/2009	1/1/2011	7/1/2009	1/1/2010	7/1/2010	1/1/2011
REP 11			6	104,485,000.00	6,094,958.33	2,612,125.00	1/1/2009	1/1/2011	7/1/2009	1/1/2010	7/1/2010	1/1/2011
REP 12			12	1,000,000,000.00	29,166,666.67	12,500,000.00	1/1/2009	1/1/2013	1/1/2010	1/1/2011	1/1/2012	1/1/2013
REP 13			9	934,241,250.00	36,331,604.17	15,570,687.50	1/1/2011	1/1/2014	10/1/2011	7/1/2012	4/1/2013	1/1/2014
REP 14			6	76,020,000.00	4,434,500.00	1,900,500.00	11/1/2011	11/1/2013	5/1/2012	11/1/2012	5/1/2013	11/1/2013
REP 15			6	80,670,000.00	4,705,750.00	2,016,750.00	9/1/2011	9/1/2013	3/1/2012	9/1/2012	3/1/2013	9/1/2013
REP 16			4.5	33,390,000.00	2,337,300.00	1,252,125.00	2/1/2012	8/1/2013	6/1/2012	11/1/2012	4/1/2013	8/1/2013

Figure 4-5: RESOM Calculation Sheet

Table 4-6: RESOM Constraints in case 3 – Portfolio based for Groups G3 (or phase 1), G4 (or phase 2) and G5 (or phase 3).

Portfolio type	Phase 1	% Phase 1	Phase 2	% Phase 2	Phase 3	% Phase 3	Check
Commercial	15	75%	5	25%	0	0%	100%
Education	1	50%	1	50%	0	0%	100%
Hospitality	2	50%	2	50%	0	0%	100%
Public services	3	100%	0	0%	0	0%	100%
Residential	0	0%	7	41%	10	59%	100%
Residential - Villas	0	0%	1	33%	2	67%	100%
Retail	6	67%	3	33%	0	0%	100%

4.2.2.1 X-Variable range in the optimization cases:

4.2.2.1.1 Zone cases 2.1 and 2.2 (6 project groups)

The variable (X) or the starting date of individual projects changes within a certain range. The range starts and ends with the starting and ending dates of the group respectively. The ranges as constraints RESOM in the different optimization cases, i.e. cases 2.1 and 2.2 and 3. The allowed range for X for Groups 1 and 2 in the original feasibility (Case 1) remain unchanged. The range changes for Groups 3, 4, 5 and 6 in the optimization cases as shown in Figures 4.6, 4.7, 4.8 and 4.9 respectively. The range of the starting dates for these groups is summarized in Table 4.3 above. It is decided to complete the projects of groups 1 and 2 as originally planned.

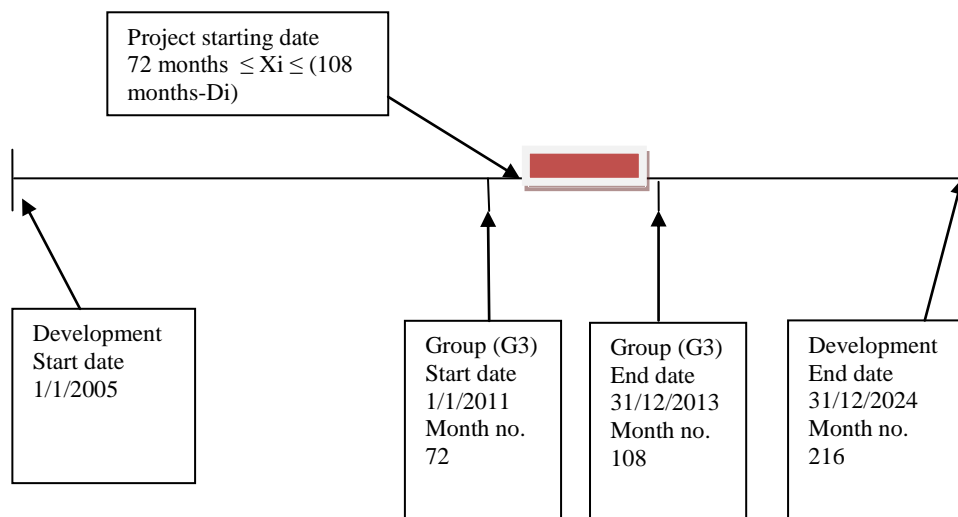


Figure 4-6: X range in the optimization process of Case 2 – Group 3

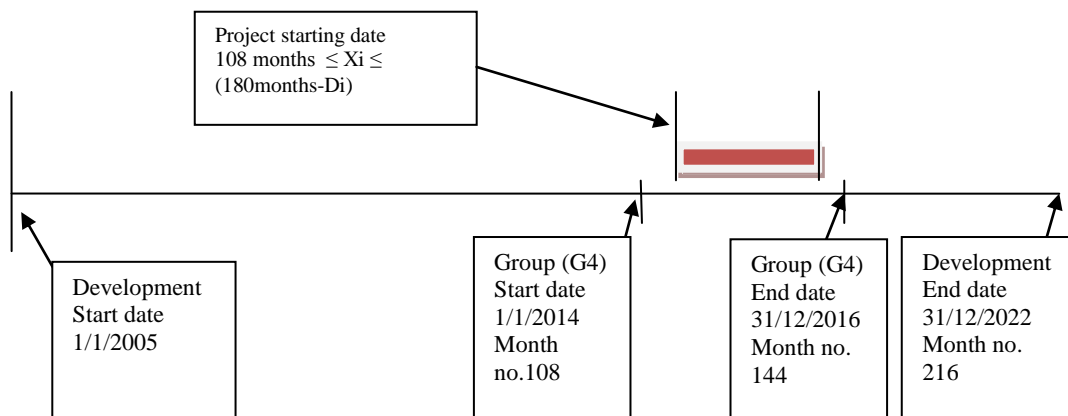


Figure 4-7: X range in the optimization process of Case 2 – Group G4

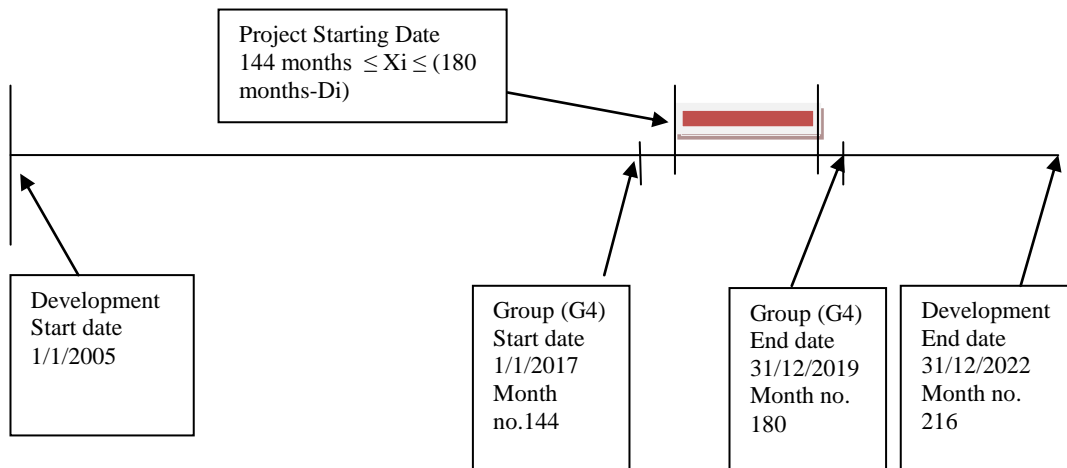


Figure 4-8: X range in the optimization process of Case 2 – Group G5

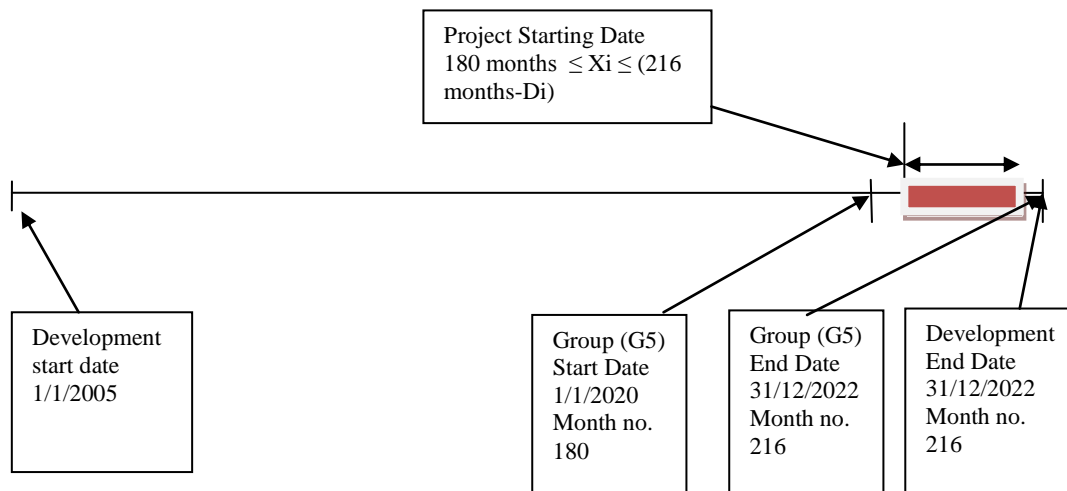


Figure 4-9: X range in the optimization process of Case 2 – Group G6

4.2.2.1.2 Portfolio case 3 (5 project groups)

The changing range of the variable (X) is given as an input to RESOM in the portfolio optimization case, i.e. case 3. The allowed range for X for Groups 1 and 2 in the original feasibility (Case 1) remain unchanged. The range changes for Groups 3, 4 and 5 in the optimization cases as shown in Figures 4.10, 4.11 and 4.12 respectively. The allowable range for changing the starting dates of the groups is shown in Table 4.3.

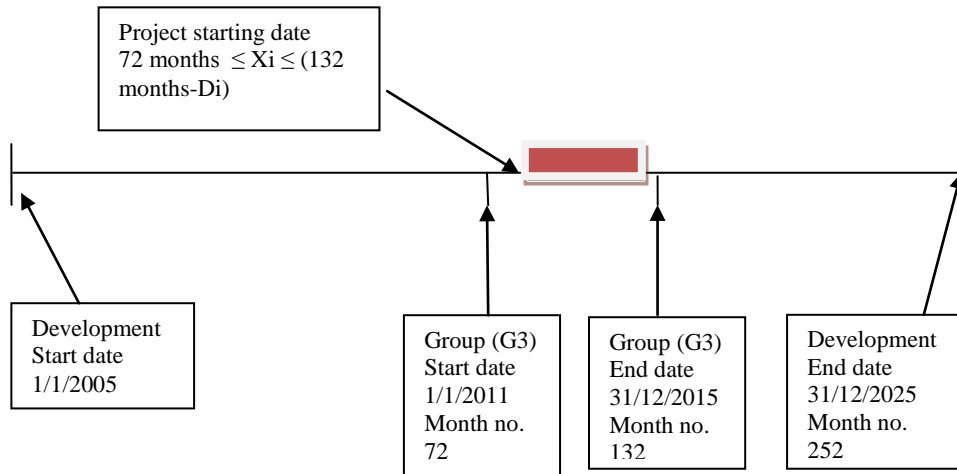


Figure 4-10: X range in the optimization process of case 3 – Group 3

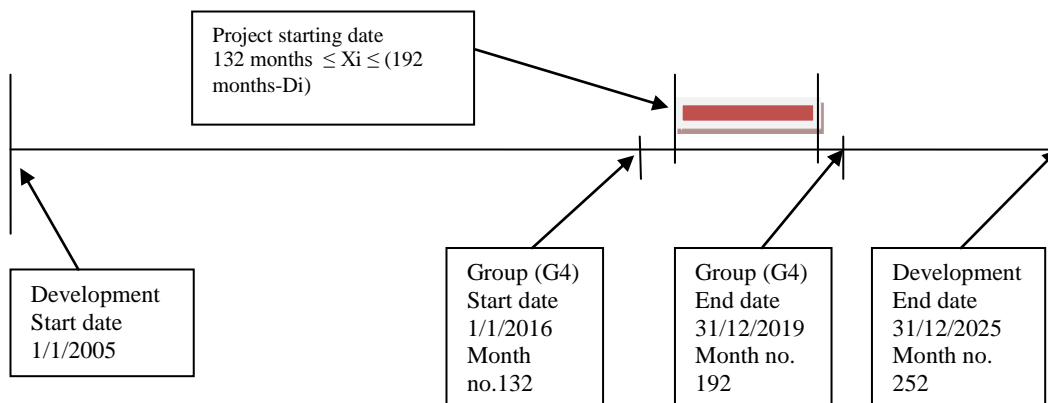


Figure 4-11: X range in the optimization process of case 3– Group G4

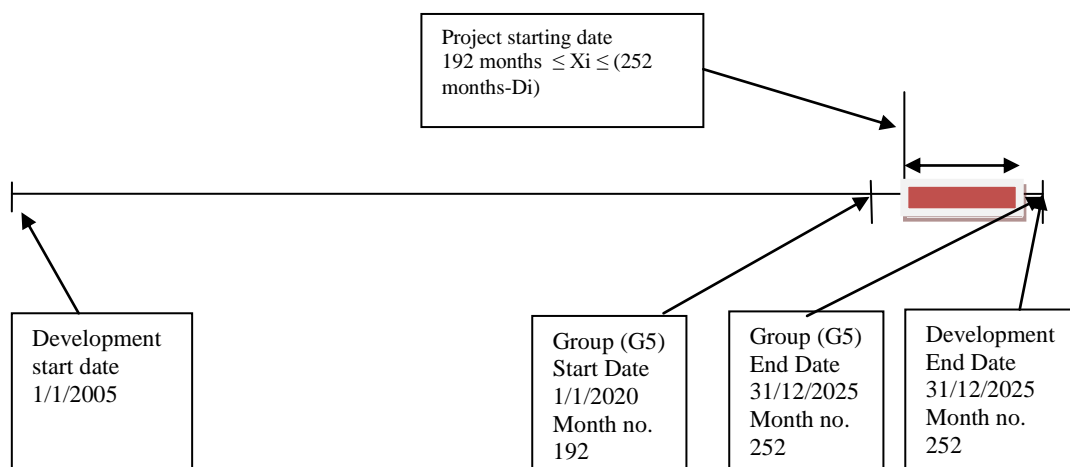


Figure 4-12: X range in the optimization process of case 3– Group G5

4.2.2.2 Cash-Out Calculation

RESOM is designed to accommodate different distributions that are used to allocate project's capital expenditure over its construction duration (D). The selection of certain distribution function above the other depends mainly on the type of the project and whether the budget is front loaded (e.g. spending more money ahead to finance huge amounts of earth works) or back loaded (e.g. purchasing electromechanical or finishing works at the end phase of construction). Planners may select the Normal Distribution, Trapezoidal Distribution or other distribution that suits their projects' construction cases. The construction of any building r within project p of type k starts after time duration X_{prk} that counts from the starting date of the whole development (as shown in Figure 4.13). In this research, and similar to the planner's assumption in the case study included in this research, the construction cost of each project is assumed distributed over its construction period d_{pr} . The expenditure is distributed over 4 equal sub-periods of $d_{pr}/4$ length each as shown in Figure 4.14. For simplicity purposes, it is assumed that 8% is spent during the first 25% period of the construction duration, followed by another expenditure of 42% of the total cost. This means an expenditure of 50% over the first half of the construction duration ($d_{pr}/2$). Similarly, it is also assumed that similar percentages are spent during the third and fourth $d_{pr}/4$ periods, i.e. 42% and 8% respectively as shown in Figures 4.13 and 4.14.

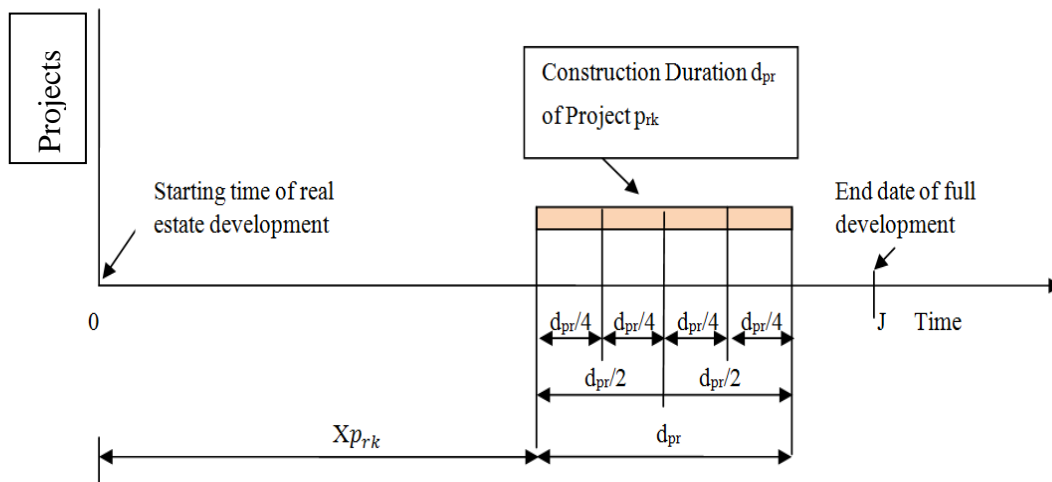


Figure 4-13: Project construction duration and its relation to the real estate development starting date.

The amount spent in each sub-period of duration length $d_{pr}/4$ is applied at the beginning of the sub-period; this is in order to assure the availability of the amount prior to starting the construction period as shown in Figure 4.14.

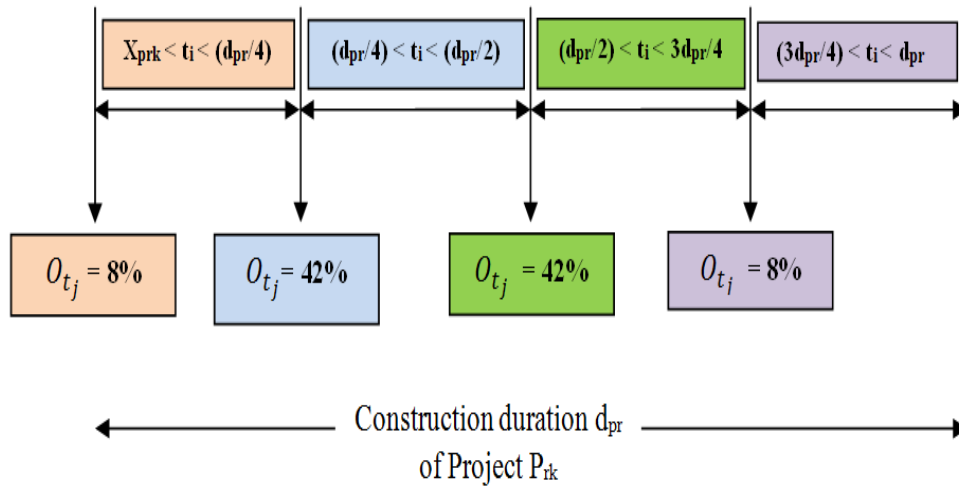


Figure 4-14: Construction cost Cash-Out assumptions

4.2.2.3 Cash-In Calculation

On the other hand, the Cash-In calculation considers two cases of marketing strategy; namely selling and renting. Defining the marketing strategy whether to sell or rent a building r depends mainly on the type of building, i.e. depending on its k value.

The unit's contract is signed off at time t which is equal to time duration of $(d_{pr} - (q_{rk}/2))$ from the starting time of project construction. At that point in time, the end user or the customer will pay 10% of the unit price followed by another 15% within g_{rk} period (1 month in this study). The end user will then pay the remaining price to the developer in installments over a period q_{rk} . In addition, delivery installment of 10% is paid upon delivering the unit and starts his occupancy as shown in Figure 4.15. It should be noted that d_{pr} starts at time Xp_{rk} that counts from the starting date of initial developing the whole real estate development as shown in the Figure.

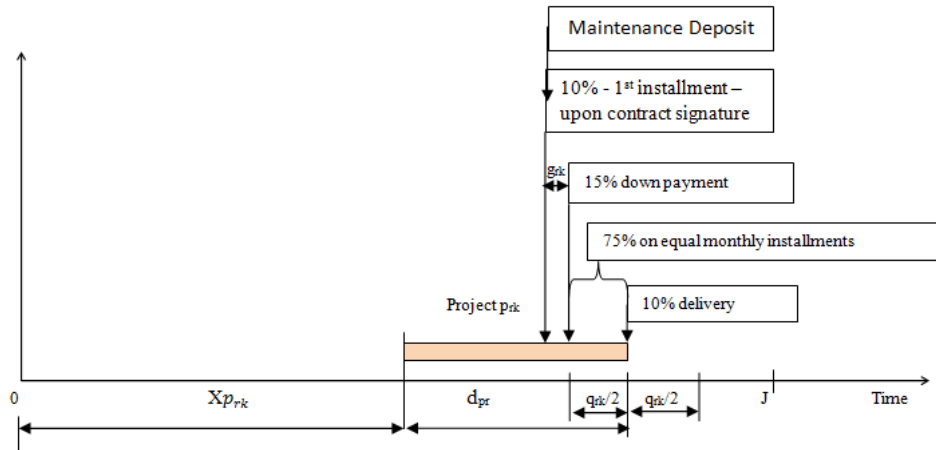


Figure 4-15: Cash-In duration assumption (selling case)

4.2.2.3.1 Rental Case

The term s is given for the taking over period between construction completion date of a project building p_r to the starting date of renting it (1 month in this study). This is shown in Figure 4.16. RESOM generates values for $X_{p_{rk}}$ as shown in Figure 4.3 above. The values that are within a given range of the start and end date of the project's group G_i as shown in the Figure.

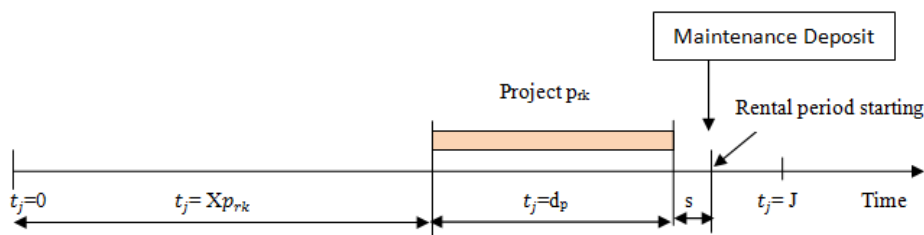


Figure 4-16: Cash-In duration assumptions

4.2.2.4 Cash Flow & EGP Calculation:

As previously explained, RESOM calculates the NPV of the Expected Gross Profit EGP by subtracting the Cash-Out from the Cash-In each month of the horizon period. RESOM provides the EGP for each of the Cases 1, 2.1, 2.2 and 3.

4.2.2.5 Optimization Attributes

The optimization attributes are as follows:

1. Population size (100)
2. Cross-over rate (80%)
3. Mutation rate (20%)
4. Stopping criteria – (36 Hours, 1,000,000)
5. Progress measurement (0.01% objective change for 100,000 trail)

These attributes are shown in Figure 4.17. The optimization function, constraints and variables are shown in Figure 4.18.

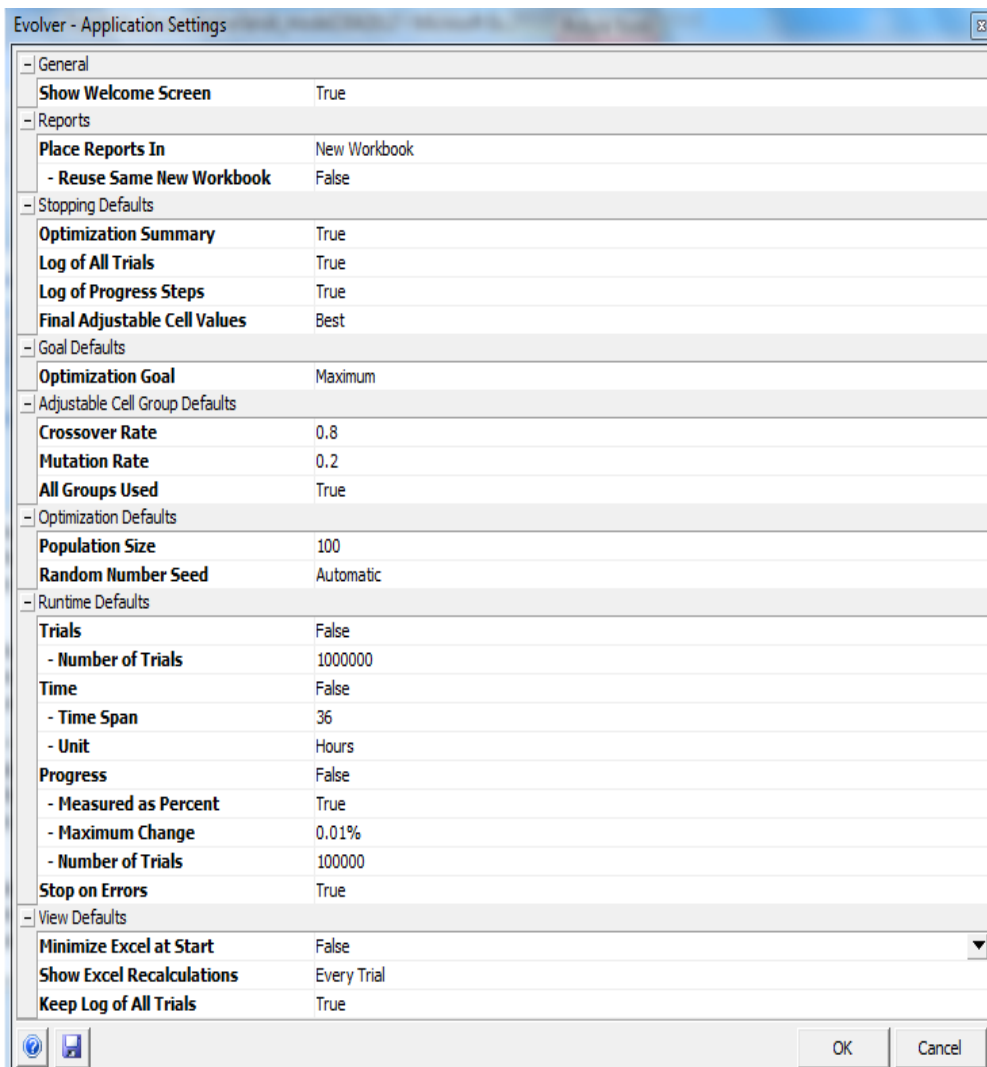


Figure 4-17: RESOM optimization process attributes

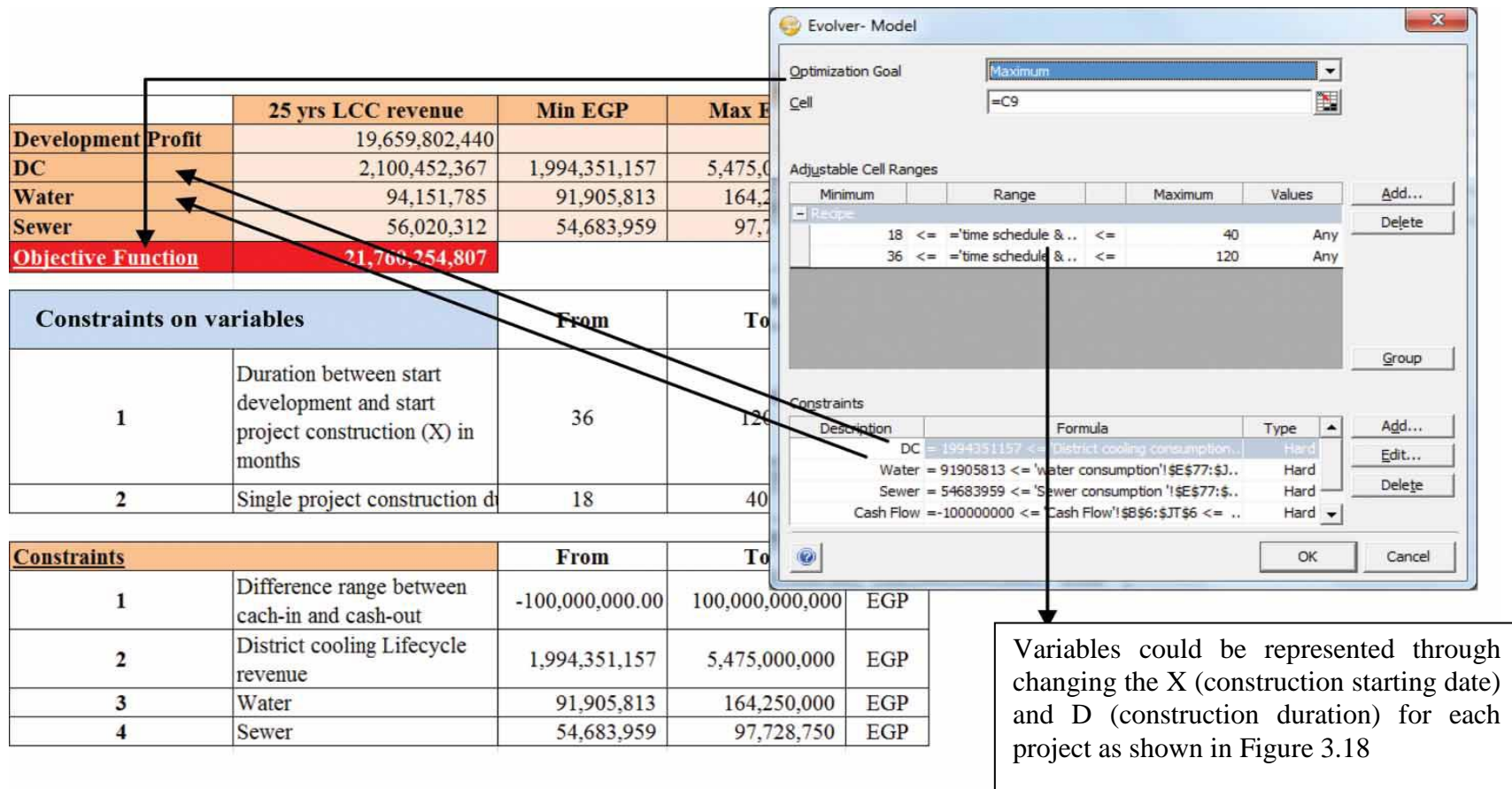


Figure 4-18: RESOM optimization screenshot

4.2.3 SLOM Model

The prestigious project includes the development of 143,000 square meters of green landscape. This paper assesses the original landscape design in terms of lifecycle cost as well as irrigation water consumption. The plant types were fed to the model along with their different parameters (irrigation water quantity in different seasons, costs,..etc.).

Planting types are included under certain groups as follows:

- a) Palms: this group includes 27 types of palm trees. These groups are either fruit palms or ornamental palms. The lifetime of this group is 30 years
- b) Like-Palms: this group includes 7 types of Like-Palm trees. These groups are classified as ornamental like-palms.
- c) Trees: this group includes 102 types of trees. Trees are either of evergreen or deciduous types.
- d) Shrubs: this group includes 48 types of shrubs. Shrubs types are either evergreen or deciduous.
- e) Climbers: this group includes 16 types of climbers. Climbers are either of evergreen or deciduous types.
- f) Ground covers: this group includes 27 types of ground covers. Ground covers are either evergreen or annual ground covers.
- g) Ornamental Grass: this group includes 5 types. Ornamental grass is of evergreen types.
- h) Grass: one type of grass is an evergreen type group.
- i) Succulents: this group includes 44 types of evergreen types.

The Database module includes landscape types such as its shape by adding their images.

4.2.3.1.1 SLOM Cases

SLOM model was used to calculate the actual CAPEX and OPEX costs based on 30 years lifecycle time for the 143,000 square meters under construction landscape project. The OPEX cost is then divided by the sellable 1.5 million m² Gross Built-up Area GBA to calculate annual operational cost per m² of the built up area which the end user will pay. This originally designed case without optimization is referred to as follows:

4.2.3.1.1.1 Case (1): Original design case

SLOM was used to provide the Cash-Out of the Landscape system in the original case of 12 Million Egyptian Pounds capital cost. SLOM then was then run to provide alternating optimized landscape plants mix design that best fit two different objective functions and constraints as follows:

4.2.3.1.1.2 Case 2: Minimum lifecycle cost design

A plants' mix design that fits the minimum lifecycle cost and calculates the annual OPEX cost per square meter of the sellable built-up area.

4.2.3.1.1.3 Case 3: Minimum irrigation water consumption

A plants' mix design that fits the minimum lifecycle irrigation water consumption calculates the corresponding lifecycle cost. It also calculates the OPEX cost per square meter of the sellable built-up area.

The case study data input to SLOM is summarized in Table 4.7. As highlighted above, the expected life time is useful for calculating the operation expenditure, or the OPEX, which includes the plants replacing costs depending on the plant life time as indicated in Table 4.10. SLOM includes other OPEX cost elements that are relating to periodically consumed material necessary to keep optimum living conditions of plants such as Nitrogen, Potassium, Phosphor, minor elements and insecticides. The costs of these elements are market related and their consumption rates were obtained from local agriculture experts. An annual inflation of 12% and WACC of 16.6% were used in the SLOM model calculations to obtain the NPV of lifecycle cost. The optimization print screen is shown in Figure 4.17.

The daily irrigation water consumption of each plant was given to SLOM as part of the model database module. The quantities of plants' irrigation water and feeding elements vary depending on the season weather conditions. Plants usually consume more water in the summer and spring time compared with the winter and autumn seasons. However SLOM considered half of the year as summer and spring seasons (181 days) and considered the other half as winter and autumn season days (182 days) in Egypt.

It should be highlighted that the originally designed case (Case 1) was designed to cover 143,000 m² of plot area. The difference was due to the fact that some plants types, e.g. grass or ground cover may be covered by trees spread crowns. This was only the case in the originally designed mix of Case (1). The area covered by the alternating optimized design mixes obtained from SLOM in Cases (2) and (3) have respected the land area 143,000 m². The Gross Built-up Area, or the so called GBA of the 1.5 million square meter is used to calculate the unit square meter charges per year in order to cover the OPEX costs. The financial module produced the NPV of the annual charges for which an inflation rate should be applied annually to obtain how much each square meter should incur to finance the OPEX costs successfully.

4.2.3.2 SLOM Application

Based on the above assumptions, the resulting mix designs and the lifecycle costs (obtained from SLOM model) for the three different cases (1), (2) and (3) are summarized in Table 4.7. The Chess Carpet Diagram CCD is used to present the images of the selected plants' types in each of the cases. The CCD presents the percentage of number of plants' types to the total number for each of the plants groups. It also presents the percentage of area covered by each of the plants' groups to the overall landscaped area. The three colors green, orange and red were used to indicate three evaluation criteria, namely Excellent, Fair and Poor respectively. An Excellent is given to a design mix that deviates 10% from the architect's given range. The grade "Fair" is given to design mixes having a number of plants or less area than the criteria given by the architect by 10% to 25%. In cases of pants groups having more than 25% deviation from the criteria are considered as "Poor" design mixes.

Table 4-7: Case study – data input to SLOM model.

Plant Group	Expected Life Time (years)	Number of plant types in each plant group	Water consumption (liter/unit/day)		Objective Function in the Optimization:		
					Case (2): Min. lifecycle cost		
			Case (3): Min. lifecycle irrigation water consumption (m ³ /30 years)			Constraints	
Spring - Summer	Winter - Autumn	Min. no. of plant types in the mix	Min. % of the area covered compared with the total area	Min. % of plant types' area in the overall mix design area			
1- Palms	30	27	100	80	8 – 14	3%-7%	0%-1.5%
2- Like-Palm	30	6	35	20	2-3	0%-3%	0%-1.5%
3- Trees	30	102	80	60	31-51	7%-10%	0%-1.5%
4- Shrubs	10	47	35	20	14-24	12%-15%	0%-3%
5- Climbers	10	16	25	15	5-8	0%-3%	0%-1.5%

Plant Group	Expected Life Time (years)	Number of plant types in each plant group	Water consumption (liter/unit/day)		Objective Function in the optimization process:		
			Spring - Summer	Winter - Autumn	Constraints		Variables
					Min. no. of plant types in the mix	Min. % of the area covered compared with the total area	Min. % of plant types' area in the overall mix design area
6- Ground Covers	2	27	15	10	8-14	20%-25%	0%-0.5%
7- Ornamental Grass	2	5	7	5	2-3	0%-3%	0%-1.5%
8- Grass	7	1	10	7	1	40%-50%	40%-50% grass
9- Succulents	30	44	1	0.5	13-22	0%-3%	0%-1.0%

Figure 4.19 shows SLOM optimization process screen shot showing the objective function, variables and constraints for the minimum LCC corresponding to the minimum irrigation water consumption case.

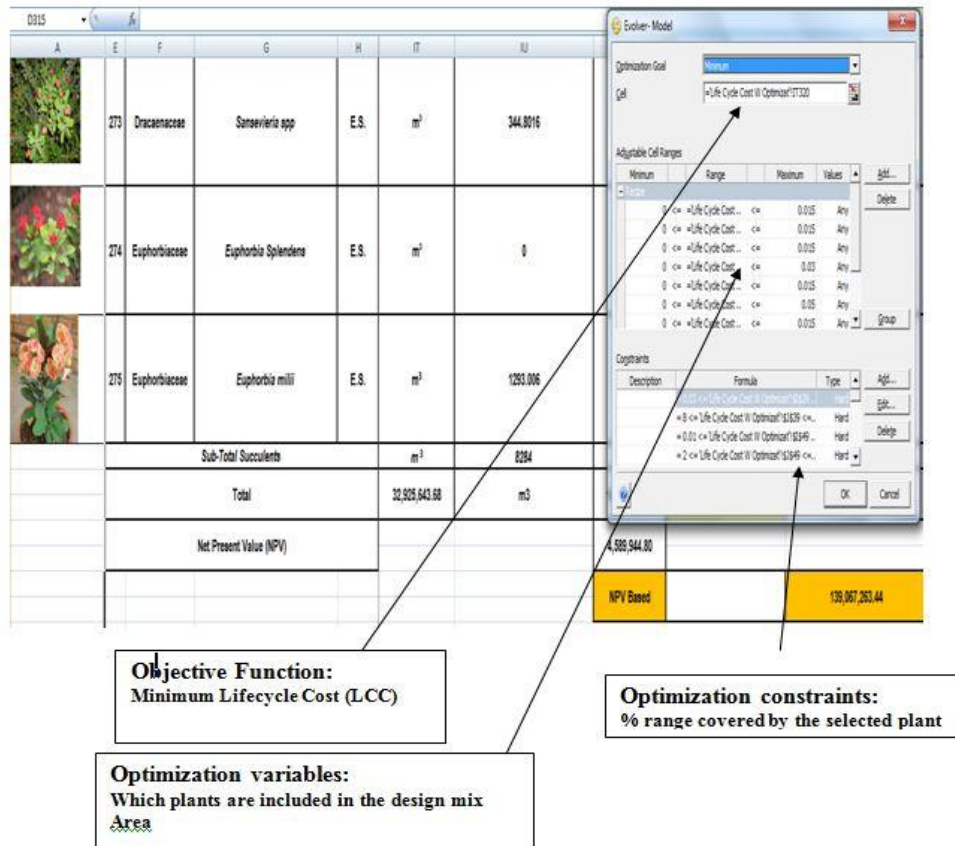


Figure 4-19: SLOM Optimization variables, constraints and objective function.

4.2.4 Water Simulation Optimization Model (WSOM)

As explained in the previous chapter, WSOM is used to provide water system lifecycle cost for four different categories. It applies a fixed amount for maintaining two categories of the system. The civil and electrical components are examples of these two categories. It is assumed that the lifecycle cost output of WSOM for the shared components between both the potable and irrigation systems is equally shared between both systems. Table 4.9 shows the cost share between the irrigation and potable water systems from the fixed rate maintenance shared category (e.g. civil building). The construction cost of the combined water utility system is 55 Million Egyptian Pounds.

WSOM optimization model is run to simulate three different cases for the potable and irrigation water demand that reflects RESOM and SLOM four study cases respectively as shown in Table 4.8. WSOM runs the optimization engine separately for the potable and irrigation components. The optimization is made in both cases for the electromechanical and pipes categories since the components of these categories are different in both the potable and irrigation cases. It should be noted that WSOM is fed in the later categories by the water profiles obtained from RESOM in order to provide the potable water pumps (representing the electromechanical components) lifecycle operating/maintenance schedule. WSOM optimization engine is run to simulate three different cases for the potable water demand that reflect the construction schedule of RESOM; namely: 1) the original feasibility-based case, 2) the risk relaxing case or the relaxed schedule due to the unexpected civil unrest situation, and 3) the optimized schedule case using the Crystal Ball simulation where stochastic monthly water demand is obtained. This is summarized in Table 4.9.

Table 4-8: The different cases in RESOM and SLOM

	Case 1	Case 2.1	Case 2.2	Case 3
RESOM	Given case	Optimized project implementation schedules		
SLOM	Given case	Optimized plant design (max. NPV EGP)		

4.2.4.1 WSOM Run Cases:

WSOM is used to run the four different categories of the water system components.

Table 4-9: WSOM integrated model – Potable water / Irrigation water

WSOM category	Potable water system	Irrigation water system
1- Fixed rate expenditure category maintenance cost (e.g. civil works items) (shared by both systems)	50%	50%
2- Regression based category maintenance cost (e.g. electrical components) (shared by both systems)	50%	50%
3- Breaking rate category maintenance cost (e.g. pipes)	Potable case	Potable case
4- Operating time-based maintenance category (e.g. electrochemical items)	RESOM output (4 cases)	SLOM output (4 cases)

The characteristics of the above items are inserted in the WSOM Database module and used by the other modules to calculate the lifecycle costs in accordance with the classification as explained above. The optimization process of the time-based maintenance category is represented by three pumps. The process calculates an amount of LE 110,000 as soon as a pump operating time reaches 20,000 hours which is the pump manufacturer requirement.

4.2.5 DCOM Model

The cooling profile obtained from the RECOM model is used to run the DCOM model. Similar to WSOM, DCOM contains calculation sheets for the 4 maintenance categories. The run cases considered 30 years lifecycle of the plant. Since the capacity of the available cooling sets is different, the optimization process is a must to obtain a nearly optimum operating / maintenance schedule for the available plant component sets, or pumps. A total number of 18 primary chiller sets (referred to as pumps in DCOM) were used to run the model cases in the operating time-based maintenance. The general service life of the industrial buildings in the UK is 30 years (Hudson et al, 1998). The 30 years lifetime is used for assessment in this application Therefore, the total number of variables is (30 years X 12 months X 18 pumps) = 6480 variables. It is considered that each pump shall operate a continuous operation for a minimum duration of one month to produce the required production following the required demand profile that is obtained from the RESOM model. Moreover, each pump should stop operation as soon as it reached 20,000 hours of operation with a cost of LE 100,000 per maintenance case. The model was run on two stages, first to reach a scenario where the number of required pumps in any month matches the number of actually proposed operating pumps by the DCOM model. The model calculates further the minimum lifecycle cost for the scenario. The cooling system capital cost (CAPEX) is 350 Million Egyptian Pounds in the case study. The Ton Refrigerant selling price is assumed LE 1.

4.2.6 RIM Results

RIM models provided results for the different cases. The results of the models are discussed here below.

4.2.6.1 RESOM Results:

RESOM provided implementation schedules for the different cases 1, 2.1, 2.2 and 3. The original feasibility-based schedule is shown in Figure 4.20. It starts with the first early stage group of projects G1 in blue followed by G2 in green,..etc. Different from Case 1, the optimized Cases 2.1 and 2.2 are shown in the schedule figures separately (the zone prioritization cases). Case 2.1 includes prioritizing Zone 1 is shown in Figure 4.21 followed by prioritizing Zone 3 in Case 2.2 in Figure 4.22. The optimized schedule of the portfolio prioritization is shown in Figure 4.23. The original development feasibility for REPs and infrastructure systems was originally based on this schedule. RESOM's output results are included in Table 4.10 for the real estate projects. The Expected Gross Profit (EGP) results for the different cases for cooling, water and landscape systems are presented in Tables 4.11, 4.12 and 4.13 respectively.

Table 4-10: EGP Results - Real Estate Projects

Case	Case description	Expected Gross Profit (EGP) – Amounts in Egyptian Pounds		
		EGP	EGP+10%	EGP-10%
Case 1	Original Case	9.5 Billion	10.45 Billion	8.55 Billion
Case 2.1	Start developing small Zone1	8.3 Billion	9.13 Billion	7.47 Billion
Case 2.2	Start developing large Zone 3	8.8 Billion	9.68 Billion	7.92 Billion
Case 3	Portfolio selection	7.9 Billion	8.69 Billion	7.11 Billion

I = 12%

WACC = 16.6%

Table 4-11: EGP Results – Cooling System

Case	Case Description	Expected Gross Profit (EGP) – Amounts in Egyptian Pounds		
		EGP	EGP+10%	EGP-10%
Case 1	Original Case	4.1 Billion	4.51 Billion	3.69 Billion
Case 2.1	Start developing small Zone1	3.6 Billion	3.96 Billion	2.97 Billion
Case 2.2	Start developing large Zone 3	3.4 Billion	3.74 Billion	3.1 Billion
Case 3	Portfolio selection	2.6 Billion	2.86 Billion	2.34 Billion

I = 12%

WACC = 16.6%

Table 4-12: EGP Results – Water Combined System

Case	Case description	Expected Gross Profit (EGP) – Amounts in Egyptian Pounds		
		EGP	EGP+10%	EGP-10%
Case 1	Original Case	36 Million	40 Million	32 Million
Case 2.1	Start developing small Zone1	34 Million	37 Million	31 Million
Case 2.2	Start developing large Zone 3	35 Million	39 Million	32 Million
Case 3	Portfolio selection	32.9 Million	36.2 Million	29.6 Million

I = 12%

WACC = 16.6%

Table 4-13: EGP Results – Landscape System

Case	Case Description	Expected Gross Profit (EGP) – Amounts in Egyptian Pounds		
		EGP	EGP+10%	EGP-10%
Case 1	Original Case	84 Million	92 Million	76 Million
Case 2.1	Start developing small Zone1	61 Million	67 Million	55 Million
Case 2.2	Start developing large Zone 3	68 Million	75 Million	61 Million
Case 3	Portfolio selection	57 Million	63 Million	51 Million

I = 12%

WACC = 16.6%

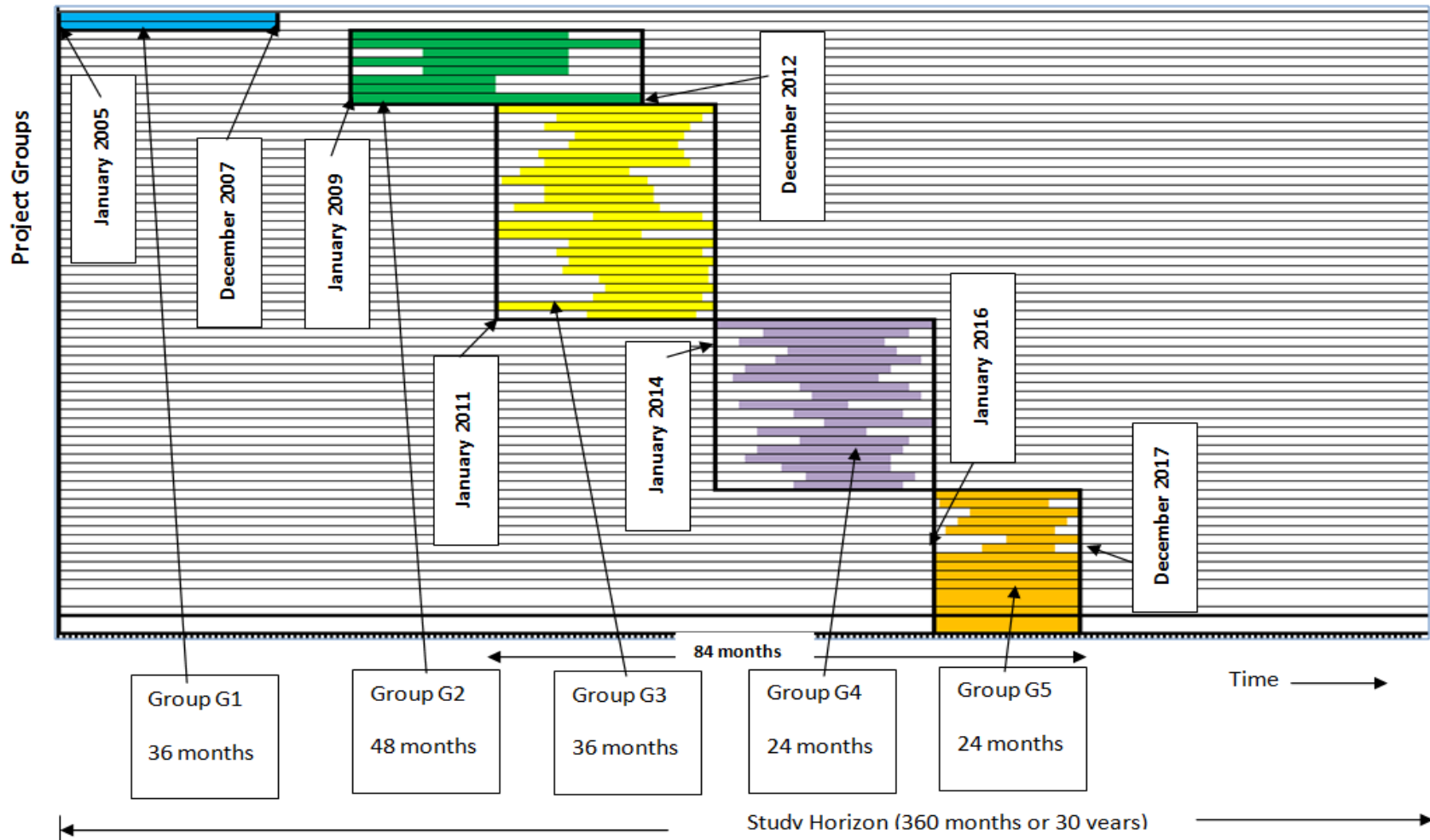


Figure 4-20: Original feasibility-based case – RESOM Schedule (84 months implementation)

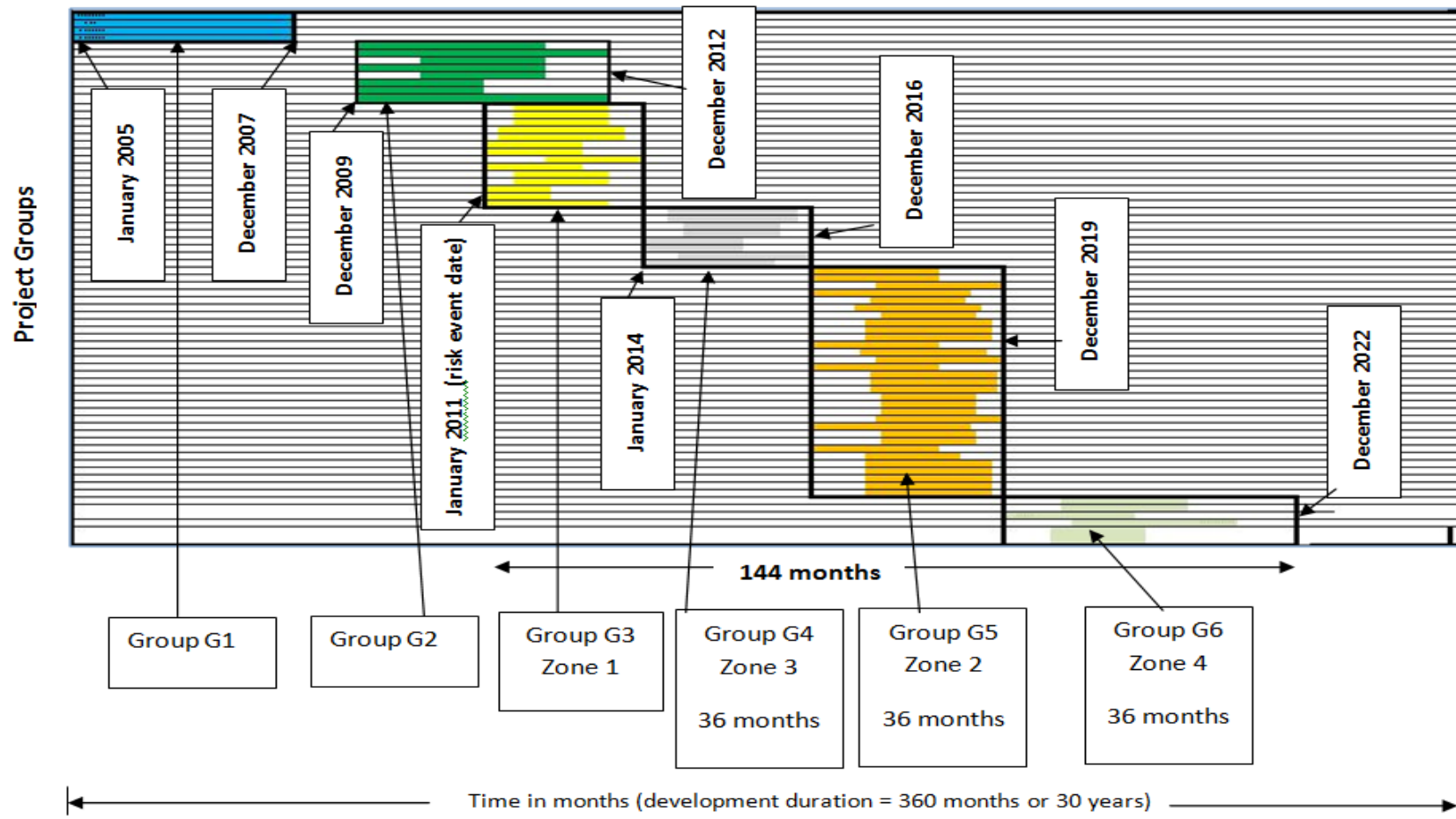


Figure 4-21: Risk impacted case –prioritized Zone 1 (144 months implementation)

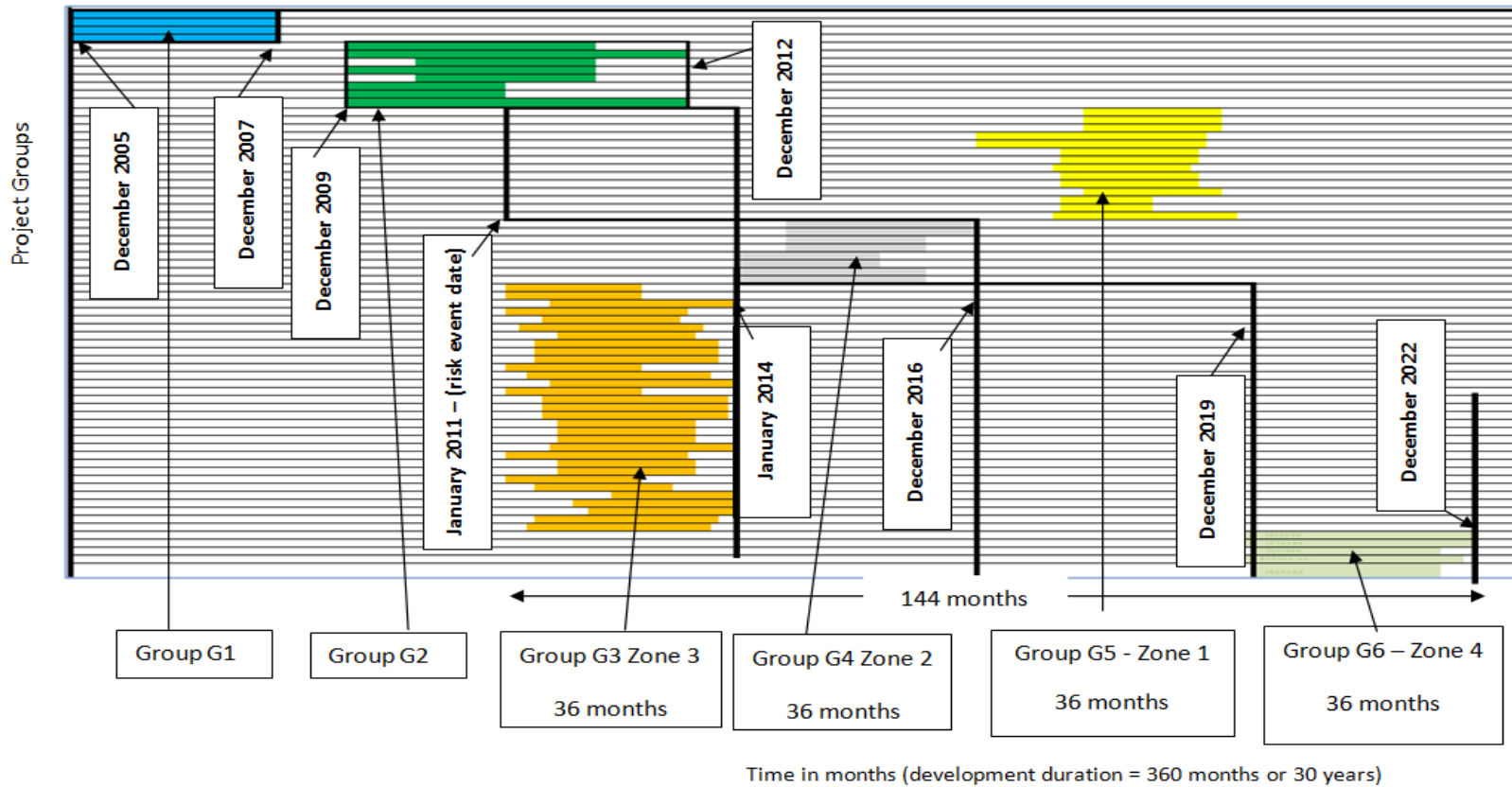


Figure 4-22: Risk impacted case –prioritized Zone 3 (144 months implementation)

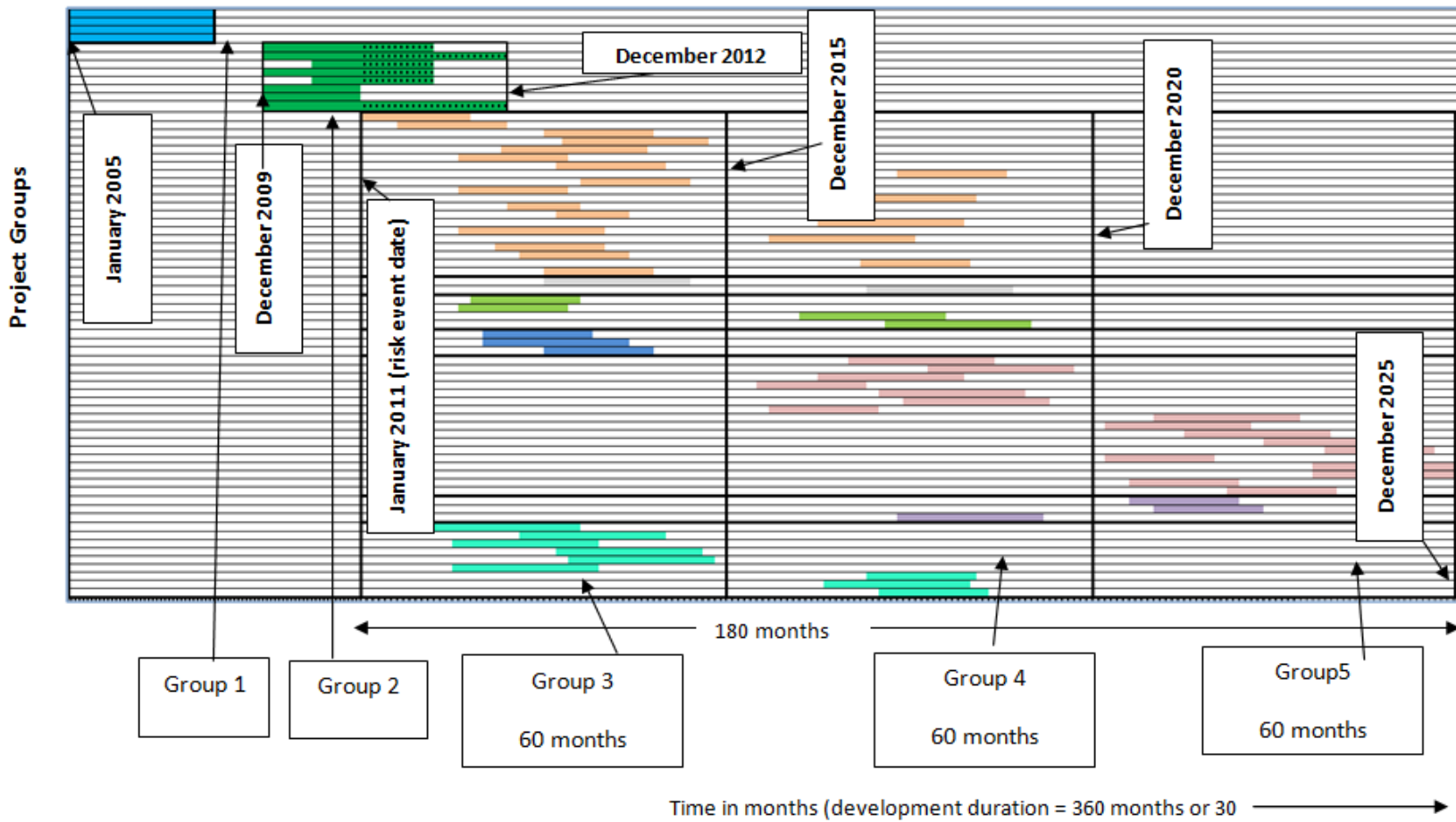


Figure 4-23: Risk impacted Case 3 – Portfolio prioritization (180 months implementation)

Year	1												2											
Pump/Month	Jan-12	Feb-12	Mar-12	Apr-12	May-12	Jun-12	Jul-12	Aug-12	Sep-12	Oct-12	Nov-12	Dec-12	Jan-13	Feb-13	Mar-13	Apr-13	May-13	Jun-13	Jul-13	Aug-13	Sep-13	Oct-13	Nov-13	
Pump 1 (4,800,000 m3/hr)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pump 2 (4,800,000 m3/hr)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Pump 3 (4,800,000 m3/hr)	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Actual Working Pumps	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Check	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Actual Consumption (m3/day)	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	6,944	
Required Consumption (m3/hr)	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	289	
Required Number of Working Pumps	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	
Maintenance of Pump 1	1	2	2	2	3	3	4	5	5	5	5	5	6	6	6	6	6	6	7	7	7	8	9	
Maintenance of Pump 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	3	4	4	4	4	4	4	
Maintenance of Pump 3	0	0	1	2	2	3	3	3	4	5	6	7	7	7	7	7	8	8	8	9	10	10	10	
Maintenance of Pump 1	1	2	0	0	3	0	4	5	0	0	0	0	6	0	0	0	0	0	7	0	0	8	9	
Maintenance of Pump 2	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	3	0	4	0	0	0	0	0	
Maintenance of Pump 3	0	0	1	2	0	3	0	0	4	5	6	7	0	0	0	0	8	0	0	9	10	0	0	
Maintenance Time of Pump 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Time of Pump 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Time of Pump 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Cost (EGP) of Pump 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Cost (EGP) of Pump 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Cost (EGP) of Pump 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Constraint of Pump 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Constraint of Pump 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
Maintenance Constraint of Pump 3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Figure 4-25: WSOM output - optimized electromechanical lifecycle operating/maintenance schedule – irrigation water case

Table 4-14: WSOM summary results – water system

Cost type	Case 1	Case 2.1	Case 2.2	Case 3
NPV CAPEX (Potable + Irrigation)	55	55	55	55
OPEX:				
1- Operating time-based maintenance category maintenance cost (Potable)	3.8	3.4	3.6	3.2
Operating time-based maintenance category maintenance cost (Irrigation)	2.8	2.1	2.1	2.1
2- Fixed rate expenditure category maintenance cost (Potable + Irrigation)	17.1	17.1	17.1	17.1
3- Regression based category maintenance cost (Potable + Irrigation)	5.3	5.1	5.2	4.9
4- Breaking rate category maintenance cost - (Potable)	4.5	4.5	4.5	4.5
Breaking rate category maintenance cost - (Irrigation)	2.1	2.1	2.1	2.1
NPV OPEX	36	34	35	34
NPV of the EGP (Potable + Irrigation)				
	91	89	90	89
Amounts in Millions Egyptian Pounds Water selling price: 3 LE/m ³ irrigation or potable water				

I = 12%

WACC = 16.6%

LE = Egyptian Pound

Table 4-15: Summary of SLOM Output

Plant Group	No. of plants' types in each group	Original design (without optimization)		Optimized design mix Objective function: Minimum Lifecycle cost (LCC)		Optimized design mix Objective Function: Min. lifecycle irrigation water demand	
		No of types	% group's area to the overall landscape area	No of types	% group's area to the overall landscape area	No of types	% group's area to the overall landscape area
Palms	27	2	1%	9	3%	7	7%
Like-Palms	6	0	0	3	0.4%	3	0.4%
Trees	102	33	3%	33	7%	36	10%
Shrubs	47	15	8%	15	12%	15	12%
Climbers	16	3	1%	5	0.7%	5	0.7%
Ground Cover	27	13	31%	12	24.7%	10	21.8%
Ornamental Grass	5	3	25%	3	1%	3	1%
Grass	1	1	14%	1	50%	1	46%
Succulents	44	8	17%	15	1.2%	15	1.1
Total	275 types	78 types	100%	96 types	100%	95 types	100%

Table 4-16: Summary of SLOM financial output for Cases (1), (2.1), (2.2) and (3) – EGP Calculations				
Cost Type	Case 1	Case 2.1	Case 2.2	Case 3
	Original design case	Minimum lifecycle cost design case		
(NPV) CAPEX (1)	12	16	16	16
OPEX Calculations:				
Irrigation water cost (2)	41	32	32	32
Plants replacement cost (3)	69	23	23	23
Other maintenance costs (4)	57	46	46	46
OPEX = (2) + (3) + (4) (5)	167	101	101	101
NPV (EGP) (=Cash In – (1+5))	84	61	68	57
Notes: - NPV calculations provided from SLOM. - Amounts in Millions Egyptian Pounds LE. - I = 12% - WACC = 16.6%				

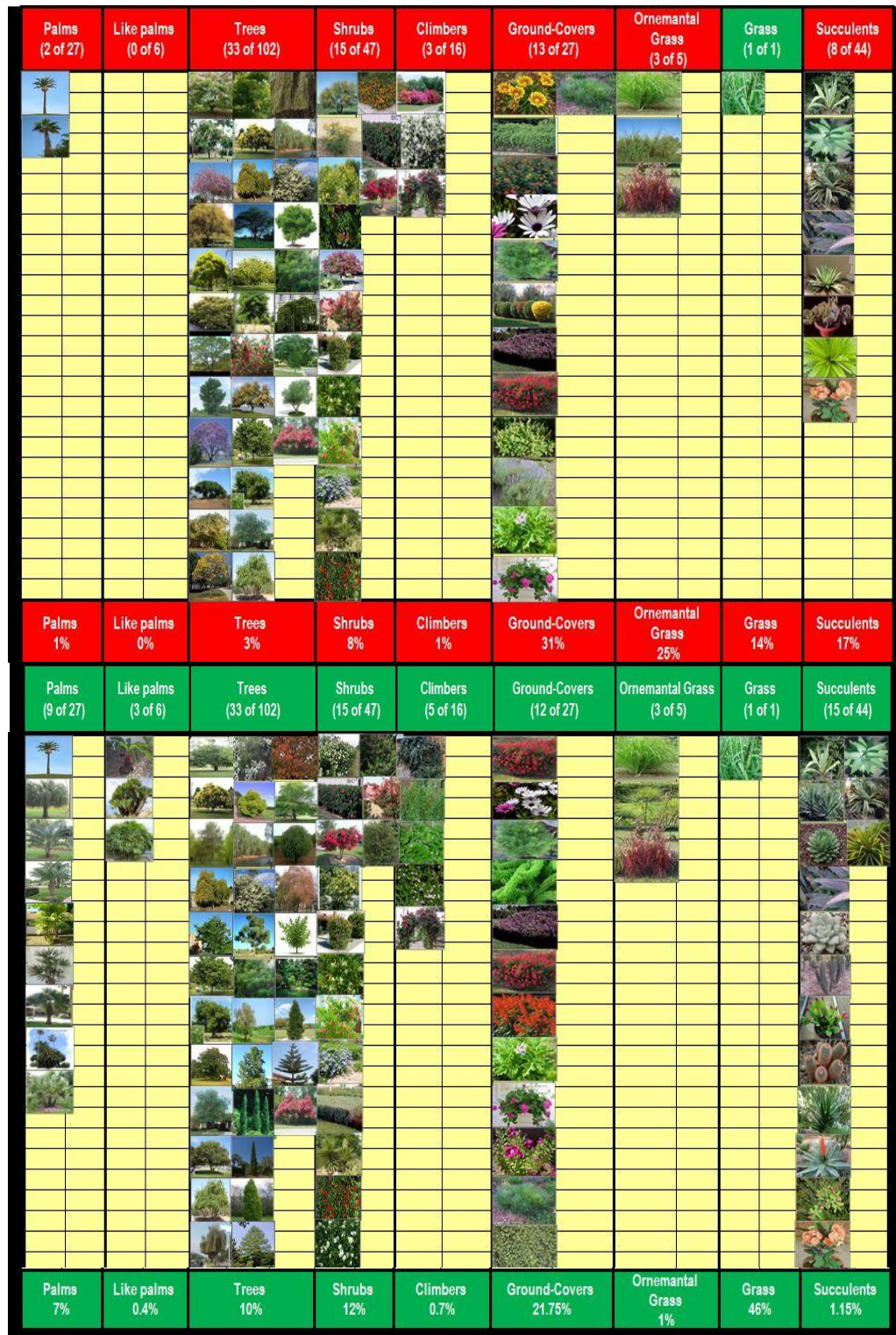


Figure 4-26: The Chess Carpet Diagram (CCD) for the original design mix case without optimization versus the optimized SLOM design

4.2.6.4 DCOM Results

Table 4.17 presents the difference between the study cases, before and after DCOM optimization. The operating/maintenance schedule for the time-maintenance category is indicated in Figure 4.27.

Table 4-17: DCOM Summary Results Cash Out (CAPEX & OPEX) – Cooling System

Cost type	Case 1	Case 2.1	Case 2.2	Case 3
a- NPV (CAPEX):	355	355	355	355
OPEX Calculations:				
1- Operating time-based maintenance category maintenance cost	45	38	41	37
2- Fixed rate expenditure category maintenance cost	60	60	60	60
3- Regression based category maintenance cost	16	16	16	16
4- Breaking rate category maintenance cost	6	6	6	6
b- NPV OPEX (=1+2+3+4)	127	120	123	119
NPV (Cash Out) (= a + b)	364	289	347	261
Amounts in Millions Egyptian Pounds I = 12% WACC = 16.6%				

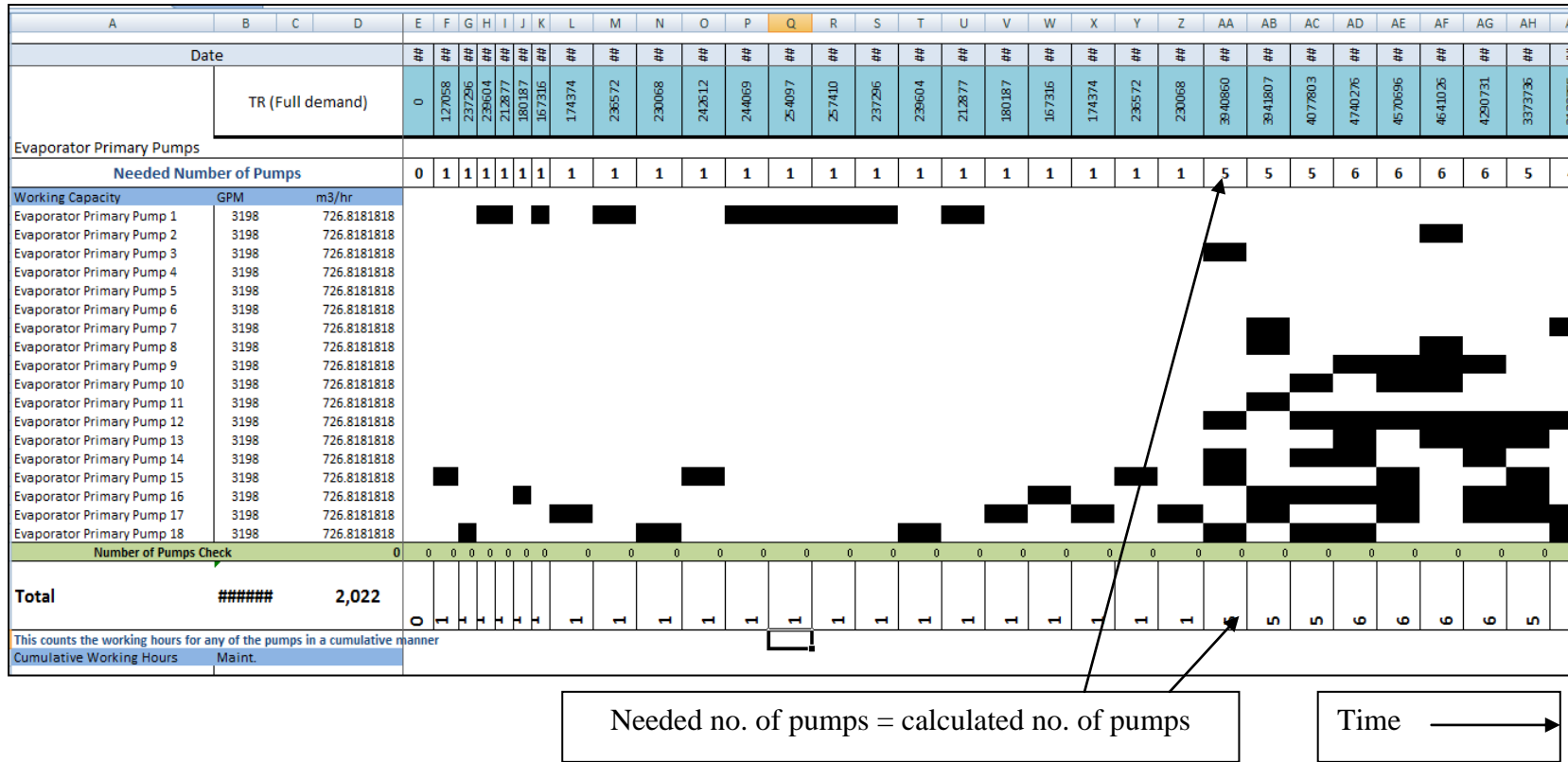
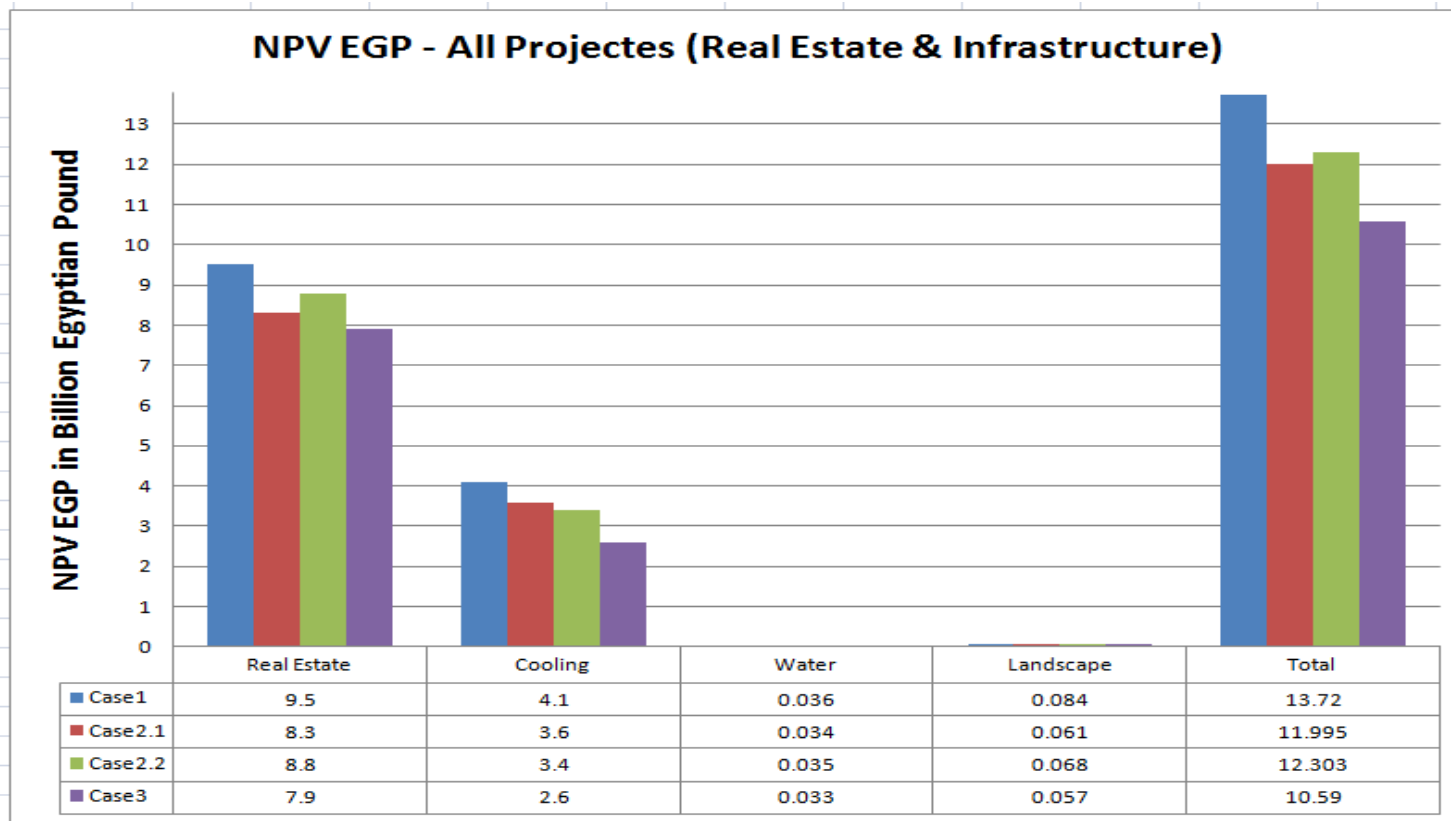


Figure 4-27: Final scenario after completing optimization model run.



I = 12%
WACC = 16.6%

Figure 4-28: RIM Final Results – All Real Estate and Infrastructure Projects

4.2.7 RIM Results

As seen above, RIM framework models provided the Expected Gross Profit EGP in the different cases, case 1 or the original feasibility-based case, the zone cases 2.1 and 2.2 for the prioritized zone 1 versus prioritized zone 3, and finally the portfolio-based case (case 3). The results summary is shown in Figures 4.28 and 4.29. It should be noted that the allowed end date for implementing cases 1, 2 and 3 are 31/12/2017, 31/12/2022 and 31/12/2025 respectively. This is considered as a factor affecting the EGP amounts in the different cases under study. The results include the NPV of the Expected Gross Profit EGP in the different cases. The EGP in Case 2.2 (prioritized Zone 3) would be a preferred option after the basic-feasibility scenario Case 1. The Risk Impact RI% in this preferred case is 10%, that is obtained from substituting in the main Equation 45; that is $\{(LE13,72 \text{ Billion} - LE12,303 \text{ Billion}) / (LE13,72 \text{ Billion})\}$.

4.2.7.1 Real Estate Projects Profits

RIM provided a schedule that maximizes the expected gross profit value EGP for the real estate projects in the different cases. The amounts do not include the infrastructure systems profits. RIM respected the given variable ranges and constraints (e.g. projects sharing the same construction end or occupancy dates). RIM's results matched the logic of the projects sequence in the different cases. The expected gross profit EGP in the original feasibility case was expected to reach LE 9.5 Billion (Case 1). The amount reduced to LE 8.3 Billion due to changing the sequence of implementing the projects in Case 2.1. This amount improved to reach LE 8.8 Billion in the case of prioritizing zone 3, which is relatively large if compared with zone 1. The gross profit reduced to LE 7.9 Billion in Case 3. The reduction is mainly caused by the longer construction period of the mixed portfolio products. RIM respected the variable ranges and constraints in all cases.

4.2.7.2 Cooling Results

The gross profit of the cooling system in the original feasibility case is LE 4.1 Billion (Case 1). The amount reduced to LE 3.6 Billion due to changing the sequence of implementing the projects in Case 2.1. The schedule change resulted in reduced Cash-In due

to delayed construction and hence occupancy. The Cash-Out has also shown difference in the three optimized situations from the original case due to the change in the plant mix design. In line with the logic expectations, the EGP in case 2.2 improved 3.4 Billion if compared with case 2.1. The EGP in the portfolio case (number 3) reduced to LE 2.6 Billion due to the longer construction period, and hence the delayed occupancy and consumption, of Case 3 compared with the other Cases 1, 2.1 and 2.2.

4.2.7.3 Water System Results

The gross profit of the water system in the original feasibility case is LE 36 Million (Case 1). The amount reduced to LE 34 Million due to changing the sequence of implementing the projects in Case 2.1. The schedule change resulted in reduced Cash-In due to delayed construction and hence occupancy. The Cash-Out has also shown fluctuations between the different cases due to the change in potable water consumption although the irrigation water remains unchanged. The EGP value improved to LE 35 Million in case 2.2 (prioritized Zone 3) but reduced to 32.9 Million in Case 3 due to the delayed occupancy of the buildings.

4.2.7.4 Landscape Results

The gross profit of the landscape system in the original feasibility case is LE 84 Million (Case 1). The amount reduced to LE 61 Million due to changing the sequence of implementing the projects in Case 2.1 and improved to LE 68 Millions in Case 2.2. The schedule change resulted in reduced Cash-In due to delayed construction and hence occupancy. The Cash-Out has also shown difference in the three optimized situations from the original case due to the change in the plant mix design. Although the CAPEX cost increased from LE 12 Million in the original design (Case 1) to 16 Million in the optimized Cases (2.1, 2.2 and 3), the OPEX reduced from LE 167 Million in Case 1 to LE 101 Million amount in the later Cases in the Table. As expected, the EGP in the portfolio, Case 3, dropped to LE 57 Million due to the delayed Cash-In profile that follows the occupancy profile.

Table 4.18 shows the effect of changing the WACC% on the Expected Gross Profit values for Annual Inflation Rate of 12%. The effect of changing the Annual Inflation Rate on the Expected Gross Profit EGP for WACC% of 16.6% is shown in Table 4.19.

4.2.7.5 RIM Results Analysis:

Through applying RIM's integrated models on the case study, the estimated EGP amount in the original feasibility is LE 9.5 Billion. RIM's optimization process provided different projects implementation schedules that represent different cases. The two cases propose implementing the remaining unconstructed projects by zones. Changing the zone priorities is the main difference between both cases. The changing real estate market demand was also considered as input to RIM as a third optimization case. It is assumed that product mix of different real estate portfolios are fed from updated market research upon the occurrence of the risk event. It is also assumed that the construction period is extended in this later case to accommodate the risk impacted market. The risk impact (RI%) on the EGP in the three optimization cases is 13%, 7% and 17% respectively. The improved result in the second optimization case corresponds to the prioritization of a large number of projects located at certain zone. The first case of prioritizing a small zone corresponds to relatively less EGP. The market input assumptions provided a worst EGP compared with the original feasibility-based figures due to extending the construction durations of the projects.

As for the Cooling System, the estimated EGP amount in the original feasibility is LE 4.1 Billion. RIM's optimization process provided different projects implementation schedules that represent different cases. It is proposed to implement the construction of the remaining unconstructed projects by zones. Changing the zones priorities is the main difference between both cases as highlighted above. The risk impact on the EGP in the three optimization cases is 12%, 17% and 37% respectively. The main reason behind the small difference is that the three optimized cases provide less irrigation water demand compared with the original case. The zoning optimization cases provided improved result due to improved Cash-In for the potable water portion that follow the early completion of projects and hence early occupancy and the more water demand.

The estimated EGP amount for the water system in the original feasibility is LE 36 Million. RIM's optimization process provided different projects implementation schedules that represent different cases. It is proposed to implement the construction of the remaining unconstructed projects by zones. Changing the zones priorities is the main difference between both cases as highlighted above. The risk impact on the EGP in the three optimization cases is 6%, 3% and 3.1% respectively. The later portfolio optimized case reflected less EGP due to the longer construction period along with late occupancy and hence less demand. The first optimization case (zone 1 prioritized) reflected less EGP compared with case 2 (zone 3 prioritized) as zone 3 contains more projects than zone 1 which increases the cooling demand upon their earlier construction completion.

The estimated EGP amount for the landscape system in the original feasibility is LE 84 Million. RIM's optimization process provided different projects implementation schedules corresponding to certain Cash-In for the landscape system. It provided also optimized plant mix selection that corresponds to minimum lifecycle cost (or Cash-Out). The risk impact on the EGP, in the three optimization cases is 27%, 19% and 32% respectively. Similar to other infrastructure systems, the improved result in the second optimization case corresponds to the prioritization of a large number of projects located at certain zone. The first case of prioritizing a small zone corresponds to a relatively less EGP. The market input assumptions (or the portfolio case) provided a worst EGP compared with the original feasibility-based figures due to extending the construction durations of the projects and hence less income generation. Summary of RIM results is shown in Figure 4.29.

4.2.7.6 Sensitivity Analysis

Tables 4.18, 4.19 show the effect of changing the WACC% and Annual inflation rate I% on the EGP amounts respectively. The effect of changing the monthly consumption rate of potable water on the Time-based maintenance expenditure is shown in Table 4.20. The effect in the latter case is not significant as the number of running equipment is limited to 3 units. In cases of larger scale water systems, it is expected that this type of maintenance costs will increase.

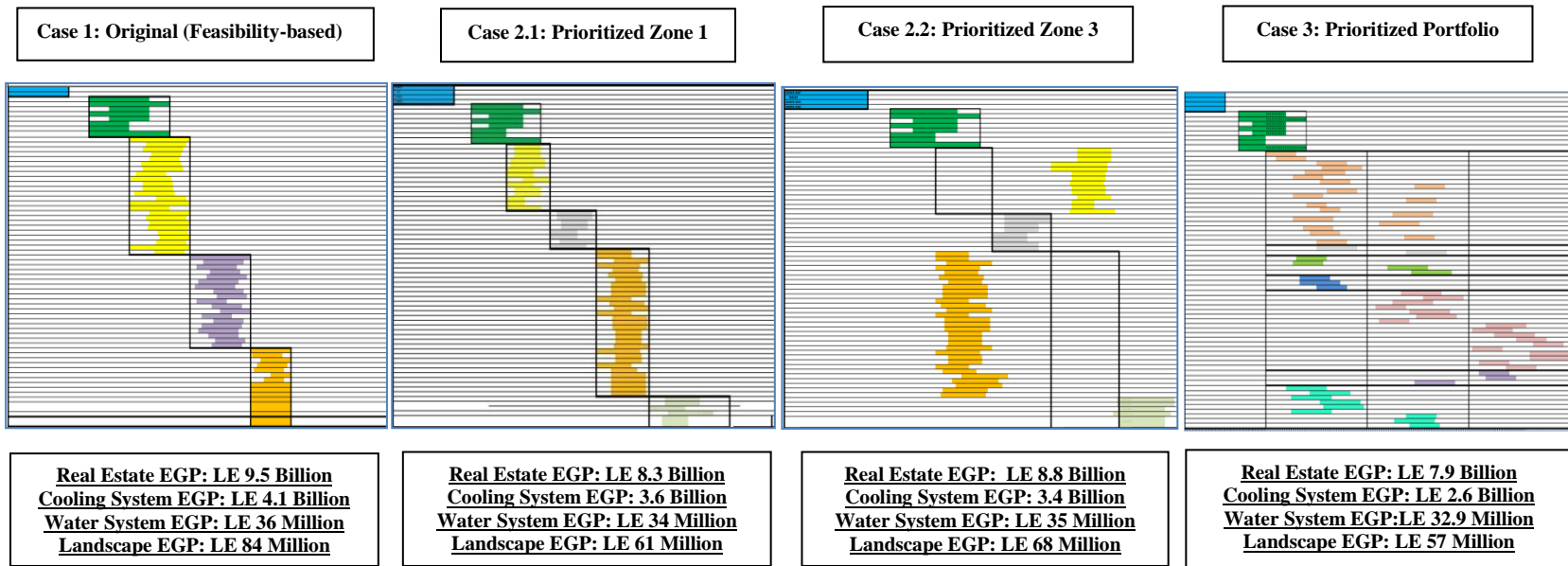


Figure 4-29: Summary of RESOM output in the different study cases

Table 4-18: Sensitivity analysis of the effect of changing the weighted average cost of capital percentage on the Expected Gross Profit (for Inflation =12%)

WACC (%)	Case 1					Case 2.1					Case 2.2					Case 3				
	a	b	c	d	Total	a	b	c	d	Total	a	b	c	d	Total	a	b	c	d	Total
12	17.000	7.337	0.064	0.150	24.552	14.853	6.442	0.061	0.109	21.465	15.747	6.084	0.063	0.122	22.016	14.137	4.653	0.059	0.102	18.951
14	13.500	5.826	0.051	0.119	19.497	11.795	5.116	0.048	0.087	17.046	12.505	4.832	0.050	0.097	17.483	11.226	3.695	0.047	0.081	15.049
16.6	9.5	4.1	.036	.084	13.72	8.3	3.6	.034	.061	12	8.8	3.4	.035	.068	12.3	7.9	2.6	.033	.057	10.59
18	6.800	2.935	0.026	0.060	9.821	5.941	2.577	0.024	0.044	8.586	6.299	2.434	0.025	0.049	8.806	5.655	1.861	0.024	0.041	7.580
20	5.000	2.158	0.019	0.044	7.221	4.368	1.895	0.018	0.032	6.313	4.632	1.789	0.018	0.036	6.475	4.158	1.368	0.017	0.030	5.574
22	3.500	1.511	0.013	0.031	5.055	3.058	1.326	0.013	0.022	4.419	3.242	1.253	0.013	0.025	4.533	2.911	0.958	0.012	0.021	3.902

Amounts in Billion Egyptian Pounds

a= Real Estate projects

b= cooling system

c= water system

d= landscape plants system

Table 4-19: Sensitivity analysis of the effect of changing the inflation percentage on the expected lifecycle gross profit

(For WACC=16.6%)

Annual Inflation (%)	Case 1					Case 2.1					Case 2.2					Case 3				
	a	b	c	d	Total	a	b	c	d	Total	a	b	c	d	Total	a	b	c	d	Total
0	2.4	1.0	0.009	0.021	3.43	2.1	0.9	0.009	0.015	3.0	2.2	0.9	0.009	0.017	3.1	2.0	0.7	0.008	0.014	2.6
2	3.8	1.6	0.014	0.034	5.488	3.3	1.4	0.014	0.024	4.8	3.5	1.4	0.014	0.027	4.9	3.2	1.0	0.013	0.023	4.2
4	5.2	2.3	0.020	0.046	7.546	4.6	2.0	0.019	0.034	6.6	4.8	1.9	0.019	0.037	6.8	4.3	1.4	0.018	0.031	5.8
6	6.2	2.7	0.023	0.055	8.918	5.4	2.3	0.022	0.040	7.8	5.7	2.2	0.023	0.044	8.0	5.1	1.7	0.021	0.037	6.9
8	7.4	3.2	0.028	0.066	10.7016	6.5	2.8	0.027	0.048	9.4	6.9	2.7	0.027	0.053	9.6	6.2	2.0	0.026	0.044	8.3
10	8.4	3.6	0.032	0.074	12.0736	7.3	3.2	0.030	0.054	10.6	7.7	3.0	0.031	0.060	10.8	7.0	2.3	0.029	0.050	9.3
12	9.5	4.1	0.036	0.084	13.72	8.3	3.6	0.034	0.061	11.995	8.8	3.4	0.035	0.068	12.303	7.9	2.6	0.033	0.057	10.59

Amounts in Billion Egyptian Pounds

a= Real Estate projects

b= cooling system

c= water system

d= landscape plants system

Table 4-20: Sensitivity Analysis for impacts on the time-related maintenance cost

Changing the potable water consumption rates in the potable water system

Change in monthly water consumption rate	Base case (RESOM case 1)	+10%	+20%	+30%	-10%	-20%	-30%
Time-related maintenance cost (*)	3.8	3.96	4.13	4.37	3.65	3.54	3.4

(*) Amounts in Millions Egyptian Pounds

WCC = 16.6%

I = 12%

4.3 Verification

The output results obtained from RESOM were proven accurate and consistent with the expectation. The calculations were repeated in Excel sheet, in isolation from the model sheet. The calculated results match the models' output which is a good indicator that the models are convenient and accurate in their calculations. The reader is referred to Figure 4.30 below which shows the same result obtained from the schedule. The summation of the monthly Cash Flow under the blue line chart for the first project of the first implemented projects' group compared with double checked calculation. Similar effort was also made for the other models (DCOM, SLOM and WSOM) in order for verification convenience purposes.

As part of the verification process; the calculated construction cost is the same as the cost obtained from the schedule (to the right)

#	Total cost (calculated)	.42 Cost/month	.08 Cost/month	Start	End	period 1	period 2	period 3	period 4	Total cost (from the schedule)
REP 1	75,000,000.00	3,500,000.00	666,666.67	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008	75,000,000.00
REP 2	58,899,000.00	2,643,900.00	503,600.00	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008	58,899,000.00
REP 3	34,525,500.00	1,611,190.00	306,893.33	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008	34,525,500.00
REP 4	34,525,500.00	1,611,190.00	306,893.33	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008	34,525,500.00
REP 5	934,241,250.00	43,597,925.00	8,304,366.67	1/1/2009	1/1/2012	10/1/2009	7/1/2010	4/1/2011	1/1/2012	934,241,250.00
REP 6	666,390,000.00	23,323,650.00	4,442,600.00	1/1/2009	1/1/2013	1/1/2010	1/1/2011	1/1/2012	1/1/2013	666,390,000.00
REP 7	119,990,000.00	8,399,300.00	1,599,866.67	1/1/2009	1/1/2012	7/1/2010	1/1/2011	7/1/2011	1/1/2012	119,990,000.00

Projects

#	.08 Cost/month	Start	End	period 1	period 2	period 3	period 4	Total cost (from the schedule)
REP 4	306,893.33	1/1/2005	1/1/2008	10/1/2005	7/1/2006	4/1/2007	1/1/2008	34,525,500.00
REP 5	8,304,366.67	1/1/2009	1/1/2012	10/1/2009	7/1/2010	4/1/2011	1/1/2012	934,241,250.00
REP 6	4,442,600.00	1/1/2009	1/1/2013	1/1/2010	1/1/2011	1/1/2012	1/1/2013	666,390,000.00
REP 7	1,599,866.67	1/1/2009	1/1/2012	7/1/2010	1/1/2011	7/1/2011	1/1/2012	119,990,000.00
REP 8	299,813.33	1/1/2009	1/1/2012	10/1/2009	7/1/2010	4/1/2011	1/1/2012	33,639,000.00
REP 10	1,959,866.67	1/1/2009	1/1/2011	7/1/2009	1/1/2010	7/1/2010	1/1/2011	79,415,000.00
REP 11	1,393,133.33	1/1/2009	1/1/2011	7/1/2009	1/1/2010	7/1/2010	1/1/2011	104,455,000.00
REP 12	6,666,666.67	1/1/2009	1/1/2013	1/1/2010	1/1/2011	1/1/2012	1/1/2013	1,000,000,000.00
REP 13	8,304,366.67	1/1/2011	1/1/2014	10/1/2011	7/1/2012	4/1/2013	1/1/2014	934,241,250.00
REP 14	1,013,600.00	1/1/2011	1/1/2013	3/1/2012	1/1/2012	3/1/2013	1/1/2013	76,920,000.00
REP 15	3,075,600.00	9/1/2011	9/1/2013	3/1/2012	3/1/2012	3/1/2013	9/1/2013	60,670,000.00
REP 16	667,800.00	2/1/2012	8/1/2013	6/1/2012	11/1/2012	4/1/2013	8/1/2013	33,390,000.00
REP 17	667,800.00	1/1/2012	7/1/2013	3/1/2012	10/1/2012	3/1/2013	7/1/2013	34,385,000.00
REP 18	1,565,733.33	8/1/2011	8/1/2013	2/1/2012	8/1/2012	2/1/2013	8/1/2013	117,430,000.00
REP 19	142,720.00	9/1/2011	9/1/2013	3/1/2012	9/1/2012	3/1/2013	9/1/2013	10,704,000.00
REP 20	901,300.00	5/1/2011	1/1/2012	9/1/2011	2/1/2012	7/1/2012	1/1/2012	45,965,000.00
REP 21	1,161,800.00	2/1/2011	2/1/2013	8/1/2011	2/1/2012	8/1/2012	2/1/2013	87,135,000.00
REP 22	324,600.00	9/1/2011	3/1/2013	1/1/2012	6/1/2012	1/1/2012	3/1/2013	26,230,000.00
REP 23	437,000.00	9/1/2011	3/1/2013	1/1/2012	6/1/2012	1/1/2012	3/1/2013	21,850,000.00
REP 24	546,966.67	4/1/2011	4/1/2013	10/1/2011	4/1/2012	10/1/2012	4/1/2013	41,024,000.00
REP 25	42,570.00	5/1/2012	11/1/2013	9/1/2012	2/1/2013	7/1/2013	1/1/2013	2,120,500.00
REP 26	8,304,366.67	1/1/2011	1/1/2014	10/1/2011	7/1/2012	4/1/2013	1/1/2014	934,241,250.00
REP 27	1,863,920.00	1/1/2011	1/1/2013	7/1/2011	1/1/2012	7/1/2012	1/1/2013	139,764,000.00
REP 28	1,911,840.00	1/1/2012	1/1/2014	7/1/2012	1/1/2013	7/1/2013	1/1/2014	143,358,000.00
REP 29	1,064,080.00	11/1/2011	11/1/2013	5/1/2012	11/1/2012	5/1/2013	11/1/2013	79,806,000.00
REP 30	843,440.00	1/1/2012	1/1/2014	7/1/2012	1/1/2013	7/1/2013	1/1/2014	63,298,000.00
REP 31	1,059,200.00	12/1/2011	12/1/2013	6/1/2012	12/1/2012	6/1/2013	12/1/2013	77,196,000.00
REP 32	427,380.00	6/1/2012	12/1/2013	10/1/2012	3/1/2013	8/1/2013	12/1/2013	21,369,000.00
REP 33	454,620.00	7/1/2012	1/1/2014	11/1/2012	4/1/2013	9/1/2013	1/1/2014	22,731,000.00
REP 34	278,220.00	5/1/2012	11/1/2013	9/1/2012	2/1/2013	7/1/2013	11/1/2013	13,911,000.00
REP 35	2,346,666.67	1/1/2011	1/1/2014	10/1/2011	7/1/2012	4/1/2013	1/1/2014	264,000,000.00
REP 36	25,250.00	4/1/2012	10/1/2013	8/1/2012	1/1/2013	6/1/2013	10/1/2013	1,262,500.00
REP 37	6,952,640.00	1/1/2014	1/1/2017	10/1/2014	7/1/2015	4/1/2016	1/1/2017	782,172,900.00

Figure 4-30: Example of the Verification Method

Time →

4.4 Validation:

This study presents the dynamic integrated decision support system RIM. RIM is developed and documented in this dissertation. The validation of RIM is implemented on two stages as follows:

4.4.1 Small Scale Cases

RIM is applied to provide the Expected Gross Profit EGP for a commercial building having an area of 5000 square meter. It is also applied to calculate the operating expenditure OPEX for a given plant mix for a landscaped area of 1,000 square meter. The analysis period for both cases is 30 years with an Annual Inflation Rate of 12% and WACC% of 16.6%. The results of both models were then verified by real estate and landscape experts respectively. The experts gave positive opinions in regards to the model calculation accuracy. The results of SLOM model Figures 4.31 and RESOM model are shown in 4.32.

Plant Group	Data Input			Data Output		
	Plant	No.	Area m ²	CAPEX	OPEX	Total
Palm	Phoenix dactylifera	2	8	2,323	31,646	33,969
	Bismarckia Nobilis	5	20	8,058	84,066	92,124
Like-Palms	Cycas revoluta	5	10	11,410	46,128	57,538
Trees	Cassia nodosa	2	8	1,266	24,107	25,373
	Parkinsonia aculeata	2	8	816	23,117	23,932
	Peltophorum africanum	2	8	966	23,117	24,114
	Populus alba	1	4	633	12,053	12,686
	Albizia lebbeck	1	4	708	12,218	12,926
Shrubs	Lantana camara	5	4	147	21,820	21,967
	Hibiscus rosa - sinensis	5	4	147	21,820	21,967
	Bougainvillea spectabilis	5	4	185	22,023	22,207
	Bougainvillea spp.	5	4	260	17,434	17,793
	Jasminum grandiflorum	5	4	260	17,434	17,793
	Clerodendron splendens	5	4	372	18,041	18,413
Ground cover	Cymbopogon citratus	10	10	294	18,579	18,873
	Pennisetum purpureum	10	10	219	16,734	16,953
	Pennisetum setacum	10	10	219	16,734	16,953
Grass	Paspalum paspalodes		876	27,331	1,466,381	1,493,712
Total			1000	55,614	1,893,452	1,949,293

Lifecycle: 30 years, Inflation: 12%

Figure 4-31: SLOM Model Verification - 1000 m² Simple Case

RESOM INPUT					RESOM OUTPUT				
GBUA m ²	Portfolio	Construction		Construction Cost (LE/m ²) (value at Year 0)	Rent Income/m ² /month (value at Year 0)	Construction Cost (inflated)	Rent Income (LE/m ²)		EGP (Expected Gross Profit, NPV at Year 0), WACC = 16.6%
		Start	End				Start	End	
1000	Commercial Building	Month 50	Month 61	5,000	120	(7,366,024)	Month 63	Month 360	7,844,458

Inflation 12%, Feasibility Horizon 30 years

WACC = 16.6%

LE = Egyptian Pounds

Figure 4-32: RESOM Model Verification - 5000 m² Commercial Building - Simple Case

4.4.2 Expert Opinion- Questionnaire Process

It is implemented on a case study in Egypt then validated through expert opinions to confirm the research conclusions. The questionnaire form and questions are attached in Appendix 2. A total number of 31 expert candidates (professionals and academic researchers) attended the validation process. The classification according to their professions is shown in Figure 4.33.

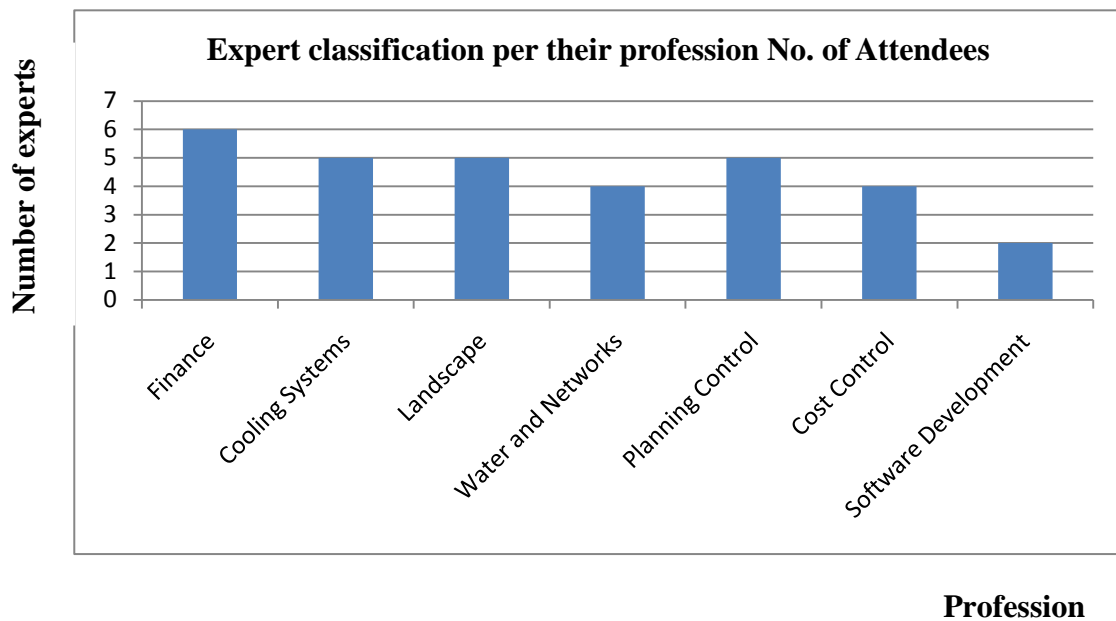


Figure 4-33: Expert classification per profession.

The selected candidates belong to a wide range of professions, academy and industry. Details of the candidates' information are shown in Table 4.21. The types of the organizations at which the experts are employed are shown in Figure 4.34.

Table 4-21: Questionnaire attendees list

	Organization Business	Finance		Cooling systems		Landscape		Water and networks		Planning control		Cost control		S/W development		Total
		No. of interviewed candidates / education / years of experience														
1	Project Management	-	-	1	BSc 20+	1	BSc 20+	1	BSc 20+	1	BSc 10+	1	BSc 10+	-	-	6
2	Real Estate Development	1	MBA 10+	1	BSC 20+	1	BSc. 20+	1	BSc 20+	1	BSc. 20+	1	BSc 20+	-	-	7
		1	BSc 20+													
3	Consultancy	-	-	1	MSc 20+	1	BSc 20+	1	BSc 20+	1	BSc 10+	1	BSc 10+	1	PhD 10+	6
4	City Management	1	BSc 20+	1	BSc 20+	1	BSc 20+	1	BSc 20+	-	-	-	-	-	-	5
		1	MBA 10+													
5	Academic Institution	-	-	1	PhD 10+	1	PhD 20+	-	-	1	PhD 10+	1	PhD 10+	1	PhD 20+	5
6	Financial	1	MBA 10+	-	-	-	-	-	-	-	-	-	-	-	-	2
		1	BSc 20+													
Total		6		5		5		4		5		4		2		31

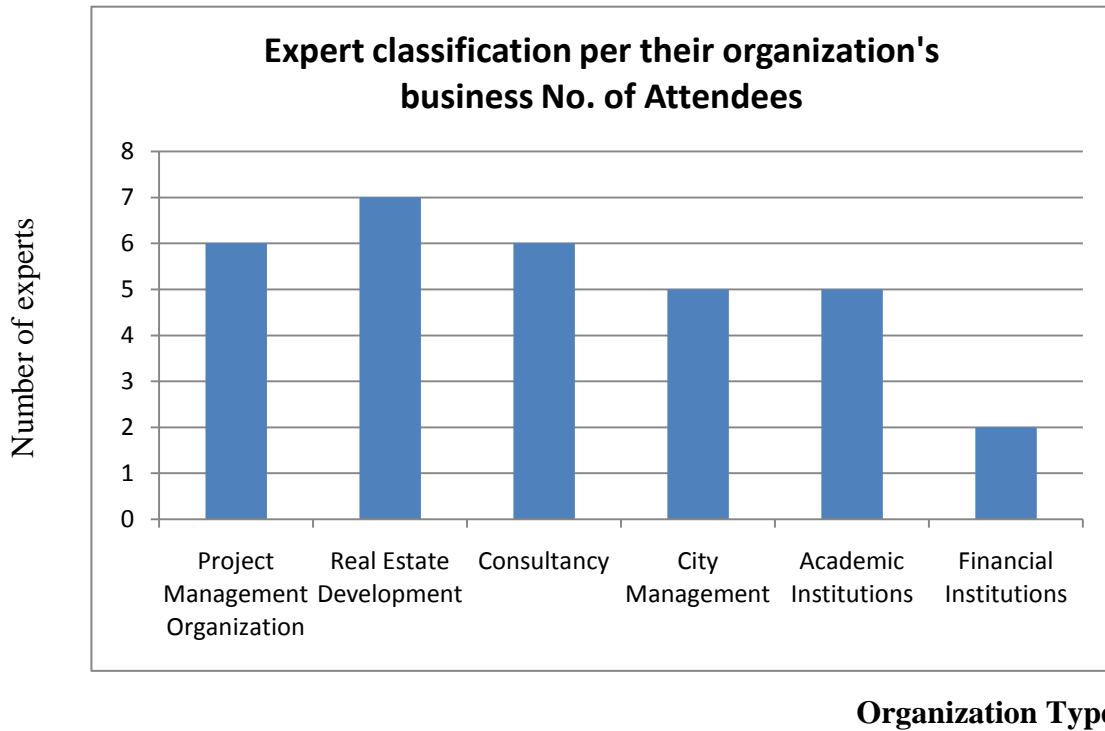


Figure 4-34: Expert classification per organization type.

Figure 4.35 illustrates the average score given by the experts for each of the verification criteria.

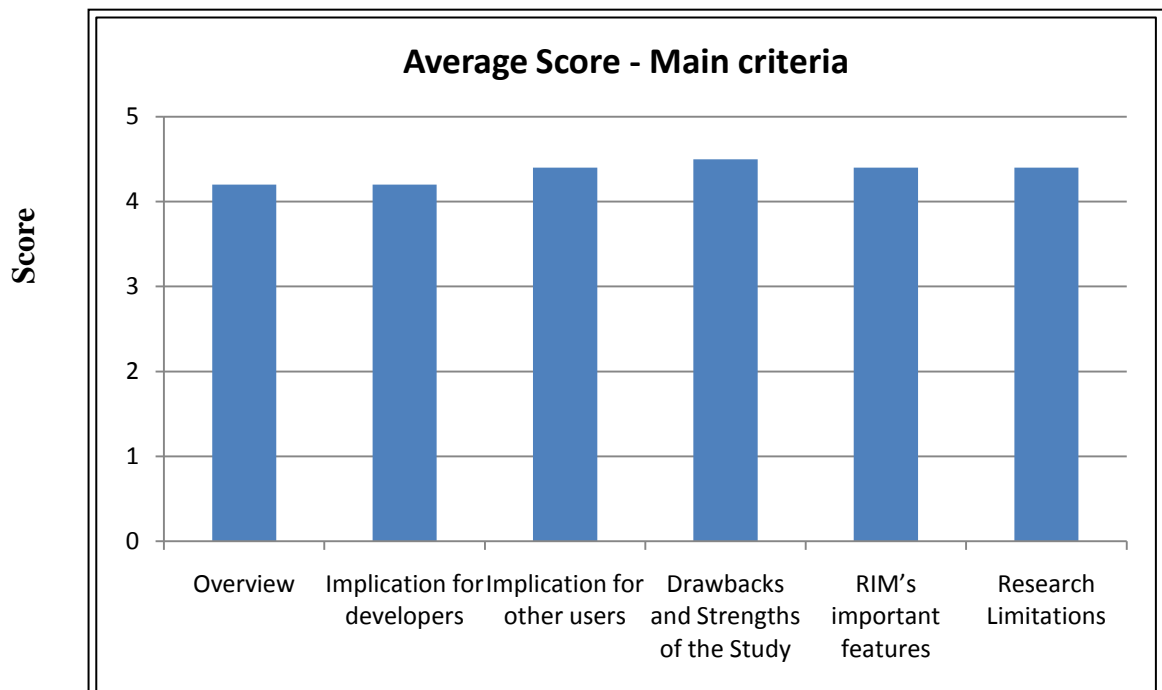


Figure 4-35: Average score for the main criteria

Main Criteria

Figure 4.36 illustrates the average score given by the experts for each of the verification criteria.

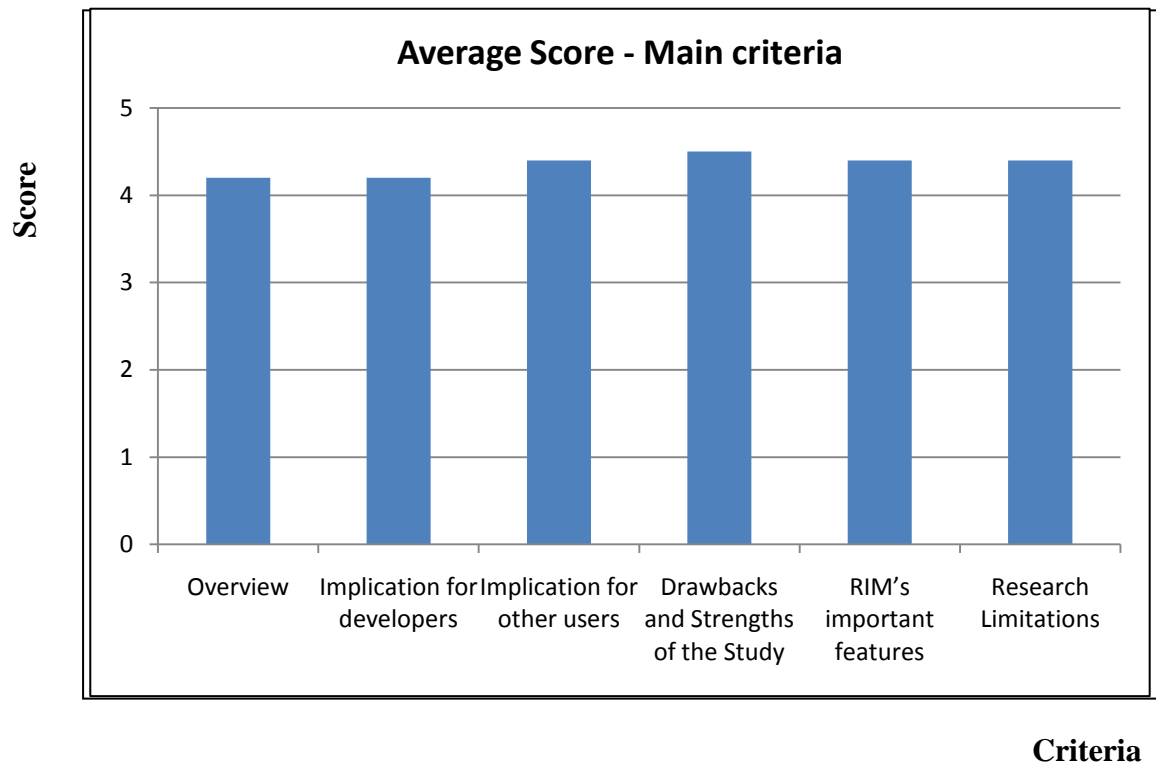


Figure 4-36: Average score for the main criteria

The questionnaire's results are summarized in Table 4.22.

Table 4-22: Validation - Questionnaire results

Question no.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	Main Criteria	Average score	Sub-criteria	Question score
	1	2	3	4	5				
1	0	1	3	15	12	Overview	4.2	Novel	4.2
2	1	0	1	13	14			Reliable	4.1
3	0	1	1	21	8			Effective	4.2
4	0	0	2	19	10	Implication for developers	4.2	-	4.3
5	0	1	1	23	6			-	4.1
6	0	0	1	18	10	Implication for other users	4.4	-	4.0
7	0	0	2	13	16			-	4.5
8	0	1	2	10	18			-	4.5
9	0	0	1	13	17			-	4.5
10	0	1	0	18	12			-	4.3
11	1	1	0	15	14			-	4.3
12	0	1	0	12	18	Drawbacks and Strengths of the Study	4.5		4.5
13	0	1	0	11	19			Flexibility	4.5
14	1	0	1	9	20			Scope	4.5
15	0	0	1	13	17			Linkage to Data Sources	4.5
16	0	0	2	15	14			Data analysis	4.4

Question no.	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree	Main Criteria	Average score	Sub-criteria	Question score
	1	2	3	4	5				
17	0	0	2	20	9	RIM's important features	4.4	Friendly Interfaces	4.2
18	0	0	0	13	18			4.6	
19	0	0	2	18	11			Saving time	4.3
20	0	0	2	16	13			Comprehensiveness	4.4
21	0	0	2	12	17			Consistent and accuracy	4.5
22	0	0	1	22	8			Integrative Synergy	4.2
23	0	0	1	18	12	Research	4.4	-	4.4
24	0	0	1	13	17	Limitations		-	4.5
25	0	1	1	17	12			-	4.3

(**) The sample size for all questions is 31 candidates.

The validation process helped in reaching the following conclusions. The conclusions below are having the same order of the questions points contained in the questionnaire. The results of experts' opinion results in this regard are collected and shown in Table 4.21. Each question included in every criterion contains its result individually then the results of all questions under each criterion are averaged to provide its average score.

4.4.5.1 Overview

As shown in Figure 4.37, the average score given to the sub-criteria included within the Overview criterion are:

1. RIM's functions are novel and innovative. RIM can dynamically integrate real estate projects' construction schedules to their serving infrastructure systems' lifecycle cost (cooling, potable water, landscape). RIM idea is innovative as the existing studies are usually performed for each of real estate development stages in isolation of the others (i.e. during the pre-development, development and post-development stages). RIM can link projects' execution plans and their changes to projects' lifecycle Cash Flow as well as to services demands and further to the economies of serving infrastructure.
2. RIM is a reliable tool. The optimized output of RIM's models is reliable with the objectives. The experts have indicated that the models output is logically changing in response to changes made to their inputs.
3. RIM can (partially) mitigate risk impacts on projects and infrastructure economies. RIM can improve projects' Cash Flow and Cash Flow and Expected Gross Profits of infrastructure systems through optimizing the implementation schedule of them. It also improves the infrastructure lifecycle cost through optimized scheduling of operating and maintenance schedules.

Questions 1 to 3 are related to this criterion. The average score of the questionnaire for the questions under this criterion is 4.17 out of 5.

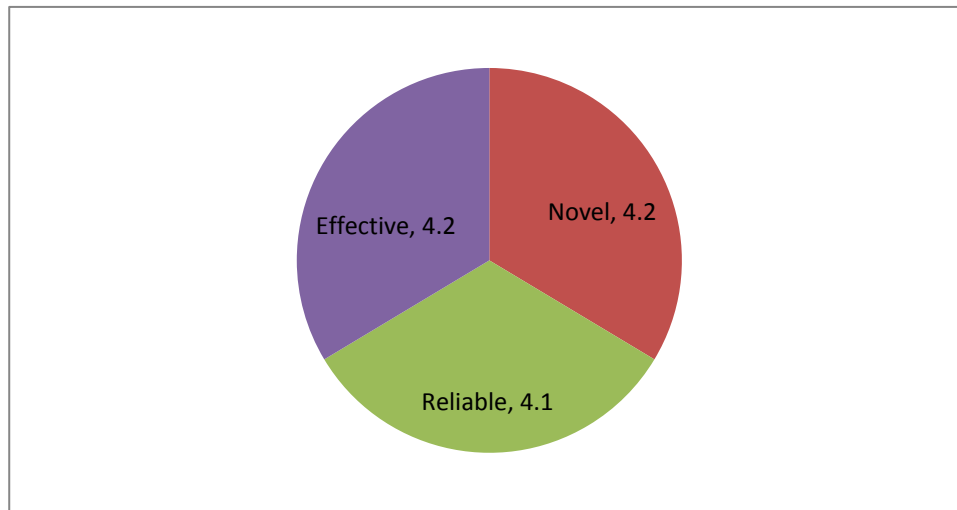


Figure 4-37: The average score for each sub-criterion in the Overview criterion

4.4.5.2 Implications for Developers

RIM is robust enough for implementation and evaluation at this development stage. The prototype however still require additional programming in order to effectively benefit developers in the field and satisfy commercial software standards. RIM can therefore furnish developers with a quick, reliable, and consistent tool for supporting decision makers in quantifying and (partially) mitigating possible impact of risk events. This application is particularly useful for public or privately developed real estate projects from small to large scales. Questions 4 and 5 are related to this criterion. The average score of the questionnaire for the questions under this criterion is 4.2 out of 5.

4.4.5.3 Implications for Other Users

A fully developed RIM will have the potential to benefit real estate investors, urban and strategic planners, utilities and marketing specialists, real estate and infrastructure economists and architects.

The validation process show that the diversity of risk impacts strengthens the need to estimate risk impacts on multiple dimensions and profession specialties (marketing, engineering, economy, infrastructure, ..etc.). The

validation proved that RIM output and sensitivity analysis can be efficiently analyzed, presented or summarized by different users without the need for pile of prints. Questions 6 to 11 are related to this criterion. The average score of the questionnaire for the questions under this criterion is 4.35 out of 5.

4.4.5.4 Drawbacks and Strengths of the Study

In addition to the questionnaire output, notes were collected from several stakeholders (consultants, conferences attendees, graduate students, professionals,..etc.) during the course of RIM development process. Several discussions were performed to list potential weaknesses and strengths of the study. Many drawbacks have been overcome as the system was developing. A number of drawbacks are listed below. Their scores are shown in Figure 4.38.

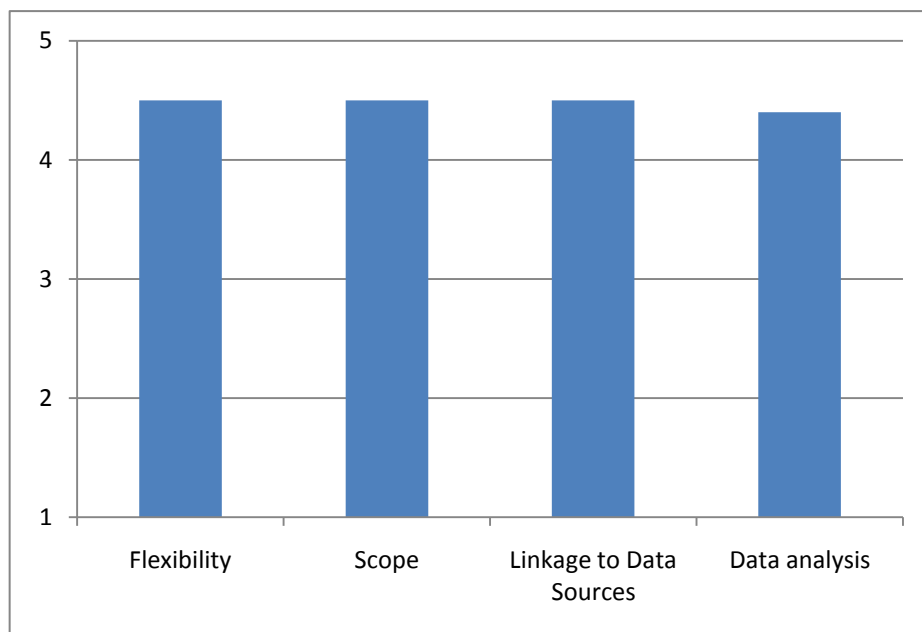


Figure 4-38: Average Score for the Drawbacks and Strengths of the Study

4.4.5.4.1.1 Flexibility

RIM was built with flexibility in mind. However and due to the fact that the logic model is customized by the potential users using Microsoft Excel®, their computers expertise may not support their quick understanding of the sophisticated model relations in RIM. Moreover, the customizing process is time

consuming and requires deep understanding of the cases under investigation. In addition, it is not possible to run the optimization engine for RIM's multiple models (i.e. RESOM, DCOM, SLOM or WSOM) simultaneously. These limitations have not affected the validation process of RIM's system but highlighted the need to further develop an advanced user friendly version of RIM. Applying Multi-Objective Optimization for all the models together would be recommended. RIM was solved using the Artificial Intelligence AI approach. Other techniques can be applied in future research to investigate differences between applying different methods (e.g. Ant-Colony, ANN, system dynamics or other mathematical solution approaches).

Questions 12 to 13 are related to this criterion. The average score of the questionnaire for the questions under this criterion is 4.5 out of 5.

4.4.5.4.1.2 Scope

The application of RIM in regards to the type of infrastructure services is limited to the water, district cooling and landscape systems. Expectedly, expanding future commercial program will facilitate more usage by more professionals of additional engineering disciplines that is not considered by RIM (e.g. electrical power supply system).

Question 14 is related to this criterion. The average score of the questionnaire for the question under this criterion is 4.5 out of 5.

4.4.5.4.1.3 Linkage to Data Sources

RIM's database is not able to link with other specialized program sources of data. This means that in order to start a new project analysis by RIM, a new database file has to be created, customized and used as an input to RIM. The developed file in each real estate development case will serve the specific case for which the file was originally created. However, a major part of the database may serve different projects of the same input data (e.g. selling prices, construction cost for specific project type, cooling profile, plant types,.. etc.).

Question 15 is related to this criterion. The average score of the questionnaire for the question under this criterion is 4.5 out of 5.

4.4.5.4.1.4 Data Analysis

In order to apply certain feature, the users should have a minimum level of knowledge to simulate certain statistical tools while running RIM. Adding additional features, while developing RIM, can help enabling end users to utilize the output statistically.

Question 16 is related to this criterion. The average score of the questionnaire for the question under this criterion is 4.4 out of 5.

4.4.5.5 RIM's important features

The average score of the sub-criteria is shown in Figure 4.39.

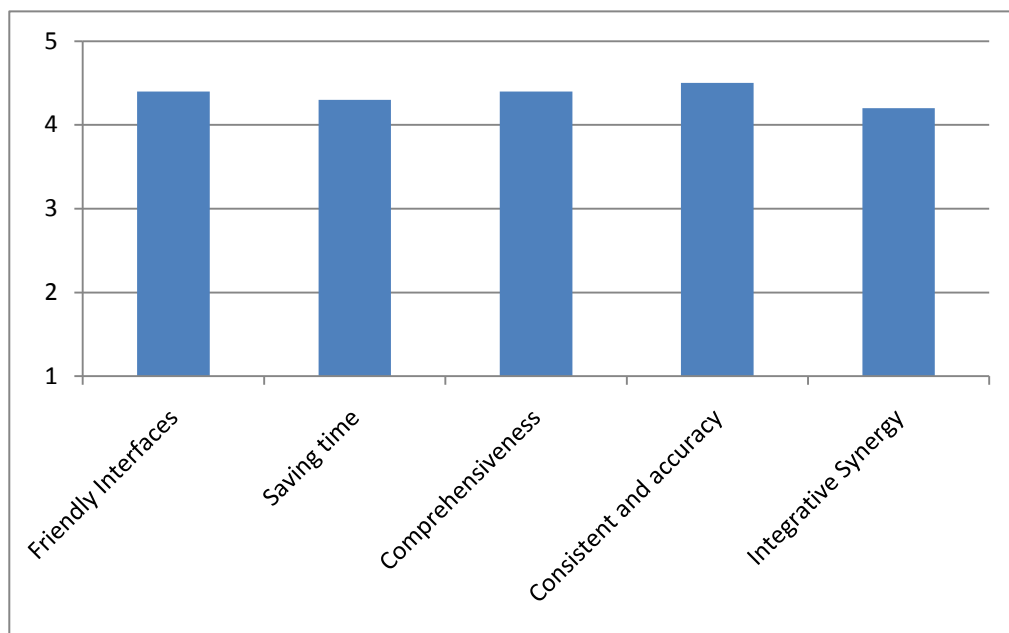


Figure 4-39: Average Score for RIM Important Features Items' Criteria

The items included in this criterion are:

4.4.5.5.1.1 Friendly Interfaces

It is possible for Excel users with basic model building knowledge to build up similar applications and achieve the same objectives for their projects. It is also expected that users in any country will be able to create spread sheets and build their models with the same interface they used to see easily.

Questions 17 and 18 are related to this criterion. The average score of the questionnaire for the questions under this criterion is 4.4 out of 5.

4.4.5.5.1.2 Saving Time

Although RIM may require longer time to develop the model, it can provide time saving tool that can link different factors all together quickly. Changing any input to the model will directly provide output data without delay. Moreover, RIM can be used for the same project as long as the projects' components are not changed.

Question 19 is related to this criterion. The average score of the questionnaire for the questions under this criterion is 4.3 out of 5.

4.4.5.5.1.3 Comprehensiveness

RIM can consider unlimited number of factors and variables which will enable decision makers to visualize impacts and perform sensitivity analysis as soon as risk event arise. The confidence level of RIM's output can be measured and improved in developed commercial software.

Question 20 is related to this criterion. The average score of the questionnaire for the question under this criterion is 4.4 out of 5.

4.4.5.5.1.4 Consistency and Accuracy

RIM's output is consistent and accurate compared with the expected results for the applied case study.

Question 21 is related to this criterion. The average score of the questionnaire for the question under this criterion is 4.5 out of 5.

4.4.5.6 Integrative Synergy

RIM prototype can provide impacts of unforeseen risk events with construction scheduling an infrastructure demand and economy.

Question 22 is related to this criterion. The average score of the questionnaire for the question under this criterion is 4.2 out of 5.

CHAPTER 5. CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH

The development of new cities and large scale real estate communities of mixed use purposes usually requires huge investments. These investments are usually distributed over lengthy construction periods. The overlap between construction activities and commencing partial occupancy of newly developed real estate projects is a phenomenon of these projects. The overlap usually takes several years and may extend to decades depending on the community size. Since most of the infrastructure systems are usually constructed at early stage of development, their economies are therefore more sensitive to delayed occupancy due to unforeseen risk events at later stages of development.

This research aims in supporting real estate developers and to minimize the effect of unforeseen risk on the economies of real estate and infrastructure projects having long implementation periods. Its objective is to develop a dynamic Decision Support System (DSS) that minimizes, at any time, the impacts of future unforeseen risks on real estate and completed infrastructure system. Another objective is also to introduce optimization Infrastructure Management Systems (IMS) that minimizes the systems' operating expenditure. A Risk Impact Mitigation (RIM) was developed. RIM consists of four models of integrating functions.

5.1 Conclusion

From the research conducted through this study, it can be concluded that:

- a- There are currently few number of Decision Support Systems that considers the impacts of unforeseen risk events that arise during the development stages of real estate projects. In response to unforeseen risk events after completing the infrastructure system at the early phase of the projects development stage may dictate decision makers to relax the implementation of the remaining unconstructed projects risk. The existing DSS does not provide the ability to dynamically link impacts of changing their implementation schedules on the profits of their infrastructure multi systems and real estate projects.

- b- The researcher introduced a dynamic DSS, called Risk Impact Mitigation (RIM) framework. The framework contains a number of models; these are:
- c- Real Estate Scheduling Optimization Model (RESOM); this model generates and optimizes the implementation schedule of remaining projects upon the occurrence of risk events. RESOM provides the profits' calculation for real estate projects. RESOM also integrates other IMS projects, whose function is to provide the infrastructure cash out. RESOM then provides the profits calculations of the infrastructure systems in addition to the real estate projects. RESOM respects certain constraints such as market, financial and regulatory zoning conditions. In addition to the cash in calculation of the infrastructure systems, RESOM provides the services demand profile for infrastructure systems (e.g. potable water and cooling). The profiles are then used by the IMS models (e.g. WSOM and DCOM) for further cash out calculations.
- d- Sustainable Landscape Optimization Model (SLOM); this model RIM is useful in selecting plant types that can be used in designing urban landscape areas. The objective of this model can either be the minimum irrigation water consumption or the minimum lifecycle expenditure (both capital and operating expenditures). The model includes a specific module that is called "Chess Carpet Diagram CCD". The CCD is a visualizing tool that can be used to present the images and design percentages of the selected plant types. SLOM provides the irrigation water profile for further usage by WSOM.
- e- District Cooling Optimization Model (DCOM); the function of this IMS model is to optimize the operating expenditure of district cooling plants. The model is integrated to RESOM so that the services demand is produced from the construction implementation schedule that is generated by using RESOM. DCOM provides operating/maintenance schedules for the time-based maintenance items.
- f- Water Simulation Optimization Model (WSOM); this model is developed to provide the cash out of a single or a combined water system that

contains potable and/or irrigation water supply systems. Similar to DCOM, WSOM provides optimized operating/maintenance schedules for the time-based maintenance items.

- g- RIM is applied on a three million square meter mixed use real estate development in Egypt. The development was subjected to difficult political and financial circumstances that were not originally forecasted while preparing original feasibility studies during the pre-development stage. RIM was used to simulate 3 different cases, the original feasibility case and three alternating post risk event new schedule cases. These cases includes an original case 1 (original feasibility-based case), two zone-based schedules (cases 2.1 and 2.2) and finally a mixed portfolio case (Case 3).
- h- The expected gross profit EGP in the original feasibility case was provided by RESOM and is expected to reach LE 9.5 Billion (Case 1). The amount reduced to LE 8.3 Billion due to changing the sequence of implementing the projects in Case 2.1. This amount improved to reach LE 8.8 Billion in the case of prioritizing zone 3 in Case 2.2, which is relatively large if compared with zone 1. The gross profit reduced to LE 7.9 Billion in Case 3. The reduction is mainly caused by the longer construction period of the mixed portfolio products.
- i- RIM's results were then tested through verification and validation processes. The calculations were made twice to assure the calculation accuracy. The validation analysis concluded that RIM is considered as a novel, reliable, consistent, comprehensive and accurate tool and resulted in considerable improved results that met its objectives. The validation proved that RIM output and sensitivity analysis can be efficiently analyzed, presented or summarized by different users without the need for pile of prints. RIM is also considered flexible.

5.2 Research Contributions

This research introduces a novel real estate development DSS framework. The research outcome is considered as a tool that widens the

angle of view while mitigating impacts of unforeseen risk events. The novelty of this research outcome is concluded as follows:

- a- It dynamically links the cash flows of large scale development projects during the construction implementation schedules that are overlapped with the occupancy and services consumption and demand during the post-development stage.
- b- RIM considers the market, financial and zoning regulatory requirements as constraints while providing implementation schedules of the remaining unconstructed projects during the optimization process. Moreover, RIM also minimizes the operating expenditure of preventive maintenance for infrastructure system components during their operation in the overlapping period. This is achieved through a newly developed dynamic link between the occupancy and their services demand profile and generated incomes from one side. It also links the implementation schedule to the infrastructure operation/maintenance optimization process from the other side.
- c- RIM also provides sustainable solutions for urban landscape systems. It supports the selection of urban landscape plant types in a way that the irrigation water consumption is minimized. The process considers architects' requirements as constraints. It then provides plant mixes of minimum capital and operating expenditure or of minimum irrigation water demand.

5.3 Research Limitations

Given the objective of this research, the following parameters are considered as limitations of the research work:

- a- RIM requires further development in order to better serve more number of users. The real estate and infrastructure governmental or public sector investment agencies as well as private sector investors.
- b- Further research may consider and assess the application of other tools such as linear Programming, System Dynamics or other

problem solving techniques to achieve solutions for its objective function and compare their results.

- c- The framework scope considered a limited number of infrastructure systems (cooling and water). It is recommended to consider other infrastructure systems such as electrical power supply or others.
- d- Although RIM's concept is considered novel using the Excel media that is usable by public users worldwide, the prototype however may require advanced programming media in order to satisfy commercial software standards and hence maximize its usefulness to the potential decision makers and users.

5.4 Recommendations for Future Research

Based on the above research conclusion and limitations, the following areas are recommended for further research:

- a- Investigating the applicability of the research concept on other infrastructure systems which are not covered under the scope of this research. This may include for example the oil and gas or the manufacturing sectors as well as the electrical power supply system.
- b- Enabling dynamic links between expanded versions of RIM to other specialized software, e.g. that software used for supporting the financial management of the different systems such as the cooling, electrical power or urban landscape services.
- c- Investigating possibilities and relative benefits of applying problem solving techniques, such as the Artificial Intelligence and Linear Integer Programming, in achieving the best solution of the objective functions under consideration.
- d- Introducing the application of Goal Optimization and Multi-Objective Optimization techniques for the optimization process. Other research media can also be introduced such as MATLAB while developing advanced DSS based on RIM's concept.

- e- Investigating the effect of applying different distribution functions while calculating the expenditure and generated income of real estate and infrastructure projects.

- f- Developing commercial software for optimizing the urban landscape plants selection. The sustainable value of the software is important since it can lower the irrigation water demand as well as the lifecycle expenditure of urban landscape systems. A fully developed RIM may serve a wide range of users.

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APPENDICES

APPENDIX 1: List of the Available Construction Planning Software

(Wikipedia, 2012)

#	Software	#	Software	#	Software
1	AceProject	26	Copper Project	51	Gemini
2	Altova MetaTeam	27	Deltek Open Plan	52	Group-Office
3	Anyplan	28	Deltek WelcomHome	53	HP Project and Portfolio Software
4	Apache Bloodhound	29	DeskAway	54	Huddle
5	Apollo	30	Doolphy	55	Hyperoffice
6	Assembla	31	dotProject	56	iManageProject
7	AtTask	32	DynaRoad	57	InLoox
8	Basecamp	33	Easy projects	58	in-Step
9	Binfire	34	Eclipse PPM software	59	JIRA
10	Bontq	35	EPM Live	60	Journyx
11	BrightWork	36	Endeavour Software Project Management	61	Kanbanery
12	Celoxis	37	eGroupWare	62	Kanban Tool
13	Central Desktop	38	enQuire	63	Kayako helpdesk software
14	Cerebro	39	FastTrack Schedule	64	KommandCore
15	Clarizen	40	Feng Office Community Edition	65	Launchpad
16	ClickHome	41	FinancialForce.com	66	LibrePlan
17	codeBeamer	42	FIT Issue Management	67	LiquidPlanner
18	Collabtive	43	FMYI	68	LisaProject
19	Compuware Changepoint	44	FogBugz	69	MacProject
20	Comindware Tracker	45	Wrike	70	MantisBT
21	Microsoft Project	46	Planisware	71	SAP Business ByDesign
22	ConceptDraw Project	47	Fossil-scm	72	Microsoft SharePoint Server
23	Contactizer	48	FusionForge	73	Microsoft Team Foundation Server
24	Contour	49	Ganttlic	74	Milestones Professional
25	Calligra Plan	50	GanttProject	75	MindGenius

#	Software	#	Software	#	Software
76	NetPoint	99	ProjectLibre	122	Teamcenter
77	NetSuite	100	Project KickStart	123	Teambox
78	MyWorkPLAN	101	ProjectManager.com	124	TeamDynamixHE
79	O3Spaces	102	Project.net	125	TeamLab
80	OmniPlan	103	Project-Open	126	Teamwork
81	Onepoint Project	104	Projectplace	127	Tenrox
82	OnTime	105	Projecturf	128	The Bug Genie
83	Open Workbench	106	Projektron BCS	129	Tom's Planner
84	OpenERP	107	Proliance	130	Trac
85	OpenProj	108	ProjectLink	131	TrackerSuite.Net
86	OpenProject	109	Prolog Manager	132	Traction TeamPage
87	Oracle Primavera EPPM (Primavera P6)	110	QuickBase	133	Trello
88	phpGroupWare	111	Rally Software	134	Ubidesk
89	PHProjekt	112	RationalPlan	135	VPMi
90	Pivotal Tracker	113	Realisor	136	web2project
91	Planbox	114	Redmine	137	WorkPLAN Enterprise
92	Plandora	115	SAP RPM	138	workspace.com
93	Xplanner	116	Sciforma	139	Zoho Projects
94	Planner Suite	117	Severa		
95	PLANTA Project	118	Smartsheet		
96	Priority Matrix	119	SwiftKanban		
97	Project Builder	120	TACTIC		
98	Project Team Builder	121	TaskJuggler		

APPENDIX 2: Validation Process

Questionnaire Content

The American University in Cairo

School of Science and Engineering

The Department of Construction and Architectural Engineering

Industry Survey Questionnaire

**A RISK MITIGATION FRAMEWORK
FOR
CONSTRUCTION/ASSETMANAGEMENT
OF REAL ESTATE AND INFRASTRUCTURE PROJECTS**

Dear Participant,

Sincere thanks for participating in this survey. The survey focuses on assessing a recently developed Risk Impact Mitigation framework (RIM) as part of my PhD research study. The results of this survey will help completing my PhD in Construction Engineering at the AUC. I do appreciate the time you are taking to complete it, and please feel free to ask for clarification in regards to RIM capability and scope.

This Survey will take you approximately “**20 minutes**” to be completed.

Confidentiality Statement

Your survey responses will be kept as strictly confidential. The data from this research will only be reported in aggregate form. Nothing related to your real IDENTITY will appear in the response sheet. All your information will be coded and will remain confidential.

If you have questions at any time about the surveys confidentiality or the procedures, you may contact:

Name: [Ahmed M. Fayad]

E-mail: [Ahmed.fayad@aucegypt.edu]

General Information

Please answer the following general questions about you and your company:

(1) What is your company's main business activity?

1. Project Management
2. Real Estate Development
3. Consultancy
4. City Management
5. Academic Institution
6. Financial
7. Other _____

(2) In which discipline is your specialty?

1. Finance
2. Cooling systems
3. Landscape
4. Water and networks
5. Planning Control
6. Cost Control
7. Software development
8. Other Please Specify _____

(2) How many years of experience in your specialty?

1. > 20 years
2. From 10 to 20 years
3. From 5 to 9 years
4. < 5 years

Questionnaire

Table 6-1: Questionnaire contents

1. RIM framework – overview		1 Strongly Disagree	2 Disagree	3 Undecided	4 Agree	5 Strongly Agree
Q1	RIM's functions are novel and innovative.					
Q2	RIM can integrate real estate projects construction schedules to their serving infrastructure systems' LCC (DC, water, landscape).					
Q3	RIM is a reliable tool that can partially mitigate post-risk impact to original feasibility studies.					

2. RIM framework – implications for developers

Q4	RIM prototype still requires additional programming support to satisfy commercial software standards and effectively benefit real estate stakeholders.					
Q5	RIM is particularly useful for public and private real estate projects. RIM can support decision makers in quantifying and (partially) mitigating possible impact of unforeseen risk events.					

3. RIM framework – implications for other users

		1 Strongly Disagree	2 Disagree	3 Undecided	4 Agree	5 Strongly Agree
Q6	A developed software version of RIM can have the potential to benefit real estate's: a- investors					
Q7	b- planners,					
Q8	c- economists					
Q9	d- marketing specialists					
Q10	The diversity of risk impacts strengthens the need for RIM's integrated assessment of multiple dimensions (marketing, engineering, financial, ..etc.).					
Q11	RIM output and sensitivity analysis can be efficiently analyzed, presented and summarized by different users without the need for pile of prints.					

4. RIM framework – drawbacks and strengths

		1 Strongly Disagree	2 Disagree	3 Undecided	4 Agree	5 Strongly Agree
Q12	<p>a. Flexibility:</p> <p>Introducing Multi-Objective optimization while developing RIM's version will help users to benefit simpler and more flexible models operation.</p>					
Q13	<p>The customizing process is time consuming and requires deep understanding of the cases under investigation. This needs to be considered while developing commercial version of RIM.</p>					
Q14	<p>b. Scope</p> <p>Expectedly, expanding future commercial program will facilitate more usage by professionals of diversified engineering disciplines (e.g. electrical power supply system).</p>					

Q15	<p>c. Linkage to Data Sources</p> <p>RIM's database needs to be dynamically linked to other sources of data input (e.g. district cooling, electricity, water or landscape demand calculation models). This needs to be considered while developing commercial version of RIM.</p>					
Q16	<p>d. Data Analysis</p> <p>In order to apply certain feature, the users should have a minimum level of knowledge to simulate certain statistical tools while dealing with RIM. This needs to be considered while developing commercial version of RIM.</p>					

5. RIM's important features

		1 Strongly Disagree	2 Disagree	3 Undecided	4 Agree	5 Strongly Agree
Q17	<p>a. Friendly Interfaces</p> <p>It is possible for Excel users with basic model building knowledge to build up similar applications and achieve the same objectives for their projects.</p>					
Q18	<p>It is expected that users in any country will be able to create spread sheets and build their models with the same interface they used to see easily.</p>					
Q19	<p>b. Saving Time</p> <p>Although RIM may require relatively longer time to develop the model, however it can provide time saving tool that can link different factors all together. RIM can be used for the same</p>					

	<p>project as long as the projects' components remain unchanged.</p>					
Q20	<p>c. Comprehensiveness</p> <p>RIM can consider unlimited number of factors and variables which enables decision makers to visualize impacts and perform sensitivity analysis.</p>					
Q21	<p>d. Consistent and accurate Output</p> <p>RIM's output is accurate and consistent with the expected results for the applied case study.</p>					
Q22	<p>e. Integrative Synergy</p> <p>RIM prototype can provide impacts of unforeseen risk events integrated with construction scheduling and infrastructure demand and economy.</p>					

6. RIM's limitations

		1 Strongly Disagree	2 Disagree	3 Undecided	4 Agree	5 Strongly Agree
Q23	Although the main research scope focuses on Egypt, it is however applicable to other domains such as villages, cities or even on national level in other countries through adapting the framework assumptions and relations.					
Q24	Further financial assumptions, that are project related, can be introduced into RIM's framework models. Examples are the opportunity cost, debit-credit calculations and financial costs					
Q25	The non-traditional optimization tools such as System Dynamics may be used in further research. The results can then be assessed and compared.					

APPENDIX 3: Glossary and Abbreviations of Accounting Terms

(Collier, 2003)

Assets	Things that the business owns.
Fixed assets	Things that the business owns and are part of the business infrastructure – fixed assets may be tangible or intangible.
Budget	A plan expressed in monetary terms covering a future period of time and based on a defined level of activity.
Budgetary control	The process of ensuring that actual financial results are in line with targets
Capital expenditure or investment expenditure (CAPEX)	The purchase of new fixed assets
Cost control	The process of either reducing costs while maintaining the same level of productivity or maintaining costs while increasing productivity.
Credit	Buying or selling goods or services now with the intention of payment following at some time in the future (as opposed to buying or selling goods or services for cash).
Debt	Borrowings from financiers
Debtors	Sales to customers who have bought goods or services on credit but who have not yet paid their debt.
Discounted cash flow (DCF)	A method of investment appraisal that discounts future cash flows to present value using a discount rate, which is the risk-adjusted cost of capital

Net present value (NPV)	<p>A discounted cash flow technique used for investment appraisal that calculates the present value of future cash flows and deducts the initial capital investment.</p> <p>The net present value method discounts future cash flows to their present value and compares the present value of future cash flows to the initial capital investment.</p>
Present Value PV	<p>Present value (PV) of cash flows = cash flow × discount factor (based on number of years in the future and the cost of capital)</p> <p>net present value (NPV) = present value of future cash flows – initial capital investment</p>
Full cost	<p>The cost of a product/service that includes an allocation of all the (production and non-production) costs of the business.</p>
Annual Interest Rate (I)	<p>The cost of money, received on investments or paid on borrowings.</p>
Internal rate of return (IRR)	<p>A discounted cash flow technique used for investment appraisal that calculates the effective cost of capital that produces a net present value of zero from a series of future cash flows and an initial capital investment.</p>
Liabilities	<p>Debts that the business owns.</p>
Lifecycle costing	<p>An approach to costing that estimates and accumulates the costs of a product/service over its entire lifecycle, i.e. from inception to abandonment.</p>
Long-term liabilities	<p>Amounts owing after more than one year.</p>
Margin	<p>The amount added to a lower figure to reach a higher figure, expressed as a percentage of the higher figure, e.g. the margin that profit represents as a percentage of selling price.</p>
Marginal cost	<p>The cost of producing one extra unit.</p>
Margin of safety	<p>A measure of the difference between the anticipated and breakeven levels of activity.</p>

Mark-up	The amount added to a lower figure to reach a higher figure, expressed as a percentage of the lower figure, e.g. cost is marked up by a percentage to cover the desired profit to determine a selling price.
Opportunity cost	The lost opportunity of not doing something, which may be financial or non-financial, e.g. time.
Payback	A method of investment appraisal that calculates the number of years taken for the cash flows from an investment to cover the initial capital outlay.
Period costs	The costs that relate to a period of time. Planning, programming and budgeting system (PPBS) A method of budgeting in which budgets are allocated to projects or programmes rather than to responsibility centers.
Process costing	A method of costing for continuous manufacture in which costs for an accounting compared are compared with production for the same period to determine a cost per unit produced.
Product market	A business's investment in technology, people and materials in order to make, buy and sell products or services to customers.
Profiling	A method of budgeting that takes into account seasonal fluctuations and estimates of when revenues will be earned and costs will be incurred over each month in the budget period.
Profit	The difference between income and expenses.
Earnings before interest and taxes (EBIT)	
Profit before interest and taxes (PBIT)	The operating profit before deducting interest and tax.

Retained profits	The amount of profit after deducting interest, taxation and dividends that is retained by the business.
Return on investment (ROI)	The net profit after tax as a percentage of the shareholders' investment in the business.
Revenue	Income earned from the sale of goods and services.
Sales mix	The mix of product/services offered by the business, each of which may be aimed at different customers, with each product/service having different prices and costs.
Sensitivity analysis	An approach to understanding how changes in one variable of cost–volume–profit analysis are affected by changes in the other variables.
Shareholders' funds	The capital invested in a business by the shareholders, including retained profits.
Sunk costs	Costs that have been incurred in the past.
Variance analysis	A method of budgetary control that compares actual performance against plan, investigates the causes of the variance and takes corrective action to ensure that targets are achieved.
Cash Flow (CF)	<p>Cash flow is the net movement in the cash balance over an accounting period. 'Net' in that it is the cash in (which is termed 'receipts') less cash out (termed 'payments').</p> <p>Thus, the formulae is, $\text{Cash flow} = \text{Receipts} - \text{Payments}$</p>
Cash Flow (CF) over an accounting period	<p>The net income or the amount in the cash balance over an accounting period t (e.g. a month or a year) before taxation.</p> <p>= Receipts - Payments</p> <p>= Cash In - Cash out</p>
Profit	The difference between income and expenses.

Expected Gross Profit (EGP) or the Profit before taxation The difference between the expected price at which goods or services are sold and the expected cost of sales before applying taxation over the feasibility horizon J.
= Income – Expenses
= Sales or Turnover – Cost of sales

Notes:

The following items are considered:

- 1- An annual inflation is applied on both the Cash In and Out
- 2- Escalation and Foreign exchange fluctuations
- 3- Cash accounting rather than Accrued accounting principle is applied; i.e. no time difference between money due and cash in or cash out

APPENDIX 4: EQUATIONS - RESOM, SLOM AND WSOM

1. RESOM Formulation:

Assuming $X =$ Decision Matrix (0,1) that refers to the project's start date as follows:

$$\begin{array}{c}
 G_1 \\
 \cdot \\
 P_3 \\
 \cdot \\
 G_g \\
 P_i
 \end{array}
 \left\{
 \begin{array}{c}
 P_1 \\
 P_2 \\
 P_3 \\
 \cdot \\
 P_4 \\
 \cdot \\
 P_i
 \end{array}
 \right.
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 BIN_{11} & BIN_{12} & BIN_{13} & BIN_{1j} \\
 BIN_{21} & BIN_{22} & BIN_{23} & BIN_{2j} \\
 \cdot & BIN_{32} & BIN_{33} & BIN_{3j} \\
 \cdot & \cdot & BIN_{43} & \cdot \\
 BIN_{i1} & BIN_{i2} & \cdot & BIN_{ij}
 \end{array} \right]
 \end{array}$$

$$\sum_{i=1}^{i=l} BIN_{t_j G_g} \quad BIN_{t_1 G_1} \quad BIN_{t_2 G_1} \quad BIN_{t_3 G_1} \quad BIN_{t_j G_1}$$

$$\sum_{i=1}^{i=l} BIN_{t_j} \quad \frac{BIN_{t_1 G_g} \quad BIN_{t_2 G_g} \quad BIN_{t_3 G_g} \quad BIN_{t_j G_g}}{BIN_{t_1} \quad BIN_{t_2} \quad BIN_{t_3} \quad BIN_{t_j}}$$

Equation 4

O_{ti} = Payments of a project i at time j = Cash Out

$$= \begin{vmatrix}
 O_{11} & O_{12} & O_{13} & O_{1t} \\
 \cdot & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \cdot \\
 O_{n1} & O_{n1} & O_{n3} & O_{it}
 \end{vmatrix}$$

Equation 5

N_{ti} = Receipts of a project I at time j = Cash In

$$= \begin{vmatrix}
 N_{11} & N_{12} & N_{13} & N_{1t} \\
 \cdot & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \cdot \\
 \cdot & \cdot & \cdot & \cdot \\
 N_{n1} & N_{n1} & N_{n3} & N_{it}
 \end{vmatrix}$$

Equation 6

The *Objective Function* is to Maximize the term EGP;

Where;

$$EGP = X \cdot NPV \left(\sum_{t=0}^{t=J} (N_{t_j} - O_{t_j}) \right)$$

Subject to the following Constraints

- 1- $X_{11}, X_{12}, \dots, X_{it}$ are integers (0 or 1)
- 2- $\sum_{t=1}^T X_{it} \leq 1$ (only one start per project)
- 3- $T_{spi} \geq T_{gsi}$ (Groups' start date constraint)
- 4- $T_{spi} + D_{pi} \geq T_{gei}$ (Groups' end date constraint)
- 5- $(T_{spi} + D_{pi}) - (T_{spn} + D_{pn}) = 0$ (linked projects' construction completion)
- 6- No. of projects type n within certain group's duration complies to product mix constraints

$$\sum_{i=1}^{i=l} X_{t_{it}} \leq y$$

Where;

$$G_s \leq y \leq G_e$$

and; T_{spk} is the starting date of a project p of type k

2. SLOM Equations

A Plant Mix Design Matrix (PMDM) that is based on using the binary digital (0/1) system is used to indicate that a plant PL of plant group G is selected or not selected in the plant mix. It uses the digits 1 and 0 to indicate selected and not selected plants in the mix respectively.

Plant Mix Design Matrix (PMDM)

		t_1	t_2	t_3	t_j	
G_1	{	PL_1	PL_2	PL_3	PL_4	
G_g	{	PL_i	$\begin{bmatrix} BIN_{11} & BIN_{12} & BIN_{13} & BIN_{1j} \\ BIN_{21} & BIN_{22} & BIN_{23} & BIN_{2j} \\ \cdot & BIN_{32} & BIN_{33} & BIN_{3j} \\ \cdot & \cdot & BIN_{43} & \cdot \\ BIN_{i1} & BIN_{i2} & \cdot & BIN_{ij} \end{bmatrix}$			
		$\sum_{i=1}^{i=l} BIN_{t_j G_g} \quad BIN_{t_1 G_1} \quad BIN_{t_2 G_1} \quad BIN_{t_3 G_1} \quad BIN_{t_j G_1}$				
		$\sum_{i=1}^{i=l} BIN_{t_j} \quad BIN_{t_1 G_g} \quad BIN_{t_2 G_g} \quad BIN_{t_3 G_g} \quad BIN_{t_j G_g}$				
		BIN_{t_1}	BIN_{t_2}	BIN_{t_3}	BIN_{t_j}	

Equation 7

t_j : is the time (j) for the total number of plants (i).

PL_i : is the plant type (i) in a certain group (g).

G_g : is the total number of groups (g).

BIN_{ij} : is a binary number (0, 1) which is being generated by SLOM to indicate the near optimal plant mix design. “0” for non-selected plant type (i) and “1” for selected plant type (i).

SLOM generates the Plant Mix Area Matrix (PMAM) provides the area proposed for each of the selected plants in the PMDM matrix

Plant Mix Area Matrix (PMAM)

$$\begin{array}{l}
 G_1 \left\{ \begin{array}{l} PL_1 \\ PL_2 \\ PL_3 \end{array} \right. \\
 G_g \left\{ \begin{array}{l} PL_4 \\ PL_i \end{array} \right.
 \end{array}
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 PMA_{11} & PMA_{12} & PMA_{13} & PMA_{1j} \\
 PMA_{21} & PMA_{22} & PMA_{23} & PMA_{2j} \\
 \cdot & PMA_{32} & PMA_{33} & PMA_{3j} \\
 \cdot & \cdot & PMA_{43} & \cdot \\
 PMA_{i1} & PMA_{i2} & \cdot & PMA_{ij}
 \end{array} \right]
 \end{array}$$

Equation 8

Where;

PMA_{ij} : is the plant covered area (i).

Through multiplying the metrics PMAM and PMDM, the resulted Selected Plant Mix Area Matrix (SPAM) in Equation 13 represents then the areas of the selected plants.

Selected Plant Mix Area Matrix (SPAM)

$$\begin{array}{l}
 G_1 \left\{ \begin{array}{l} PL_1 \\ PL_2 \\ PL_3 \end{array} \right. \\
 G_g \left\{ \begin{array}{l} PL_4 \\ PL_i \end{array} \right.
 \end{array}
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 SPA_{11} & SPA_{12} & SPA_{13} & SPA_{1j} \\
 SPA_{21} & SPA_{22} & SPA_{23} & SPA_{2j} \\
 \cdot & SPA_{32} & SPA_{33} & SPA_{3j} \\
 \cdot & \cdot & SPA_{43} & \cdot \\
 SPA_{i1} & SPA_{i2} & \cdot & SPA_{ij}
 \end{array} \right]
 \end{array}$$

Equation 9

SPA_{ij} : is the selected individual plant areas (i) which is the multiplication of PMDM and PMAM matrices.

The first step of SLOM calculations is to provide the lifecycle cost of certain plant mix that is generated by SLOM mix generation. If the available number of plant groups is j, and the maximum number of available plant types in all plant groups is I, then the **Life Cycle Unit Cost Matrix (LCUCM)** will be of I plant types and

J months (study horizon) in the Life Cycle Unit Costs Matrix (LCUCM) as follows:

Life Cycle Unit Costs Matrix (LCUM)

$$\begin{array}{c}
 \begin{array}{c} G_1 \\ \\ \\ G_g \end{array}
 \left\{ \begin{array}{c} PL_1 \\ PL_2 \\ PL_3 \\ PL_4 \\ PL_i \end{array} \right.
 \begin{bmatrix} LCU_{11} & LCU_{12} & LCU_{13} & LCU_{1j} \\ LCU_{21} & LCU_{22} & LCU_{23} & LCU_{2j} \\ \cdot & LCU_{32} & LCU_{33} & LCU_{3j} \\ \cdot & \cdot & LCU_{43} & \cdot \\ LCU_{i1} & LCU_{i2} & \cdot & LCU_{ij} \end{bmatrix}
 \end{array}$$

Equation 10

LCC_{ij} : is the life cycle costs for plant type i in group j.

The LCC_{ij} detailed calculations are illustrated in the below equations:

The equations below illustrate the model’s capability to calculate the Life Cycle Costs (LCC). As described below, the 1st equation describes the calculation process for both the CAPEX and OPEX obtained for the different cases. In addition, Equation (8) calculates the planting costs as a part of the CAPEX. Finally, Equations (9) and (10) calculates the materials and insecticides required for maintenance and the replacement costs respectively.

CAPEX and OPEX calculation:

$$\begin{aligned}
 &LCC \text{ (Present)}_{ijk} \\
 &= \sum_{i=1}^n \sum_{j=1}^m \left\{ \left(\left[\left(\frac{X\%_{ij} * A}{SPR_{ij}} \right) \right. \right. \right. \\
 &\quad \left. \left. \left. * \langle PUC_{ij} + (SSQ_{ij} * SSUC) + (MQ_{ij} + MUC) \rangle \right] \right) \right. \\
 &\quad \left. + \sum_{k=1}^p \left(\left[\left(\frac{X\%_{ij} * A}{SPR_{ij}} \right) \right. \right. \right. \\
 &\quad \left. \left. \left. * \left(MIPMUC_{ijk} + RUC_{ijk} + \left(SSWC_{ij} * (WUC * (1 + in\%)^k) \right) \right) \right. \right. \right. \\
 &\quad \left. \left. \left. + \left(AWWC_{ij} * (WUC * (1 + in\%)^k) \right) \right) \right] \right) * \left(\frac{1}{(1 + dr\%)^{k-PR}} \right) \right\}
 \end{aligned}$$

Equation 11

Where;

n is the total number of groups

i is the counter for the groups

m is the total number of plants within each group

j is the counter for the number of plants within each group

p is the lifecycle time for the landscape design

k is the counter for the lifecycle time

X% is the Percentage Design for the plant in the required area

A is the total landscape area

SPR is the Spread for each plant item

PUC is the Planting Unit Cost

SSQ is the Sweet Sand Quantity (m³)

SSUC is the Sweet Sand Unit Cost

MQ is the Manur Quantity (m³)

MUC is the Manur Unit Cost

MIPMUC is the Materials and Insecticides for Maintenance Unit Cost

RUC is the Replacement Unit Cost

SSWC is the spring and summer water consumption

AWWC is the autumn and winter water consumption

WUC is the water unit cost

in% is the annual inflation rate

d_r % is the discount rate

PR is the Present Year where the Net Present Value (NPV) calculations refers to

Planting Costs (CAPEX)

$$PUC_{ij} = \sum_{i=1}^n \sum_{j=1}^m [SP_{ij} + (TR\%_{ij} * SP_{ij}) + (IN\%_{ij} * SP_{ij}) + (RF\%_{ij} * SP_{ij}) + (RMT\%_{ij} * SP_{ij}) + (P\%_{ij} * SP_{ij})]$$

Equation 12

Where;

SP is the Supplying Price for each plant item.

TR is the Transportation cost as a percentage from the supplying price for each plant item.

IN is the installation cost as a percentage from the supplying price for each plant item.

RF is the Risk Factor as a percentage from the supplying price taken into consideration while transportation and installation.

RMT is the Routine Maintenance cost as a percentage from the supplying price performed directly after installation. P is the Profit as a percentage from the supplying price. Materials and Insecticides for Maintenance (OPEX)

$$MIPMUC_{ijk} = \sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^p [(NQ_{ij} * NYF * (NUC * (1 + in\%)^k)) + (PQ_{ij} * PYF * (PUC * (1 + in\%)^k)) + (PHQ_{ij} * PHYF * PHUC * (1 + in\%)^k) + (MEQ_{ij} * MEYF * (MEUC * (1 + in\%)^k)) + (IYF * (IUC * (1 + in\%)^k))]$$

Equation 13

Where;

NQ is the Nitrogen Quantity.

NYF is the Yearly Frequency for adding Nitrogen

NUC is Nitrogen Unit Cost

PQ is the Potassium Quantity

PYF is the Yearly Frequency for adding Potassium

PUC is the Potassium Unit Cost

PHQ is the Phosphor Quantity

PHYF is the Yearly Frequency for adding Phosphor

PHUC is the Phosphor Unit cost

MEQ is the other Minor Elements Quantity required for the yearly maintenance

MEYF is the Yearly Frequency for adding other Minor Elements required for maintenance

MEUC is the Minor Elements Unit Cost

IYF is the Yearly Frequency for adding Insecticides

IUC is the Insecticides Unit cost

Replacement Costs (OPEX)

$$RUC_{ijk} = \sum_{i=1}^n \sum_{j=1}^m \sum_{k=1}^p \{ [SP_{ij} + (TR\%_{ij} * SP_{ij}) + (IN\%_{ij} * SP_{ij}) + (RF\%_{ij} * SP_{ij}) + (RMT\%_{ij} * SP_{ij}) + (P\%_{ij} * SP_{ij})] * (1 + in\%)^k \}$$

Equation 14

In order to mathematically simulate the above equations and calculations in this module, the plants are classified in a number of groups. Each group is composed of a number of plant types with different attributes.

Irrigation Water Unit Consumption Matrix (IWCM)

$$\begin{array}{c}
 \begin{array}{c}
 G_1 \\
 \\
 \\
 \\
 G_g
 \end{array}
 \left\{
 \begin{array}{c}
 PL_1 \\
 PL_2 \\
 PL_3 \\
 PL_4 \\
 PL_i
 \end{array}
 \right.
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 IWC_{11} & IWC_{12} & IWC_{13} & IWC_{1j} \\
 IWC_{21} & IWC_{22} & IWC_{23} & IWC_{2j} \\
 \cdot & IWC_{32} & IWC_{33} & IWC_{3j} \\
 \cdot & \cdot & IWC_{43} & \cdot \\
 IWC_{i1} & IWC_{i2} & \cdot & IWC_{ij}
 \end{array} \right]
 \end{array}
 \end{array}$$

Equation 15

IRW_{ij} : is the irrigation water consumption for plant type (i) in group (g).

Life Cycle Costs Matrix (LCCM)

$$\begin{array}{c}
 \begin{array}{c}
 G_1 \\
 \\
 \\
 \\
 G_g
 \end{array}
 \left\{
 \begin{array}{c}
 PL_1 \\
 PL_2 \\
 PL_3 \\
 PL_4 \\
 PL_i
 \end{array}
 \right.
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 LCC_{11} & LCC_{12} & LCC_{13} & LCC_{1j} \\
 LCC_{21} & LCC_{22} & LCC_{23} & LCC_{2j} \\
 \cdot & LCC_{32} & LCC_{33} & LCC_{3j} \\
 \cdot & \cdot & LCC_{43} & \cdot \\
 LCC_{i1} & LCC_{i2} & \cdot & LCC_{ij}
 \end{array} \right]
 \end{array}
 \end{array}$$

$$\sum_{i=1}^{i=l} LCC_{t_j} \quad LCC_{t_1} \quad LCC_{t_2} \quad LCC_{t_3} \quad LCC_{t_j}$$

Equation 16

LCC_{ij} : is the lifecycle cost for plant type (i) in group (g) within a time horizon j. It is the multiplication of SPAM and LCUM matrices.

LCC_{t_j} : is the lifecycle cost for time j after the summation of all plant types (i) within group (g) at a certain point in time j.

Irrigation Water Consumption Matrix (IWCM)

$$\begin{array}{c}
 \begin{array}{c}
 G_1 \\
 \\
 \\
 \\
 G_g
 \end{array}
 \left\{
 \begin{array}{c}
 PL_1 \\
 PL_2 \\
 PL_3 \\
 PL_4 \\
 PL_i
 \end{array}
 \right.
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 IRW_{11} & IRW_{12} & IRW_{13} & IRW_{1j} \\
 IRW_{21} & IRW_{22} & IRW_{23} & IRW_{2j} \\
 \cdot & IRW_{32} & IRW_{33} & IRW_{3j} \\
 \cdot & \cdot & IRW_{43} & \cdot \\
 IRW_{i1} & IRW_{i2} & \cdot & IRW_{ij}
 \end{array} \right]
 \end{array}
 \end{array}$$

$$\sum_{i=1}^{i=l} IRW_{t_j} \quad IRW_{t_1} \quad IRW_{t_2} \quad IRW_{t_3} \quad IRW_{t_j}$$

Equation 17

IRW_{ij} : is the water consumption for plant type (i) in group (g) within a time horizon j. It is the multiplication of SPAM and IWCM matrices.

IRW_{t_j} : is the total water consumption for time j after the summation of all plant types (i) within group (g) at certain point in time j.

1. SLOM Objective Function is:

$$\text{Min. } \sum_{j=1}^{j=J} \frac{LCC_{t_j}}{(1+in)^j}$$

or

$$\text{Min. } \sum_{j=1}^{j=J} IRW_{t_j}$$

Equation 22 refers to selecting plant mix that produces minimum inflated lifecycle cost (represented by LCCM Matrix in Equation 20) and irrigation water consumption (represented by matrix IWCM in Equation 21) respectively.

SLOM Constraints:

SLOM variables are the area percentage to be covered by each plant type that should be within a given range by the architect. In addition, the area percentage of each group's types should also be within certain range given also by project's architect. The constraints formulation is as follows:

$$\sum_{G=1}^{G=g} SPA_{G_g} \text{ within a certain area range given by the project architect}$$

$$\sum_{t=1}^{t=j} \sum_{G=1}^{G=g} BIN_{t_j G_g} \text{ is within a certain range number given by the project architect}$$

3. WSOM Equations

All equations are valid for both irrigation and potable water calculations except if mentioned otherwise.

3.1 Fixed Rate Category

The lifecycle cost of this category is calculated using the following equation:

LCC_{ij} : is the life cycle costs for pump i on the time j after multiplying the NSM with the MCM.

LCC_{t_j} : is the life cycle costs for pump i on the time j after the summation of all the pumps at a certain point in time j.

I is the total number of pumps. (I is 3 in this study)

The Objective function thus is:

$$\text{Min. } \sum_{j=1}^J \frac{LCC_{t_j}}{(1+I)^j}$$

Where;

J is the time horizon considered in the study. (J is 30 years in our study)

Constraints:

$NSt_{ij} = WC_{t_j}$ is the RESOM output in the potable water case

$NSt_{ij} = IRW_{t_j}$ is the SLOM output in the irrigation water case

3.4 Regression-Based Category

Numerical Status Matrix (NSM)

$$\begin{matrix} & t_1 & t_2 & t_3 & t_j \\ \begin{matrix} EM_1 \\ EM_2 \\ EM_3 \\ EM_4 \\ EM_i \end{matrix} & \begin{bmatrix} NSt_{11} & NSt_{12} & NSt_{13} & NSt_{1j} \\ NSt_{21} & NSt_{22} & NSt_{23} & NSt_{2j} \\ \cdot & NSt_{32} & NSt_{33} & NSt_{3j} \\ \cdot & \cdot & NSt_{43} & \cdot \\ NSt_{i1} & NSt_{i2} & \cdot & NSt_{ij} \end{bmatrix} \end{matrix}$$

Equation 27

NSt_{ij} : is the numeric status of the electro-mechanical items i on the time j. It could be either “0” for the operating electro-mechanical items or “1” for the electro-mechanical items that need maintenance.

Maintenance Costs Matrix (MCM)

$$\begin{matrix} & t_1 & t_2 & t_3 & t_j \\ \begin{matrix} EM_1 \\ EM_2 \\ EM_3 \\ EM_4 \\ EM_i \end{matrix} & \begin{bmatrix} MC_{11} & MC_{12} & MC_{13} & MC_{1j} \\ MC_{21} & MC_{22} & MC_{23} & MC_{2j} \\ \cdot & MC_{32} & MC_{33} & MC_{3j} \\ \cdot & \cdot & MC_{43} & \cdot \\ MC_{i1} & MC_{i2} & \cdot & MC_{ij} \end{bmatrix} \end{matrix}$$

Equation 28

MC_{ij} : is the maintenance costs for electro-mechanical items i on the time j .
 Where; as the electro-mechanical items' condition becomes worse, the maintenance cost will dramatically increase (For instance: $MC_{13} \gg MC_{11}$)

Life Cycle Costs Matrix (LCCM)

$$\begin{array}{c}
 \\
 \\
 EM_1 \\
 EM_2 \\
 EM_3 \\
 EM_4 \\
 EM_i \\
 \sum_{i=1}^{i=I}
 \end{array}
 \begin{array}{c}
 t_1 \quad t_2 \quad t_3 \quad t_j \\
 \left[\begin{array}{cccc}
 LCC_{11} & LCC_{12} & LCC_{13} & LCC_{1j} \\
 LCC_{21} & LCC_{22} & LCC_{23} & LCC_{2j} \\
 . & LCC_{32} & LCC_{33} & LCC_{3j} \\
 . & . & LCC_{43} & . \\
 LCC_{i1} & LCC_{i2} & . & LCC_{ij}
 \end{array} \right] \\
 \hline
 LCC_{t_{14}} \quad LCC_{t_{24}} \quad LCC_{t_{34}} \quad LCC_{t_{j4}}
 \end{array}$$

Equation 29

LCC_{ij} : is the life cycle costs for electro-mechanical items i on the time j after multiplying the NSM with the MCM.

LCC_{t_j} : is the life cycle costs for electro-mechanical items i on the time j after the summation of all the electro-mechanical items at a certain point in time j .

I is the total number of electro-mechanical items.

Objective Function:

$$\text{Min. } \sum_{j=1}^{j=J} \frac{LCC_{t_{j4}}}{(1+I)^j}$$

Where;

J is the time horizon

WSOM Final Objective Function is therefore:

$$\text{Min. } \sum_{j=1}^{j=J} \frac{(LCC_{t_{j1}} + LCC_{t_{j2}} + LCC_{t_{j3}} + LCC_{t_{j3}})}{(1+I)^j}$$