Open Access Dissertations

Theses and Dissertations

Fall 2014

Project portfolio evaluation and selection using mathematical programming and optimization methods

Hugo Caballero
Purdue University

Follow this and additional works at: https://docs.lib.purdue.edu/open_access_dissertations

Part of the Business Administration, Management, and Operations Commons

PURDUE UNIVERSITY
GRADUATE SCHOOL
Thesis/Dissertation Acceptance

This is to certify that the thesis/dissertation prepared

By Hugo Caballero

Entitled PROJECT PORTFOLIO EVALUATION AND SELECTION USING MATHEMATICAL
PROGRAMMING AND OPTIMIZATION METHODS

For the degree of ___Doctor of Philosophy___

Is approved by the final examining committee:

Dr. Edie. K. Schmidt

Dr. Mary Johnson

Dr. Chad Laux

Dr. Jonathan Davis

To the best of my knowledge and as understood by the student in the Thesis/Dissertation Agreement, Publication Delay, and Certification/Disclaimer (Graduate School Form 32), this thesis/dissertation adheres to the provisions of Purdue University's "Policy on Integrity in Research" and the use of copyrighted material.

Dr. Edie. K. Schmidt

Approved by Major Professor(s): _____

Approved by: Dr. James Mohler   12/11/2014

Head of the Department Graduate Program   Date

PROJECT PORTFOLIO EVALUATION AND SELECTION USING MATHEMATICAL

PROGRAMMING AND OPTIMIZATION METHODS

A Dissertation

Submitted to the Faculty

of

Purdue University

by

Hugo Caballero

In Partial Fulfillment of the

Requirements for the Degree

of

Doctor of Philosophy

December 2014

Purdue University

West Lafayette, Indiana

To God for be good with me. To my wife Ita – for her love and support during this learning journey. To my little daughter Alejandra for being part of this growth process – to my family in Colombia, my mom Blanca, my dad Guido, my sister Idania, for their love and help during all this time. To my grandma Miti, my grandpa Allen and my mother in law Judith, whom are in heaven, thanks for their support and be part of our lives.

ACKNOWLEDGEMENTS

I would like to thank my committee for their guidance and support throughout this research process. Dr. Schmidt for her confidence and the chance to develop this research with freedom and creativity. Dr. Johnson for her sharp insights and sharing her great knowledge with me during the classes I took with her and during the revision of this research. Dr. Laux provided good review and perspective focus on the target audience of this research and the way this knowledge can be transferred. Finally, Dr. Davis, with his experience in developing tools for project management, provided me good comments during the presentation and revision process.

I would also like to thank my fellow graduate students for their friendship and making this learning experience more enjoyable. Diana, Shweta, Kim, Lin, Jeremy, Ricardo, Raymond, Tandreia, Sophia and Zhen will be always my friends.

Finally, my wife, Ita, has made this journey a growing process for both and has listened to my ideas and given me advice during this process.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure   Page

ABSTRACT

Caballero, Hugo. Ph.D., Purdue University, December 2014. Project Portfolio Evaluation and Selection Using Mathematical Programming and Optimization Methods. Major Professor: Edie K. Schmidt.

Project portfolio selection is an essential process for portfolio management and plays an important role in accomplishing organizational goals. This research explores the feasibility of developing a project portfolio selection tool by using mathematical programming and optimization models, specifically 0-1 integer programming (one objective portfolio) and goal programming (multiple objectives portfolio). These methods select the set of projects which deliver the maximum benefit (e.g., net present value, profit, etc.) represented for objective functions subjected to a series of constraints (e.g., technical requirements and/or resources availability) considering the scheduling of selected projects in a planning horizon, interdependence relationship among projects (e.g., complementary projects and mutually exclusive projects) and especial cases like mandatory and ongoing projects.

Based on the proposed model, a Decision Support System (DSS) will be developed and tested for accuracy, flexibility and ease of use. This computational tool will be designed for decision makers and users that are not familiar with mathematical programming models.

CHAPTER 1.   INTRODUCTION

1.1   Introduction and Motivation

Portfolio categorization, evaluation and prioritization are essential processes for portfolio management and play important roles in its efforts to accomplish organizational strategic goals. Selection processes based on qualitative and quantitative criteria have been used for decision making to justify capital investment and resources allocation. In many cases, financial criteria are the only criteria considered in project selection decisions. In others, the decision making process is still based on the experience and feeling of top management. Usually the decision that results from these methodologies can be very debatable. Despite the importance of portfolio selection processes for the organizations, there is little research about standard procedures.

The role of projects in the organization is closely related to the growth and sustainability of the operations. The success of a project in a project lifecycle depends not only on the proper execution but also on an accurate selection process. Consequently, a successful project implies doing the best projects in the most efficient way possible. This dissertation explored models for project portfolio selection that maximizes the benefits of an organization considering its strategic goals, requirements (e.g., production performance) and constraints (e.g., financial resources, manpower).

Project portfolio selection aims to allocate the resources among the best candidate projects in order to ensure the development of the strategy of the organization. For this reason, project selection is essentially an optimization problem. The use of optimization models to address the project selection seems to be a very suitable approach, however the use of these models in the industry is not generalized. Some reasons are the complexity of this approach compared with others methods and the lack of knowledge or training in optimization techniques within the portfolio managers and top managers responsible for the decision making process.

1.2   Statement of the Problem

The development of this research considered the following two research questions:

1. How to define a model to select the project portfolio that optimizes the resource allocation and maximizes the benefits of an organization?

2. How to develop an accurate, flexible, and ease of use computational tool for project portfolio selection?

This research developed a model and a computational tool (Decision Support System, DSS) for project portfolio selection that can help organizations to maximize the benefits considering strategic goals, requirements and constraints (financial resources, manpower, equipment, etc.). This DSS was developed to be used by users with no experience or knowledge of optimization models but that need insights to make better decisions of great value to the organization. The research methodology included

reviewing the best practices for portfolio selection available, studying alternative process and techniques and developing a multi-criteria model and a computational tool to select and schedule the set of projects that provide most value for the organization, that is, the set that maximizes the benefits.

1.3 Scope

This research adopted a model for project portfolio selection based on two mathematical programming approaches, Integer Linear Programming (ILP) and Goal Programming (GP). These models can consider one or multiple optimization goals, different constraints including technical requirements, resources constraints or interdependency among projects. Based on this model, a computational tool to assist decision makers was developed. This tool meet three main goals: first, accuracy in finding the optimal set of project under different conditions, second, flexibility in order to deal with one or multiple optimization criteria and different kind of constraints that model the requirements of the organization, and finally, ease of use for people that are not familiar with the formulation and solution of mathematical programming problems. The computational tool was integrated as a Decision Support System for portfolio management with a broad possibilities of expansion and integration with databases.

The project selection cases analyzed in this research are focused mainly on projects in profit organizations due to their prevalence. These organizations usually undertake projects in order to increase profit through an increase in production, new product development or reduce costs through implementation of new and more

efficient technologies. Specifically, the model and the DSS were tested with a portfolio selection process in a cement company in Colombia. However, the DSS, can be configured to be used in many kinds of organizations with different strategic goals.

1.4   Significance

Projects that meet the scope, cost and planned schedule are generally recognized as successful; however, in addition to this criteria, in order to be successful a project must add the maximum possible value to the organization and its customers.

The process of developing a successful project starts with a comprehensive business case, followed by project evaluation, accurate selection and alignment with company strategy, and finally, execution of the project. The organization should not only focus on successful project management but also on a methodical and well defined project selection process. Project alignment with strategic objectives is even more critical when the organization is simultaneously undertaking a set of projects that demands the use of its resources (Bible & Bivins, 2011).

An incorrect project selection may have a negative impact in the future performance of the organization or even threaten its sustainability. According to the Project Management Institute [PMI] "without a successful evaluation and selection process, unnecessary or poorly planned projects can come into the portfolio and increase the workload of the organization, thus hampering the benefits realized from truly important and strategic projects" (PMI, 2008b, p. 39). The consequences of an unsuccessful project selection would be low effectiveness in the achievement of

strategic objectives, low efficiency in the use of resources (financial resources, people and production systems), low performance in the financial results (bottom line) and even low morale among the employees.

The significance of this research is that the computational tool (DSS) developed can be used for decision makers, without any knowledge or experience in optimization models, to optimize the use of resources in any organization that undertakes a project portfolio. The optimal selection process is a complex problem that must consider multiple criteria besides financial aspects, such as technical or environmental requirements and optimal use of scarce resources (financial, manpower, etc.) of the organization. Flexibility is one of the strong points of the developed DSS because the user can consider multiple criteria and multiple kind of constraints. The portfolio selection process, besides the evaluation of benefits, may also consider the risks associated with each alternative through the analysis of potential scenarios.

1.5   Assumptions

This research relied on the following assumptions:

- The organization has clearly established its strategic goals as a result of the strategic planning process. Strategic goals should contribute to achieve the mission and vision of the organization.

- The organization has a list of candidate projects that supports the strategy. Any candidate project must address at least one strategic goal in order to guarantee that this project adds value to the organization.

- The main attributes of candidate projects are known or can be estimated. These attributes include financial benefits (Net Present Value, Return of Investment, etc.), capital expenditure, resource requirements and associated risks.

- The organization has defined some interdependence relationships among candidate projects such as dependent projects, mutually exclusive projects and mandatory projects.

- The organization has defined a planning horizon and available resources (financial resources, manpower, equipment, etc.) to be used in the execution of the project portfolio.

- The qualitative criteria defined by the organization, if any, can be rated in a quantitative score using judgment of experts. This assumption makes it possible to consider qualitative criteria that can be important to the decision maker.

1.6   Limitations

The limitations relative to this research included the following:

- There might be some uncertainty associated to some critical data for the portfolio selection problem such as capital expenditures, Net Present Value, etc. The risks associated with uncertainty in some critical data can be managed using

some kind of sensitivity and scenario analysis. The implementation of stochastic programming in order to deal with stochastic parameters and variables is discussed in chapter 5 in the section of further research.

- Some selection criteria depend on organizational policies and procedures. Although this framework and tool have some flexibility to suit project selection requirements in most companies, the formulation and coding of some especial constraints may be necessary in order to adjust the model to specific policies or requirements in some organizations. The implementation of additional kind of constraints is discussed in chapter 5 in the section of further research.

1.7 Delimitations

This research had the following delimitations:

- The model and computational tool were tested with a small project portfolio selection case (8 candidate projects) in order to run many problem configurations and check the validity of the model with different constraint conditions (28 tests). In spite of this, the tool can find the optimal solution for large project selection cases within a reasonable processing time.
- The computational tool was also tested using real data of project portfolio in a cement company with large portfolio (more than 100 candidate projects in 2014), these tests helped to demonstrate the usefulness of the tool, limitations

and potential improvements. These results can be extended to different kinds of

project portfolios in other industries.

1.8   Definitions

Analytical Hierarchy Process (AHP).   Comprehensive and rational method for group

decision making considering goals, criteria and alternatives organized in a

hierarchy and assuming these elements are independent (Saaty, 2008).

Analytical Network Process (ANP).   A more general form of AHP with the elements

organized as a network and these elements could be dependent (Saaty, 2008).

Decision Support System (DSS). Interactive computational system that assists decision-

makers to solve an unstructured (or semi structured) problem based on a

mathematical model (Sprague & Carlson, 1982).

Goal Programming Problem (GP). A multicriteria optimization problem which looks for

satisfying the desired targets for several goals minimizing the deviation of

satisfying these goals (Eiselt & Sandblom, 2012).

Integer Linear Programming Problem (ILP). Linear programing problem with the

requirement that the variables should be integer (Eiselt & Sandblom, 2012).

Internal Rate of Return (IRR). An estimate of rate of return of the investment that

produces NPV zero (Blocher, Stout, & Cokins, 2010)

Linear Programming Problem (LP).   Type of mathematical programming problem which

looks for the values of a set of continuous variables that maximize (or minimize)

an objective function while satisfying some linear constraints (Chen, Batson &

Dang, 2010)

Mathematical Programming (MP). Field of Operations Research that studies models

which aim to find the best available values of some objective function given a

defined set of constraints.

Mixed Integer Linear programming (MILP). Type of integer programing problem that

requires some but not all of the variables to be integer (Eiselt & Sandblom, 2012).

Net Present Value (NPV) - It is the difference between the present value of cash inflow

and outflow for an investment (Mantel, Meredith, Shafer, & Sutton, 2011).

Payback Period (PBP). Time required for the cumulative cash inflow (after-tax) to

recover the initial investment (Mantel et al., 2011).

Profitability Index (PI). Net present value per amount invested (Blocher et al., 2010)

1.9   Summary

This chapter provided an overview of the research project, including statement

of purpose, scope, significance, assumptions, limitations and delimitations. The next

chapter outlines a literature review of the different methods currently used for project

evaluation and selection with main emphasis on mathematical programming models

CHAPTER 2.   REVIEW OF LITERATURE

This chapter presents a summary of the body of knowledge used as theoretical

background for this research. The main subjects are project portfolio management

concepts, portfolio management process, projects and organizational strategy and

project selection grossly models used in industry, making emphasis in mathematical

programming models. The last part of this chapter is an introduction to Cementos Argos,

the company, whose project portfolio data were used to test the computational tool.

The sources used in this literature review included papers and books in the fields of

project and portfolio management, optimization modeling, operations research, integer

and goal programming, and optimization software.

2.1   Projects, Programs and Portfolio

In the context of well managed organizations (profit, nonprofit and

governmental) there is a close relationship between projects and organizational

strategy. Projects are basic building blocks that contribute to the achievement of the

vision of the organization through alignment with its strategic goals and objectives.

Consequently, in order to optimize the use of the resources, organizations should select

and undertake the projects that maximize the benefits aligned with its strategy. For a

better understanding of this relationship it is necessary to start from reviewing the concepts of project, portfolio and portfolio management and the relationship of portfolio management process with strategic planning process.

A project can be defined as a planned sequence of managerial and technical activities which employ resources to produce a particular desired outcome. The PMI defines a project as "a temporary endeavor undertaken to create a unique product, service, or result" (PMI, 2008a, p. 5). This definition shows two main features of projects: their temporary nature and unique outcome.

Project Management includes the application of process and best practices in order to ensure quality of the project outcome, this is referred to as "the application of knowledge, skills, and techniques to project activities to meet the project requirements" (PMI, 2008a, p. 6). A project that meets the requirements produces the expected results within a defined scope, budget, and schedule and produces deliverables that meet specifications and satisfy the customer (Mantel et al., 2011).

Projects can be grouped into programs and portfolios. A program is defined as "a group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually" (PMI, 2008a, p.7). Programs allow companies to enhance the performance of related projects sharing resources and synchronizing efforts. In a broader context, a portfolio is a "collection of projects or programs and other work that are grouped together to facilitate effective management of that work to meet strategic business objectives" (PMI, 2008a, p.8). In the case of

portfolios, the projects and programs associated are not necessarily interdependent but should contribute to reach strategic goals of the organization.

<div align="center">2.2   Project Portfolio Management</div>

Project portfolio management (PPM), refers to the activities to manage the components of a portfolio (projects and programs) in a coordinated manner to reach organizational objectives (PMI, 2008b). Project portfolio management can be considered as a group of processes that break down the strategic planning to a project level.

Bible and Bivins (2011) defined Project Portfolio Management as a process that "can be thought of as the actionable management process necessary to achieve the organization's strategic objectives through project portfolio selection, implementation, monitoring and control, and evaluation" (Pg. 3). This process is essentially iterative because strategic planning is a dynamic process and its components such as goals and objectives can change according to external and internal factors off the organization. Bible and Bivins (2011) claimed that "the essence of PPM is reasoned decision making" (Pg. 3). PPM involves a methodical process of decision making focused on optimizing the use of resources to achieve the desired objectives through a set of projects that add more value to the organization.

According to the Standard for Portfolio Management (PMI, 2008b), portfolio management processes can be grouped into two groups: portfolio alignment and portfolio monitoring and control. Portfolio alignment includes portfolio planning

activities that make possible to identify, categorize, evaluate, select, prioritize, balance, and authorize projects that would be undertaken by the organization. Portfolio monitoring and control process includes the evaluation of portfolio performance during the execution phase and checks that it meets a strategic goal. Figure 2.1 shows the sequence of the process within the portfolio alignment group.
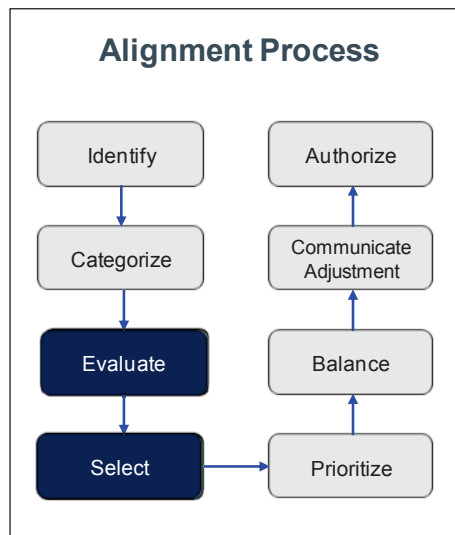
Figure 2.1. Aligment and Selection Process in Portfolio Management. Adapted from "The standard for portfolio management" by Project Management Institute, 2008, Newtown Square, PA: Project Management Institute, p.11.

2.3   Project Portfolio and Organizational Strategy

The vision, mission, and strategic objectives are the result of the strategic planning cycle of the organization. Vision represents the future desired position for the organization, mission represents the current statement to add value to customers and shareholders, and strategic objectives represent the individual achievements that allow the organization to meet the vision. In general, organizations perform projects to

maintain competitiveness and the sustainability of their operations. The motivations to execute projects include:

- Increase production capacity (e.g., new equipment or facilities);

- Operations optimization (e.g., new technology and process);

- Business opportunities (e.g., development of new products or new market);

- Customer or market requirements; and

- Legal/environmental requirement.

Figure 2.2 shows the relationship between strategic planning, operations and project portfolio, suggesting that both operations and project portfolio contribute to achieve organizational objectives.

Figure 2.2. Relationship between Strategic Planning and Project Portfolio. Adapted from "The standard for portfolio management" by Project Management Institute, 2008, Newtown Square, PA: Project Management Institute, p.9.

Archer and Ghasemzadeh (2004) claimed "to ensure a maximum return on selected projects, the selection process must be linked to the business strategy of the organization" (pg. 237). Project selection process is a critical phase of portfolio management and constitutes one of the subjects of research of this proposal.

2.4   Project Success and Portfolio Management

Project success is an important concept in the theory and practice of project management in organizations. Performance of project managers, project management teams, and their organizations is usually measured according to success of the projects in which they are stakeholders. People involved in program and portfolio management also need to understand the concept of how project success is defined because program and portfolio success can be considered an aggregate result of project success (Judvev & Muller, 2005).

The notion of project success has evolved in the last decades and now is considered a concept that includes some important interrelated dimensions: technical, economic, behavioral, business and strategic dimensions (McLeod, Doolin & MacDonell, 2012). The evolution in the concept of project success is the result of the analysis of the lesson learned from projects executed in many organizations and the satisfaction level of the stakeholders. The following paragraphs discuss the concept of project success in the context of project/portfolio management and in the context of project/product lifecycle.

2.4.1 Project Success and Project and Portfolio Management

From the project management perspective, the performance of a project is usually measured by the degree to which the project is completed according the specified cost, time and scope (Mantel et al., 2011). The scope consists of the deliverables of the project according to specifications required by the customer. These specifications include features, performance and quality levels. The cost and time (schedule) are defined during the project planning phase. Finally, the baselines of scope cost and time are formally approved by the customer and sponsor before the execution phase.

Even with a good project planning process, uncertainty during project execution can make it difficult to deliver the project according to the initial budget, schedule and scope specifications. Bible and Bivins (2011) claimed that "project management is the business of meeting the triple constraints of schedule, cost and quality, while at the same time, producing deliverables that meet specifications and satisfy the customer" (Pg. 1). These factors are related in such a way that if any one changes, at least one other factor is affected.

The project team is the one who "assesses the situation and balances the demands in order to deliver a successful project" (PMI, 2008a, p.7). However, meeting the triple constraint or, in other words, completing projects on time, within budget and specified scope, has little value if the projects do not contribute to the achievement of the organization's strategic objectives (Bible & Bivins, 2011).

Project portfolio management has as a main purpose to link projects and programs to the goals and strategy of the organization, and optimizing the use of resources. Bible and Bivins (2011) claimed that "not only do organizations want to complete the projects successfully by doing the work right, but they also want to successfully complete the right projects"(Pg. 2). Efficiency is associated with doing the things right and effectiveness with doing the right things (Judvev & Muller, 2005). Figure 2.3 represents the integration of these factors in the definition of project success and integration of project management and portfolio management.
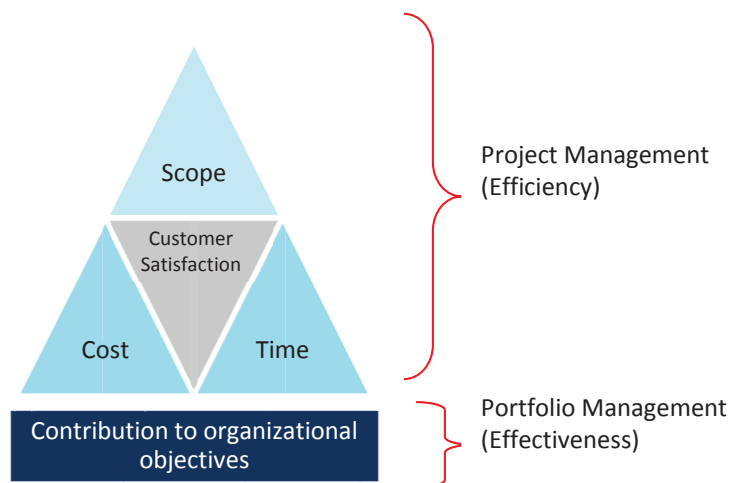
Figure 2.3. Project Management Successful Factors. Relationship among the Triple Constraint, Project Mangament and Portfolio Management.

In summary, project management is focused in doing things right while portfolio management is focused on doing the right things (Bible & Bivins, 2011) and a truly successful project should meet the triple constrain (scope, time and cost) and add value to the organization, that is, contribute to the achievement of its strategic goals.

2.4.2 Project Success and Project and Product Lifecycle

PMI (2008a) defines the product life cycle as:

a collection of generally sequential and sometimes overlapping projects phases

whose name and number are determined by the management and control need

of the organization or organizations involved in the project, the nature of the

project itself, and its area of application. (p.7)

The project life cycle involves all the activities needed to produce the

deliverables of the project. The PMI describes project life cycle as an element of product

life cycle which includes conception, development, operation and finally

decommissioning or withdrawal of a product or process (PMI, 2008a, p.7). Project

portfolio management extends project success beyond the project lifecycle, so project

success can be viewed as an integrated and holistic result.

Shenhar et al (2002) proposed a comprehensive framework that defines four

dimension of project success. The first dimension, associated with the project life cycle,

includes meeting the triple constraint (i.e., scope, time, and budget). The second

dimension measures the benefit for the customer (i.e., fulfill customer needs, customer

satisfaction, use of the product/service). The third dimension measures the benefit for

the organization and it is related with competitiveness (achieve commercial success,

increase market share) and finally, a fourth dimension measures the impact on the

future of the organization (development of new products, technology and new market).

Figure 2.4 shows these dimensions, the critical successful factors associated and the

domain of project and portfolio management.

Project Efficiency	Impact on customer	Impact on business	Impact on future
• Schedule • Cost • Scope	• Fulfill needs • Customer satisfaction • Use of product • Solving a problem	• Commercial success • Increase market share	• Creating new market • Creating new product • Creating new technology
Project Management	**Portfolio Management**		
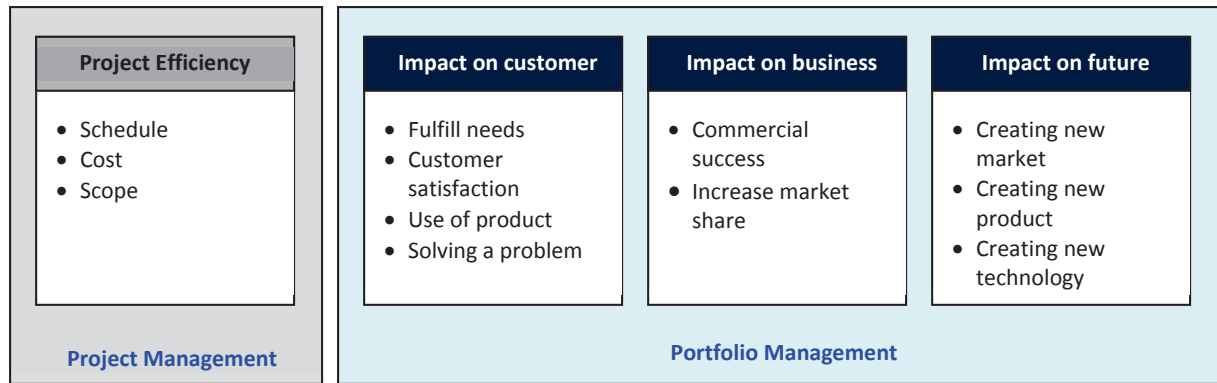
Figure 2.4. Project Successful Dimensions. Adapted from "A retrospective look at our evolving understanding of project success" by Jugdev, K., & Muller, R., 2005. Project Management Journal, 36(4), 19–31.

Competiveness and the need to achieve economic objectives through projects make organizations to view success as a combination of project management (efficiency) and portfolio management (effectiveness) (Judvev & Muller, 2005). This is a comprehensive model of project success beyond the traditional concept of the triple constraint.

In the same direction, Nelson (2005) describes the notion of project success from two approaches: a process-based approach and an outcome-based approach as shown in Figure 2.5. The components of success according to the process-based approach include time, cost and product (scope). These are the elements of the triple constraint.
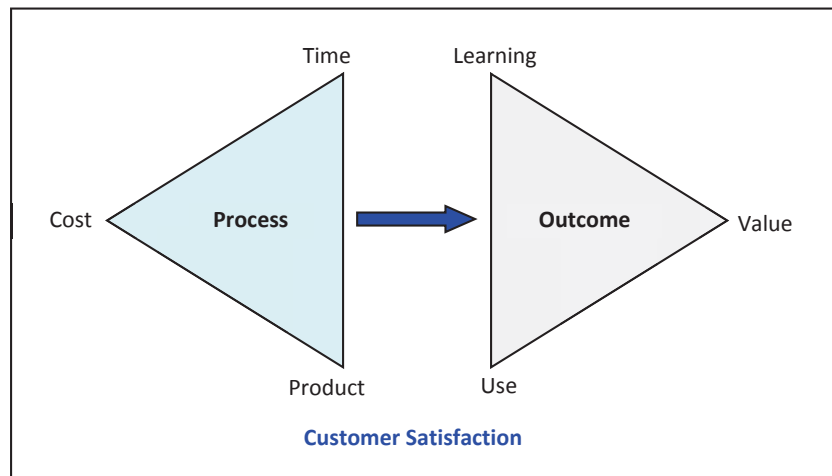
Figure 2.5. Project Success Criteria. Adapted from "Project retrospectives: evaluating project success, failure, and everything in between" by Nelson, R., 2005. MIS Quarterly Executive, 4(3), 361–371.

As a complement, the components of success according to the outcome-based approach include use, learning and value. The use is associated with the impact on the customers and implies that the product or services resulting from the project are being used by its target users. The learning corresponds to the impact on the future and means that the project helps to prepare the organization for the future. Finally, the value corresponds to the impact of the project on the business, referred as the improvement of the efficiency and/or effectiveness of the organization (Nelson, 2005).

In summary, the modern perspectives of project success go beyond the traditional concept of the triple constraint and include the impact of the outcome (product) of the project on the stakeholders.

2.5   <u>Project Portfolio Selection Methods</u>

Project evaluation and selection are important processes in the portfolio

management activities of the organization. Portfolio selection is a process that involves

the assessment of a set of available project proposals in order to undertake a group of

them that makes it possible to achieve some strategic goals (Mantel et al., 2011).

Portfolio selection is a periodic process that must guarantee that the selected projects

are inside the resource constraints of the organization (Ghasemzadeh & Archer, 2000).

The objective of the project selection process is to derive a portfolio of projects

providing maximum benefit subjected to resources constrains and other limitations

imposed by the organizations (Bible and Bivins, 2011). Portfolio selection seeks the best

balance in terms of return, capital investment, risk, timing, sustainability, and other

factors according to the organization needs and policies.

Project selection methodologies play an important role in portfolio

management. However, there is a plethora of project selection methodologies, and

there is no agreement on which is the most effective (Archer & Ghasemzadeh, 2004).

Consequently, organizations choose the methodology that best reflects their project

management maturity level, organizational culture, and kind of projects developed.

Mantel et al. (2011) classifies the project selection methods in two categories:

nonnumeric and numeric. The following sections describe the main methodologies for

project selection.

2.5.1   Nonnumeric Selection Methods

Nonnumeric selection methods are used in the industry because these methods are simple and take into consideration the experience and know-how of the decision makers. Some of these methods are described in the following paragraphs.

2.5.1.1   Sacred Cow

In this approach, a high level executive based on her or his experience, knowledge, and authority level decides that the organization must develop a specific project (Mantel et al., 2011). This method is common in many kinds of businesses; however, resulting decisions might be questionable due to subjective assessment of the decision maker or poor technical and economic justifications.

2.5.1.2   Operating/Competitive Necessity.

This method selects the projects that are needed to keep the business running (Mantel et al., 2011). Under certain circumstances, an organization must undertake some projects to assure its sustainability in the long term.

2.5.1.3   Comparative Models

Comparative models relate one candidate project either to another project or to some subset of candidate projects, in such a way that the obtained benefits have meaning only in relation to the set of candidate projects evaluated. Therefore, whenever a candidate project is added or deleted from the set under evaluation, the

entire process must be repeated (Heidenberger & Stummer, 1999). The main

comparative models used in project selection are Q-sort approach and Analytical

hierarchy process (AHP).

2.5.1.3.1   Q-Sort

Q-sort uses a pool of experts that ranks a set of alternatives in a sequence

considering quantitative and qualitative criteria. At the end, this methodology produces

a list of ranked projects according to the judgment of the members in the decision pool

(Mantel et al., 2011). Figure 2.6 shows the Q-sort rank sequence.
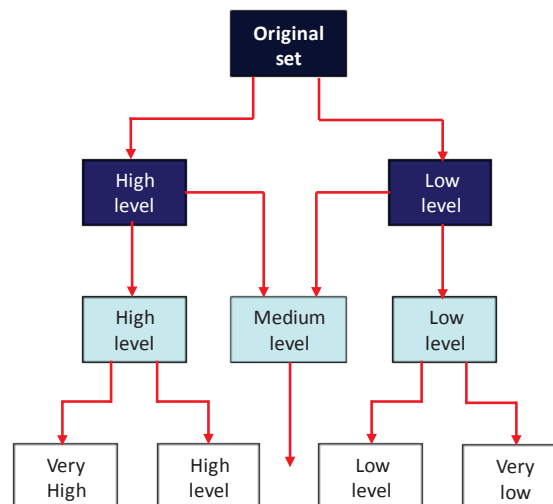
Figure 2.6. The Q-sort Method. Adapted from "Project Management in Practice (4th ed.)" by Mantel, S. J., Meredith, J. R., Shafer, S. M., & Sutton, M. M. , 2011, Hoboken, NJ: John Wiley & Sons, p.12.

In four to five steps, each member divides and subdivides the given projects

according to a single criterion in five sets. Finally each project can be shifted to another

set if necessary. This procedure provides flexibility and interaction between the

members of the decision team (Heidenberger & Stummer, 1999).

2.5.1.3.2   The Analytic Hierarchy Process (AHP)

The analytic hierarchy process is a multicriteria decision making model that can

use both qualitative and quantitative factors and is based on pair-wise comparison by

which the judgment of experts produces a recommendation. As project selection is a

decision making process, AHP can be used as a project selection methodology (Saaty,

2008).

AHP allows a decision maker to structure a project evaluation in the form of a

hierarchy with the projects at the bottom and the various criteria (or objectives) at

respective higher levels. At any level, each alternative has the same order of magnitude

or importance and is evaluated in relation to its peers with respect to its importance for

the objectives immediately above. Pairwise cardinal comparisons lead to a matrix

whose eigenvector contains the weights or priorities. This process is repeated for all

levels in the hierarchy. Then, the matrices of eigenvectors that summarizes the

priorities between levels are multiplied to finally determine the compound priorities of

the project alternatives according to their influence on the overall goal of the hierarchy

(Heidenberger & Stummer, 1999).

There are many examples in the literature that show the application of AHP in

project selection problems. Dey (2006) applied AHP for a project selection case study of

a cross-country petroleum pipelines project in India. This case includes identification of

alternatives, identification of factors to be considered (technical, environmental, and socio- economic criteria), creation of the AHP framework for deployment of the main and secondary decision factors according to each criteria, comparison of pairwise alternatives for each factor and, finally, aggregating the results.

An advantage of AHP models is that both quantitative and qualitative criteria can be used. A major disadvantage is the large number of comparisons involved, making them difficult to use in large portfolios. However, the use of computational tools such as Expert Choice can support the management of large portfolios. Bible and Bivins (2011) illustrated the use of Expert Choice in Project Portfolio Management activities including project selection.

Vaidya and Kumar (2006) claimed that "the specialty of AHP is its flexibility to be integrated with different techniques like Linear Programming, Quality Function Deployment, Fuzzy Logic, etc" (p.2). This makes it possible to combine AHP with other project selection models taking advantage of their strengths.

2.5.2   Numeric Selection Methods

Numeric selection methods rate the candidate projects according quantitative and qualitative normalized criteria. These criteria usually include financial benefits, productivity, reliability, environmental impact and risks associated with each project alternative. Numeric methods are used in the industry because these methods can provide a more accurate assessment of benefits for each candidate project to the decision maker. Some of these methods are described in the following paragraphs.

2.5.2.1 <u>Financial Assessment Models</u>

Traditional economic models attempt to calculate the cost-benefit. These methods typically require financial estimates of investment and income flows over the time frame of the project. These models are generally used in construction projects, where possible estimate costs and schedule are with some accuracy based on experience in similar projects (Archer & Ghasemzadeh, 2004).

The results of the financial evaluation for different project alternatives can be used in raking the potential benefits for decision making purpose. Blocher et al. (2010) described the financial methods for capital investments evaluation according to two categories: discounted cash flow (DCF) models and non-DCF models.

2.5.2.1.1 Discounted Cash-Flow Methods (DCF)

DFC methods consider the value of money in time and include performance indicators such as net present value (NPV), internal rate of return (IRR), and profitability index (PI). NPV is the difference between the present value of cash inflow and outflow for an investment as calculated in Equation 1 (Mantel et al., 2011). A positive NPV means the project earns more than the required rate of return and that the project may be accepted.

$$NPV = -Io + \sum_{t=1}^{n} \frac{Ft}{(1+k)^t} \tag{1}$$

Where: *Io* is the initial investment

Ft is the net cash flow in the period t

k is the required rate of return

n is the number of periods in life of the project

The internal rate of return (IRR) is an estimate of rate of return of the investment that produces NPV zero. The project is accepted if the IRR exceeds the discount rate set by the organization. The profitability index (PI) is the ratio between net present values per invested amount. Equation 2 shows this relationship (Blocher et al., 2010)

$$PI = NPV/Io \tag{2}$$

2.5.2.1.2 Non-Discounted Cash-Flow Methods

Non-DFC methods do not consider the value of money in time; however they can be used to prescreen some project alternatives. The most used non-DCF indicator is the payback period (PBP), defined as the time required for the cumulative cash inflow (after-tax) to recover the initial investment. PBP is considered a measure of risk of investment, longer PBP means higher risk to the organization. Equation 3 shows how to determine the PBP with uniform annual net cash inflow (Mantel et al., 2011).

$$PBP = Io/F \tag{3}$$

Where: *F* is the estimated annual net cash inflow

Financial methods are broadly employed. Blocher et al. (2010) claimed that three of four firms use both NPV and IRR for capital-budgeting purposes. All these financial methodologies are powerful tools to evaluate the economic benefits of a project; however, they ignore non-financial considerations, such as social or environmental impact.

2.5.2.2   Scoring Methods

Scoring methods consider more than one criterion and can combine qualitative and quantitative factors. Some advantages of these models are that they are probably the easiest to use of all methods and, that projects can be added or deleted from the set without recalculating the score of other projects (Archer & Ghasemzadeh, 2004). Scoring methods include the unweighted and the weighted factor scoring method.

2.5.2.2.1   The Unweighted 0-1 Factor Model (or Checklist Approach)

This model lists some factors which are desirable for the projects under review and a decision committee checks off which criteria are satisfied (Mantel et al., 2011). The score is related to the number of criteria the alternative meets and can be calculated according to Equation 4 (Heidenberger & Stummer, 1999):

$$S_i = \sum_{j=1}^{n} s_{ij} \qquad (4)$$

$$s_{ij} = \begin{cases} 1, & if\ project\ i\ meet\ criterion\ j \\ 0, & otherwise \end{cases} \qquad (5)$$

Where: S_i is the total score of the ith project

              s_{ij} is the score of the ith project on the jth criterion

This method assumes that all criteria are equally important. In case this assumption is not true, the ranking may be misleading.

2.5.2.2.2   The Weighted Factor Scoring Model

The weighted factor model considers a set of factors that have their associated relative importance weight which can be estimated according to expert judgment or consensus in a decision committee. A project alternative is evaluated on how well it meets a criterion, and the final score for each alternative is the product of criterion score and weight (Mantel et al., 2011). One assumption of this model is the linearity of the score. Equation 6 shows how to determine the final score for each alternative (Heidenberger & Stummer, 1999):

$$S_i = \sum_{j=1}^{n} s_{ij} \cdot w_j \tag{6}$$

Where: w_j is the weight of importance of the jth criterion

The standard for portfolio management of PMI describes this model for evaluation, selection, and prioritization of portfolio components. This standard presents a scoring model comprising weighted key criteria using a simple 1-5-10 scale for each

criterion and then evaluating components according to groups of criteria. The sum of the weights of the criteria should be 100% (PMI, 2008b).

The weighed factor scoring model is broadly used in the industry because this model considers multiple criteria, is ease to implement and understand by the decision makers. However, this model have the following drawbacks:

- The problem of weights assignment is not considered in this model and could be subject to the interests of the persons involved in the process. This problem could be solved by integrating a group decision making technique such as AHP for weights assignment.

- Scoring models do not consider any type of relationship between candidate projects and this could be important in some problems of project selection with dependent or mutually exclusive projects.

- Scoring models do not guarantee the optimal allocation of the resources of the organization because these models do not include resource constraint.

- The reliability of the values for each alternative is not considered. This might be a source of risk in the decision making process.

There are numerous examples of the application of weighted factor scoring methods in different kinds of projects and industry sectors. Sarkis, Presley, and Liles (1997) illustrated a framework for strategic multi-attribute evaluation for business process reengineering (BPR) projects. In this work, a link between the projects and the strategic goals of the organization is established. Three types of strategic metrics

categories are used in the analysis: financial, quantitative, and qualitative criteria. The

scores for each criterion are normalized using linear utility functions. Finally, weights of

criteria are assigned for a decision team.

Strang (2011) showed an action research case study using a weighted multi-

criteria scoring model in a selection process of technical proposals for a project in a

nuclear facility. This model applies AHP to estimate the weights of criteria and the

transformation of original-scaled values into dimensionless values to get the total score

of each alternative. The case study considers some important elements in the decision

process such as estimation of the factor weights using AHP, which considers the opinion

of experts and reliability factors for the values of the main variables for each project.

2.5.2.3   Optimization Models

Optimization models are based on operation research tools and use some form

of mathematical programming to select a set of projects which deliver maximum benefit

(e.g., NPV, profit) represented for and objective function subjected to a series of

constraints (e.g., cost, people). There are some cases in the literature about using

optimization models combined with some of the other models mentioned before. For

example, Schniederjans and Wilson (1991) showed a model using goal programming and

AHP while Lee and Kim (2000) showed an application of goal programming and

Analytical Network Process (ANP). However, Archer and Ghasemzadeh (2004) claimed

that the use of mathematical programming models in the practical is not generalized

because they can be highly complex and require a significant amount of data.

The next section describes the use of mathematical programming models with some detail and emphasizes the mathematical formulation of the model including the definition of the decision variables, objective function and the most relevant constraints: resource constraints, technical requirements and interdependence among projects.

2.6 Mathematical Programming Models for Project Selection

The basic objective of mathematical programming problem is to maximize or minimize an objective function and meet some constraints. The formulation of the linear programming problem includes defining decision variables, objective function, and constraints. There are many forms of mathematical programming for optimization including linear and non-linear programming, integer programming, goal programming, dynamic programming and stochastic programming (Heidenberger & Stummer, 1999). Nonetheless, two approaches seem to be more suitable and easy to apply in project selection problems: Integer linear programming model when the decision maker is focused on optimizing one objective and goal programming model when the decision maker considers satisfying multiple objectives.

2.6.1 Integer Linear Programming Models (ILP)

The integer programming model selects a set of projects which maximize a benefit (objective). This section focuses on the formulation of project selection problems using integer programming and considering two cases: in the first one, it is

assumed the projects are executed at the same time, so the resources are available to

be used by the selected projects in one period of time. In the second case, project

selection and scheduling during a time horizon is considered, so the projects can be

executed in different moments according to resources availability during each period

and relationship between candidate projects.

2.6.1.1   0-1 ILP Project Selection without Scheduling (Single Period)

This model is the most simplified approach and assumes all resources are

available to execute the selected candidate projects at the same time (a single period),

that is, the resources are available to be used for simultaneous project execution. This

problem known as Capital Budgeting Problem, is described in Chen, Batson and Dang

(2010) and the formulation is shown in Equations (7) to (9). This model considers n

candidate projects and each project i have an associated decision variable which is

defined as follows:

$$X_i = \begin{cases} 1, & if\ project\ i\ is\ selected \\ 0, & otherwise \end{cases} \tag{7}$$

for i = 1, …, n, where n is the total number of projects being considered

The objective function Z is the total benefit of any project set. The solution seeks

to maximize Z as follows:

$$Max \ Z = \sum_{i=1}^{n} c_i X_i \tag{8}$$

Where: Z is the criterion to be maximized and corresponds to the total benefit of the

portfolio. Usually Z is the overall NPV of the portfolio.

c_i is the benefit provided by the project i

Constrains are functions that consider the availability of resources (money,

people, facilities, etc.) for project execution or describe some requirements (technical,

environmental, etc.) that projects must meet. In general, resources constraints can be

defined by Equation 9.

$$\sum_{i=1}^{n} a_{ij} X_i \le b_j \tag{9}$$

Where a_{ij} is the use of resource j by project i and b_j is the availability of resource j to be

used for execution of the project portfolio. In the case of constraints related with

requirements, these constraints can be represented by an inequality ($\ge$ or $\le$) or a strictly

equal (=) constraint.

Integer programming models can consider interdependent projects within a

portfolio such as contingent projects, mutually exclusive projects, parallel and

mandatory projects (Heidenberger & Stummer, 1999). These conditions are described

by using constraints equations relating candidate projects. For example, consider the

case of dependent projects where if project j is selected, then project i must also be

selected, but the opposite is not a condition. This circumstance is described by Equation

10 (Winston & Venkataramanan, 2003).

$$X_j \leq X_i \; or \; X_j - X_i \leq 0 \tag{10}$$

The case of mutually exclusive projects (i.e., if project j is selected, then project i

cannot be selected) is described by Equation 11 (Winston & Venkataramanan, 2003):

$$X_j + X_i \leq 1 \tag{11}$$

Finally, if project i is mandatory and its execution affects the amount of

resources available for other candidate projects, it must be included in the project

selection model using Equation 12 (Winston & Venkataramanan, 2003):

$$X_i = 1 \tag{12}$$

2.6.1.2   <u>0-1 ILP Project Selection With Scheduling (Multiple Periods)</u>

More complex models can consider the starting time and duration of the

candidate projects in the decision variables (Heidenberger & Stummer, 1999). This is a

more real approach to portfolio management in corporate environments and can be

used for the optimal distribution of the resources over the planning horizon when a

project portfolio should be executed. Ghasemzadeh, Archer, and Iyogun (1999) present

a model for project selection and scheduling using zero-one linear programming. The

basic formulation is shown in Equations 13 and 14. This model considers *n* candidate

projects and *t* periods of time. The decision variables are defined as follows:

$$X_{ij} = \begin{cases} 1, & \text{if project } i \text{ is selected and starts in period } j \\ 0, & \text{otherwise} \end{cases} \qquad (13)$$

for *i* = 1, …, *n*, where *n* is the total number of projects being considered

j = 1, …, *t*, where *t* is the total number of periods in the planning horizon.

The objective function *Z* is the total benefit of any project set. The solution seeks

to maximize *Z* as follows.

$$Max\ Z = \sum_{i=1}^{n} \sum_{j=1}^{t} c_i X_{ij} \qquad (14)$$

Where: *Z* is the criterion to be maximized and corresponds to the total benefit of the

portfolio and is related to the organizational goals. Usually *Z* is the overall

NPV of the portfolio.

c_i is the benefit provided by the project *i*

The inclusion of time for starting a project implies the use of some set of

constraints to control the flow of execution, the availability of resources in each period j

and the interdependence relationship of some candidate projects. The constraint

represented in Equation 15 ensures that each project, if selected, will be started only

once during the planning horizon (Ghasemzadeh, Archer, & Iyogun, 1999).

$$\sum_{j=1}^{t} X_{ij} \leq 1 \qquad\qquad \text{for } i = 1, ..., n \qquad\qquad (15)$$

Another important condition is that all selected projects should be finished within the planning horizon. In this case, all projects selected should be finished by the end of period *t*. This is described in Equation 16 (Ghasemzadeh, Archer, & Iyogun, 1999):

$$\sum_{j=1}^{t} j X_{ij} + d_i \leq t + 1 \qquad\qquad \text{for } i = 1, ..., n \qquad\qquad (16)$$

Where d_i is the duration of project *i* (number of periods required to be completed)

The availability of resources (e.g., financial resources, machinery, workforce) may vary during the planning horizon. For example, the organization may have availability of financial resources according to cash flow (budget). This set of constraints is shown in Equation 17 (Ghasemzadeh, Archer, & Iyogun,1999):

$$\sum_{i=1}^{n} \sum_{j=1}^{k} a_{i,k+1-j} X_{ij} \leq b_k \qquad\qquad \text{for } k = 1, ..., t \qquad\qquad (17)$$

Where b_k is the cumulated amount of resource available in period *k* and a_{k+1-j} is the cumulated amount of resources required by project *i* in the period *k*.

In a project portfolio selection, it is possible to consider interdependence among candidate projects, such as complementary, mutually exclusive and mandatory projects. The modeling of this constraints are shown in Equations 18, 19 and 20 (Ghasemzadeh,

Archer, & Iyogun,1999). In the case of complementary projects, if project A depends on project B and C, then if project A is selected, projects B and C must be included in the portfolio. However, projects B and C could be selected even if project A is not included. This condition is considered in the following set of constraints

$$\sum_{j=1}^{t} X_{ij} \geq \sum_{j=1}^{t} X_{lj} \qquad\qquad \text{for } i \in S_l \qquad\qquad (18)$$

Where S_l is the set of complementary projects for a particular project l. If the precursor projects must be finished before the dependent project l, the following set of constraints is necessary:

$$\sum_{j=1}^{t} j X_{lj} + (t+1) * \left(1 - \sum_{j=1}^{t} X_{lj}\right) - \sum_{j=1}^{t} j X_{ij} \geq d_i \sum_{j=1}^{t} X_{lj} \qquad\qquad (19)$$

Regarding mutually exclusive projects, here only one project of a mutually exclusive set of project can be selected. If P sets of mutually exclusive projects are considered, the corresponding relationship is described by Equation 20.

$$\sum_{i \in Sp} \sum_{j=1}^{t} X_{ij} \leq 1 \qquad\qquad \text{for } p = 1, ..., P \qquad\qquad (20)$$

Where S_p is a set of mutually exclusive projects.

It is important to consider the set of mandatory projects because these projects consume part of the available resources of the organization during the planning horizon.

The following set of constraints allows the inclusion of mandatory projects in the final

portfolio:

$$\sum_{j=1}^{t} X_{ij} = 1 \qquad\qquad \text{for } i \in S_m \qquad\qquad (21)$$

Where S_m is the set of mandatory projects

Ongoing projects should be also included in the final portfolio because

organizations may decide they should be continued in the following planning horizon

and these projects also consume some resources of the organization. The following

constraints guarantee the inclusion of ongoing projects in the final portfolio:

$$X_{i1} = 1 \qquad\qquad \text{for } i \in S_o \qquad\qquad (22)$$

Where S_o is the set of ongoing projects. It is assumed here that mandatory projects are

not interrupted and they continue in period 1 of the planning horizon.

2.6.2   Goal Programming Model (GP)

Goal programming is a technique that helps the decision maker meets his goals

as close as possible. Goal programming models select a set of projects which exactly or

approximately meets some target goals while satisfying some constraints. Goal

programming models can be linear or non-linear, and integer or non-integer in their

objective function or constraints (Heidenberger & Stummer, 1999). There are two

approaches of goal programming that can be applied to the project selection problem,

depending how the decision maker values the importance of the target goals and the

way the objective function is defined: weighted and lexicographic goal programming.

2.6.2.1   Weighted Goal Programming Without Scheduling (Single Period)

The general goal programming formulation is shown by Jones and Tamiz (2010).

A specific formulation for the project selection problem developed by the author of this

research is shown in Equations 23 through 25. This model considers *n* candidate

projects, *m* goals and some constraints. Each project *i* has an associated decision

variable which is defined by Equation 23.

$$Xi = \begin{cases} 1, & if\ project\ i\ is\ selected \\ 0, & otherwise \end{cases} \tag{23}$$

For *i* = 1, 2, …, n, where n is the total number of projects being considered.

Each goal *p* has associated a target value g_p and a goal weight W_p according its

relative importance. Any possible solution (set of projects) has two deviational variables

defined as follows:

S_{ep} : amount by which the project set numerically exceeds the *p*th goal

S_{up} : amount by which the project set is numerically under the *p*th goal

The objective function *Z* is the total deviation of the any project set from the

goals. The solution seeks to minimize *Z* as follows:

$$Min \; Z \; = \; \Sigma_{p=1}^{m} \left(\frac{W_p \times S_p}{Q_p} \right) \tag{24}$$

Where $S_p = \begin{cases} Se_p \; if \; goal \; p \; is \; a \; minimization \; target \; (\leq) \\ Su_p \; if \; goal \; p \; is \; a \; maximization \; target \; (\geq) \end{cases}$

Q_p is a normalization constant associated with the pth goal. This constant ensures that

the objective function is consistent with the units when the problem in consideration

has goals with different units.

The goals are defined as a set of m equations in the model, one equation for

each goal, as shown in Equation 25:

$$\sum_{i=1}^{n} c_{pi} X_i + Su_p - Se_p = g_p \tag{25}$$

Where c_{pi} is the contribution to the pth goal by the project i and g_p is the target of goal p

As in the 0-1 Integer programming model, constrains are functions that limit

resources for project execution or enforce some requirements (technical,

environmental, etc.) that projects must satisfy. In general, resources constraints can be

defined by Equation 26.

$$\sum_{i=1}^{n} a_{iq} X_i \leq b_q \tag{26}$$

Where a_{iq} is the use of resource q by the project i and b_q is the availability of the

resource q to be used for the execution of the project portfolio. In the case of

constraints related with requirements, these constraints can be represented by an

inequality ($\geq$ or $\leq$) or a strictly equal ($=$) constraint.

The interdependence between projects can be represented with the Equations 10, 11 and 12 as was described in section 2.6.1.1. The solution of the problem is the set of projects that minimize the objective function Z (i.e. the set of projects that minimizes the deviation from the goals).

2.6.2.2 Weighted Goal Programming With Scheduling (Multiple Periods)

The formulation for the project selection with multiple objectives can be modified in order to consider the availability of resources during a planning horizon. This model considers n candidate projects, m goals, t periods and some constraints. The decision variables are defined as follows:

$$X_{ij} = \begin{cases} 1, & \text{if project } i \text{ is selected and starts in period } j \\ 0, & \text{otherwise} \end{cases} \tag{27}$$

for i = 1, ..., n, where n is the total number of projects being considered and

j = 1, ..., t, where t is the total number of periods considered in the planning

horizon.

Each goal p has associated a target value g_p and a goal weight W_p according its relative importance. Any possible solution (set of projects) has two deviational variables defined as follows:

S_{ep} : amount by which the project set numerically exceeds the pth goal

S_{up} : amount by which the project set is numerically under the pth goal

The objective function *Z* is the total deviation of the any project set from the goals. The solution seeks to minimize *Z* as follows:

$$Min\ Z\ =\ \sum_{p=1}^{m}\left(\frac{W_p \times S_p}{Q_p}\right) \tag{28}$$

$$\text{Where } S_p = \begin{cases} Se_p \text{ if goal } p \text{ is a minimization target } (\leq) \\ Su_p \text{ if goal } p \text{ is a maximization target } (\geq) \end{cases}$$

Q_p is a normalization constant associated with the *p*th goal. This constant ensures that the objective function is consistent with the units when the problem in consideration has goals with different units.

The goals are defined as a set of *m* equations in the model, one equation for each goal, as shown in Equation 29:

$$\sum_{i=1}^{n} c_{pi}\left(\sum_{j=1}^{k} X_{ij}\right) + Sup - Se_p = g_p \tag{29}$$

Where c_{pi} is the contribution to the *p*th goal by the project *i* and g_p is the target of goal *p*

The constraints describing flow execution (Equations 15 and 16), resources availability in the planning horizon (Equation 17), projects interdependence (Equations 18 to 20), mandatory projects (Equation 21) and ongoing projects (Equation 22) are also applicable in goal programming with scheduling. The solution of the problem is the set of projects that minimize the objective function Z (i.e. the set of projects that minimizes the deviation from the goals).

2.6.2.3   Lexicographic Goal Programming

Lexicographic goal programming (or preemptive goal programming) does not use weighted criteria but a number of priority levels, that is, the algorithm seeks to satisfy first the goal with the highest priority, and then continues with the second more important and so on. The decision maker assigns the level of importance *P* for each goal. If *k* is the number of goals and each goal has a priority level, then the objective function can be described as follows (Jones & Tamiz, 2010):

$$Min \; a = \; [Z_1(S), Z_2(S), \dots, Z_k(S)] \tag{30}$$

$$Z_j = \; \sum_{j=1}^{k} P_j \left(\frac{S_j}{Q_j} \right) \tag{31}$$

Where S_j = $\begin{cases} Se_j \; if \; goal \; j \; is \; a \; minimization \; target \; (\leq) \\ Su_j \; if \; goal \; j \; is \; a \; maximization \; target \; (\geq) \end{cases}$

P_j is the priority factor associated with the *j*th goal

Q_j is a normalization constant associated with the *j*th goal

The priority factors are defined in such a way that the satisfaction of the set of goals of higher priority is much more important than the satisfaction of sets of goals of lower priority (Heidenberger & Stummer, 1999). The decision maker must rank the goals from the most important (goal 1) to the least important (goal *k*). The priority factor associated with the *j*th goal is such that:

$$P_1 \gg P_2 \gg \cdots \gg P_k \tag{32}$$

The definition of the priority factors ensure that the algorithm tries to satisfy the most important goal (goal 1) first, then using the feasible points that satisfy goal 1, it tries to come as close as possible to satisfying goal 2, and so forth (Winston & Venkataramanan, 2003). The equations for the goals and constraints are the Equations 25 and 26 shown for the weighted goal programming formulation.

There are some examples of project selection models using goal programming. Lee and Kim (2000) showed a methodology for project selection that uses a zero-one goal programming model for information system (IS) projects, which objective is minimizing the costs associated with several projects that have some interdependency. In this application, Analytical Network Process (ANP) is used to determine the relative importance of the criteria considered.

2.6.3 Solution of Mathematical Programming Models

The solution of mathematical programming problems is a topic of intense study in the field of math and operations research. As the problems become more complex with many variables and constraints, the efficiency and robustness of the algorithms to solve the problems are a critical factor for its implementation in a computational tool.

2.6.3.1   Algorithm for Solving Mathematical Programming Problems

The solution of the set of equations is the set of projects that maximizes the

objective function *Z*. This corresponds to the set of projects that maximizes the benefit.

Linear programming problems are usually solved applying simplex or Karmakar's

algorithm and integer linear programming problems are solved using branch-and-bound

or cutting plane algorithm (Winston & Venkataramanan, 2003).

2.6.3.2   Solution of Mathematical Programming Problems with Software

The increasing application of mathematical programming in many areas in

business (e.g., production scheduling, inventory, logistics) and the formulation of more

complex problems (e.g., large number of variables and constraints) have made

indispensable the use of specialized software. In the last decades, both the

development of more efficient algorithms and the increasing capacity of processors

have made possible the solution of large-scale mathematical programming in a

reasonable time.

In order to solve a problem of optimization, the first step is the formulation that

translates the real world problem in algebraic language defining the decision variables,

objective function and constraints. After a model is formulated, a computer package is

used to solve the problem. During this step, the programmer must translate the

formulation into a code that the software can recognize. According to Chen, Batson and

Dang (2010) the main components of a software for mathematical programming include modeling language, presolver, solver and the data and application interface.

1. Modeling languages emerged in the mid-to late 1980s and introduced the use of sets, symbolic parameters, indexed variables and constraints, operators and control flow commands. The modeling languages makes possible to define a symbolic algebraic model of the problem, by keeping separated the model and the data. This feature allows running the model with different set of data creating instances of the same problem and comparing results. The modeling language works as two-way communication channel between user and solver, that is, it communicates the data from the user to the solver and the results from the solver to the user (Chen, Batson & Dang, 2010). Among the most popular algebraic modeling languages are AMPL, GAMS, MPL, LINGO, and AIMMS.

2. The presolver applies preprocessing techniques in order to get a better formulation that is easier to solve. The preprocessing techniques, which depend on the kind of algorithm to be applied, adjust the variables and constraint in order to increase the computational efficiency (Chen, Batson & Dang, 2010).

3. The solver receives the model from the algebraic modeling language and tries to find an optimal solution for a particular set of data applying the more convenient algorithm according to the kind of problem. For example linear programming (LP) problems are solved using the simplex algorithm, while integer (IP) and mixed integer (MIP) problems can be solved using branch and bound algorithm

(Winston & Venkataramanan, 2003). Among the most used solvers used for MIP are CPLEX, GUROBI, MOSEK, BARON, CBC and XA.

4. Data and application interfaces are more critical when the model requires a significant amount of data. The modeling language can read data from external structured data sources such as databases, spreadsheets or simple text files to generate a matrix that the solver can use to run the solution algorithm. Application interfaces (APIs) developed in commercial programming languages as Java or C++ allow to call modeling languages and solvers from customized applications (Chen, Batson & Dang, 2010).

Some modeling languages incorporate a presolver, a data interface and solvers from different solver providers in order to offer an integrated environment of application software development. A list of the main commercial modeling languages and solvers are published by INFORMS (Fourer, 2013, June).

2.7   Project Portfolio Selection with Commercial Software

The project portfolio selection problem is part of the planning cycle of many organizations. There is some commercial software that assists the decision maker in this task. Most of these commercial software offer comprehensive suite for Project Portfolio Management (PPM) and the component for project selection is just a part of the package, they require a considerable investment and specialized training for the users. These commercial software are usually based on any of the methods described in

section 2.5. In the next paragraphs there is a description of some of the commercial software that support the project selection process.

- Expert Choice Comparion. The use of this software for portfolio selection is illustrated in detail in Bible and Bivins, (2011). This application is a web-based decision making tool based on Analytical Hierarchy Process (AHP). This tool allows a decision making team to facilitate the collaboration and structure decisions based on quantitative and qualitative data. In the case of project portfolio selection, the decision makers should have identified a main goal of the portfolio, a list of objectives associated to that goal and a group of alternatives (candidate projects). In the first step, the participants have to make a series of pairwise comparisons to provide judgments about the relative importance of the objectives. After all objectives have been compared to each other, the objective priorities for each participant are calculated. In the next step, the participant should rate how well each alternative contributes to each of the objectives. Expert Choice provides different ways to compare the goals and rate alternatives including numerical, verbal and graphical methods. In the final step, after all the participants have rated objectives and alternatives, Expert Choice combines and synthesizes the results to produce an overall ranking. Expert Choice allows making a sensitivity analysis by changing the relative priorities of the objectives to see how the portfolio changes (Expert Choice, 2014).

- GenSight. This application is a fully integrated web-based portfolio management system. This software includes forms to enable the capture of the business case, extensive workflow capabilities for the study, approval and execution of the portfolio components, decision support tools to prioritize projects and support approval gates. GenSight supports all common financial analysis including profitability, NPV, ROI, etc. Project selection is based on weighted multi-criteria methods. GenSight includes utility functions to normalize diverse quantitative metrics, qualitative utility scales and pairwise comparison. The Portfolio Analyst Workbench is a tool of GenSight that works offline and provides 2D and 3D graphical visualization and 'what if' scenario planning. Finally the GenSight Optimizer is a tool that incorporates proprietary genetic optimization algorithm to find the best combination of portfolio elements to maximize the return from constrained resources or assets. This tool is packaged as an optional add-on module to the Portfolio Analyst Workbench (The GenSight group, 2011).

- CANEA Projects. This software, developed in Sweden, integrates project, portfolio and resource management with support for the whole organization. CANEA Projects can be integrated with CANEA Improof, a workflow solution for many types of administrative processes, and CANEA Docpoint, a document management system for all the components associated with a Portfolio. CANEA Projects enables the selection and prioritization of projects using scoring models (CANEA Consulting Group, 2011).

2.8   <u>Case Study: Project Portfolio Selection in Cementos Argos</u>

This study included a case study of project portfolio selection in Cementos Argos, the main Colombian Portland cement producer, with an extensive portfolio including projects in industrial facilities for increasing production, operations optimization, projects that allow compliance of environmental regulations, projects aims improving the supply chain and logistics, etc.

This section contains a summary about Portland cement as product, the Portland cement production process and a description of Cementos Argos as a company. The purpose of this case study is to evaluate the improvement in the quality of the proposed portfolio when using the DSS for project selection vs. using the Argos's current selection method. This corresponds to the first research question that aims develop a model which finds the best portfolio for an organization. The data and results of this case study are presented in detail in chapter 4.

2.8.1   Portland Cement

The American Society for Testing and Materials (ASTM, 2012) defines Portland cement as:

> hydraulic cement (cement that not only hardens by reacting with water but also forms a water-resistant product) produced by pulverizing clinkers consisting essentially of hydraulic calcium silicates, usually containing one or more of the forms of calcium sulfate as an interground addition.

Portland cements is the most common type of cement and the basic constituent of concrete, mortar, stucco and grout.

According the Portland Cement Association, Portland cement was originally developed and patented in England by Joseph Aspdin of Leeds, early in the 19th century by burning powdered limestone and clay presenting a texture similar to Portland stone (PCA, 2014). The Portland cement is a fine powder produced in a chemical process combining calcium, silicon, aluminum and iron. The materials used to manufacture cement include limestone or marl ($CaCO_3$) combined with clay (Al_2O_3), slate, blast furnace slag or silica sand (SiO_2), and iron ore (Fe_2O_3). The low cost and widespread availability of these raw materials make Portland cement one of the lowest-cost materials used in the world (PCA, 2014).

2.8.2   Portland Cement Production Process

Cement production involves physical and chemical processing of raw materials in specialized equipment that require high investment. Cement production facilities, located near raw materials sources, require large amount of energy as electrical power feeding many processing and conveying equipment as well as fuels for drying and burning raw materials and environmental pollution control equipment. Currently, most cement is produced in a technology called Dry Process (PCA, 2014). Figure 2.7 and the following paragraphs describe the production process applied in a modern cement plant using dry process.
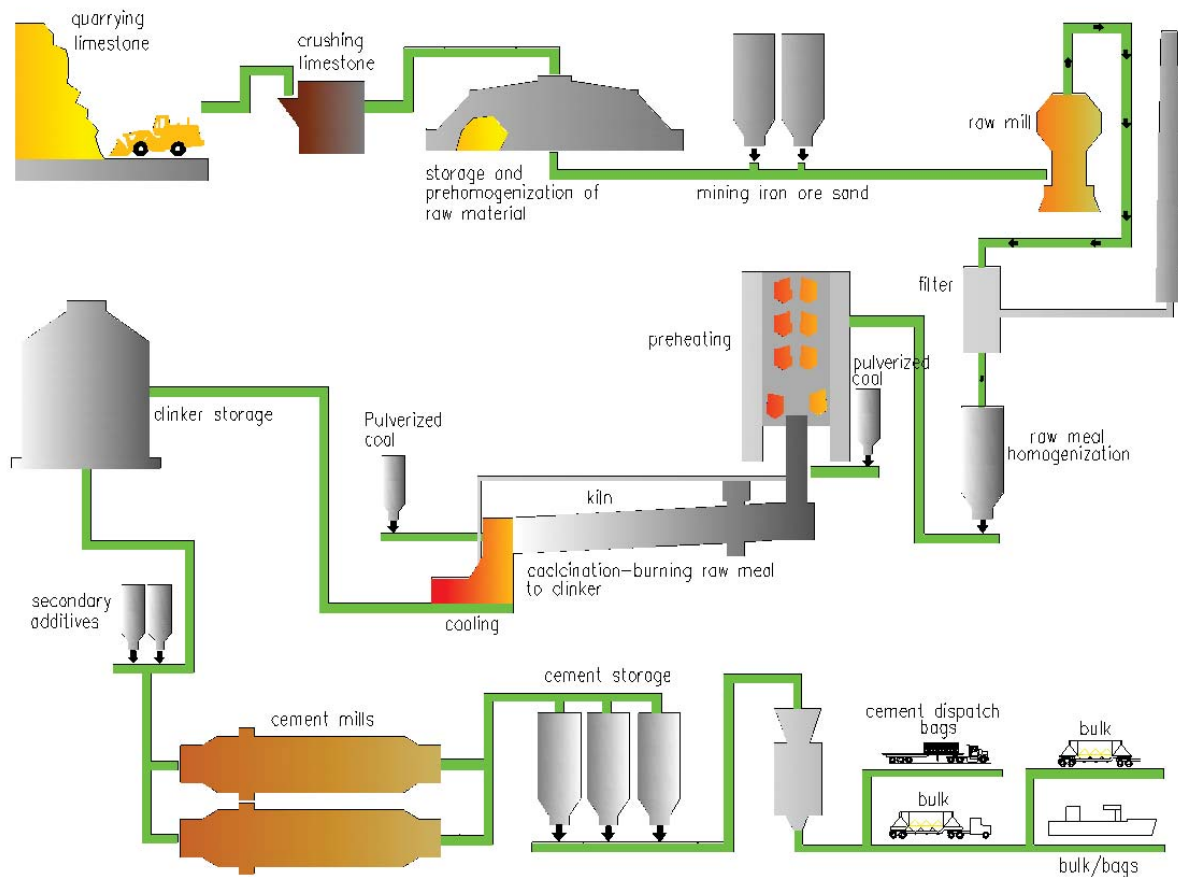
Figure 2.7. Cement Production in Dry Process. Adapted from "Sand & Cement Cogeneration Plant" by DSMAC, 2014

1. Quarrying. The materials necessary for production such as limestone rich in

    calcium and argillaceous materials such as clay are scraped from the quarry and

    transported to a crushing system (CEMEX, 2011).

2. Crushing. Rocks as big as 1 meter are being crushed to sizes less than 80 mm.

3. Pre-blending. Crushed materials are analyzed to determine their composition. A

    stacker creates piles of materials to reduce the variation (CEMEX, 2011).

4. Raw meal grinding and blending. The pre-blended raw material are conveyed to bins where a weighing feeder proportions it and then passes it through a raw mill which grinds them. The powdered raw meal is then transported into a blending storage silo (CEMEX, 2011).

5. Clinkerization. Raw mix is fed into a pre-heater and then into the rotary kiln. The raw feed slowly pass through the kiln in counter current to the burner flame. Pulverized coal or natural gas are used as heating fuel. The heat of the kiln breaks the chemical components and turn the raw mix into a semi-molten state (1,350-1,400 °C). The raw materials form compounds that produce the cement properties and change into solid nodules known as clinker and discharge into the clinker cooler. The clinker cooler cools the hot granular mass of clinker by quenching air. Conveyors transport then the cooled clinker to a storage silo (CEMEX, 2011).

6. Cement grinding. Clinker is transferred to the clinker bin. It passes through a weighing feeder, which controls its flow in proportion with additive materials. Gypsum is added to the clinker and then fed to the mills. The mixture is pulverized in the cement mills. Cement is then transferred to cement silos (CEMEX, 2011).

7. Packing and distribution. The cement is packed into bags or loaded as bulk and finally distributed (CEMEX, 2011).

2.8.3   About Cementos Argos

According the Argos Integrated Report, Cementos Argos is a Colombian cement company founded in 1.934 with operations in twelve countries distributed in three geographical regions in the American continent with 8,500 employees. The company, business model is focused on the customer and on sustainable development that is, being economically viable, respectful towards people and responsible with the environment (Cementos Argos, 2013).

2.8.3.1   Cementos Argos Operations

In the cement business, Argos has a total installed capacity of 19.26 million tons of Portland cement per year and is the marker leader in Colombia, the fifth largest producer in Latin America and the second largest in the South-East of the United States. The company has thirteen integrated cement plants, nine in Colombia, three in the United States, and one in Honduras. Argos has nine clinker grinding facilities located in the Unites States, the Dominican Republic, Haiti, Panama, Honduras, Surinam and French Guiana. For receipt, packaging and distribution of the product, Argos has twenty three ports and terminals (Cementos Argos, 2013).

In the concrete business, the company has a total installed capacity of 18 million cubic meters of concrete per year and is the market leader in Colombia and the second biggest producer in the United States. Argos has 388 concrete plants located in Colombia, United States, the Dominican Republic, Haiti, Panama and Surinam

(Cementos Argos, 2013). Figure 2.8 shows the operations of Argos and Table 2.1 shows

the production capacity per region.
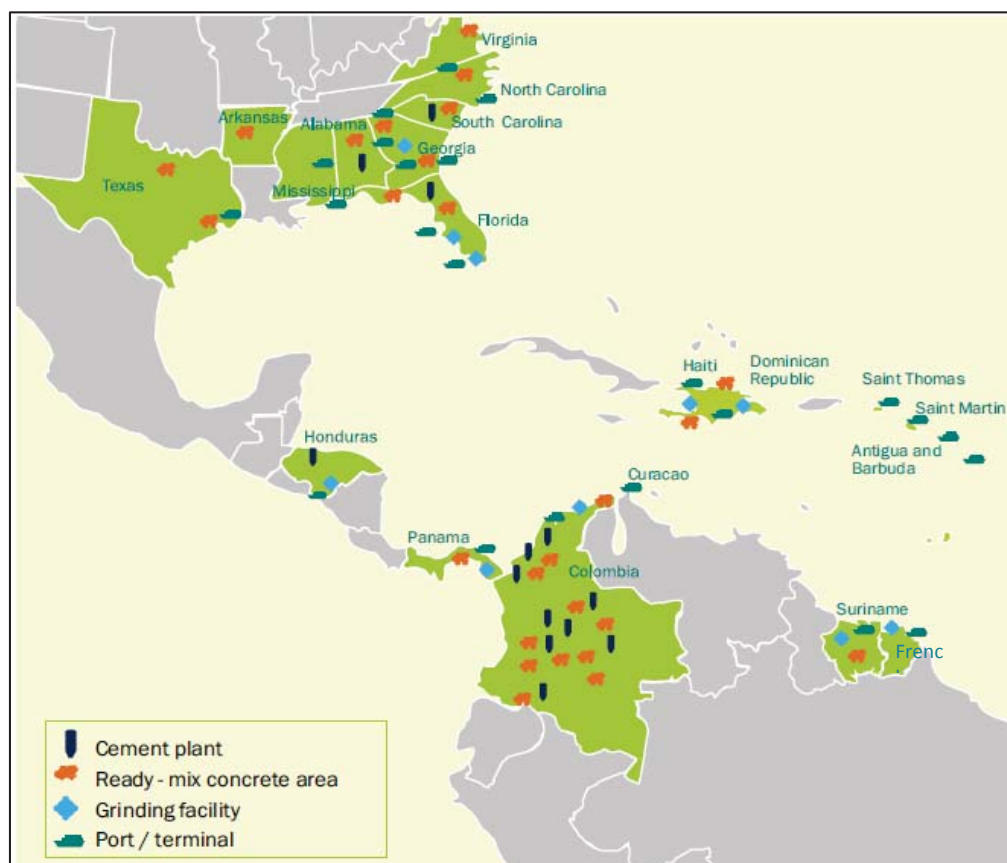
Figure 2.8. Argos Facilities Location in the American Continent. Adapted from *Argos Integrated Report* (p. 20), by Cementos Argos, 2013, Medellin, Colombia: Cementos Argos

Table 2.1

Cementos Argos's Production Capacity by Regional Division

United States	Caribbean and Central America
Cement Second largest producer in the Southeast Seventh largest producer in the US • Installed capacity: 6.64 million TPY • Number of integrated plants: 3 • Number of grinding facilities: 3 • Ports: 12 **Concrete** • Installed capacity: 13.09 million m3/year • Number of plants: 307 • Number of mixer trucks: 1,882	Operations in Honduras, Panama, Haiti, the Dominican Republic, Suriname, Saint Maarten, Saint Thomas, Antigua, Dominica, Curacao and French Guiana **Cement** Market Leader in Honduras Market Leader in Panama • Installed capacity: 3.8 million TPY • Number of integrated plants: 1 • Number of grinding facilities: 5 • Ports and terminals: 10
Colombia **Cement** Market Leader • Installed capacity: 9.88 million TPY • Number of integrated plants: 9 • Number of grinding facilities: 1 • Ports: 1 **Concrete** • Installed capacity: 3.99 million m3/year • Number of plants: 67 • Number of mixer trucks: 610	**Concrete** • Installed capacity: 0.95 million m3/year • Number of plants: 14 Number of mixer trucks: 178

Note: Adapted from *Argos Integrated Report* (p. 21), by Cementos Argos, 2013, Medellin, Colombia: Cementos Argos

2.8.3.2   Cementos Argos Financial Performance

According to Argos Integrated Report, in 2013 the company had sales of 11.3 millions of tons of cement and 9.3 millions of cubic meters of concrete and exported cement and clinker to 30 countries. The consolidated operation income was 2,656 million USD and the consolidated EBITDA was 524 million USD, the highest in the organization's history (Cementos Argos, 2013). Table 2.2 summarizes financial performance during 2013.

Table 2.2

Cementos Argos Financial Performance in 2013 (Argos, 2013)

Consolidated Income from Operations	2,656 million USD
Consolidated EBITDA	524 million USD
Earnings from Operations	313.3 million USD
EBITDA Margin	19.7%
Market CAP	6.9 Billion USD
Consolidated Assets	6,037 Billion USD
Consolidated Net Liabilities	2,086 Billion USD
Equity	3,759 Billion USD
Social Investment	9.7 million USD

2.8.3.3   Cementos Argos Strategic Priorities

Argos Integrated Report (Cementos Argos, 2013) defines the seven strategic priorities of the organization. These priorities represent the driver for the project portfolio of the organization according to the strategy and are summarized as follows:

- Consolidation and Expansion. Argos aims to have organic and inorganic growth within the American continent in order to become a regional market leader. Argos continuously looks for opportunities of expansion through projects increasing the capacity of the existing plants, new green field plants or acquisitions. During 2013, the company purchased cement assets from Lafarge in Honduras for USD 305 million and cement and concrete assets from Vulcan Materials Company in Florida and Georgia for USD 720 million.

- Capital structure. With the purpose of levering its growth, Argos looks for the availability of diverse sources of financial flexibility, keeping optimal levels of long-term indebtedness. During 2013, the company raised USD 880 million undertaking an issuance of shares with preferred dividend, both in domestic and international markets. This represents a source of financial flexibility that can support the growth of the organization.

- Operational models. At the same time Argos is expanding the operations, the company is working on the standardization and alignment of processes in order to create synergies as a business group. During 2013, the Synergy Project allows the company the standardization of the business core process and the implementation of SAP platform in the Colombia and USA Regional Divisions with an investment of USD 61.86 million.

- Organizational excellence. Argos's management model is based on excellence which will make the organization more competitive and profitable. Argos is promoting projects that increase operational efficiency and contribute to decrease cost of production and distribution. This includes initiatives to lower the clinker/cement factor, increase the run factor of the kilns, and reduce energy consumption and the use of alternative fuels.

- Innovation. Research and Development guarantee the continuous transformation and reinvention of the company towards sustainable competitiveness in the business world. Innovation in Argos is focused on four

lines: innovation management, new businesses, research and development and the use of alternative resources. During 2013, income stemming from the sale of innovating products reached a total of USD 252.9 million, which is 9.8% of the total company income. Beside this, the company had USD 3.3 million saving thanks to innovative ideas.

- Strategic projects. Argos is undertaking important investments with emphasis on improving the profitability and sustainability of the markets in which the company operates. During 2013, the strategic projects in execution were the expansion of capacity in three plants in Colombia in 900,000 tons of cement per year with an investment of USD 120 million, a new distribution center in Cartagena of 1 million tons of cement with an investment of USD 35 million and the installation of a new cement mill at the Harleyville plant in the USA with a capacity of 0.5 million tons of cement per year with an investment of USD 48 million.

- Sustainability. Cementos Argos develops its operations managing impacts, risk, and opportunities from the economic, social and environmental points of view. As a result of this policy, the company was included in the Dow Jones Sustainability Index (DJSI) in 2013, in the World category, as well as in that of Emerging Markets. The DJSI is the first and most important index that measures management in terms of sustainability. Argos is one of four cement companies worldwide to be included in this index.

2.9 <u>Summary</u>

This chapter has provided an overview of methodologies for project selection, including nonnumeric and numeric methods with more emphasis in optimization methods using mathematical programming. An overview of commercial solutions for portfolio project selection was also included and finally an introduction to Cementos Argos and the case study of project selection that is discussed in detail in chapter 4.

CHAPTER 3.   METHODOLOGY

The main goal of this research was to develop the formulation of a model and a computational tool (Decision Support System) to assist decision makers in the process of project portfolio selection. The model developed was based on a combination of mathematical programming techniques. This research includes the mathematical formulation of the model, the design and development of a computational tool for the end user, the verification and validation of the DSS and, finally, the application of the computational tool on a case study to evaluate its usefulness. This chapter presents the framework for project selection, a description of the computational tool, the verification and validation process, experimental design and analysis.

3.1   Portfolio Selection and Optimization Framework

Project selection tools should be used to support an integrated portfolio selection process as a part of the portfolio management of the organization. A critical successful factor in the implementation of a DSS for project selection is the adoption of a basic framework. PMI (PMI, 2008b) presents a standard for portfolio management described in Chapter 2. The main activities make it possible to identify, categorize, evaluate, select, prioritize, and balance the portfolio.

Bible and Bivins (2011) developed a detailed Project Portfolio Management

(PPM) framework with a screening phase and a selection phase. In the screening phase

candidate projects are screened according to some criteria and the results of a business

case. The selection phase includes the evaluation of project benefits, followed by the

selection of initial portfolio and, finally, an optimization based on a 'what if' analysis.

Archer and Ghasemzadeh (1999) proposed a general framework for project

selection considering the entire project lifecycle from conception to closing phase. This

research adopts this framework with some modifications such as the inclusion of

reviewing for alignment with strategy in the pre-screening stage and reviewing for

feasibility according economical, technical and sustainability criteria in the screening

stage. Figure 3.1 shows this framework and the main stages are described as follows:

- Candidate projects definitions. During this stage, a set of candidate projects are

  proposed. These initiatives can come from customer requirements, market

  opportunity, legal/environmental requirement, new technology available,

  research and development of new products or process, etc.

- Pre-Screening Stage. During this stage, candidate projects are reviewed if they

  are linked to at least one strategic goal of the organization. Any project that

  does not meet this criterion should be eliminated from the selection process in

  this stage.
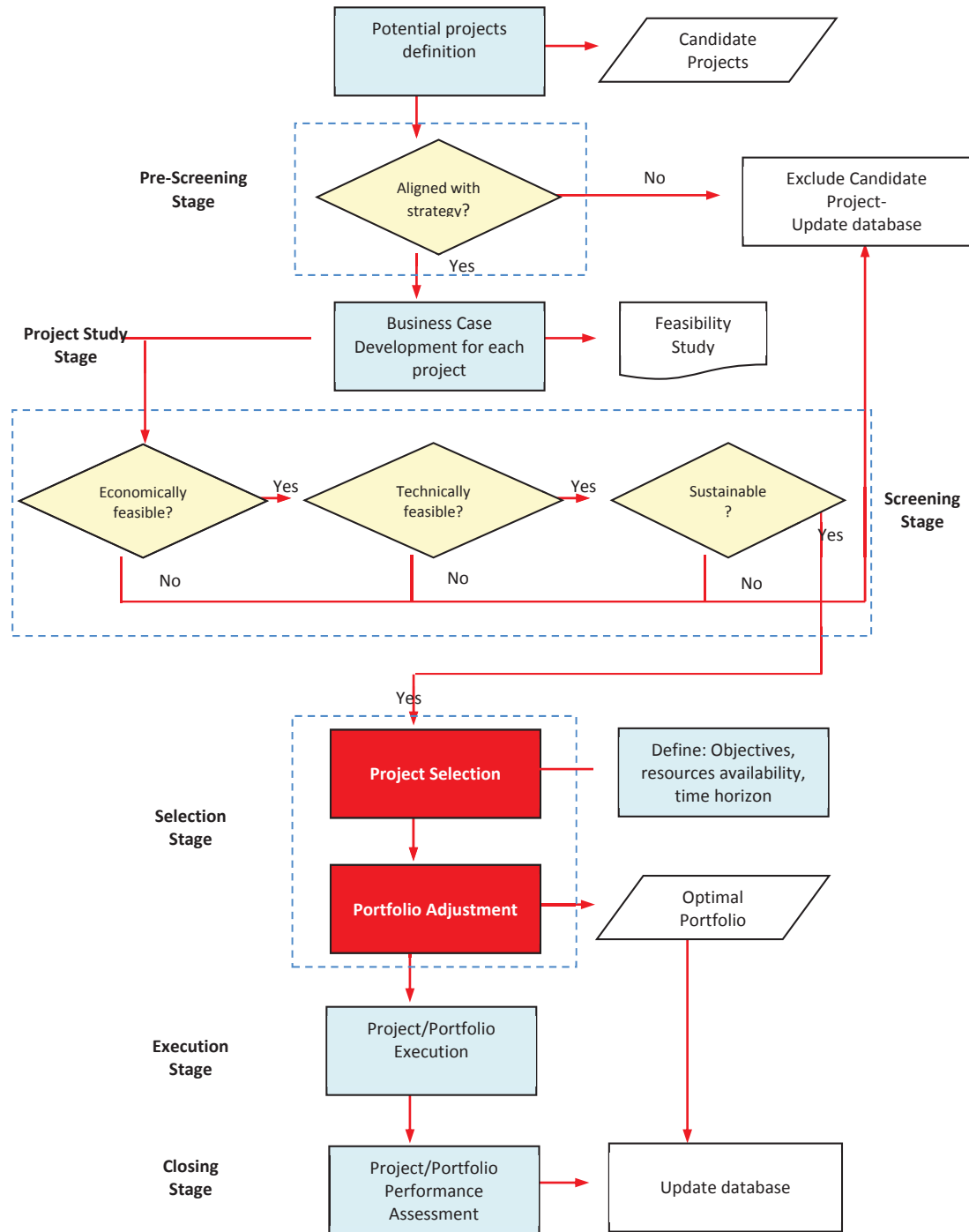
Figure 3.1.Framework for Project Portfolio Selection. Adapted from "An integrated framework for project portfolio selection" by Archer, N., & Ghasemzadeh, F., 1999. International Journal of Project Management, 17(4), 207–216

- Project Study. This stage has as a goal developing a business case of potential projects with the purpose of defining some main attributes of the projects such as NPV, costs, demand of technical and human resources, duration and risk level.

- Screening Stage. This stage considers the assessment of different criteria that are critical success factors for any project and includes economic and technical feasibility and sustainability assessment. The economic evaluation ensures the project is profitable for the organization. Technical feasibility ensures the organization can obtain the technology and resources to undertake the project. The sustainability assessment includes environmental and social impact considerations.

- Selection Stage. This stage has two parts: project selection and portfolio adjustment. The main purpose of this research is designing and implementing a Decision Support System (DSS), based on mathematical programming techniques which find the optimal set of projects that maximize the benefits subjected to customized constraints (technical requirements, resources constraints and interdependence among projects). After an optimal solution is found, the decision making team has the possibility to make adjustments in the final portfolio through a sensitivity analysis (e.g., including or excluding some candidate projects or modifying the constraints).

- Execution Stage. This stage includes the activities required to develop all deliverables of the project according to scope, time and cost approved.

- Closing Stage. This stage should include the assessment of project performance and verification that the goals of the project were met. This stage gives valuable information and learned lessons to the organization for future projects.

3.2   Project Portfolio Selection Model

This research focuses on developing a DSS to assist the decision makers during the selection stage of the project portfolio selection process illustrated in Figure 3.1. The project selection approach is based on mathematical programming and applies two approaches according to the conditions of the problem:

1. 0-1 Integer linear programming (ILP) when the decision maker wants to optimize one goal. For default, in this approach the objective function seeks to maximize NPV, even though is possible to define other criterion of optimization such as throughput or revenue. The corresponding mathematical model was described in Section 2.6.1 of this document.

2. Weighted goal programming (GP) when the decision maker wants to satisfy multiple goals. In this case, the decision maker will define its goals and targets. These objectives should be linked to the strategic goals of the organization. The relative importance of the goals (weights) may be defined by direct assignation in case of one decision maker, or using a technique such as analytical hierarchy process (AHP) or analytical network process (ANP) in the

case of a decision making team. The corresponding mathematical model for this approach was presented in Section 2.6.2 of this document.

The DSS gives the possibility of project selection and scheduling considering the availability of resources in the planning horizon, which results in two possibilities:

1. Project selection assuming all projects are undertaken at the same time and with a defined amount of resources available for project execution. In this case it is considered only one period of time.

2. Project selection considering a planning horizon for project execution and availability of resources according to each period. In this case, the DSS finds the best set of projects and the sequence of execution.

The DSS can incorporate the following kinds of constraints:

1. Available resources of the company to develop the portfolio, including financial resources, manpower, production and logistic resources.

2. Technical requirements such as productivity level, specifications, risks, or environmental requirements.

3. Project interdependence within the portfolio such as contingent projects, mutually exclusive projects, mandatory and ongoing projects.

The complete formulation of the mathematical programming for all these models are summarized in the Table 3.1 to Table 3.4. All the equations were described in sections 2.6.1 and 2.6.2.

Table 3.1

Formulation Project Selection Applying 0-1 ILP Single Period

Item		Equations	Notes
Decision Variables		$X_i = \begin{cases} 1, & \text{if project } i \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$	for $i = 1, …, n$, where n is the total number of projects
Objective Function		$Max\ Z = \sum_{i=1}^{n} c_i X_i$	Z : Criterion to be maximized c_i: Benefit provided by the project i
Constraints			
Resources ($\leq$) Requirements ($\leq, \geq$ or =)		$\sum_{i=1}^{n} a_{ij} X_i \leq b_j$	a_{ij} : Use of resource j by the project i b_j : Availability of the resource j
Inter-dependence	Complementary	$X_j \leq X_i \text{ or } X_j - X_i \leq 0$	if project j is selected, then project i must also be selected, (the opposite is not a condition)
	Exclusive	$X_j + X_i \leq 1$	if project j is selected, then project i cannot be selected
	Mandatory	$X_i = 1$	if project i is mandatory

Note: This formulation is based on the Capital Budgeting Problem described by Chen, Batson and Dang (2010). The Interdependence constraints were developed by Winston and Venkataramanan (2003).

Table 3.2

Formulation Project Selection Applying 0-1 ILP Multiple Periods

Item		Equations	Notes
Decision Variables		$X_{ij} = \begin{cases} 1, if\ project\ i\ is\ selected \\ \quad and\ starts\ in\ period\ j \\ 0, otherwise \end{cases}$	for i = 1, …, n, where n is the total number of projects j = 1, …, t, where t is the total number of periods
Objective Function		$Max\ Z = \sum_{i=1}^{n} \sum_{j=1}^{t} c_i X_{ij}$	Z : Criterion to be maximized c_i: Benefit provided by the project i
Constraints			
Resources ($\leq$) Requirements ($\leq$, $\geq$ or =)		$\sum_{i=1}^{n} \sum_{j=1}^{k} a_{i,k+1-j} X_{ij} \leq b_k$	for k = 1, …, t b_k: cumulated amount of resource available in period k a_{k+1-j}: cumulated amount of resource required by project i in period k.
Inter-dependence	Exclusive	$\sum_{i \in Sp} \sum_{j=1}^{t} X_{ij} \leq 1$	for p = 1, …, P S_p set of mutually exclusive projects
	Complementary	$\sum_{j=1}^{t} X_{ij} \geq \sum_{j=1}^{t} X_{lj}$	for $i \in S_l$ S_l: set of complementary projects for a particular project l
	Mandatory	$\sum_{j=1}^{t} X_{ij} = 1$	for $i \in S_m$ S_m: set of mandatory projects
	Ongoing	$X_{i1} = 1$	for $i \in S_o$ S_o: set of ongoing projects
Flow execution	Starting constraint	$\sum_{j=1}^{t} X_{ij} \leq 1$	for i = 1, …, n Each project, if selected, will be started only once
	Finishing constraint	$\sum_{j=1}^{t} jX_{ij} + d_i \leq t+1$	for i = 1, …, n d_i: duration of project i All projects selected should be finished by the end of period t

Note: This formulation was developed by Ghasemzadeh, Archer, and Iyogun (1999).

Table 3.3

Formulation Project Selection Applying Weighted GP Single Period

Item		Equations	Notes
Decision Variables		$X_i = \begin{cases} 1, & \text{if project } i \text{ is selected} \\ 0, & \text{otherwise} \end{cases}$	for $i = 1, ..., n$, where n is the total number of projects
Objective Function		$Min\ Z = \sum_{p=1}^{m} \left(\frac{W_p \times S_p}{Q_p} \right)$ $Sp = \begin{cases} Se_p \text{ if goal } j \text{ is a min } (\leq) \\ Su_p \text{ if goal } j \text{ is max } (\geq) \end{cases}$	Z : total deviation of the any project set from the goals Q_p :normalization const. of pth goal S_p :deviation of the pth goal
Constraints			
Goal Constraints		$\sum_{i=1}^{n} c_{pi} X_i + Su_p - Se_p = g_p$	C_{pi} : contribution to the pth goal by the project i g_p : target of goal p
Resources ($\leq$) Requirements ($\leq$, $\geq$ or =)		$\sum_{i=1}^{n} a_{iq} X_i \leq b_q$	a_{iq} : Use of resource q by the project i b_q : Availability of the resource q
Inter-dependence	Complementary	$X_j \leq X_i$ or $X_j - X_i \leq 0$	if project j is selected, then project i must also be selected, (the opposite is not a condition)
	Exclusive	$X_j + X_i \leq 1$	if project j is selected, then project i cannot be selected
	Mandatory	$X_i = 1$	if project i is mandatory

Note: This formulation was developed by the author. The Interdependence constraints were developed by Winston and Venkataramanan (2003).

Table 3.4

Formulation Project Selection Applying Weighted GP Multiple Periods

Item		Equations	Notes
Decision Variables		$X_{ij} = \begin{cases} 1, & \text{if project } i \text{ is selected} \\ & \text{and starts in period } j \\ 0, & \text{otherwise} \end{cases}$	for $i = 1, …, n$, where n is the total number of projects $j = 1, …, t$, where t is the total number of periods
Objective Function		$Min\ Z = \sum_{p=1}^{m} \left(\frac{W_p \times S_p}{Q_p} \right)$ $Sp = \begin{cases} Se_p & \text{if goal } j \text{ is a min } (\leq) \\ Su_p & \text{if goal } j \text{ is max } (\geq) \end{cases}$	Z : total deviation of the any project set from the goals Q_p : normalization const. of pth goal S_p : deviation of the pth goal
Constraints			
Goal Constraints		$\sum_{i=1}^{n} c_{pi} \left(\sum_{j=1}^{k} X_{ij} \right) + Sup - Se_p = g_p$	c_{ji} : contribution to the pth goal by the project i g_p : target of goal p
Resources ($\leq$) Requirements ($\leq, \geq$ or $=$)		$\sum_{i=1}^{n} \sum_{j=1}^{k} a_{i,k+1-j} X_{ij} \leq b_k$	for $k = 1, …, t$ b_k: cumulated amount of resource available in period k a_{k+1-j}: cumulated amount of resource required by project i in period k.
Inter-dependence	Exclusive	$\sum_{i \in Sp} \sum_{j=1}^{t} X_{ij} \leq 1$	for $p = 1, …, P$ S_p set of mutually exclusive projects
	Complementary	$\sum_{j=1}^{t} X_{ij} \geq \sum_{j=1}^{t} X_{lj}$	for $i \in S_l$ S_l: set of complementary projects for a particular project l
	Mandatory	$\sum_{j=1}^{t} X_{ij} = 1$	for $i \in S_m$ S_m: set of mandatory projects
	Ongoing	$X_{i1} = 1$	for $i \in S_o$ S_o: set of ongoing projects
Flow execution	Starting constraint	$\sum_{j=1}^{t} X_{ij} \leq 1$	for $i = 1, …, n$ Each project, if selected, will be started only once
	Finishing constraint	$\sum_{j=1}^{t} jX_{ij} + d_i \leq t + 1$	for $i = 1, .., n$ d_i: duration project i All projects selected should be finished by the end of period t

Note: This formulation was developed by the author. The resources constraint, interdependence and flow execution constraints were developed by Ghasemzadeh, Archer, and Iyogun (1999).

Some of the assumptions of the project selection tool are the following:

- All the candidate projects are linked with the organizational strategy. Any candidate project must address at least one strategic goal in order to guarantee that this project adds value to the organization.

- Main attributes of candidate projects are known or can be estimated during the project study stage. This attributes may include financial benefits, project duration, resources (e.g., budget, manpower, facilities) and risks level.

- Some qualitative criteria can be normalized using judgment of experts. This assumption makes it possible to include qualitative criteria that may be relevant.

3.3   Decision Support System

This project designed and implemented a Decision Support System (DSS) for portfolio selection based on the model described in the previous section. A Decision Support System (DSS) is a computer-based system that integrates data and some algorithms to produce information that helps in a decision making process. The proposed DSS included the components shown in Figure 3.2:
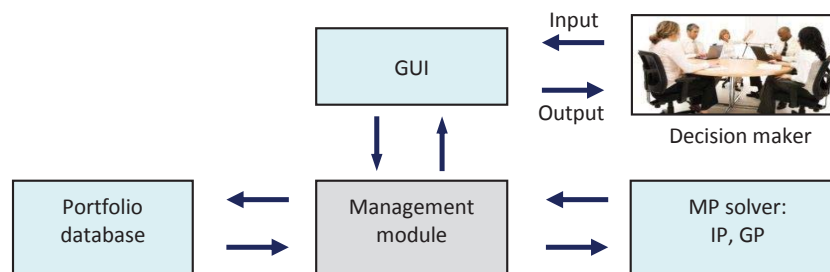
Figure 3.2   Components of a Decision Support System for Project Selection

- Mathematical programming (MP) solver which applies the algorithms to solve the optimization problem.

- Project portfolio database that keeps all the information of the candidate and selected projects.

- Graphical user interface (GUI) that allows the decision maker to interact with the system.

- Management module that addresses the flow of data and information between the different components of the system

The proposed DSS provides the following information to the decision makers:

- The set of projects that maximize the benefit (objective function) meeting all the constraints (one objective problem).

- The set of projects that satisfy the target goals meeting all the constraints (multiple-objective problem).

- Sequence of project execution (scheduling) in case of defining a planning horizon.

The DSS can be customized according to the needs of the organization, policies regarding resources allocation, and portfolio management. This tool does not replace knowledge and experience of experts, but provides insights for the decision making team.

3.4   Modeling Language Selection

As described in section 2.6.3, developing a decision support system requires the

use of a modeling language and solvers. The following commercial software tools were

considered in this research: AIMMS, AMPL, LINGO, MPL and Solver SDK Platform. All

these programming languages have incorporated solvers of last generation for LP, IP

and MIP and are very popular in the academia. The following paragraphs briefly

describe the programming languages considered in this research.

- AIMMS, which stands for "Advanced Interactive Multidimensional Modeling

  System" is an integrated optimization modeling language developed by Paragon

  Decision Technology in 1993. It consists of an algebraic modeling language and

  an integrated development environment for creating optimization models and

  their corresponding graphical user interfaces. AIMMS support a wide range of

  optimization models including linear, nonlinear, mixed Integer, stochastic

  programming and robust optimization. AIMMS incorporates multiple solvers

  including CPLEX, Gurobi, MOSEK and KNITRO. It also facilitates the use of

  external data sources such as spreadsheets, databases, XML and text files

  (Roelofs & Bisschop, 2013).

- AMPL, which stands for "A Mathematical Programming Language" is a powerful

  and one of the most popular modeling languages for linear and nonlinear

  optimization problems, in discrete or continuous variables. AMPL was

  developed by Bell Laboratories in 1985 and supports many solvers, both open

source and commercial, including CPLEX, Gurobi, and KNITRO. AMPL is available

for 32 and 64-bit platforms including Linux, Mac OS X and Windows (Fourer, Gay,

& Kernighan, 2003).

- LINGO is a Fortran-based optimization software designed by LINDO Systems, Inc.

  in 1988. LINGO incorporates a presolver for model reformulation and all the

  solvers (linear, integer, nonlinear, etc) are linked to its modeling environment in

  such a way that LINGO automatically sends the model to the most suitable

  solver. LINGO solves the LP problems using any variation of simplex algorithm

  and IP problems using branch and bound algorithm. LINGO supports Windows

  and UNIX and allows interfacing with some of the most used programming

  languages such as Visual Basic, C/C++, Fortran and Visual Java (Chen, Batson &

  Dang, 2010).

- MPL, which stands for "Mathematical Programming Language", is produced by

  Maximal Software, Inc. MPL can be used with many commercial and open

  source solvers. MPL has a friendly graphical user interface in Windows and offers

  an easy coding syntax similar to the algebraic language used in problem

  formulation. Besides Windows, MPL supports UNIX and have a good interface

  with spreadsheets and databases (Chen, Batson & Dang, 2010).

- Solver SDK Platform is a comprehensive software development kit created by

  Frontline Solvers, the developers of the Excel Solver add-in application, and

  allows creating custom applications for optimization and Monte Carlo simulation

using languages such as Visual basic, C/C++, Java and Matlab. Solver SDK

supports Windows and Linux and allows integration with other Windows

applications such as Microsoft Excel.

Table 3.5 describes the most relevant criteria considered by the author for

selecting the programming language. The criteria considered are the following:

- Software type: This criterion makes reference to whether the programming

    language is integrated with solvers or not. It is more convenient have a

    programming language that is integrated with solvers.

- Platform: Operating system that supports the programming language. It is

    desirable that the software can run under windows because this is a broadly

    used operating system.

- Academic License: This criterion refers to the cost of the license for academic

    purposes.

- Data compatibility: capacity of import and export data from different sources. It

    is desirable that the software has at least the capacity of importing and

    exporting data to Excel because many companies use spreadsheets to storage

    and analyze data.

- Variable types: This criterion refers to the nature of the variables that the

    software can handle. The problems related to project selection correspond to

    Integer Linear Programming (ILP) and Mixed Integer Linear Programming (MILP),

therefore, it is necessary that the software has the capacity to manage continuous, integer and binary variables.

- Algorithm: Types of algorithms included in the software. For ILP and MILP problems, it is necessary the software include Branch and Cut algorithm.

- Development time: Estimated time for developing an application from the definition of variables and parameters to the design of the end-user interface. Programming platforms with an integrated development environment include modeling language, solver, communication with another applications and tools for development of end-user application. These features could dramatically reduce the development time compared to software in which the programming environment is not integrated.

Table 3.5

Modeling Languages Comparative Chart

Criteria	AIMMS	AMPL	LINGO	MPL	Solver
Software Type	Integrated Modeling+Solver	Modeling	Integrated Modeling+Solver	Integrated Modeling+Solver	Integrated Modeling+Solver
Platform	Windows, Linux	Windows, Linux, Mac OS	Windows, Linux	Windows, Linux, Mac OS	Windows, Linux
Academic Lincense	Free	US$ 400	Free	Free	Free
Data Compatibility	Spreadsheet, Database, Text	Spreadsheet, Database, Text	Text	Spreadsheet, Database, Text	Spreadsheet, Database, Text
Variable Types	Integer, Binary, Continuous, Stochastic, Adjustable	Integer, Binary, Continuous	Integer, Binary, Continuous	Integer, Binary, Continuous, Stochastic	Integer, Binary, Continuous
Algorithm	Simplex, Interior point, Branch-and-Cut	Simplex, Interior point, Branch-and-Cut, Heuristic	Simplex, Interior point, Branch-and-Cut, Heuristic	Simplex, Interior point, Branch-and-Cut, Heuristic	Simplex, Interior point, Branch-and-Cut, Heuristic
Development Time	Low	High	High	Low	Medium

After review the features of all of this platforms, AIMMS was chosen for this research due to the following reasons:

1. AIMMS is an optimization development environment which offers the state of the art in algorithms, solvers and connectivity with external data and applications. The last update of AIMMS is 3.13 released in 2013.

2. AIMMS modeling language includes a powerful combination of multidimensional definitions and procedural execution and a rich set of mathematical, statistical and financial functions.

3. AIMMS includes modeling language, preprocessor, world class solvers (e.g., CPLEX, Gurobi and CONOPT) and a tool for constructing a custom graphical user interface (GUI) for a particular application.

4. AIMMS can deal with many kinds of optimization problems including linear programming (LP), integer programming (IP), mixed integer programming (MIP), quadratic programming (QP), nonlinear programming (NLP), stochastic programming and robust optimization.

5. AIMMS academic version is free and totally functional.

6. Paragon technology has many information resources about AIMMS including manuals, tutorials, examples and online workshops.

7. AIMMS offers connectivity with external data, spreadsheets and databases using ODBC or OLE DB.

8. AIMMS support linkages to other applications using Application

   Programming Interface (API) as well as Component Object Model (COM)

   interface.

9. Finally, the development time in AIMMS could be less than the time required

   in other platforms because AIMMS is an integrated development software

   which includes a graphical programming environment with many toolbars

   that facilitate the coding and debugging process, the communication with

   other software (spreadsheet and database) and the development of the end-

   user interface.

AIMMS include solvers for Linear Programming (LP), Mixed Integer Programming
(MIP), Nonlinear Programming (NLP), Quadratic Programming (QP), Quadratically
Constrained Programming (QCP), Mixed Integer Quadratic Programming (MIQP), Mixed
Integer Quadratically Constrained Programming (MIQCP), Mixed Complementary
Problems (MCP), Mathematical Programs with Complementarity Constraints (MPCC)
and Mixed Integer Nonlinear Programming (MINLP). The Figure 3.3 shows a screenshot
of the AIMMS solver configuration, which indicates the solvers included and the type of
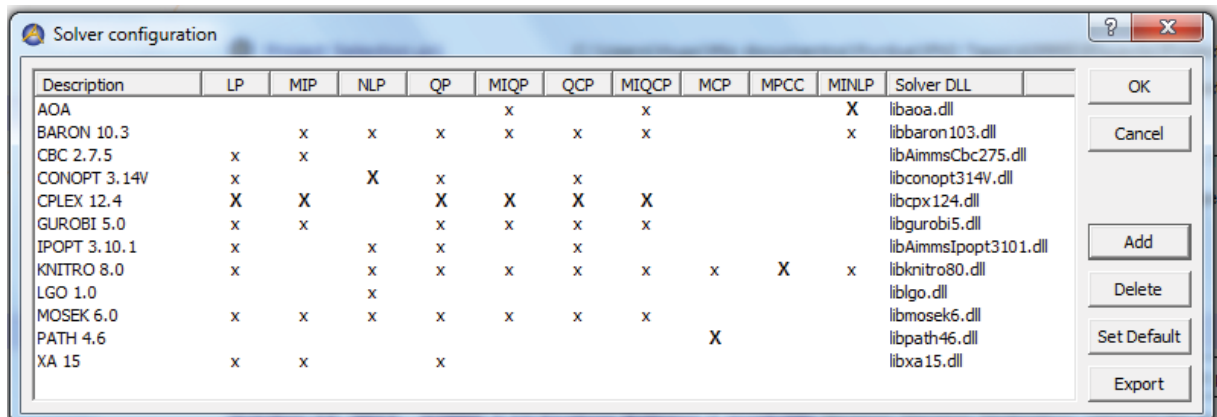associated problems.

Figure 3.3. Screenshot of the Solver Configuration Page in AIMMS

The project portfolio selection problem corresponds to a Mixed Integer Programming Problem, for these types of problems, AIMMS uses by default CPLEX as solver. The other options are BARON, CBC, Gurobi, MOSEK and XA. The programmer can select the solver to be used by AIMMS.

3.5   DSS Development

The development of the computational tool for project portfolio selection required the following steps:

1. Definition of the problem. The needs and requirements of the decision makers were studied by analyzing the type of criteria considered, objectives, constraints, assumptions and the kind of information required as output to support the decision making process.

2. Model construction (mathematical model). This step translates the real world problem and creates (or select) a mathematical formulation that includes

functions, equations and inequalities that describe the objective function and constraints. This step also verifies that all the assumptions for Mixed Integer Programming (MIP) are satisfied. These assumptions are described in Chen, Batson and Dang (2010) and summarized as follows:

- Divisibility: All continuous variables are real numbers.

- Integrality: All integer variables are integer or binary (0 or 1) numbers.

- Certainty: All the parameters can be estimated and are constant

- Proportionality: All objective functions and constraints are linear

- Additivity: all objective functions and constraints can be expressed as a sum of several functions, each of them containing a single variable.

- Single-objective: All problems can be expressed as a single-objective function, including the goal programming case with multiple goals.

- Simultaneousness: Any feasible solution must satisfy simultaneously all the constraints.

3. Model coding. This step translates the mathematical formulation in a computational code using the programming language AIMMS. This step includes the following:

- Definition of the set of decision variables and parameters with its attributes.

- Definition of the objective function and the objective variable according to the formulations shown in Tables 3.1 to 3.4

- Definition of all the constraints with inequalities corresponding to the formulations shown in Tables 3.1 to 3.4

- Assembly of each type of mathematical programing (MP) considered in the DSS. Each MP definition includes the objective variable, direction of optimization (minimization of maximization) the set of decision variables, the set of constraints and the solver to be used.

4. Development of Graphical User Interface (GUI). The GUI makes possible the interaction of the end user with the DSS. The GUI considered input pages, where the user can specify the data for the problem configuration, candidate projects, objectives and constraints. The output pages show the solution of the problem including information of the optimal portfolio, the objectives and the constraints.

5. Creation of Reports. This step comprises the design of printable page templates that contain all the relevant information of the solution.

6. Integration with Excel. In this step, the interfaces required to import and export data to Excel are developed.

After the development process, the verification and validation process was undertaken in order to ensure the DSS is running free of errors and producing an accurate solution for each problem. The verification and validation processes are shown in the following section.

3.6 DSS Verification and Validation

The development of any DSS needs a verification and validation process that guarantee the model and its implementation in a software platform are reliable. The usefulness of a DSS is based on the confidence the tool offers to the modeler and the potential user provided by a verification and validation process. This section describes the verification and validation process employed by the author during the development of the DSS for Project Portfolio Selection.

3.6.1 DSS Verification

Verification is the process that ensures the model behaves as intended (Kelton, Sadowski & Swets, 2010). In the context of software development, verification is normally called debugging. In a logical order, verification precedes the validation process.

Verification deals with problems regarding model formulation, logical and programing errors. These errors can cause infeasible solutions or unexpected results. Inefficiently formulated statements can also cause excessively high execution times. The verification process is usually carried out simultaneously with the coding process, so after each piece of code is introduced in the main program, the proper operation is verified in each running test. Some problems can be easy to find and another ones not-so-obvious. AIMMS, the software platform chosen by the author, offers some tools for the verification process as follows:

- The AIMMS debugger helps in finding the location of the source of error in declaration of variables, constraints or statement in procedures in the model.

- The AIMMS profiler helps to solve computational time issues locating the most time consuming process.

The author conducted a verification process while the elements of the mathematical programming were integrated to the model using the AIMMS debugger. A performance check was also done by monitoring the execution time during the validation test using the AIMMS profiler.

3.6.2   DSS Validation

After the model is free of logical and programming errors and the execution time is reasonable for a determined problem size (number of decision variables and constraints), a validation is conducted. According Robinson (2008) a "valid model is sufficiently accurate for the purpose at hand". In this case, the DSS should accurately find the best solution, which is the optimal portfolio, considering the variables, parameters and constraints defined by the user.

In order to validate the DSS, the logical procedure is solving a problem whose solution can be known for other method and compare the answers. The author uses a basic problem with some variations, with the purpose of testing the functionality of the DSS with one and multiples goals, different resources or requirements constraints and projects interdependence relationship.

For the validation process, a basic problem proposed by Winston and Venkataramanan (2003) was adapted as shown below:

A small aerospace company is considering eight projects for the portfolio. These projects are described below.

- Project 1: Develop an automated test facility

- Project 2: Barcode all company inventory and machinery

- Project 3: Introduce a CAD/CAM system

- Project 4: Buy a new lathe and deburring system

- Project 5: Institute FMS (flexible manufacturing system)

- Project 6: Install a LAN (local area network)

- Project 7: Develop AIS (artificial intelligence simulation)

- Project 8: Set up a TQM (total quality management)

Each project has been rated on five attributes: ROI, cost, productivity improvement, worker requirements, and degree of technological risk. These ratings are given in the table below

Goals	Proj 1	Proj 2	Proj 3	Proj 4	Proj 5	Proj 6	Proj 7	Proj 8
ROI ($)	2,070	456	670	350	495	380	1,500	480
Cost ($)	900	240	335	700	410	190	500	160
Productivity	3	2	2	0	1	0	3	2
People	18	18	27	36	42	6	48	24
Risks	3	2	4	1	1	0	2	3

The company has set the following five goals (listed in order of priority):

- Goal 1: Achieve a ROI of at least $3,250

- Goal 2: Limit cost to $1,300

- Goal 3: Achieve a productivity improvement of at least 6

- Goal 4: Limit manpower use to 108

- Goal 5: Limit technological risk to a total of 4. (pg. 201)

Variations of this basic problem were used, creating 28 versions for validation purpose of the DSS. These experiments are described in the following paragraphs.

3.6.2.1   DSS Validation Experimental Design

Proper performance of the DSS can be validated comparing the optimal solution found by the DSS with the best portfolio found through systematic enumeration of all feasible solutions in a Microsoft Excel spreadsheet. The number of possible solutions (portfolios) that can be generated with n candidate projects is described by:

$$\sum_{i=1}^{n} \frac{n!}{i!(n-i)!} = 2^n - 1$$

(33)

Where n is the total number of candidate projects

With $n=8$ candidate projects, we have $S=2^{10}-1=255$ portfolio configurations. Naturally, the constraints will decrease the number of feasible solutions for each

problem. Using Excel filters, its relatively easy find the best portfolio that meets the

constraints, providing a reliable solution to compare with the solution produced by the

DSS.

In order to validate the accuracy of the DSS and evaluate their functionality it is

necessary make multiple tests under different problem configuration such as number of

goals, kind of constraints, and interdependence of projects. The author developed a

series of validation tests with variations of the basic problem with one objective and

multiple goals. These tests are described below.

3.6.2.1.1   DSS Validation with one objective

The validation tests for the case with one objective considered the following

variants:

- Direction of optimization: Maximization and minimization objective

- Constraints: Resource constraint ($\leq$) and requirement constraint ($\geq$)

- Project Interdependence: Mandatory, mutually exclusive and dependent

  projects

Table 3.6 shows the first 14 experiments with some variations of the base

problem (shown in section 3.5.2) considering the elements described above. For

example, the objective of Test 5 is maximizing NPV, limiting total cost to $1,300 with a

couple of mutually exclusive projects.

Table 3.6

DSS Validation Tests: One Objective Problem

Test	Objectives			Constraint			Constraint Interdependence		
	Goals	Direction	Objective	Constraint	Direction	Target	Mandatory	Exclusive	Dependent
Test 1	1	Max	NPV	Cost	≤	1,300			
Test 2	1	Max	NPV	Cost	≤	1,300	x		
Test 3	1	Max	NPV	Cost	≤	1,300		x	
Test 4	1	Max	NPV	Cost	≤	1,300			x
Test 5	1	Max	NPV	Cost	≤	1,300		x	x
Test 6	1	Max	NPV	Cost	≤	1,300	x		x
Test 7	1	Max	NPV	Cost	≤	1,300	x	x	x
Test 8	1	Min	Cost	NPV	≥	3,250			
Test 9	1	Min	Cost	NPV	≥	3,250	x		
Test 10	1	Min	Cost	NPV	≥	3,250		x	
Test 11	1	Min	Cost	NPV	≥	3,250			x
Test 12	1	Min	Cost	NPV	≥	3,250		x	x
Test 13	1	Min	Cost	NPV	≥	3,250	x		x
Test 14	1	Min	Cost	NPV	≥	3,250	x	x	x

3.6.2.1.2   DSS Validation with multiple goals

The validation tests for the case with multiple goals considered the following:

- 2 Goals: NPV (70%) and cost or manpower (30%)

- Constraints: Manpower or cost (≤)

- Project Interdependence: Mandatory, mutually exclusive and dependent

   projects

Table 3.7 shows the first 14 experiments with some variations of the base

problem (shown in section 3.5.2) considering the elements described above. For

example, the goals of Test 23 are to achieve a NPV of at least $3,250 (70%) and to limit

cost to $1,300 (30%), limiting manpower use to 108 persons and including a mandatory

project.

Table 3.7

DSS Validation Tests: Multiple Goals Problems

Test	#	Goals						Constraint			Constraint Interdependence		
		Goal 1	Weight	Target	Goal 2	Weight	Target	Constraint	Direction	Target	Mandatory	Exclusive	Dependent
Test 15	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300			
Test 16	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300	x		
Test 17	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300		x	
Test 18	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300			x
Test 19	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300		x	x
Test 20	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300	x		x
Test 21	2	NPV	70%	3,250	Manpower	30%	108	Cost	≤	1,300	x	x	x
Test 22	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108			
Test 23	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108	x		
Test 24	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108		x	
Test 25	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108			x
Test 26	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108		x	x
Test 27	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108	x		x
Test 28	2	NPV	70%	3,250	Cost	30%	1,300	Manpower	≤	108	x	x	x

The definition of which projects should be mandatory, mutually exclusive and dependent are shown in chapter 4. The selection of these conditions depends on the solution of the base-line problem, which is the problem without any interdependent constraints.

3.6.2.2   Model Verification and Validation Analysis

The verification of the model included the requirement of running free of logical and programming error at solving time suitable for the number of variables considered. The validation of the model and the effectiveness of the DSS was tested with the requirement of finding the optimal solution for project portfolios under different problem configurations. The DSS should be able to find the optimal solution in 100% of the cases. The results of the verification and validation process are shown in Chapter 4.

3.7   Case Study: Project Portfolio Selection in Cementos Argos - Metodology

This research includes the application of the DSS in a case of project selection in Cementos Argos. The purpose of this case study is to evaluate the performance of the DSS with real data, the information that the tool can provide for decision making and explore the type of analysis that can be done. This case study have two parts as follows:

1. Project Portfolio Selection in Cementos Argos, 2006. In 2006, the company evaluated 17 candidate projects for its portfolio using a weighted scoring model based on financial criteria (NPV, IRR, PI and Payback). This case study is a retrospective analysis which evaluated the potential improvement in the quality of the proposed portfolio found using the DSS based on optimization vs. the portfolio defined using the scoring model. A sensitivity analysis for the optimal portfolios for different levels of budget constraint is included.

2. Project Portfolio Selection in Cementos Argos, 2014. In 2014, the company considered 102 candidate projects for its portfolio. This case study is a prospective analysis which found the best portfolio using the DSS considering two approaches, the first is a global optimization considering all the projects compete for the resources (budget constraint) vs a local optimization where the projects compete for the resources in each regional division (the Caribbean, USA and Colombia). The analysis shows the difference in terms of the distribution of the portfolio per region, total benefit (NPN) and total cost of investment.

The development of the case study, results and analysis are shown in Chapter 4 of this document.

3.8   Discussion

The project portfolio selection is basically a decision making process that should be reasonable, accurate and unbiased. The selection problem may be complex when the portfolio managers and top managers should considerer many candidate projects, selection criteria, resources constraints and requirements. A DSS based on optimization should have capacity and flexibility to find the best portfolio considering all this elements.

The process of develop a DSS follows a general Operation Research modeling process which comprises the following steps: review of the real world problem, formulation of a mathematical model for the problem, coding of the model in a programming language, verification or debugging process, validation of the computational tool and, finally, the deployment of the DSS in the organization. An important part of the process was the interaction with potential users (portfolio managers and top managers) to define their information needs for making decisions regarding the project selection process. The interaction with the potential users during the deployment of the application was also important. Tests with real data and the development of case studies as the case shown in this document allowed to make adjustments to the tool and engage the potential users with the use of the tool.

3.9 <u>Summary</u>

This chapter has provided an overview of a framework for project selection, a summary of the formulation of the model based on mathematical programming, a description of the components of the DSS and the description of the verification and validation process. The results of the verification and validation and a case study of project portfolio selection in Cementos Argos are discussed in detail in chapter 4.

CHAPTER 4.   DEVELOPING OF A DECISION SUPPORT SYSTEM FOR PROJECT PORTFOLIO
SELECCTION-ARGOS CASE STUDY

This chapter presents a summary of architecture, execution flow and

functionality of the DSS for portfolio project selection included in the scope of this

research, the verification and validation process and results, and a case study of

Cementos Argos. This Case Study includes a portfolio selection process with historical

data of 2006 compared with the standard selection method employed by the company

and an application of project selection for 2015 projects.

4.1   Decision Support System for Project Portfolio Selection (DSS)

The main purpose of a Decision Support System is to provide insights that allow

decision makers to analyze the best alternatives and reduce the risk associated in a

decision making process. A DSS for project portfolio selection provides the portfolio that

adds more value to the organization.

This section describes the design features considered for the development of the

project portfolio selection tool, the architecture of the DSS and the functionality

indicating its capabilities.

4.1.1 DSS Design Features

The following design features were considered during the development of the Project Portfolio Selection tool:

- Simplicity. In most organizations the project portfolio selection process is developed for a decision making team involving project managers and top management, however these persons usually are not familiar with operations research and optimization techniques. This DSS should guide the user during the mathematical programming formulation, solution and analysis of results. The process should be straightforward and error-free for the user.

- User friendly. A simple and intuitive Graphical User Interface (GUI) in a windows environment can makes easier the flow of information between user and DSS for data input and data output. The representation of the results in graphical mode using charts like bubble charts and Gantt charts, helps to draw conclusions about the suggested project portfolios. AIMMS, the programming language selected, allows the development of a GUI in the same programing environment avoiding the necessity of using a different developing software for the GUI.

- Flexibility. The developed DSS for project selection should be flexible enough to be used in diverse organizations with different strategic objectives, categories of projects, resources constraints, requirements and policies regarding the assignment of resources for capital projects. This flexibility was achieved separating the data from the application using multidimensional sets, symbolic

parameters, indexed variables and constraints and control flow commands. The user can configure the selection problem: one or multiple objectives, single or multiple periods, resource constraints, requirements, and project interdependence.

- Connectivity. When the amount of data in a project selection case is large, besides the capability of input data through the GUI, the tool should be able to import data from spreadsheets, text files or databases. In the same way, transfer the solution to a spreadsheet or database for further analysis and data storage is important. The developed tool should read data from and write the results to Microsoft Excel Spreadsheets. Besides, for future development, it is possible to read and write data with Open Database Connectivity (ODBC) and Object Linking and Embedding for Databases (OLE DB) compliant databases such as Microsoft Access, Microsoft SQL Server and Oracle.

- Scalability. A DSS should be developed considering future expansions of functionality. This scalability is achieved with a modular architecture of the code that makes possible the integration with future components. For example, the constraint equations are grouped in a set, and it is possible to add new constraints to the set to consider in the problem formulation. The developed DSS can incorporate new project categories, types of constraints, and even stochastic parameters and variables.

4.1.2   DSS Architecture

The DSS developed in this thesis, is a software that integrates components in order to solve four kind of mathematical problems (MP) regarding project portfolio selection. The DSS has a modular architecture that integrates common elements (for example, the project input module) with certain elements according to the kind of problems to solve. The general architecture is shown in Figure 4.1 and its main components are described in the following sections.

4.1.2.1   <u>Configuration Module</u>

This module allows the user to define the project selection problem to solve, including the number of objectives (one or multiple), and the number of periods (single or multiple). This options leads to one of the four kinds of problem formulation.

- Project portfolio selection with one objective and single time period. The mathematical programing model corresponds to 0-1 Integer Linear Programming and the mathematical formulation was summarized in the Table 3.1. In this case the decision variables, objective function, and constraints do not consider the time horizon.

- Project portfolio selection with one objective and multiple time periods. The mathematical programing model corresponds to a 0-1 Integer Linear Programming and the formulation was summarized in the Table 3.2. In this case the decision variables, objective function and constraints consider the time

horizon in order to find execution sequence of the selected projects (portfolio roadmap).

- Project portfolio selection with multiple goals and a single time period. The mathematical programing model corresponds to Weighted Goal Programming and the mathematical formulation was summarized in the Table 3.3. In this case the decision variables, objective function and constraints do not consider the time horizon.

- Project portfolio selection with multiple goals and multiple time periods. The mathematical programing model corresponds to Weighted Goal Programming and the mathematical formulation was summarized in the Table 3.4. In this case the decision variables, objective function and constraints consider the time horizon in order to find an execution sequence of the selected projects (portfolio roadmap).

4.1.2.2   Data Input Module

This module includes all the screens that allow the reception of data from the user as follows:

- Candidate projects. Relevant information in this section includes the number of candidate projects, NPV, cost, risk, duration, and two project categories that can be customized. Additional criteria can be included. This module allows importing

data from an Excel spreadsheet, which is helpful when the number of candidate projects is large.

- Objectives/Goals. This section includes the definition of objectives and direction of the optimization (maximization or minimization) for one objective. In the case of multiple goals, the relevant information comprises the criteria, weights and targets. The direction in this case is always minimizing the total deviation of the goals.

- Constraints. This section allows the user to define constraints. The relevant information consists of the defined criteria as resource or requirement, the directions ($\geq$ or $\leq$) and the thresholds or limits for the constraints.

- Project Interdependence. This section allows the user to set some relationship between candidate projects. Some projects can be mandatory, so they should be included in the recommended portfolio. Others can form groups of mutually exclusive projects and finally some projects can be dependent on others.

4.1.2.3   Mathematical Program Generator

This module assembles the mathematical program (MP) including the main elements in its formulation: decision variables set, objective function with its direction and the constraints set. The MP generator translates the algebraic language of the formulation in a computer language and integrates it with user data.
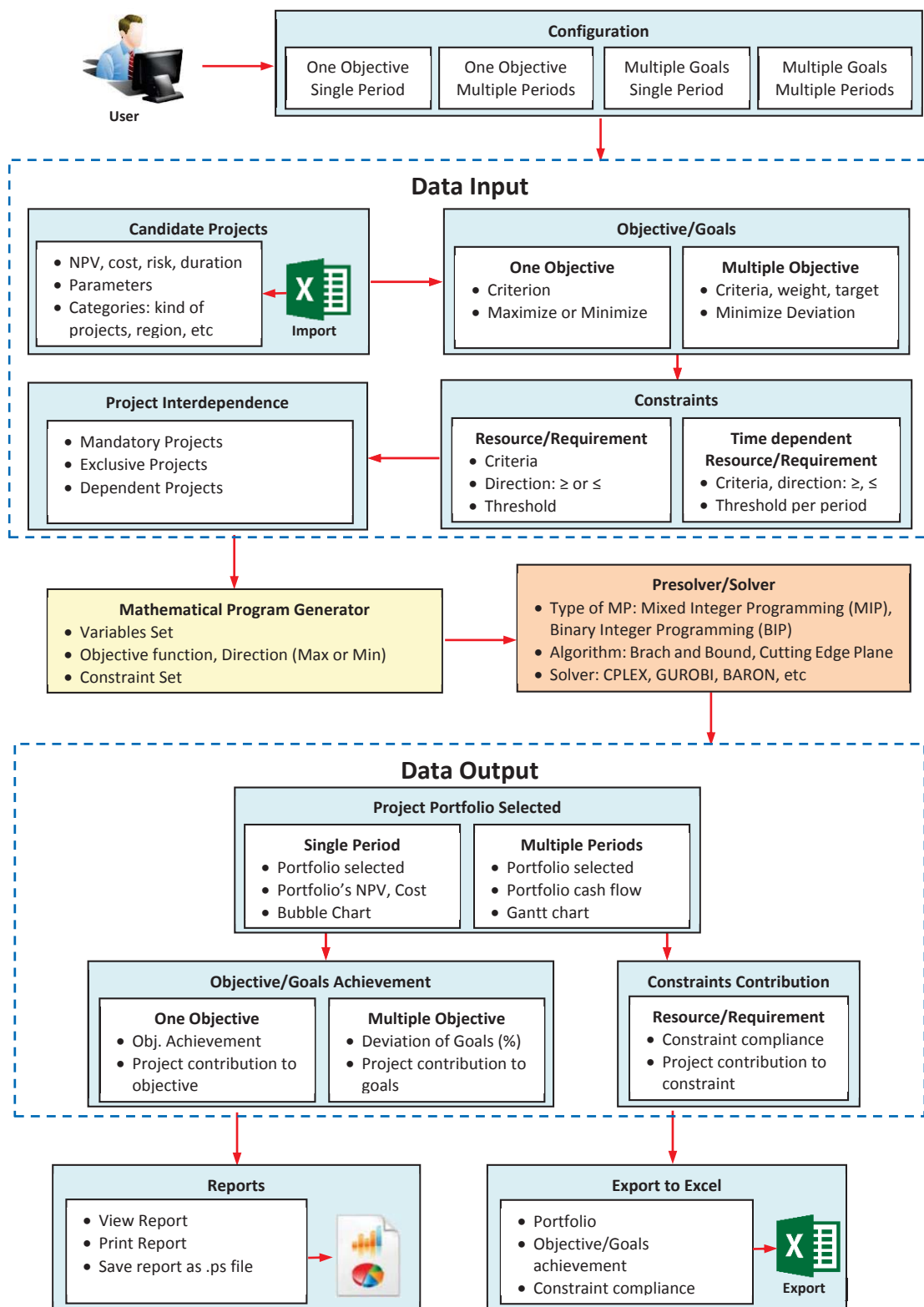
Figure 4.1 . Architecture of the DSS for Project Portfolio Selection

4.1.2.4   Presolver/Solver

AIMMS, as a modern algebraic modeling language, includes a presolver which applies techniques to the original formulation with the purpose of get a formulation easier to solve. Once the formulation is processed, the solver receives the model and a specific set of data (instance of the problem), applies an algorithm and returns the optimal solution. In the case of the DSS for project selection, the problem corresponds to a pure binary integer programming (BIP) for one objective problem and mixed integer programming (MIP) for multiple goals problem. AIMMS automatically selects the solver that can solve these kinds of problems by applying an appropriate algorithm (branch and bound, cutting edge plane, etc). AIMMS by default uses CPLEX, developed by IBM, for this type of problems.

4.1.2.5   Data Output Module

This module includes all the screens that allow to display the solution of the MP including the following elements:

- Portfolio. The relevant information in this section includes the number of selected projects and the total NPV, portfolio cost. A bubble chart depicts the selected projects. In the case of a problem with multiple periods, a page shows a Gantt chart with the portfolio roadmap in the planning horizon and the portfolio cash flow in case cost is a time dependent constraint.

- Objective/Goals Achievement. This section includes the optimal value of the objective and the contribution of each project to this objective. In the case of multiple goals, the weighted deviation of the goals (%), the estimated achievement of each goal vs the target and the contribution of each project in the portfolio to each goal.

- Constraints. This section includes the expected value of each constraint vs the threshold and the contribution of each project to each constraint.

4.1.2.6   Reports Module

This module allows the user to view, print and save (as a .ps file) the report showing the solution information. The report includes the same information shown in the data Output Module.

4.1.2.7   Export to Excel Module

This module allows exporting the results to an Excel spreadsheet. This is a very useful feature for further information processing and analysis.

4.1.3   DSS Functionality

In the design of the DSS, the author considered elements in the formulation that make possible to find the best project portfolio in diversity cases and problem configurations. The functionality of the Decision Support System for project selection is

determined by the formulation employed, the parameters, variables and constraints.

Table 4.1 shows the main functionality features of the DSS designed by the author. A

tutorial for the use of the computational tool is included in the Appendix.

Table 4.1

Functionality of the DSS for Project Portfolio Selection

Category	Element	Features
INPUT		
Projects	Candidate projects	n candidate projects 2 customizable projects categories
Objective/Goals	One Objective	Maximization/Minimization
	Multiple Goals	Minimization deviation to targets
Constraints	Resources	Any resource (Constraint type ≤)
	Requirements	Any requirement (Constraint type ≤ or ≥)
	Mandatory Projects	Set of k mandatory projects
	Mutually exclusive Projects	l Sets of mutually exclusive projects
	Dependent Projects	m tuple of dependent projects
	Time dependent resources	Any resource dependent on time (Constraint type ≤)
OUTPUT		
Portfolio	Selected projects	Portfolio NPV, Cost, Risk Bubble chart
	Portfolio Roadmap	Gantt chart, cash flow
Objective/Goals	Objective optimization	Objective achievement Project contribution to objective
	Goal satisfying	% deviation of the goals Goals achievement Project contribution to goal
Constraint	Resource	Resource consumption Project´s resource consumption
	Requirements	Requirements achievement Project contribution to requirement
REPORTS/CONNECTIVITY		
Reports	Solution Reports	View, Save and Print Report
Connectivity to spreadsheet	Excel input	Project data input
	Excel output	Portfolio, objectives and constraint information

4.2   DSS Verification and Validation Results
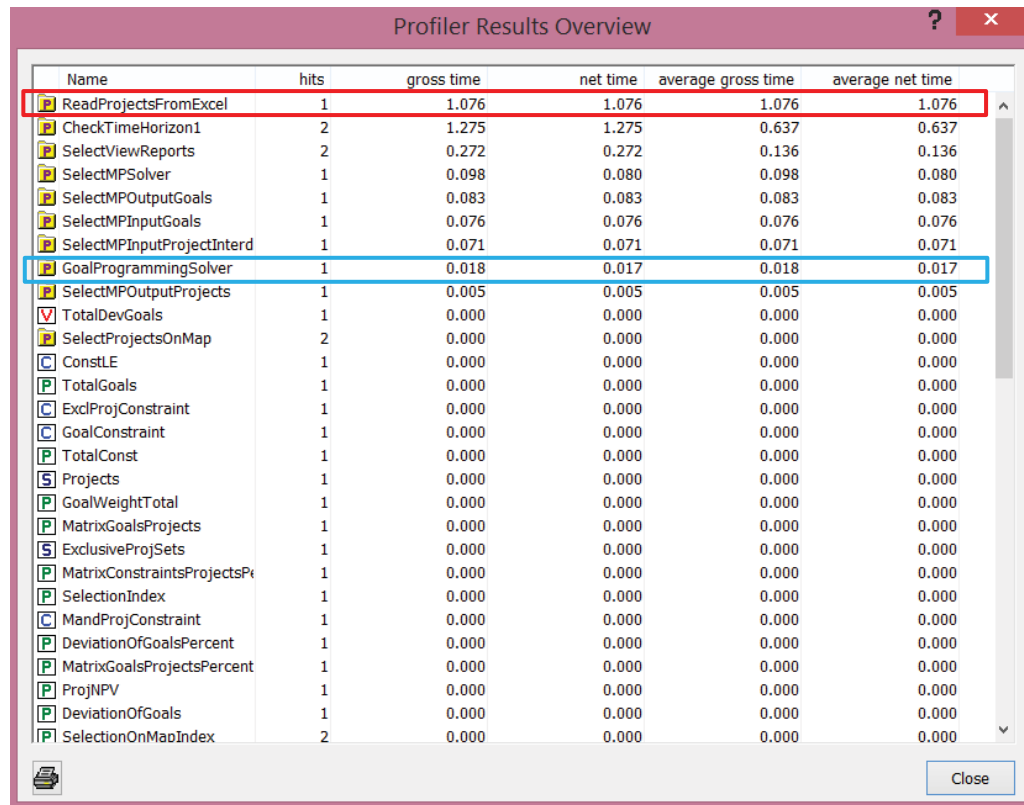
The following section contains an abbreviated summary of the verification and

validation test results of the DSS for Project Portfolio Selection. This section ends with a

results analysis.

4.2.1   DSS Verification Results

During the coding in AIMMS for the different formulations considered in the

Project Portfolio Selection process, the AIMMS debugger was used to find the location

of the source of errors in declaration of variables, constraints and statement in

procedures in the model. At the end of the verification and debugging process, the DSS

was free of errors and running flawless. The verification finished checking the execution

time of the procedures and statements included in the code. AIMMS profiler helps to

check computational time issues locating the most time consuming processes. If the

total execution time was unacceptably high, it could have been caused by the time

required by the solver to find the solution or by data manipulation statements.

Figure 4.2 shows a screenshot of the AIMMS Profiler Results Overview dialog box

after running the validation Test 28 (see Table 3.7) with the problem described in

section 3.5.2. In this example, Test 28 has as first goal to achieve a NPV of at least

$3,250 (weight 70%), and as second goal to limit cost to $1,300 (weight 30%). As a hard

constraint, the total manpower use should be less than or equal to 108, project 2 is

mandatory, projects 6 and 7 are mutually exclusive, and finally, if project 1 is selected,

project 5 must be selected too.

Figure 4.2. AIMMS Profiler Results Overview Screenshot after the Validation Test 28

Figure 4.3. AIMMS Progress Window Screenshot after the Validation Test 28

Figure 4.3 shows the AIMMS Progress window and the end of the solution of

Test 28. According to AIMMS profiler, the procedure consuming the most time was to

import data from Excel, whit is approximately 1 second (red rectangle in Figure 4.2). On

the other hand, the time used by CPLEX, the solver used in this case, was only 0.018

seconds (blue rectangle in Figure 4.2), requiring 25 iterations to find the optimal

solution with a memory use of 78.5 Mb of 4096 Mb available. This seems to be a pretty

good performance, so the DSS had a reasonable execution time in this problem.

4.2.2   DSS Validation

The validation of the DSS was accomplished according to the procedure

presented in section 3.5.2. A total of 28 tests were developed based on variations of the

base problem described in the same section. The following sections describe the

execution of the test labeled "Test1" and summarize the results of all validation tests.

4.2.2.1   DSS Validation Test example

The validation test procedure is shown in this section using as example Test 1

that corresponds to the basic problem with one objective as shown in Table 3.6. The

objective of Test 1 was to maximize NPV, limiting total cost to $1,300 and it does not

include any project interdependence constraints. Figure 4.4 shows the screenshot with

the Configuration Page in the DSS. In this page, the options "One Objective" and "One

Period" are selected, and all the criteria considered in the original problem are included.

Figure 4.4. Screenshot of the Configuration Page for Test 1

After the test was configured, data of the candidate projects, objectives and constraints were introduced. Figure 4.5 shows the screenshot of the Projects Input page for Test 1. The data was imported from the spreadsheet shown in Figure 4.6.

Figure 4.5. Screenshot of the Projects Input Page for Test 1

Figure 4.6. Screenshot of Excel Spreadsheet with Data for Test 1

Figure 4.7 shows the screenshot of the objective input page and Figure 4.8

shows the screenshot for the constraints input page.

Figure 4.7. Screenshot of the Objective Input Page for Test 1

Figure 4.8. Screenshot of the Constraint Input Page for Test 1

After all the data are included, the optimal portfolio was found. Figure 4.9 shows the screenshot of the Optimal Portfolio page. In the red rectangle are shown the optimal portfolio which includes projects 2, 3, and 8. The maximal NPV achieved was $3,106 and the total cost of the Portfolio was $1,235, which is lower than the budget constraint of $1,300.
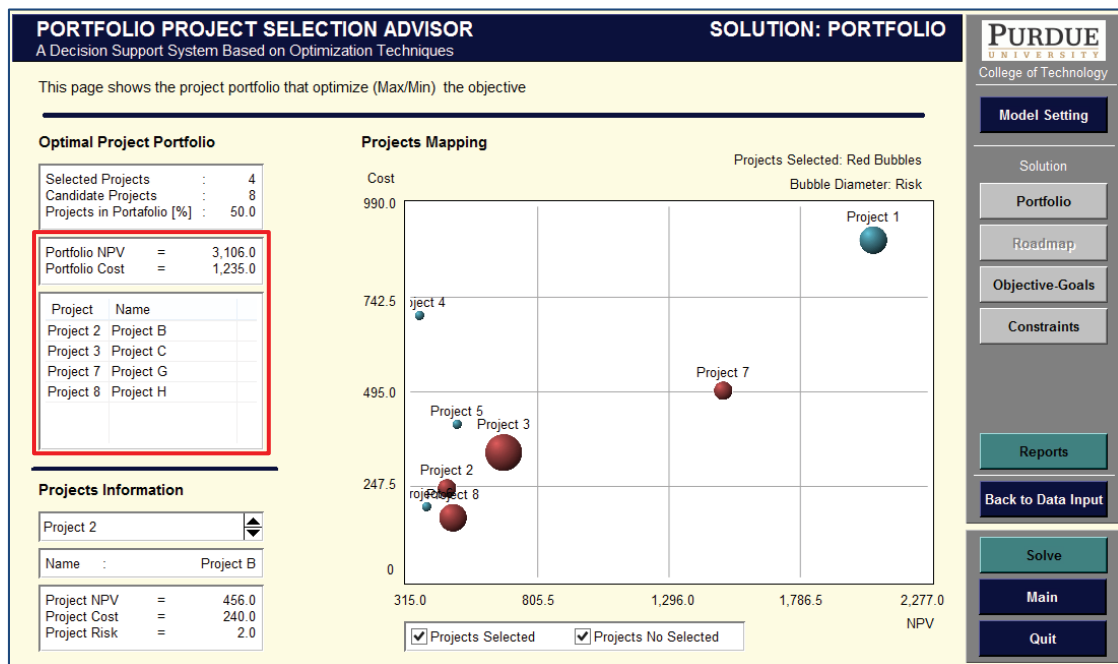
Figure 4.9. Screenshot of the Solution Page for Test 1

In order to validate this result, the 255 project combinations (2^8-1 potential portfolios) are listed on a spreadsheet. The optimal portfolio as shown in Figure 4.10, is found by filtering the portfolios with a cost lower or equal to $1,300 and sorting the list by decreasing NPV. It is also possible, to find the optimal solution using the Solver function of Excel, indicating the objective cell, which contains NPV, the variables cells (binary) and the constraint cells, which contains the cost, as shown in Figure 4.11.

Figure 4.10 Screenshot of the Excel Spreadsheet with the Solution for Test 1

Figure 4.11 Screenshot of the Solver Parameters in Excel for Test 1

Figures 4.9, 4.10 and 4.11 confirm that the DSS found the true optimal portfolio for the problem of Test 1. The same procedure was employed during Test 2 to Test 28 for different versions of the basic problem. The summary of the results are shown in the following sections.

4.2.2.2 DSS Validation of Project Portfolio Selection with One Objective

The first 14 tests validated the functionality of the DSS solving problems with one objective. These tests were shown in Table 3.6 in Chapter 3. Test1 has as objective to maximize NPV, limiting total cost to $1,300 and it does not include any project interdependence constraint. This test constitutes a problem base for Tests 2 to 7, because they are variations of the same problem with additional constraints. It is logical to anticipate that the maximal NPV occurs in Test 1.

Test 8 has the objective of minimizing cost (investment), achieving a NPV of at least $3,250 and it does not include any project interdependence constraints. This test constitutes a base-line problem for Tests 9 to 14, because they are variations of the same problem with additional constraints. It is logical to anticipate that the minimal cost would be expected in Test 8. Table 4.2 shows the results of the validation tests.

4.2.2.3 DSS Validation of Project Portfolio Selection with Multiple Goals

The last 14 tests validated the functionality of the DSS solving problems with multiple goals. These tests were shown in Table 3.7 in the Chapter 3 and all tests

consider two goals. The first goal of Test 15 was to achieve a NPV of at least $3,250

(weight 70%), and the second goal was to limit manpower use to 108 (weight 30%). As a

hard constraint the total cost should be less than or equal to $1,300 and it does not

include any project interdependence constraints. This test constitutes a problem base

for Tests 16 to 21 and the minimal deviation of the goals occurs in this problem.

The first goal of Test 22 was to achieve a NPV of at least $3,250 (weight 70%),

and the second goal was to limit cost to $1,300 (weight 30%). As a hard constraint the

total manpower use should be less than or equal to 108 and it does not include any

project interdependence constraints. This test constitutes a problem base for Tests 23

to 28 and the minimal deviation of the goals occurs in this test. Table 4.3 shows the

results of the validation tests.

4.2.2.4   DSS Validation Analysis of Results

During the 28 validation tests, the DSS found the best Portfolio meeting the

constraints and considering the project interdependence relationships. The execution

time was less than 0.5 second. The execution time was checked with more variables

during the case study in the next section. After finishing the verification and validation

test, no errors in DSS were found in the formulation or code and the solving time was

less than one second.

Table 4.2

DSS Validation Tests Results: One Objective Problems

Test	Objective				# Constraint				Constraint Interdependence			Portfolio									Excel
	Goals	Direction	Objective	Expected	Constraint	Direction	Target	Expected	Mandatory	Exclusive	Dependent	Proj 1	Proj 2	Proj 3	Proj 4	Proj 5	Proj 6	Proj 7	Proj 8	# Projects	Validation
Test 1	1	Max	NPV	3,106	Cost	≤	1,300	1,235					1	1				1	1	4	ok
Test 2	1	Max	NPV	2,855	Cost	≤	1,300	1,260	P5							1	1	1	1	4	ok
Test 3	1	Max	NPV	3,030	Cost	≤	1,300	1,185		P2,P3				1			1	1	1	4	ok
Test 4	1	Max	NPV	3,006	Cost	≤	1,300	1,265			D:P8,I:P5		1	1			1	1		4	ok
Test 5	1	Max	NPV	2,740	Cost	≤	1,300	1,235		P6,P7	D:P8,I:P5	1		1						2	ok
Test 6	1	Max	NPV	2,855	Cost	≤	1,300	1,260	P8		D:P8,I:P5					1	1	1	1	4	ok
Test 7	1	Max	NPV	2,475	Cost	≤	1,500	1,070	P8	P6,P7	D:P8,I:P5					1		1	1	3	ok
Test 8	1	Min	Cost	1,400	NPV	≥	3,250	3,570				1						1		2	ok
Test 9	1	Min	Cost	1,885	NPV	≥	3,250	3,380	P4					1	1		1	1	1	5	ok
Test 10	1	Min	Cost	1,425	NPV	≥	3,250	3,486		P1,P7			1	1			1	1	1	5	ok
Test 11	1	Min	Cost	1,490	NPV	≥	3,250	3,386			D:P7,I:P5	1	1				1		1	4	ok
Test 12	1	Min	Cost	1,585	NPV	≥	3,250	3,600		P2,P8	D:P7,I:P5	1		1			1		1	4	ok
Test 13	1	Min	Cost	1,500	NPV	≥	3,250	3,311	P7		D:P7,I:P5		1			1	1	1	1	5	ok
Test 14	1	Min	Cost	1,595	NPV	≥	3,250	3,525	P7	P2,P8	D:P7,I:P5			1		1	1	1	1	5	ok

D: Dependent Project
I: Independent Project

Table 4.3

DSS Validation Tests Results: Multiple Goals Problems

Test	Goals									# Constraint				Constraint Interdependence			Portfolio									Excel
	Goal 1	Weight	Target	Expected	Goal 2	Weight	Target	Expected	Deviation %	Constraint	Direction	Target	Expected	Mandatory	Exclusive	Dependent	Proj 1	Proj 2	Proj 3	Proj 4	Proj 5	Proj 6	Proj 7	Proj 8	# Projects	validation
Test 15	NPV	70%	3,250	3,030	Manpower	30%	108	105	4.74	Cost	≤	1,300	1185						1			1	1	1	4	ok
Test 16	NPV	70%	3,250	3,006	Manpower	30%	108	99	5.26	Cost	≤	1,300	1265	P2				1	1			1	1		4	ok
Test 17	NPV	70%	3,250	3,006	Manpower	30%	108	60	5.26	Cost	≤	1,300	1300		P7,P8		1	1	1				1	1	3	ok
Test 18	NPV	70%	3,250	3,006	Manpower	30%	108	99	5.26	Cost	≤	1,300	1265			D:P8,I:P5		1	1			1	1		4	ok
Test 19	NPV	70%	3,250	2,740	Manpower	30%	108	45	10.98	Cost	≤	1,300	1235		P6,P7	D:P8,I:P5	1		1			1			2	ok
Test 20	NPV	70%	3,250	2,855	Manpower	30%	108	120	11.84	Cost	≤	1,300	1260	P8		D:P8,I:P5					1	1	1	1	4	ok
Test 21	NPV	70%	3,250	2,475	Manpower	30%	108	114	18.36	Cost	≤	1,300	1070	P8	P6,P7	D:P8,I:P5					1	1	1	1	3	ok
Test 22	NPV	70%	3,250	3,570	Cost	30%	1,300	1,400	2.31	Manpower	≤	108	66				1						1		2	ok
Test 23	NPV	70%	3,250	3,386	Cost	30%	1,300	1,490	4.38	Manpower	≤	108	66	P2			1	1				1			4	ok
Test 24	NPV	70%	3,250	3,220	Cost	30%	1,300	1,395	2.84	Manpower	≤	108	69		P1,P7		1		1					1	3	ok
Test 25	NPV	70%	3,250	3,030	Cost	30%	1,300	1,185	4.74	Manpower	≤	108	105			D:P1,I:P5			1			1	1	1	4	ok
Test 26	NPV	70%	3,250	3,235	Cost	30%	1,300	1,645	8.28	Manpower	≤	108	87		P6,P7	D:P1,I:P5	1				1	1			3	ok
Test 27	NPV	70%	3,250	3,006	Cost	30%	1,300	1,265	5.26	Manpower	≤	108	99	P2		D:P1,I:P5		1	1			1	1		4	ok
Test 28	NPV	70%	3,250	3,501	Cost	30%	1,300	1,710	9.46	Manpower	≤	108	102	P2	P6,P7	D:P1,I:P5	1	2			1			1	5	ok

114

D: Dependent Project
I: Independent Project

4.3   <u>Case Study: Project Portfolio Selection in Cementos Argos – Results and Analysis</u>

This section reviews the current portfolio selection process in Cementos Argos, a retrospective analysis of the portfolio selection work in 2006 using the standard model vs the information generated using the DSS and finally, a prospective of the portfolio selection work for 2015 using the DSS.

4.3.1   Project Portfolio Selection Model in Cementos Argos

The selection of the projects for execution is an annual process in Cementos Argos. The Financial planning department, which is part of the Financial Vice-presidency (VP), is responsible for the evaluation and selection of the project portfolio of the organization.

The process starts at the beginning of each year with the study of potential projects in different Vice-presidencies and Regional Divisions (Colombia, Caribbean and The USA). This business case study includes goals, scope, benefits, investment, financial assessment and schedule. By the month of October, the Financial Planning Department receives all the candidate projects from all VPs of the company. Currently, Financial Planning Department considers only financial criteria and using a weighted scored model for project portfolio selection. The criteria considered were Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI) and Payback period.

Candidate projects are scored in a scale from 0 to 5, where 5 is assigned to the project with the best score for the criterion in consideration (e.g., 5 points to the project

with the highest NPV, 5 points to the project with the lowest Pay Back). The total score

for project *i* is found as was shown in Equation 6

$$S_i = \sum_{j=1}^{n} s_{ij} \cdot w_j \qquad (6)$$

Where w_j is the weight of importance of the *j*th criterion

s_{ij} is the score of the project *i* for the *j*th criterion

4.3.2 Project Portfolio Selection in Cementos Argos in 2006

4.3.2.1 Project Portfolio Selection in Cementos Argos in 2006 with Scoring Weighted Model

During 2006, the company considered 17 candidate projects for the cement,

concrete and logistics unit business to be executed during 2007. The projects comes

from Technical, Environmental, Concrete and Logistics VPs. The company provided a

business case for each of these projects and Table 4.4 summarizes their data. These

projects were then scored on a scale from 0 to 5, where 5 is assigned to the project with

the best score for the criteria considered. Table 4.5 shows the score for candidate

projects for each criterion. The projects in this table are sorted from best to worst

according to the score.

Table 4.4

Candidate Projects Considered by Cementos Argos in 2006

Project	Name	Category1	Category2	NPV [M USD]	Cost [M USD]	IRR [%]	PayBack [Years]	PI [%]
Project 1	Separator MC1 Tolu	Technical	Cement Colombia	5.4	1.2	83.0%	1.2	442%
Project 2	Washing Plant Cartagena	Concrete	Concrete Colombia	3.3	0.3	84.0%	1.0	1188%
Project 3	Power Plant Rioclaro	Enviromental	Cement Colombia	5.9	11.1	21.8%	6.0	53%
Project 4	Pregrinding MC4 Cartagena	Technical	Cement Colombia	2.6	1.1	29.0%	2.5	239%
Project 5	Dosifier Aditions Barranquilla	Technical	Cement Colombia	1.4	0.5	44.0%	2.0	286%
Project 6	Kiln 5 Nare	Technical	Cement Colombia	3.7	12.0	16.2%	9.0	31%
Project 7	Warehouse Rioclaro	Logistics	Cement Colombia	1.8	1.7	26.5%	4.0	108%
Project 8	Power Plant Sogamoso	Enviromental	Cement Colombia	2.7	11.6	16.9%	7.0	23%
Project 9	Port Cemas	Logistics	Cement Colombia	1.9	8.4	17.7%	6.0	23%
Project 10	Crushing Plant El Carmen	Concrete	Concrete Colombia	1.0	0.4	24.9%	7.0	242%
Project 11	Concrete Plant Bogota	Concrete	Concrete Colombia	0.5	0.9	20.5%	5.0	52%
Project 12	Cement Silo Tolu	Technical	Cement Colombia	0.5	3.2	15.0%	5.0	15%
Project 13	Coal Mine Trinidad	Enviromental	Cement Colombia	0.0	2.8	15.3%	7.0	0%
Project 14	Crushing Plant Cairo	Technical	Cement Colombia	-0.9	3.9	14.4%	10.0	0%
Project 15	New Conveyors	Logistics	Logitrans	-0.4	4.7	11.5%	50.0	0%
Project 16	Warehouse Cairo	Logistics	Cement Colombia	-0.4	1.0	6.6%	50.0	0%
Project 17	Crushing Plant San Antonio	Concrete	Concrete Colombia	-3.0	0.5	0.0%	50.0	0%
TOTAL					**65.2**			

Table 4.5

Score of the Candidate Projects Considered by Cementos Argos in 2006

Criterion 1: NPV	NPV	Score
Power Plant Rioclaro	$5,921,702	5.0
Separator MC1 Tolu	$5,358,723	4.5
Kiln 5 Nare	$3,690,000	3.1
Washing Plant Cartagena	$3,267,867	2.8
Power Plant Sogamoso	$2,720,426	2.3
Pregrinding MC4 Cartagena	$2,637,872	2.2
Port Cemas	$1,914,630	1.6
Warehouse Rioclaro	$1,793,191	1.5
Dosifier Aditions Barranquilla	$1,447,826	1.2
Crushing Plant El Carmen	$1,049,565	0.9
Cement Silo Tolu	$488,936	0.4
Concrete Plant Bogota	$451,000	0.4
Coal Mine Trinidad	$11,299	0.0
New Conveyors	-$419,887	0.0
Warehouse Cairo	-$422,553	0.0
Crushing Plant Cairo	-$852,253	0.0
Crushing Plant San Antonio	-$2,992,609	0.0

Criterion 2: IRR	IRR [%]	Score
Washing Plant Cartagena	84.0%	5.0
Separator MC1 Tolu	83.0%	4.9
Dosifier Aditions Barranquilla	44.0%	2.6
Pregrinding MC4 Cartagena	29.0%	1.7
Warehouse Rioclaro	26.5%	1.6
Crushing Plant El Carmen	24.9%	1.5
Power Plant Rioclaro	21.8%	1.3
Concrete Plant Bogota	20.5%	1.2
Port Cemas	17.7%	1.1
Power Plant Sogamoso	16.9%	1.0
Kiln 5 Nare	16.2%	1.0
Coal Mine Trinidad	15.3%	0.9
Cement Silo Tolu	15.0%	0.9
Crushing Plant Cairo	14.4%	0.0
New Conveyors	11.5%	0.0
Warehouse Cairo	6.6%	0.0
Crushing Plant San Antonio	0.0%	0.0

Criterion 3: Pay Back	Pay Back	Score
Washing Plant Cartagena	1.00	5.0
Separator MC1 Tolu	1.20	5.0
Dosifier Aditions Barranquilla	2.00	5.0
Pregrinding MC4 Cartagena	2.50	4.9
Warehouse Rioclaro	4.00	4.9
Concrete Plant Bogota	5.00	4.8
Cement Silo Tolu	5.00	4.7
Power Plant Rioclaro	6.00	4.6
Port Cemas	6.00	4.5
Crushing Plant El Carmen	7.00	4.3
Power Plant Sogamoso	7.00	4.2
Coal Mine Trinidad	7.00	4.1
Kiln 5 Nare	9.00	3.9
Crushing Plant Cairo	10.00	0.0
New Conveyors	50.00	0.0
Warehouse Cairo	50.00	0.0
Crushing Plant San Antonio	50.00	0.0

Criterion 4: Profitability Index	PI [%]	Score
Washing Plant Cartagena	1188%	5.0
Separator MC1 Tolu	442%	1.9
Dosifier Aditions Barranquilla	286%	1.2
Crushing Plant El Carmen	242%	1.0
Pregrinding MC4 Cartagena	239%	1.0
Warehouse Rioclaro	108%	0.5
Power Plant Rioclaro	53%	0.2
Concrete Plant Bogota	52%	0.2
Kiln 5 Nare	31%	0.1
Power Plant Sogamoso	23%	0.1
Port Cemas	23%	0.1
Cement Silo Tolu	15%	0.1
Coal Mine Trinidad	0%	0.0
Crushing Plant Cairo	0%	0.0
New Conveyors	0%	0.0
Warehouse Cairo	0%	0.0
Crushing Plant San Antonio	0%	0.0

Table 4.4 shows some candidate projects with NPVs lower or equal to zero. Some of these projects were proposed by the Regional Divisions or different VPs and the VPs committee decided whether to include these projects in the portfolio because of strategic or legal (environmental) reasons.

During the 2006 selection process, the Financial Planning Department assigned a weight for each criteria as follows: NPV 40%, IRR 20%, Payback 20%, PI 10%, and Risk 10%. However, the risk was not rated, because they did not have any methodology to measure it. Table 4.6 shows the results of the weighted scoring model for the four criteria in consideration.

Table 4.6

Project Selection Results Using a Scoring Model in Cementos Argos in 2006

CEMENTOS ARGOS
PORTFOLIO SELECTION TABLE
Method: Weihgted Scoring Model
Criteria: NPV, IRR, Pay Back, PI

							Weights					
						NPV	IRR	Pay	PI	Risk		
						40.0%	20.0%	20.0%	10.0%	10.0%		
								Score				
Ranking	Project	Cost [MUS$]	NPV [MUS$]	IRR	Pay Back	PI	NPV	IRR	Pay Back	PI	Risk	SCORE
1	Separator MC1 Tolu	$1.2	$5.4	83.0%	1.2	442%	4.5	4.9	5.0	1.9		4.0
2	Washing Plant Cartagena	$0.3	$3.3	84.0%	1.0	1188%	2.8	5.0	5.0	5.0		3.6
3	Power Plant Rioclaro	$11.1	$5.9	21.8%	6.0	53%	5.0	1.3	4.6	0.2		3.2
4	Pregrinding MC4 Cartagena	$1.1	$2.6	29.0%	2.5	239%	2.2	1.7	4.9	1.0		2.3
5	Dosifier Aditions Barranquilla	$0.5	$1.4	44.0%	2.0	286%	1.2	2.6	5.0	1.2		2.1
6	Kiln 5 Nare	$12.0	$3.7	16.2%	9.0	31%	3.1	1.0	3.9	0.1		2.2
7	Warehouse Rioclaro	$1.7	$1.8	26.5%	4.0	108%	1.5	1.6	4.9	0.5		1.9
8	Power Plant Sogamoso	$11.6	$2.7	16.9%	7.0	23%	2.3	1.0	4.2	0.1		2.0
9	Port Cemas	$8.4	$1.9	17.7%	6.0	23%	1.6	1.1	4.5	0.1		1.8
10	Crushing Plant El Carmen	$0.4	$1.0	24.9%	7.0	242%	0.9	1.5	4.3	1.0		1.6
11	Concrete Plant Bogota	$0.9	$0.5	20.5%	5.0	52%	0.4	1.2	4.8	0.2		1.4
12	Cement Silo Tolu	$3.2	$0.5	15.0%	5.0	15%	0.4	0.9	4.7	0.1		1.3
13	Coal Mine Trinidad	$2.8	$0.0	15.3%	7.0	0%	0.0	0.9	4.1	0.0		1.0
14	Crushing Plant Cairo	$3.9	-$0.9	14.4%	10.0	0%	0.0	0.0	0.0	0.0		0.0
15	New Conveyors	$4.7	-$0.4	11.5%	50.0	0%	0.0	0.0	0.0	0.0		0.0
16	Warehouse Cairo	$1.0	-$0.4	6.6%	50.0	0%	0.0	0.0	0.0	0.0		0.0
17	Crushing Plant San Antonio	$0.5	-$3.0	0.0%	50.0	0%	0.0	0.0	0.0	0.0		0.0
TOTAL		$65.2	$26.1									

In 2006, the company approved investment for 25 M USD, the portfolio included projects 1 to 6 with a cost of 26.2 M USD and an expected benefit of 22.3 M USD of NPV.

4.3.2.2   Project Portfolio Selection in Cementos Argos in 2006 with the DSS Based on

  Optimization

The DSS was used to find the optimal portfolio for Cementos Argos for the

planning year 2006 using the historical data shown in the Table 4.4 and considering the

following assumptions:

- In order to simplify the analysis, the selection model considered one objective,

  to maximize NPV, and a single period for the planning horizon.

- The only resource constraint considered was the budget available of 25 M USD.

  However, with the intention of demonstrating how to use the DSS, a sensitivity

  analysis was run with the investment budget ranging from 10 to 65 M USD in

  increments of 5 M USD.

- Payback was considered in the model as a project risk measure, however, it was

  not considered as a goal or constraint.

- No projects were considered mandatory.

- No dependency relation were considered among these candidate projects.

Once the test was configured in the DSS, data of the candidate projects,

objective and budget constraints were introduced. Figure 4.12 shows the screenshot of

the Projects Input page. These data were imported from an Excel spreadsheet.

Figure 4.12 Screenshot of the Projects Input Page for Cementos Argos in 2006

Once all the data were included, the optimal portfolio was found. Figure 4.13 shows the screenshot of the Optimal Portfolio page. In the red rectangle are shown the optimal portfolio which included projects 1, 2, 3, 4, 5, 7, 9 and 10. The expected total NPV of the portfolio was 23.4 M USD and the total cost was 24.7 M USD, which is lower than the budget constraint of 25 M USD.

Figure 4.14 shows the Expected Objective page which shows the contribution of each project to the total NPV. According to this page, projects 3, 1 and 2 have the highest contribution to the total NPV with 25.9%, 22.9% and 14% respectively. Figure 4.15 shows the Constraint page. This page illustrates the contribution of each project to the portfolio cost, and according to this page, projects 3 and 9 have the highest contribution to the portfolio cost with 45% and 34.1% respectively.
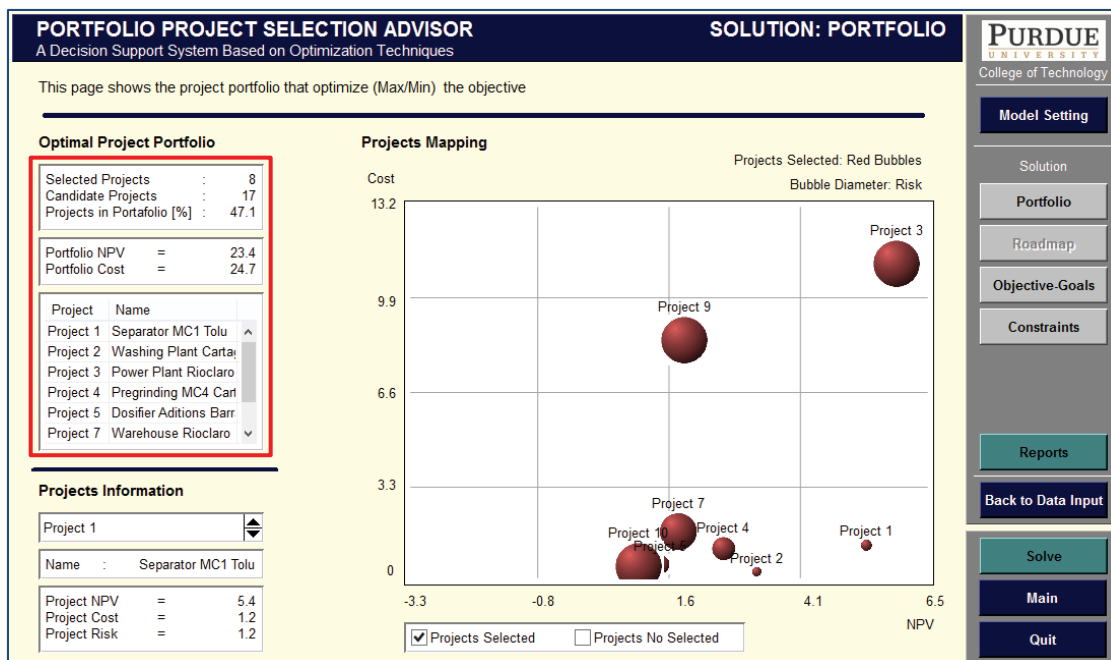
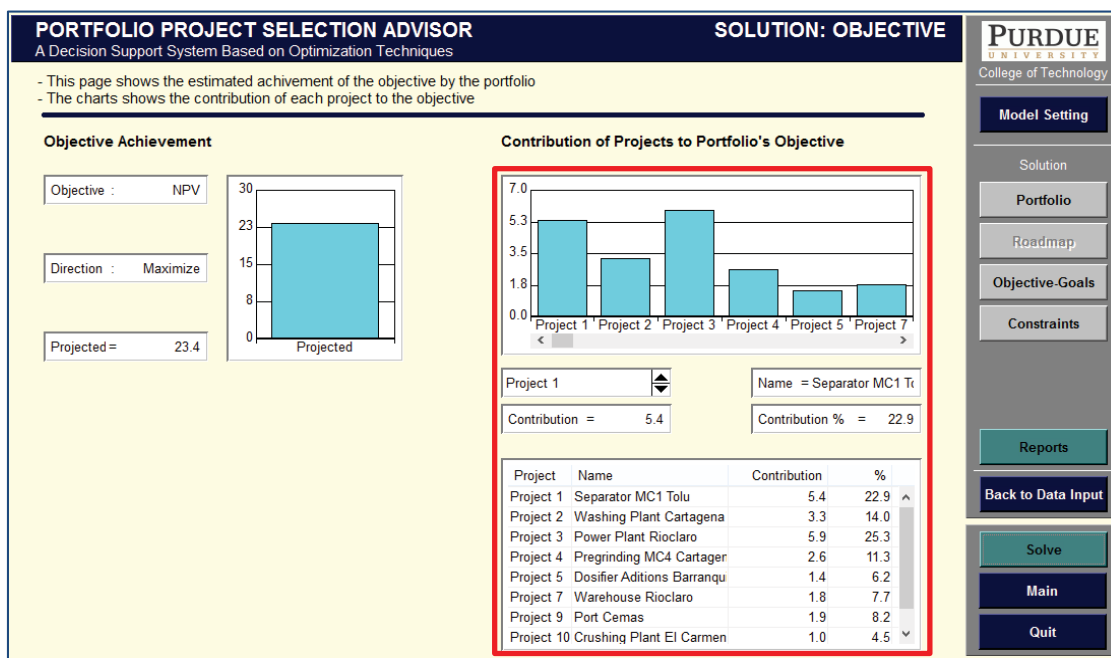*Figure 4.13*   Screenshot of the Solution Page of the Optimal Portfolio for Cementos Argos in 2006

Figure 4.14   Screenshot of the Objective Page of the Optimal Portfolio for Cementos Argos in 2006
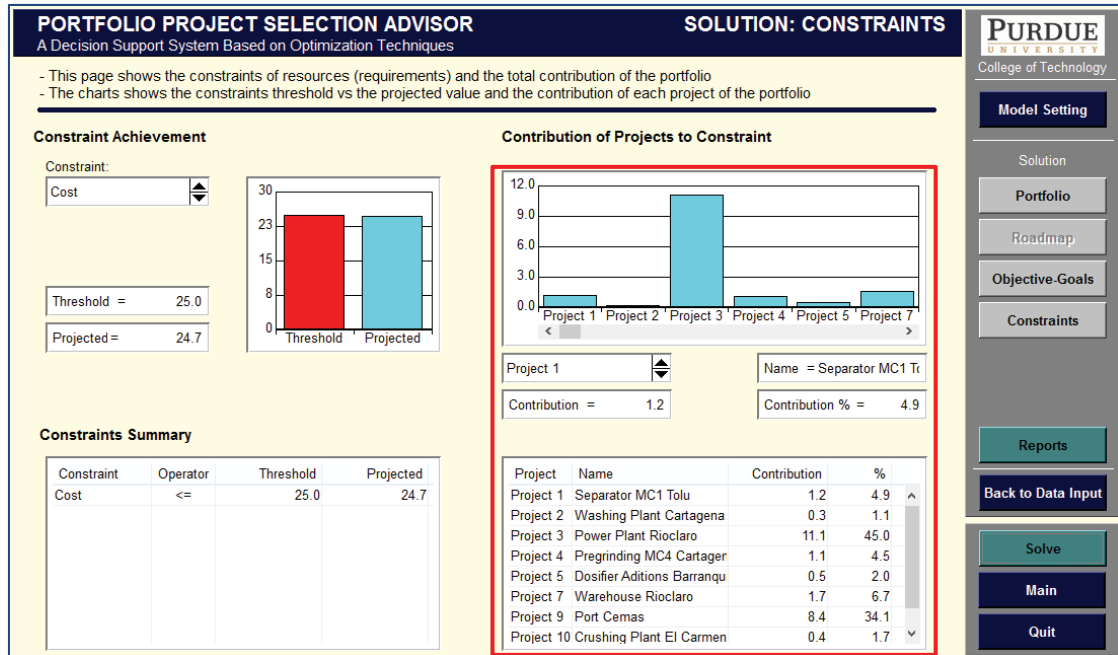
Figure 4.15 Screenshot of the Constraint Page of the Optimal Portfolio for Cementos Argos in 2006

4.3.2.3 Analysis of Results Project Portfolio Selection in Cementos Argos in 2006

Comparing the portfolios found using both models the following differences can be observed:

- The scoring model selected six projects (1 to 6), while the DSS selected eight projects (1 to 5 + 7, 9 and 10).

- The expected NPV for the portfolio selected with the scoring model was 22.3 M USD while the NPV of the portfolio selected with DSS was 23.4 M USD

- The expected investment for the portfolio with the scoring model was 26.2 M USD while the investment of the portfolio found by DSS was 24.7 M USD.

These numbers demonstrate that the portfolio found by the DSS was better than the portfolio found using the standard scoring model.

Sensitivity analysis showed the optimal portfolios changing the budget constraint from 10 to 65 M USD, and increasing 5 M USD. The results are summarized in Table 4.7. This table shows twelve portfolios according to the budget constraints, selected projects, number of projects, expected investment of the portfolio, expected NPV of the portfolio and finally the ratio NPV/Cost.

Table 4.7

Optimal Portfolios for Budget Constraint Ranging from 10 to 65 MUSD

Portfolio	Cost Constraint [MUSD]	Projects																	# Projects	Total Cost [MUSD]	Total NPV [MUSD]	NPV/Cost
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17				
1	10	1	1		1	1		1			1	1	1						8	9.3	16.5	1.77
2	15	1	1	1	1	1					1								6	14.7	19.7	1.34
3	20	1	1	1	1	1		1			1		1						8	19.5	22.0	1.13
4	25	1	1	1	1	1		1		1	1								8	24.7	23.4	0.95
5	30	1	1	1	1	1	1	1			1	1							9	29.1	25.6	0.88
6	35	1	1	1	1	1	1	1			1	1	1						10	32.3	26.1	0.81
7	40	1	1	1	1	1	1	1	1		1								9	39.9	27.9	0.70
8	45	1	1	1	1	1	1	1	1		1	1	1						11	44.0	28.8	0.65
9	50	1	1	1	1	1	1	1	1	1	1	1							11	49.2	30.3	0.62
10	55	1	1	1	1	1	1	1	1	1	1	1	1						12	52.4	30.7	0.59
11	60	1	1	1	1	1	1	1	1	1	1	1	1	1					13	55.2	30.8	0.56
12	65	1	1	1	1	1	1	1	1	1	1	1	1	1					13	55.2	30.8	0.56

Figure 4.16 shows the same information in a graphical way. The graph contains the budget constraint curve (red), the expected investment curve (blue) and the expected NPV of the portfolio (green). The graph also includes also some bars representing the number of projects in each optimal portfolio.
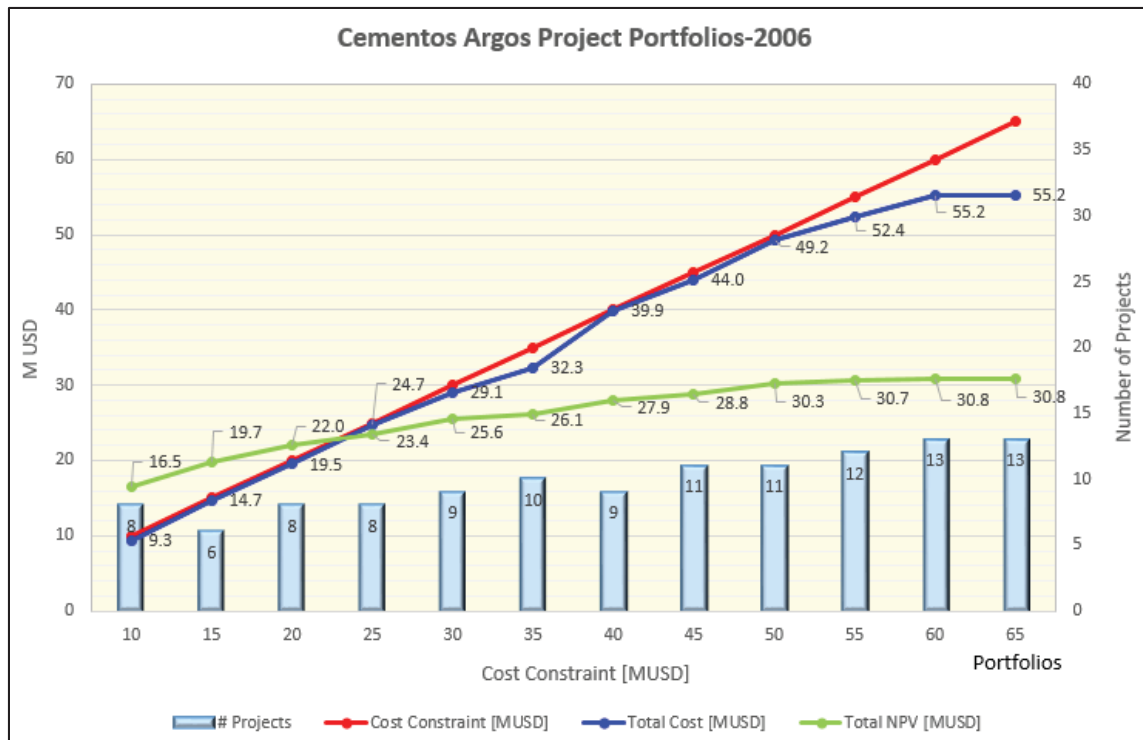
Figure 4.16　　Optimal Portfolios for Cementos Argos in 2006 for Budget Constraint Ranging from 10 to 65 MUS

The following conclusions can be drawn by analyzing Table 4.7 and Figure 4.16:

- The optimal portfolio (and the number of projects) changes according to the changes in the budget constraint without a defined pattern. However some projects appear in all portfolios (projects 1, 2, 4, 5 y 10). The company should pay special attention to these projects because they appear in all the optimal solutions constituting the main elements of the portfolio.

- The optimization model ensures that the constraint is met, and for this reason the expected investment line (blue) is below and close to the budget constraint line (red). However in the last portfolios (10 to 12), these lines are more

separated because the DSS did not find better projects to include in the

portfolio.

- The NPV line (green) at the beginning is above the expected investment line

  (blue), however, in the following portfolios, the lines intercepts and then the

  NPV line continues below the expected investment line. This can be explained in

  the following way: the best projects are chosen in the first portfolios (with the

  lower budget constraint), then the DSS chose goods projects and finally the DSS

  selected the projects that add some value in the last portfolios (with higher

  budget constraint). The profitability of the portfolio decreases as the slope of the

  NPV curve approximates zero in the last portfolios. This seems to be a pattern in

  this kind of problems.

- The company could define the investment budget as a function of the candidate

  projects and the expected profitability of the portfolio. This could change from

  year to year, according to the potential of the candidate projects to add value to

  the organization.

4.3.3   Project Portfolio Selection in Cementos Argos in 2014

In 2014, the company is considering 102 candidate projects for execution for

2015. The list of these projects includes cost, NPV and Payback. Table 4.8 shows the

candidate projects. The name of the projects is changed for confidential reasons and

Payback is considered here a risk measure.

Table 4.8

Candidate Projects Considered by Cementos Argos in 2014

Project	Name	Category1	Category2	Duration	NPV [K USD]	Cost [K USD]	Risk	PayBack
Project 1	Proyecto 1	Caribbean	Concrete		60.0	400	3.42	3.42
Project 2	Proyecto 3	Caribbean	Concrete		25.2	140	5.75	5.75
Project 3	Proyecto 4	Caribbean	Concrete		9.0	45	4.50	4.50
Project 4	Proyecto 5	Caribbean	Concrete		20.0	80	2.42	2.42
Project 5	Proyecto 6	Caribbean	Concrete		13.5	30	6.67	6.67
Project 6	Proyecto 7	Caribbean	Concrete		192.0	400	6.83	6.83
Project 7	Proyecto 8	Caribbean	Concrete		4.8	80	4.25	4.25
Project 8	Proyecto 9	Caribbean	Concrete		893.0	1,900	3.08	3.08
Project 9	Proyecto 10	Caribbean	Cement		182.7	1,075	6.33	6.33
Project 10	Proyecto 11	USA	Cement		804.7	2,515	4.75	4.75
Project 11	Proyecto 12	USA	Cement		200.0	400	5.83	5.83
Project 12	Proyecto 13	USA	Cement		28.9	85	3.17	3.17
Project 13	Proyecto 14	USA	Cement		235.0	500	1.00	1.00
Project 14	Proyecto 15	USA	Cement		9.0	450	2.67	2.67
Project 15	Proyecto 16	USA	Cement		9.9	90	5.75	5.75
Project 16	Proyecto 17	USA	Cement		180.0	600	2.58	2.58
Project 17	Proyecto 18	USA	Cement		157.5	450	5.75	5.75
Project 18	Proyecto 19	USA	Cement		137.5	275	5.25	5.25
Project 19	Proyecto 20	USA	Cement		50.0	200	2.83	2.83
Project 20	Proyecto 21	USA	Cement		9.0	100	6.00	6.00
Project 21	Proyecto 22	USA	Cement		27.0	100	0.83	0.83
Project 22	Proyecto 23	USA	Cement		30.0	100	1.58	1.58
Project 23	Proyecto 24	USA	Cement		576.0	1,200	5.25	5.25
Project 24	Proyecto 25	USA	Cement		277.5	5,550	4.08	4.08
Project 25	Proyecto 26	USA	Cement		837.0	3,100	6.83	6.83
Project 26	Proyecto 27	USA	Concrete		2,760.0	6,000	4.17	4.17
Project 27	Proyecto 28	USA	Concrete		21.6	120	3.67	3.67
Project 28	Proyecto 29	USA	Concrete		26.5	115	4.33	4.33
Project 29	Proyecto 30	USA	Concrete		75.0	300	3.00	3.00
Project 30	Proyecto 31	USA	Concrete		470.0	1,000	0.75	0.75
Project 31	Proyecto 32	USA	Concrete		108.5	350	5.75	5.75
Project 32	Proyecto 33	Colombia	Cement		44.8	149	6.42	6.42
Project 33	Proyecto 34	Colombia	Cement		1,380.0	3,000	1.33	1.33
Project 34	Proyecto 35	Colombia	Cement		26.9	149	5.92	5.92
Project 35	Proyecto 36	Colombia	Cement		45.8	100	4.50	4.50
Project 36	Proyecto 37	Colombia	Cement		477.6	995	4.25	4.25
Project 37	Proyecto 38	Colombia	Cement		78.4	174	2.58	2.58
Project 38	Proyecto 39	Colombia	Cement		174.1	498	1.92	1.92
Project 39	Proyecto 40	Colombia	Cement		43.0	239	3.75	3.75
Project 40	Proyecto 41	Colombia	Cement		84.6	498	6.17	6.17
Project 41	Proyecto 42	Colombia	Cement		59.7	299	1.58	1.58
Project 42	Proyecto 43	Colombia	Cement		53.3	157	3.00	3.00
Project 43	Proyecto 44	Colombia	Cement		44.8	100	2.17	2.17
Project 44	Proyecto 45	Colombia	Cement		7.5	50	6.75	6.75
Project 45	Proyecto 46	Colombia	Cement		140.3	299	4.50	4.50
Project 46	Proyecto 47	Colombia	Cement		16.9	100	6.58	6.58
Project 47	Proyecto 48	Colombia	Cement		17.9	100	6.67	6.67
Project 48	Proyecto 49	Colombia	Cement		1,474.0	3,008	4.33	4.33
Project 49	Proyecto 50	Colombia	Cement		437.3	2,186	4.25	4.25
Project 50	Proyecto 52	Colombia	Cement		207.9	2,599	1.17	1.17
Project 51	Proyecto 53	Colombia	Cement		1,507.9	3,077	2.17	2.17

(continued)

Table 4.8

Candidate Projects Considered by Cementos Argos in 2014 (continued)

Project	Name	Category1	Category2	Duration	NPV [K USD]	Cost [K USD]	Risk	PayBack
Project 52	Proyecto 54	Colombia	Cement		163.4	5,446	6.92	6.92
Project 53	Proyecto 55	Colombia	Cement		2,672.9	5,455	3.42	3.42
Project 54	Proyecto 56	Colombia	Cement		230.3	606	6.50	6.50
Project 55	Proyecto 57	Colombia	Cement		176.6	491	4.92	4.92
Project 56	Proyecto 58	Colombia	Cement		497.5	995	6.75	6.75
Project 57	Proyecto 59	Colombia	Cement		350.7	746	1.75	1.75
Project 58	Proyecto 60	Colombia	Cement		264.2	2,032	6.42	6.42
Project 59	Proyecto 61	Colombia	Cement		427.9	995	0.50	0.50
Project 60	Proyecto 63	Colombia	Cement		600.0	1,200	1.33	1.33
Project 61	Proyecto 64	Colombia	Cement		154.3	964	0.75	0.75
Project 62	Proyecto 65	Colombia	Cement		220.0	880	6.42	6.42
Project 63	Proyecto 66	Colombia	Cement		93.6	1,170	3.50	3.50
Project 64	Proyecto 67	Colombia	Cement		202.3	2,890	5.92	5.92
Project 65	Proyecto 68	Colombia	Cement		367.0	834	0.75	0.75
Project 66	Proyecto 69	Colombia	Concrete		1,131.1	2,308	4.67	4.67
Project 67	Proyecto 70	Colombia	Concrete		14.4	289	3.42	3.42
Project 68	Proyecto 71	Colombia	Concrete		11,062.2	24,583	3.20	3.20
Project 69	Proyecto 72	Colombia	Concrete		960.0	6,000	1.33	1.33
Project 70	Proyecto 73	Colombia	Concrete		2,160.0	6,000	1.83	1.83
Project 71	Proyecto 74	Colombia	Concrete		9.8	489	1.33	1.33
Project 72	Proyecto 75	Colombia	Concrete		144.3	289	2.25	2.25
Project 73	Proyecto 76	Colombia	Concrete		51.9	433	1.33	1.33
Project 74	Proyecto 77	Colombia	Concrete		89.6	995	5.67	5.67
Project 75	Proyecto 78	Colombia	Concrete		164.8	1,030	6.67	6.67
Project 76	Proyecto 79	Colombia	Concrete		199.5	554	6.50	6.50
Project 77	Proyecto 80	Colombia	Concrete		34.7	96	4.67	4.67
Project 78	Proyecto 81	Colombia	Concrete		522.0	1,800	5.08	5.08
Project 79	Proyecto 82	Colombia	Concrete		0.0	0	3.08	3.08
Project 80	Proyecto 83	Colombia	Concrete		449.3	1,045	6.33	6.33
Project 81	Proyecto 84	Colombia	Concrete		28.4	75	3.25	3.25
Project 82	Proyecto 85	Colombia	Concrete		15.7	52	2.75	2.75
Project 83	Proyecto 86	Colombia	Concrete		20.5	73	3.08	3.08
Project 84	Proyecto 87	Colombia	Concrete		37.8	100	2.50	2.50
Project 85	Proyecto 88	Colombia	Concrete		5.5	50	4.75	4.75
Project 86	Proyecto 89	Colombia	Concrete		80.3	473	6.08	6.08
Project 87	Proyecto 90	Colombia	Concrete		453.7	945	2.42	2.42
Project 88	Proyecto 91	Colombia	Concrete		70.2	270	3.67	3.67
Project 89	Proyecto 92	Colombia	Concrete		207.2	715	6.17	6.17
Project 90	Proyecto 93	Colombia	Concrete		128.9	348	2.50	2.50
Project 91	Proyecto 94	Colombia	Concrete		319.3	743	2.67	2.67
Project 92	Proyecto 95	Colombia	Concrete		64.3	715	4.25	4.25
Project 93	Proyecto 96	Colombia	Concrete		8.1	270	1.33	1.33
Project 94	Proyecto 97	Colombia	Concrete		142.9	715	5.58	5.58
Project 95	Proyecto 98	Colombia	Concrete		122.9	473	7.00	7.00
Project 96	Proyecto 99	Colombia	Concrete		20.9	174	0.58	0.58
Project 97	Proyecto 100	Colombia	Concrete		15.7	174	1.58	1.58
Project 98	Proyecto 101	Colombia	Concrete		445.9	910	5.42	5.42
Project 99	Proyecto 102	Colombia	Concrete		12.0	600	6.17	6.17
Project 100	Proyecto 103	Colombia	Concrete		61.2	680	1.33	1.33
Project 101	Proyecto 104	Colombia	Concrete		119.0	700	0.67	0.67
Project 102	Proyecto 105	Colombia	Concrete		13.4	45	2.25	2.25
TOTAL [K USD]					40,561	125,435		

The company stablished a budget constraints for business unit (cement or concrete) and for business regions. This information is shown in Table 4.9.

Table 4.9

Total Cost of Candidate Projects and Budget Constraints in 2014

Business Unit	Investment Projects [KUSD]	Budget Constraint [K USD]
Caribbean	**4,150**	**3,800**
Cement	1,075	984
Concrete	3,075	729
Colombia	**97,686**	**50,050**
Cement	42,478	21,764
Concrete	55,208	12,300
USA	**23,600**	**18,600**
Cement	15,715	12,385
Concrete	7,885	4,138
TOTAL [K USD]	**125,435**	**72,450**

At the moment of writing this document, the Financial Planning Department is working on the selection of the portfolio for 2015 and this research shows an alternative to the scoring model used in the last 8 years.

The DSS was used to find the optimal portfolio for Cementos Argos for the year 2015, using the project data shown in Table 4.8 and considering the following assumptions:

- With the aim of simplifying the analysis, the selection model considered one objective, which is to maximize NPV and a single period for the planning horizon.

- The only resource constraint considered was the budget available

- There are no mandatory projects in this exercise.

- There is no relationship of dependency among candidate projects.

Two approaches are proposed to find the optimal portfolio according to the resource constraints defined by the company and showed in Table 4.9 as follows:

1. Portfolio selection for the entire company, meaning, globally optimizing the portfolio according to the total budget constraint of 72,450 K USD. This means, finding the optimal portfolio for the company with all candidate projects from all regions competing for the resources.

2. Portfolio selection per region, meaning, locally optimizing the portfolios according to the budget constraints defined per region which are 3,800 K USD for the Caribbean, 18,600 K USD for USA and 50,050 K USD for Colombia. Then, this means finding the optimal portfolio per region with the projects and the budget associated with each region.

Other alternative approaches can be studied, for example, optimizing the portfolio by considering the budget constraint per business unit (cement or concrete business), however, for the Financial Planning Department is more interested in the analysis per regions. The purpose of studying these approaches is to compare and analyze the solutions found in each case and make a recommendation.

4.3.3.1   Project Portfolio Selection in Cementos Argos in 2014-Global Optimization

In this selection process, 102 candidate projects were considered, all in competition, and the budget constraint is 72,450 KUSD. The following paragraphs illustrate some screenshots with the use of the DSS and the results.

Initially the test is configured on the DSS for one objective and a single period of time; then data of the candidate projects, objective and budget constraint are introduced. Figure 4.17 shows the screenshot of the projects input page.

Figure 4.17   Screenshot of the Projects Input Page for Cementos Argos in 2014.

Once all the data are included, the optimal portfolio is found. Figure 4.18 shows the screenshot of the Optimal Portfolio page. Forty projects were selected, the expected NPV of the portfolio was 32,771.6 K USD and the total cost was 72,439 K USD, which is

lower than the budget constraint of 72,450 K USD. In the project mapping graph is

possible to identify a triangular region where the selected projects are located.
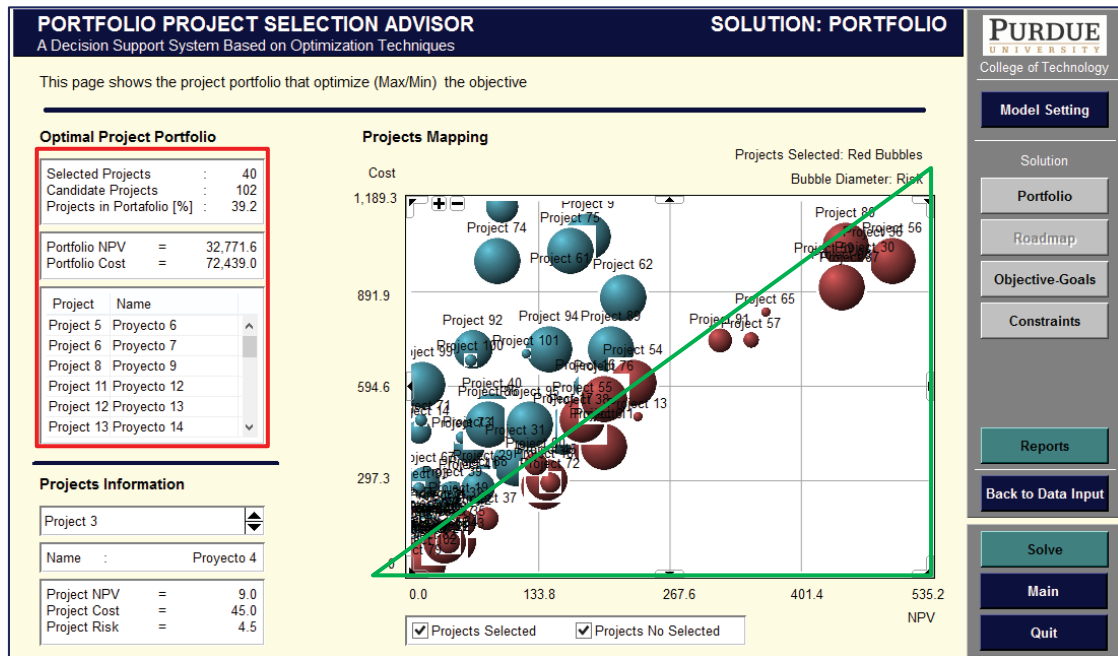
Figure 4.18   Screenshot of the Solution Page of the Optimal Portfolio for Cementos Argos in 2014

In order to review the selected projects, the solution was exported to an Excel

file as shown in the Figure 4.19 in the Reports Menu Page. The Excel file screenshot is

shown in Figure 4.20 and the complete table with the selected projects is shown in

Table 4.10.
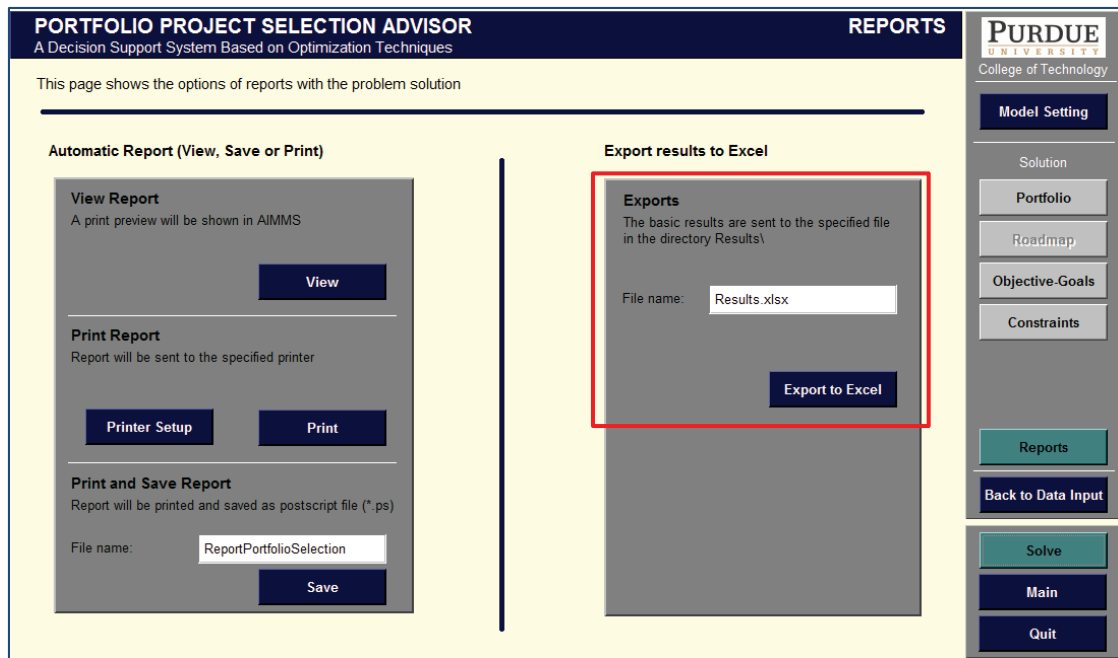
Figure 4.19   Screenshot of the Reports Page Menu

Figure 4.20   Screenshot of the Excel Spreadsheet with the Optimal Portfolio for Cementos Argos in 2014

Table 4.10

Optimal Portfolio in Cementos Argos According to Global Optimization in 2014

Projects	Name	Category1	Category2	NPV	Cost	Risk
Project 5	Proyecto 6	Caribe	Concreto	13.5	30.0	6.7
Project 6	Proyecto 7	Caribe	Concreto	192.0	400.0	6.8
Project 8	Proyecto 9	Caribe	Concreto	893.0	1,900.0	3.1
Project 11	Proyecto 12	USA	Cemento	200.0	400.0	5.8
Project 12	Proyecto 13	USA	Cemento	28.9	85.0	3.2
Project 13	Proyecto 14	USA	Cemento	235.0	500.0	1.0
Project 18	Proyecto 19	USA	Cemento	137.5	275.0	5.3
Project 23	Proyecto 24	USA	Cemento	576.0	1,200.0	5.3
Project 26	Proyecto 27	USA	Concreto	2,760.0	6,000.0	4.2
Project 30	Proyecto 31	USA	Concreto	470.0	1,000.0	0.8
Project 33	Proyecto 34	Colombia	Cemento	1,380.0	3,000.0	1.3
Project 35	Proyecto 36	Colombia	Cemento	45.8	99.5	4.5
Project 36	Proyecto 37	Colombia	Cemento	477.6	995.0	4.3
Project 37	Proyecto 38	Colombia	Cemento	78.4	174.1	2.6
Project 38	Proyecto 39	Colombia	Cemento	174.1	497.5	1.9
Project 42	Proyecto 43	Colombia	Cemento	53.3	156.7	3.0
Project 43	Proyecto 44	Colombia	Cemento	44.8	99.5	2.2
Project 45	Proyecto 46	Colombia	Cemento	140.3	298.5	4.5
Project 48	Proyecto 49	Colombia	Cemento	1,474.0	3,008.2	4.3
Project 51	Proyecto 53	Colombia	Cemento	1,507.9	3,077.4	2.2
Project 53	Proyecto 55	Colombia	Cemento	2,672.9	5,454.9	3.4
Project 54	Proyecto 56	Colombia	Cemento	230.3	606.0	6.5
Project 55	Proyecto 57	Colombia	Cemento	176.6	490.5	4.9
Project 56	Proyecto 58	Colombia	Cemento	497.5	995.0	6.8
Project 57	Proyecto 59	Colombia	Cemento	350.7	746.3	1.8
Project 59	Proyecto 61	Colombia	Cemento	427.9	995.0	0.5
Project 60	Proyecto 63	Colombia	Cemento	600.0	1,200.0	1.3
Project 65	Proyecto 68	Colombia	Cemento	367.0	834.0	0.8
Project 66	Proyecto 69	Colombia	Concreto	1,131.1	2,308.5	4.7
Project 68	Proyecto 71	Colombia	Concreto	11,062.2	24,582.7	3.2
Project 70	Proyecto 73	Colombia	Concreto	2,160.0	6,000.0	1.8
Project 72	Proyecto 75	Colombia	Concreto	144.3	288.6	2.3
Project 76	Proyecto 79	Colombia	Concreto	199.5	554.3	6.5
Project 77	Proyecto 80	Colombia	Concreto	34.7	96.4	4.7
Project 80	Proyecto 83	Colombia	Concreto	449.3	1,044.8	6.3
Project 84	Proyecto 87	Colombia	Concreto	37.8	99.5	2.5
Project 87	Proyecto 90	Colombia	Concreto	453.7	945.3	2.4
Project 90	Proyecto 93	Colombia	Concreto	128.9	348.3	2.5
Project 91	Proyecto 94	Colombia	Concreto	319.3	742.5	2.7
Project 98	Proyecto 101	Colombia	Concreto	445.9	910.0	5.4
TOTAL				32,771.6	72,439.0	

The Figure 4.21 illustrates a screenshot of the AIMMS Profiler Results Overview dialog box after running the optimization. Figure 4.22 shows the AIMMS Progress window after the solution was found. According to the AIMMS profiler the required time by CPLEX, the solver used by AIMMS in this case, was only 0.042 seconds (red rectangle in Figure 4.21) making 122 iterations to find the optimal solution with a memory use of 75.1 Mb from 4,096 Mb available. This is a good performance for the tool running in a personal computer considering the number of variables (102 variables).

Name	hits	gross time	net time	average gross time	average net time
P ReadProjectsFromExcel	1	1.106	1.106	1.106	1.106
P SelectMPSolver	1	0.119	0.077	0.119	0.077
P SelectMPInputGoals	1	0.094	0.094	0.094	0.094
P IntegerProgrammingSolver	1	0.042	0.041	0.042	0.041
V TotalObjectiveOP	1	0.001	0.001	0.001	0.001
S Projects	1	0.000	0.000	0.000	0.000
C ConstLE	1	0.000	0.000	0.000	0.000
P ProjCost	1	0.000	0.000	0.000	0.000
P MatrixGoalsProjects	1	0.000	0.000	0.000	0.000
P ProjRisks	1	0.000	0.000	0.000	0.000
P MatrixConstProjects	1	0.000	0.000	0.000	0.000
P MatrixConstLEProjects	1	0.000	0.000	0.000	0.000
P ProjNPV	1	0.000	0.000	0.000	0.000
Ps ProblemDate	1	0.000	0.000	0.000	0.000
P CreateYearInPeriod	1	0.000	0.000	0.000	0.000
C ExclProjConstraint	1	0.000	0.000	0.000	0.000
S ConstLESet	1	0.000	0.000	0.000	0.000
P MaxCost	1	0.000	0.000	0.000	0.000
P SelectionIndex	1	0.000	0.000	0.000	0.000
S PortfolioSelected	1	0.000	0.000	0.000	0.000
P PortfolioNPV	1	0.000	0.000	0.000	0.000
S PortfoliosOnMap	1	0.000	0.000	0.000	0.000
P MaxNPV	1	0.000	0.000	0.000	0.000
S CriteriaNoGoals	1	0.000	0.000	0.000	0.000
P MinCost	1	0.000	0.000	0.000	0.000
S ExclusiveProjSets	1	0.000	0.000	0.000	0.000
Ps ObjectiveSelected	1	0.000	0.000	0.000	0.000
P MinNPV	1	0.000	0.000	0.000	0.000

Figure 4.21   AIMMS Profiler Results Overview Screenshot for the Optimization of the Portfolio of Cementos Argos in 2014

Figure 4.22   AIMMS Progress Window Screenshot for the Optimization of the

Portfolio of Cementos Argos in 2014

4.3.3.2   Project Portfolio Selection in Cementos Argos in 2014-Local Optimization

In the case of local optimization per regional division, 9, 22 and 71 candidate

projects with budget constraints of 3,800 K USD, 18,600 K USD and 50,050 K USD were

considered for the Caribbean region, USA and Colombia respectively.

Figures 4.23, 4.24 and 4.25 show the screenshots of the Optimal Portfolio pages

and Tables 4.11, 4.12 and 4.13 show the selected projects for the Caribbean region, USA

and Colombia respectively.

According to the results, for the Caribbean region, 8 projects were selected, the

expected NPV of the portfolio was 1,340.2 K USD and the total cost was 3,749.6 K USD,

which is lower than the budget constraint of 3,800 K USD. In the case of the USA, 21

projects were selected, the expected NPV of the portfolio was 6,753 K USD and the total

cost was 18,049.7 K USD, which is lower than the budget constraint of 18,600 K USD.

Finally, for Colombia, 19 projects were selected, the expected NPV of the portfolio was

23,307 K USD and the total cost was 50,037.4 K USD, which is lower than the budget

constraint of 50,050 K USD.

Consolidating these results for the three regions, 48 projects were selected, the

expected NPV of the portfolio was 31,400 K USD and the total cost was 71,837 K USD,

which is lower than the budget constraint of 72,450 K USD.
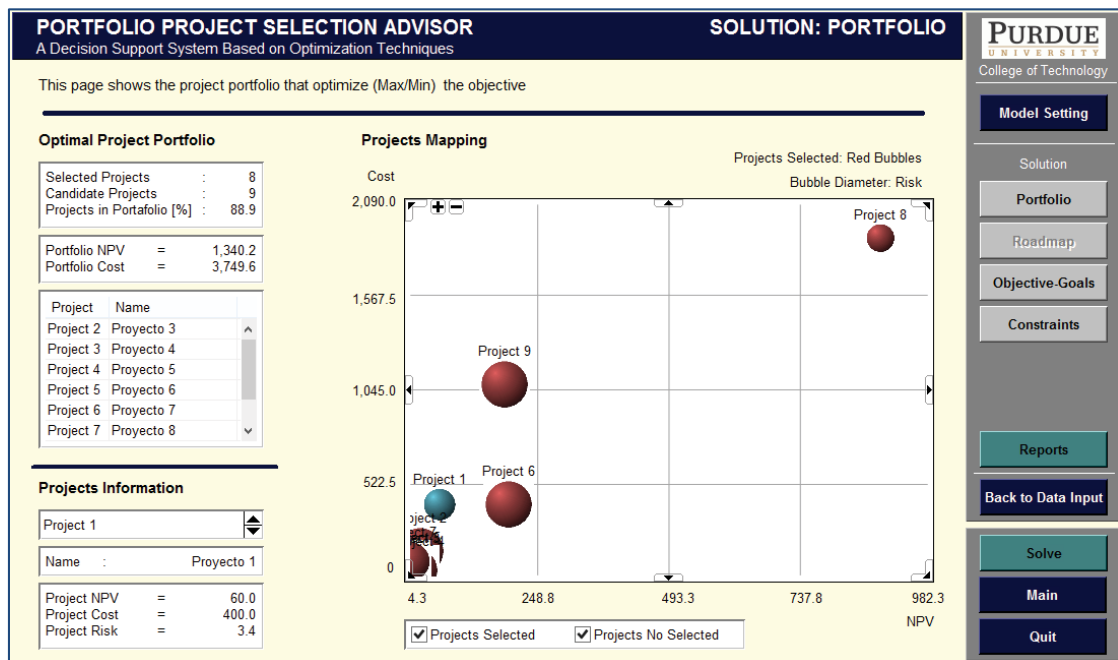
Figure 4.23 Screenshot of the Solution Page of the Optimal Portfolio for Cementos
Argos in 2014 for the Caribbean Region (Local Optimization)
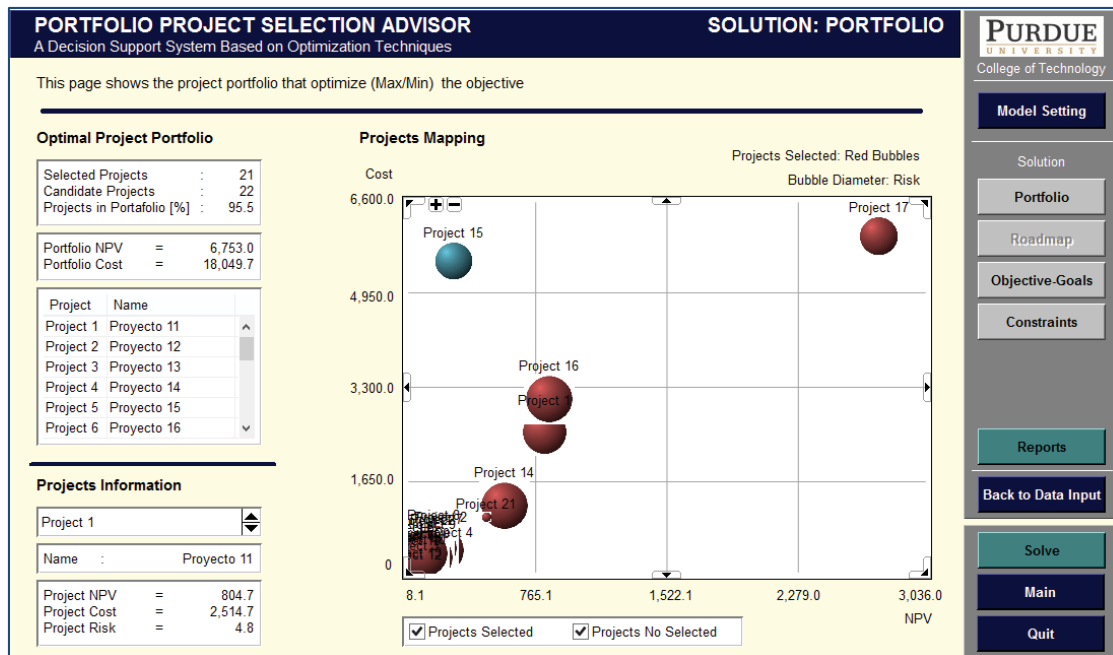
Figure 4.24 Screenshot of the Solution Page of the Optimal Portfolio for Cementos Argos in 2014 for the USA (Local Optimization)
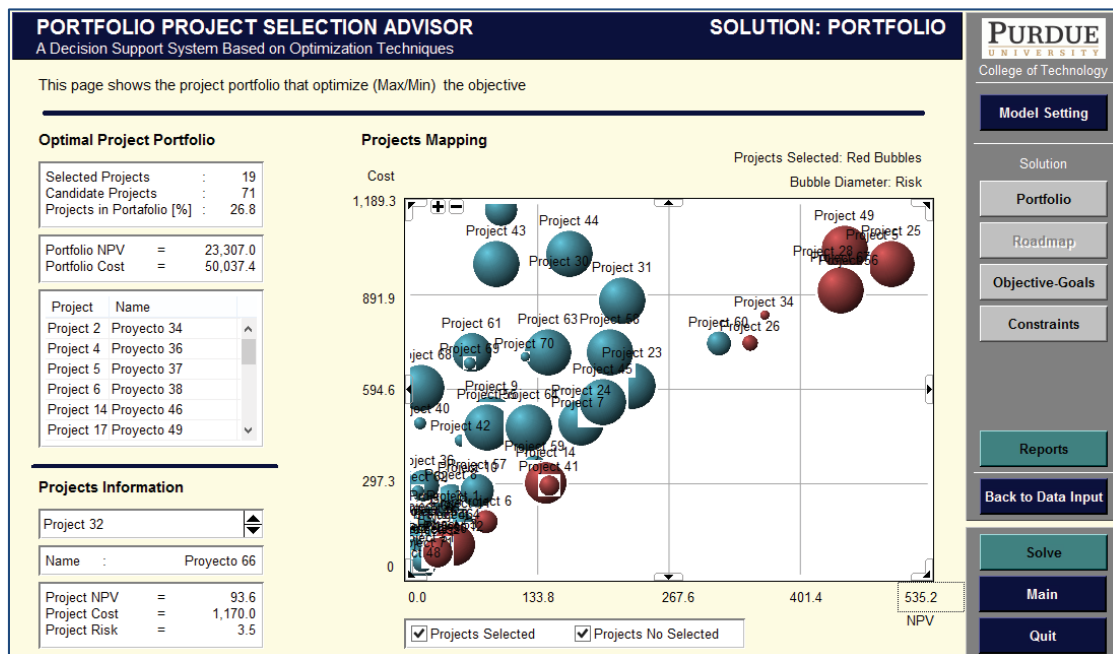
Figure 4.25 Screenshot of the Solution Page for the Optimal Portfolio for Cementos Argos in 2014 for Colombia (Local Optimization)

Table 4.11

Optimal Portfolio in Cementos Argos According to Local Optimization for the Caribbean Regional Division in 2014

Projects	Name	Category1	Category2	NPV [K USD]	Cost [K USD]	Risk
Project 2	Proyecto 3	Caribbean	Concrete	25.2	140.0	5.8
Project 3	Proyecto 4	Caribbean	Concrete	9.0	45.0	4.5
Project 4	Proyecto 5	Caribbean	Concrete	20.0	80.0	2.4
Project 5	Proyecto 6	Caribbean	Concrete	13.5	30.0	6.7
Project 6	Proyecto 7	Caribbean	Concrete	192.0	400.0	6.8
Project 7	Proyecto 8	Caribbean	Concrete	4.8	80.0	4.3
Project 8	Proyecto 9	Caribbean	Concrete	893.0	1,900.0	3.1
Project 9	Proyecto 10	Caribbean	Cement	182.7	1,074.6	6.3
TOTAL				1,340.2	3,749.6	

Table 4.12

Optimal Portfolio in Argos According to Local Optimization for the USA Regional Division in 2014

Projects	Name	Category1	Category2	NPV [K USD]	Cost [K USD]	Risk
Project 1	Proyecto 11	USA	Cement	804.7	2514.7	4.8
Project 2	Proyecto 12	USA	Cement	200.0	400.0	5.8
Project 3	Proyecto 13	USA	Cement	28.9	85.0	3.2
Project 4	Proyecto 14	USA	Cement	235.0	500.0	1.0
Project 5	Proyecto 15	USA	Cement	9.0	450.0	2.7
Project 6	Proyecto 16	USA	Cement	9.9	90.0	5.8
Project 7	Proyecto 17	USA	Cement	180.0	600.0	2.6
Project 8	Proyecto 18	USA	Cement	157.5	450.0	5.8
Project 9	Proyecto 19	USA	Cement	137.5	275.0	5.3
Project 10	Proyecto 20	USA	Cement	50.0	200.0	2.8
Project 11	Proyecto 21	USA	Cement	9.0	100.0	6.0
Project 12	Proyecto 22	USA	Cement	27.0	100.0	0.8
Project 13	Proyecto 23	USA	Cement	30.0	100.0	1.6
Project 14	Proyecto 24	USA	Cement	576.0	1200.0	5.3
Project 16	Proyecto 26	USA	Cement	837.0	3100.0	6.8
Project 17	Proyecto 27	USA	Concrete	2760.0	6000.0	4.2
Project 18	Proyecto 28	USA	Concrete	21.6	120.0	3.7
Project 19	Proyecto 29	USA	Concrete	26.5	115.0	4.3
Project 20	Proyecto 30	USA	Concrete	75.0	300.0	3.0
Project 21	Proyecto 31	USA	Concrete	470.0	1000.0	0.8
Project 22	Proyecto 32	USA	Concrete	108.5	350.0	5.8
TOTAL				6753.0	18049.7	

Table 4.13

Optimal Portfolio in Argos According to Local Optimization for Colombia Regional Division in 2014

Projects	Name	Category1	Category2	NPV [K USD]	Cost [K USD]	Risk
Project 2	Proyecto 34	Colombia	Cement	1,380.0	3,000.0	1.3
Project 4	Proyecto 36	Colombia	Cement	45.8	99.5	4.5
Project 5	Proyecto 37	Colombia	Cement	477.6	995.0	4.3
Project 6	Proyecto 38	Colombia	Cement	78.4	174.1	2.6
Project 14	Proyecto 46	Colombia	Cement	140.3	298.5	4.5
Project 17	Proyecto 49	Colombia	Cement	1,474.0	3,008.2	4.3
Project 20	Proyecto 53	Colombia	Cement	1,507.9	3,077.4	2.2
Project 22	Proyecto 55	Colombia	Cement	2,672.9	5,454.9	3.4
Project 25	Proyecto 58	Colombia	Cement	497.5	995.0	6.8
Project 26	Proyecto 59	Colombia	Cement	350.7	746.3	1.8
Project 29	Proyecto 63	Colombia	Cement	600.0	1,200.0	1.3
Project 34	Proyecto 68	Colombia	Cement	367.0	834.0	0.8
Project 35	Proyecto 69	Colombia	Concrete	1,131.1	2,308.5	4.7
Project 37	Proyecto 71	Colombia	Concrete	11,062.2	24,582.7	3.2
Project 41	Proyecto 75	Colombia	Concrete	144.3	288.6	2.3
Project 49	Proyecto 83	Colombia	Concrete	449.3	1,044.8	6.3
Project 50	Proyecto 84	Colombia	Concrete	28.4	74.6	3.3
Project 56	Proyecto 90	Colombia	Concrete	453.7	945.3	2.4
Project 67	Proyecto 101	Colombia	Concrete	445.9	910.0	5.4
TOTAL				23,307.0	50,037.4	

4.3.3.3   Analysis of Results of Project Portfolio Selection in Cementos Argos in 2014

Table 4.14 shows a comparative table of results when using the DSS with local optimization vs global optimization of the resource (budget constraint). Figure 4.26 shows the composition of the optimal portfolio according to each approach. Figure 4.27 shows the change of the benefits (NPV) and the total investment vs the budget constraint (red line). Finally, Figure 4.28 shows the profitability (ratio NPV/Investment) and the use of the resource (ratio expected investment/budget constraint) for the both approaches.

Table 4.14

Comparative Chart of the Portfolio Using Local vs Global Optimization

Optimization Approach	Region	# Projects Selected	# Candidate Projects	Projects Selected [%]	NPV [K USD]	Budget Constraint [K USD]	Investment [K USD]	Cost/Budget Const [%]	NPV/Cost [%]
Local Optimization	Caribbean	8	9	88.9%	1,340	3,800	3,750	98.67%	35.7%
	USA	21	22	95.5%	6,753	18,600	18,050	97.04%	37.4%
	Colombia	19	71	26.8%	23,307	50,050	50,037	99.97%	46.6%
	TOTAL	**48**	**102**	**47.1%**	**31,400**	**72,450**	**71,837**	**99.15%**	**43.7%**
Global Optimization	Caribbean	3	9	33.3%	1,099		2,330		47.1%
	USA	7	22	31.8%	4,407		9,460		46.6%
	Colombia	30	71	42.3%	27,266		60,649		45.0%
	TOTAL	**40**	**102**	**39.2%**	**32,772**	**72,450**	**72,439**	**99.98%**	**45.2%**
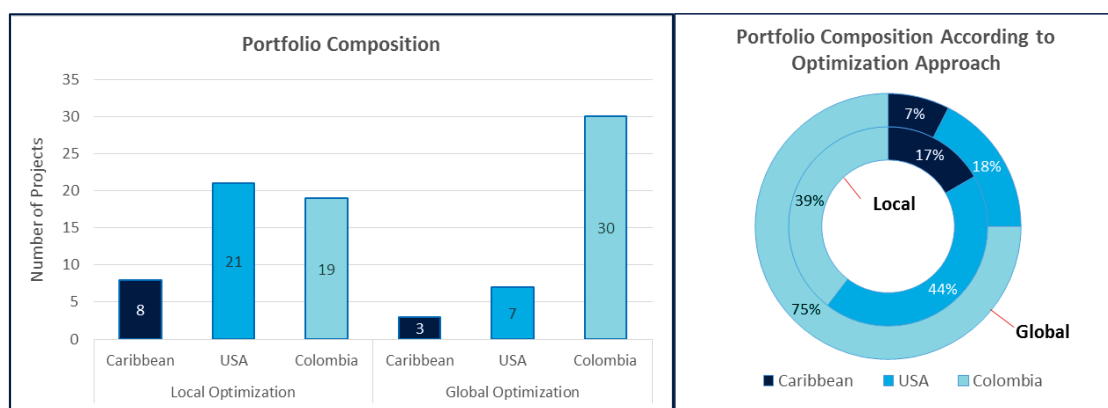
Figure 4.26 Portfolio Composition for Cementos Argos Using Local vs Global Optimization
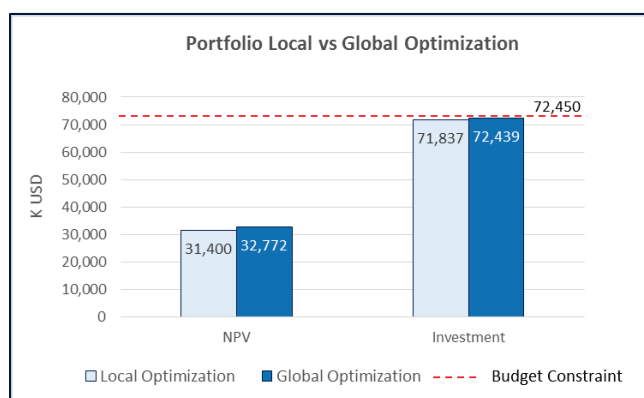
Figure 4.27 NPV and Investment Using Local vs Global Optimization for the Portfolio of Cementos Argos in 2014
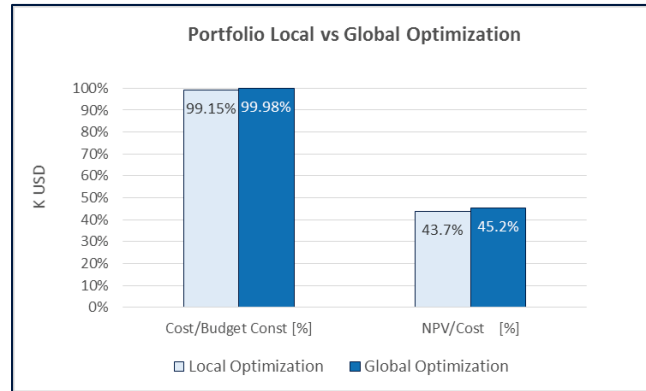
Figure 4.28   Cost/Budget Constraint Ratio and NPV/Investment Ratio Using Local vs Global Optimization for the Portfolio of Cementos Argos in 2014

Analyzing Table 4.14 and Figures 4.26 to 4.28, the following conclusions can be drawn:

- Regarding the composition of the optimal portfolio, the number of selected projects decrease from 48 to 40, from local to global optimization, and the distribution by regions changes dramatically. The portfolio decreases from 8 to 3 (17 to 7 %) projects in the Caribbean region and from 21 to 7 (44 to 18%) projects in the USA, while in Colombia the number of selected projects increases from 19 to 30 (39 to 75%). This means that Colombia has better candidate projects than other regions which are chosen when all projects compete in a global optimization approach.

- In any case, the optimization model ensures the constraint is met, however in the global optimization approach, the exploitation of the resource is higher than in the local approach. The total investment increased changing local to global

optimization from 71,437 K USD to 72,439 KSUD with a budget constraint of 72,450 KUSD.

- In any approach, the optimization model ensures the maximization of benefits (NPV); however in the global optimization approach it gives the highest possible benefit compared to any other approach. The expected NPV increased changing local to global optimization from 31,400 K USD to 32,772 KSUD.

- The profitability of the portfolio is better in a global optimization approach than in a local optimization approach because the benefits are higher with a better exploit of the resources. In this case, the ratio NPV/Investment increased changing local to global optimization from 43.7 to 45.2%.

- As a recommendation, the company should work using a global optimization approach and include only some strategic projects by regions as mandatory projects. In this way, most of the projects compete for the resources and only the best projects are chosen independently of the region or business unit.

CHAPTER 5.   DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions, limitations y recommendations of this

research which developed a computational tool for portfolio selection focused on end

users. The application has potential improvements which are described in the section of

further research included at the end of this chapter.

5.1   Discussion

This research described the main process of project portfolio management, the

project selection framework, and the predominant models for project evaluation and

selection. Projects portfolios are essential in the development of the strategic plan of

the organization. The execution of the strategy demands many resources, so the

projects that add more value and fulfill the strategic objectives should be selected. With

this perspective in mind, the project portfolio selection is an optimization problem and

optimization models, applied in operations research provide powerful tools that can

assist the top management and decision makers in finding the best portfolio for the

organization

According to the literature and the experience of the author as project engineer, the use of optimization models in project selection is not generalized due to the its complexity compared to conventional models, the amount of data required in the process and the lack of knowledge about optimization models among project and portfolio managers. The goal of this research was to develop/integrate a model based on mathematical programming and implement a computational tool to select the best project portfolio of an organization with minimum effort. The target audience of this application are the portfolio managers and decision makers that lack of knowledge of operations research models or time available to spend in formulating and coding a selection problem.

5.2   Conclusions

This research implemented two approaches of mathematical programming for project selection: 0-1 integer linear programming for problems with one objective, and weighted goal programming for problems with multiple goals. Single and multiple periods in the time horizon were considered for both alternatives. The author used the mathematical formulation for 0-1 integer linear programming (Ghasemzadeh, Archer & Iyogun, 1999) and developed a specific model for project selection based on goal programming. The most common kind of constraints such as resources, requirements, and interdependence among projects were included in the model.

The computational tool for project selection was developed using the modeling language AIMMS v3.14 as programming platform. The implementation of the tool

required coding a general structure that includes generic variables, parameters and equations for objective functions and constraints. The tool includes a friendly graphical user interface (GUI) and communication with Excel spreadsheets for input data and output results.

The application was tested with different problem configurations with one and multiple goals and different kind of constraints. The verification process showed the tool was running flawless without programming errors and the execution time was 0.042 seconds with 102 variables (candidate projects) running in a personal computer with common specifications (Intel i7, 8 MB RAM, 256 MB Hard drive, Windows 8). The validation process demonstrated the effectiveness of the tool by finding the optimal solution for all the different problem configurations considered.

This research included a business case of the company Cementos Argos with two project selection problems from the years 2006 and 2014, respectively. This case study allows to draw the following conclusions:

- The project selection problem from 2006 evidenced that the optimization model produces better (or at least equal) solution than those obtained with the weighted scoring models.

- This case study also helped to understand how the benefits (NPV) of the portfolio change as the level of resources (budget) changes. The trend shows that the profitability of the portfolio (ratio NPV/budget constraint) decreases as the resources constraint increases. This inverse relation appears because the

optimization tool selects the best projects first, and then continue including more projects as the resources increase until the point where there are no more good projects to be included in the portfolio is reached. This means that the organization can choose how many resources to invest in a portfolio depending on the expected profitability, considering that in any case, it is selecting the best possible portfolio with the candidate projects available.

- The case study shows that some projects appear in many portfolios. This indicates that these projects constitute the base for the optimal solutions and, consequently, they are the projects the organization should pay special attention to.

- The project selection problem with data from 2014, showed that project portfolio found using a global optimization approach is better than the portfolio found using a local optimization approach. This result occurs because in the global approach all projects from different business units and regions should compete for the resources in order to find the best solution for the organization. The DSS can help to define how to allocate the resources of the organization by business units or regional divisions.

Another potential uses of the DSS in the organization are described as follows:

- The DSS can find the optimal portfolio road map for the long term planning when the organization has defined the availability of the resources in a planning horizon,

- The DSS can consider another criteria different to the financial.

- The DSS could be used to define and optimize specific portfolios creating project categories for example Industrial, Innovation (R&D) and sustainability projects

5.3   Assumptions and Limitations

The computational tool for project portfolio selection developed in this research relies on some assumptions for its successful implementation as follows:

- First, this approach requires reliable data of the candidate projects for each criteria defined by the user. The reliability of the solution depends on the data included in the problem. This implies that the organization should study each candidate project in order to ensure that the project is aligned with some strategic goal, and the availability of the information of the required resources (money, personnel, etc.) and the expected benefits (financial and nonfinancial).

- Second, this tool requires that all the constraints (either resource or requirement constraints) are linear. For example resources such as money, people, materials, equipment can be expressed as a linear combination of the decision variables and the corresponding parameters. The current formulation included in the code does not admit nonlinear constraints; however AIMMS offers the possibility of

implementing nonlinear integer programming (MINLP) problems which can be

solved by using the solvers AOA, BARON and KNITRO (see Figure 3.3).

The computational tool for project portfolio selection has some limitations as

follows:

- Currently the optimization algorithm can find one optimal portfolio for a set of

  candidate projects, given one or multiple goals and some constraints.   However,

  it is possible (although infrequent) to find situations in which one set of

  candidate projects can produce more than one optimal. In this case only the first

  optimal solution found by the solver is shown and the decision maker might be

  interested in having the other optimal portfolios. To make this possible, it is

  necessary to implement an additional algorithm. This is discussed as further

  research in this chapter.

- Finally, when the user is working with multiple goals, the model uses weighted

  goal programming which requires the user to include the weights in the

  problem. These weights can be defined as a policy by the company decision

  makers or can be the result of a team decision making process using a pairwise

  comparative technique such as Analytical Hierarchy Process (AHP) or some

  similar technique. The definition of the weights depends heavily on the needs of

  the user and is outside the boundaries of this research project. However it is

possible link the tool with a pairwise comparative model to assist the decision

maker in the definition of the weights.

5.4   Recommendations

The use of a computational tool for project selection based on optimization can

provide important insights to the top management and portfolio managers about how

to optimize the use of resources and get the maximum benefits for the organization.

Nonetheless, the successful implementation and deployment of this tool requires

careful consideration of the following recommendations:

- The use of this tool is based on the concept of project portfolio and the

  implementation of a framework of portfolio management as described in section

  3.1. This is a key successful factor for the best use of the optimization model and

  the tool. A strong Project Management Office (PMO) working with the Financial

  Department could carry out this function in the organization and support Top

  Management and Decision Makers.

- The organization of the information in a project data base can facilitate the

  collaborative work between the personal in charge of the technical, financial and

  feasibility studies of the candidate projects. Further, it is possible to link this tool

  with any database that has connectivity ODBC or OLE DB, making the flow of

  data and information much easier.

- The algorithm does not limit the number of candidate projects, goals or constraints. However, in practice the amount of data that the application can successfully handle might be limited by the computational power of the machine where AIMMS is running. It is obvious that the processing time will increase as the size of the problem increases, so it is very important to consider this at the time of implementing the tool.

- The deployment of an end-user application in AIMMS in a business environment requires the acquisition of a license for end users like most of the modeling languages used in optimization applications. However it is possible to install a free application called AIMMS Viewer to check the configuration and results of and optimization problem.

- Finally, the familiarization of the user with the tool is very important. This document includes a brief user manual in the appendix that shows the application of the tool step-by-step.

5.5   Further Research

The development of this Decision Support System for project portfolio selection has many improvement possibilities that are mentioned in the paragraphs below starting in the order of priority according the criteria of the author.

5.5.1   Implementation of an Algorithm to Find Multiple Solutions

In optimization a practical difficulty may arise when the optimal solution of the problem is not unique. The solver presents the first optimal solution found and the process is stopped. It could be useful for the user to know all the possible optimal portfolios in a decision making process. The AIMMS reference manual (Roelofs & Bisschop, 2013) describes the implementation of an algorithm to deal with this problem which uses a new and second objective function specifically designed to deal with eliminating the multiplicity of solutions. The second objective function could be a modification of the original objective function. The second objective function is optimized only after the problem with the first objective function is solved and its optimal value has been added as a constraint.

5.5.2   Implementation of Sensitivity Analysis

The concepts of duality and shadow prices applied in Linear Programming (continuous variables) used to develop sensitivity analysis are not applicable in problems of Integer Programming (discrete variables) (Bisschop, 2013) which are the kind of problems studied in this research. Nevertheless, it is possible to implement a type of sensitivity analysis as described in the business case in section 4.3.2, which shows how the solution changes as the level of a constraint changes. This is relatively easy to implement by defining a set of optimal portfolios depending on the level of a particular target constraint.

5.5.3 Implementation of More Types of Linear Constraints

Currently, this application includes linear constraints for resources, requirements, mandatory projects, mutually exclusive projects and depending projects. However, it is relatively easy to add more types of linear constrains according to the needs of the decision maker. One example of such constrains is the maximum (or minimum) number of projects selected for each project category or the maximum (or minimum) number of projects for the whole portfolio. This can be useful to balance the portfolio and the resources in different business units.

5.5.4 Implementation of Nonlinear Constraints

The implementation of nonlinear constraints is an important improvement of this tool because some criteria can be modeled as nonlinear functions, for example the Payback Period of the portfolio is not the sum of the payback periods of the selected projects. It makes more sense to define the average payback period of the portfolio as the average of the paybacks of the selected projects. The average depends on the number of projects in the portfolio and the number of projects is an unknown making this constraint nonlinear. The implementation of this kind of constraints in the formulation and code is relatively easy, but it is necessary to validate the effectiveness of the solver used by AIMMS for Mixed Integer Nonlinear Programing (MINLP) to find the optimal solution.

5.5.5 Implementation of Optimization with Stochastic Parameters

The possibility of working with stochastic parameters would make the tool more robust and able to deal with the uncertainty of the data (risks). For example, parameters such as investment or NPV of a project in real life are stochastic because there is uncertainty about the actual cost of the project or the NPV achieved. There are two approaches to deal with stochastic data, one is Stochastic Programming and the other one is Robust Optimization.

Stochastic Programming. Finds a solution that is feasible for a set of possible scenarios and maximizes the expected return (objective). Scenarios and probabilities are known. Robust Optimization is suitable when the range of the uncertainty is known and not necessarily the distribution. The robustness of your decisions is measured in terms of the best performance against all possible realizations of the parameters values (Roelofs & Bisschop, 2013).

AIMMS offers support for generating a stochastic (or robust optimization) model from any given deterministic LP/MIP model, without the need to reformulate any of the constraint definitions. By only supplying additional attributes for selected parameters, variables and constraints, AIMMS can generate both a deterministic and a stochastic (or robust optimization) model. A deterministic model, a stochastic model and a robust optimization model can again co-exist within the same master model and their respective solutions can be compared (Roelofs & Bisschop, 2013).

REFERENCES

REFERENCES

Archer, N., & Ghasemzadeh, F. (1999). An integrated framework for project portfolio selection. . *International Journal of Project Management, 17* (4)*, 207–216.

Archer, N., & Ghasemzadeh, F. (2004). Project portfolio selection and management. In P. W. G. Morris & J. K. Pinto (Eds.), *The Wiley guide to managing projects* (pp. 237–255). Hoboken, NJ: John Wiley & Sons

ASTM. *ASTM C150 / C150M-12, Standard Specification for Portland Cement*, West Conshohocken, PA, 2012, ASTM International

Bisschop, J., (2013). *AIMMS: Optimization modeling*. Haarlem, The Netherlands: Paragon Decision Technology

Blocher, E., Stout, D., & Cokins, G. (2010). *Cost management: A strategic emphasis.* (5th ed.). New York, NY: McGraw-Hill Irwin

Bible, M. J., & Bivins, S. S. (2011). *Mastering project portfolio management*. Fort Lauderdale, FL: J. Ross Publishing, Inc.

CANEA Consulting Group (2011). *CANEA projects - project management system*. Retrieved from http://www.canea.com/it-solutions/canea-projects/canea-projects-2011

Cementos Argos (2013). *Argos integrated report 2013*, Medellin, Colombia: Cementos Argos

CEMEX (2011). *How we produce cement*. Retrieved from http://www.cemexbangladesh.com/ce/ce_cb_pf.html

Chen, D., Batson, R. G., & Dang, Y. (2010). *Applied integer programming.* Hoboken, NJ: John Wiley & Sons.

Dey, P. K. (2006). Integrated project evaluation and selection using multiple-attribute decision-making technique. *International Journal of Production Economics, 103*(1), 90–103

DSMAC. (2014). *Sand and cement cogeneration plant*. Retrieved from http://www.dscrusher.com/solutions/production-line/sand-cement-cogeneration-production-line.html

Eiselt, H. A., & Sandblom, C. (2012). *Operations research: A model-based approach.* (2nd ed.). New York, NY: Springer

Expert Choice. (2014). *Comparion for project portfolio management*. Retrieved from http://expertchoice.com/comparion/applications/project-portfolio-management

Fourer, R., Gay, D. & Kernihan, B. (2003). *AMPL: A modeling language for mathematical programming.* (2nd ed.). Pacific Grove, CA: Brooks/Cole-Thompson Learning.

Fourer, R. (2013, June). Linear programming software survey. *OR/MS Today, 40*(3). Retrieved from http://www.informs.org/ORMS-Today/

Ghasemzadeh, F. , Archer, N., & Iyogun, P. (1999). A Zero-one model for project portfolio selection and schedulling. *The Journal of the Operation Research Society, 50* (7)*,* 745–755.

Ghasemzadeh, F., & Archer, N. P. (2000). Project portfolio selection through decision support. *Decision Support Systems, 29*(1), 73–88.

Heidenberger K., Stummer C. (1999) Research and development project selection and resource allocation: A review of quantitative modeling approaches, *International Journal of Management Reviews*, 1 (2), 197-224

Jones, D., & Tamiz, M. (2010). *Practical goal programming*. New York, NY: Springer.

Jugdev, K., & Muller, R. (2005). A retrospective look at our evolving understanding of project success. *Project Management Journal, 36*(4), 19–31.

Kelton, D., Sadowski, R., & Swets, N. (2010). *Simulation with Arena.* (5th ed.). New York, NY: McGraw-Hill

Lee, J. W., & Kim, S. H. (2000).Using analytic network process and goal programming for interdependent information system project selection. *Computer and Operation research, 27*(4), 367–382.

McLeod, L., Doolin, B., & MacDonell, S. (2012). A perspective-based understanding of project success. *Project Management Journal, 43*(5), 68–86.

Mantel, S. J., Meredith, J. R., Shafer, S. M., & Sutton, M. M. (2011). *Project management in practice* (4th ed.). Hoboken, NJ: John Wiley & Sons.

Nelson, R. R. (2005). Project retrospectives: evaluating project success, failure, and everything in between. *MIS Quarterly Executive, 4*(3), 361–371.

PCA-The Portland Cement Association (2014). *America's Cement Manufacturer*. Retrieved from http://www.cement.org/cement-concrete-basics/how-cement-is-made

Project Management Institute. (2008a). *A guide to the project management body of knowledge (PMBOK® guide)* (4th ed.). Newtown Square, PA: Project Management Institute.

Project Management Institute. (2008b). *The standard for portfolio management* (2nd ed.). Newtown Square, PA: Project Management Institute.

Robinson, S. (2008). Conceptual modeling for simulation part I: Definitions and requirements. *Journal of Operations Research Society*, 59 (3): 278-290

Roelofs, M., & Bisschop, J, (2013). *AIMMS: The user guide*. Haarlem, The Netherlands: Paragon Decision Technology.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences, 1*(1)*,* 83–98.

Sarkis, J., Presley, A., & Liles, D. (1997). The strategic evaluation of candidate business process reengineering projects. *International Journal of Production Economics, 50*(2–3), 261–274.

Schniederjans, M. J., & Wilson, R. L. (1991). Using the analytic hierarchy process and goal programming for information system project selection. *Information and Management, 20*(1991), 333–342.

Shenhar, A. J., Levy, O., & Dvir, D. (1997). Mapping the dimensions of project success. *Project Management Journal, 28*(2), 5–13.

Sprague, R. H, & Carlson, E.D. (1982). *Building effective decision support systems*. Englewood Cliffs, NJ: Prentice Hall

Strang, K. D. (2011). Portfolio selection methodology for a nuclear project. *Project Management Journal, 42*(2), 81–93.

The GenSight group (2011). *New product portfolio managemen*t. Retrieved from http://www.gensight.com/Project-Portfolio-Management/Process/New-Product-Portfolio-Management.htm

Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: An overview of applications. *European Journal of Operation Research, 169*(1), 1–29.

Winston, W. L., & Venkataramanan, M. (2003). *Introduction to mathematical programming. Operations research: Volume one* (4th ed.). Belmont, CA: Cengage.

APPENDIX

APPENDIX

DSS PROJECT PORTFOLIO SELECTION-TUTORIAL

This section contains a brief guide for the use the DSS for project section. This

guide shows the solution of a simple problem step-by-step.

STEPS IN THE SOLUTION OF A PROBLEM IN THE DSS

The solution of a project selection problem in the DSS has the following

sequence:

1. Problem configuration

2. Data Input: Projects, Objectives and Constraints

3. Solution: Portfolio, Objective Achievement and Constraints

4. Reports

PROBLEM STATEMENT

This problem is an adaptation of a problem proposed by Winston and

Venkataramanan (2003) as follows:

A small aerospace company is considering eight projects for the portfolio. Each

project has been rated on five attributes: NPV, cost, productivity improvement,

worker requirements, and degree of technological risk. These ratings are given in the table below:

Table A.1.

Criteria and Candidate Projects

Goals	Proj 1	Proj 2	Proj 3	Proj 4	Proj 5	Proj 6	Proj 7	Proj 8
ROI ($)	2,070	456	670	350	495	380	1,500	480
Cost ($)	900	240	335	700	410	190	500	160
Productivity	3	2	2	0	1	0	3	2
People	18	18	27	36	42	6	48	24
Risks	3	2	4	1	1	0	2	3

The problem in this tutorial is labeled as "Test 1". The objective of Test 1 is to maximize NPV, limiting total cost to $1,300 and it does not include any project interdependence constraints. No other criteria are considered in this test.

MAIN PAGE

Figure A.1 shows the screenshot with the initial page of the DSS (Main Page) which

contains a brief information of the DSS and se sequence to solve a problem.
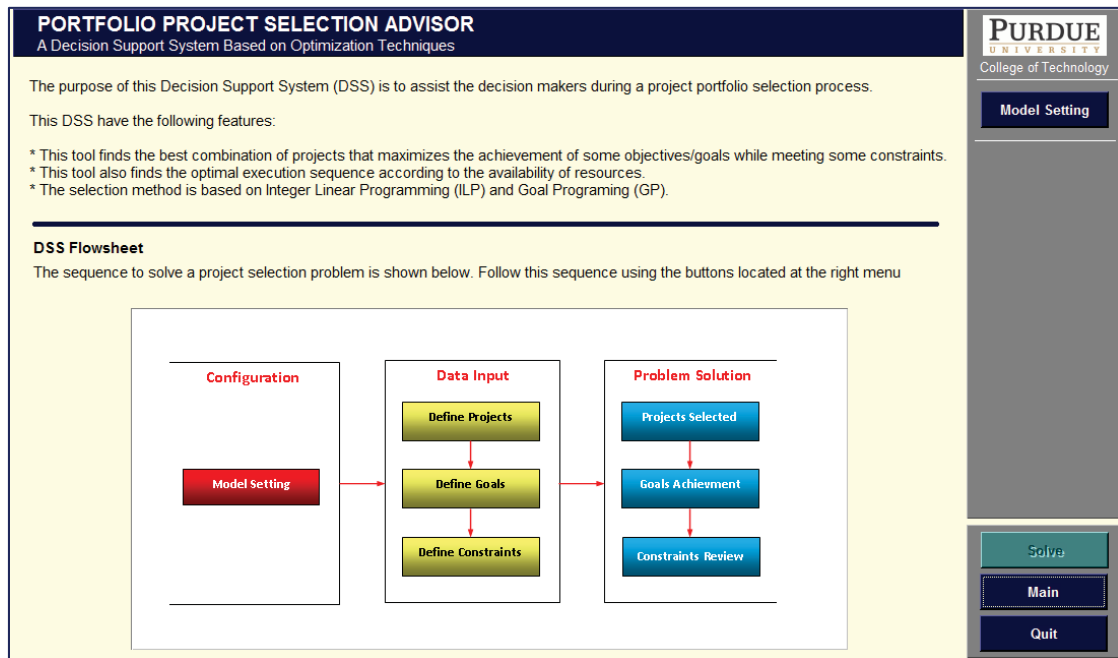
Figure A.1   Screenshot of the Main Page of the DSS

On the right menu bar you have the following options:

- Press "Model Setting" button to continue

- Press "Quit" button if you want to Exit the DSS

Each time you select the "Main" button in the DSS you will be returned to this page

STEP 1: PROBLEM CONFIGURATION

Figure A.2 shows the screenshot with the Configuration Page in the DSS.

Figure A.2   Screenshot of the Configuration Page for Test 1

1. Company, User, and Reference: Input the name of the company, user and a reference to this selection problem respectively.

2. Date/Time: This field is filled in automatically.

3. Goals: Select one goal.

4. Periods: Select one period.

5. Criteria: include all the criteria considered in the problem: NPV, Cost, Risk, Productivity and Manpower.

6. Go to the menu bar and press the "Candidate Projects" button.

STEP 2: INPUT: CANDIDATE PROJECTS

Figure A.3 shows the screenshot of the Projects Input page for Test 1.

Figure A.3 Screenshot of the Projects Input Page for Test 1

1. Candidate Projects: Input the number of candidate projects

2. Fill in the project information. There is two ways of input the projects data:

- Filling the fields for the candidate projects: Input the information for each

  project candidate: name, category 1, category 2 and duration as default fields.

  Add the information for each criteria you have defined in the Configuration Page.

- Import from Excel: In order to import the information from Excel, the data

  should be input as shown in Figure A.4 staring in the cell A1. Project number,

  name, category 1, category 2 and duration are default fields. The criteria start

from column F in the same order as was included in Figure A.2. In the Page,

input the Excel file name and the sheet name that contains the data.

Figure A.4 Screenshot of the Excel Spreadsheet with Data for Test 1

3. Go to the menu bar and press the "Objective-Goals" button

STEP 3: INPUT: OBJECTIVE

Figure A.5 shows the screenshot of the objective input page.

Figure A.5 Screenshot of the Objective Input Page for Test 1

1. Objective: In the upper Drop Down List, select the objective from the criteria list.

   In this case select "NPV".

2. Objective Information: For the objective selected, define the direction of the

   optimization (Maximize or Minimize). In this case, select "Maximize" in the Drop

   Down List labeled as Direction.

3. Go to the menu bar and press the "Constraints" button.

STEP 4: INPUT: CONSTRAINTS

Figure A.6 shows the screenshot of the constraint input page.

Figure A.6 Screenshot of the Constraint Input Page for Test 1

1. Constraints: In the upper checkboxes, select the constraints from the criteria list. In this case select "Cost".

2. Constraint Information: For the constraint selected, define the operator (≥ or ≤) and the threshold. In this case, select "Cost", the operator "≤" and the threshold "$1,300".

3. Go to the menu bar and press the "Solve" button

STEP 5: SOLUTION: PORTFOLIO
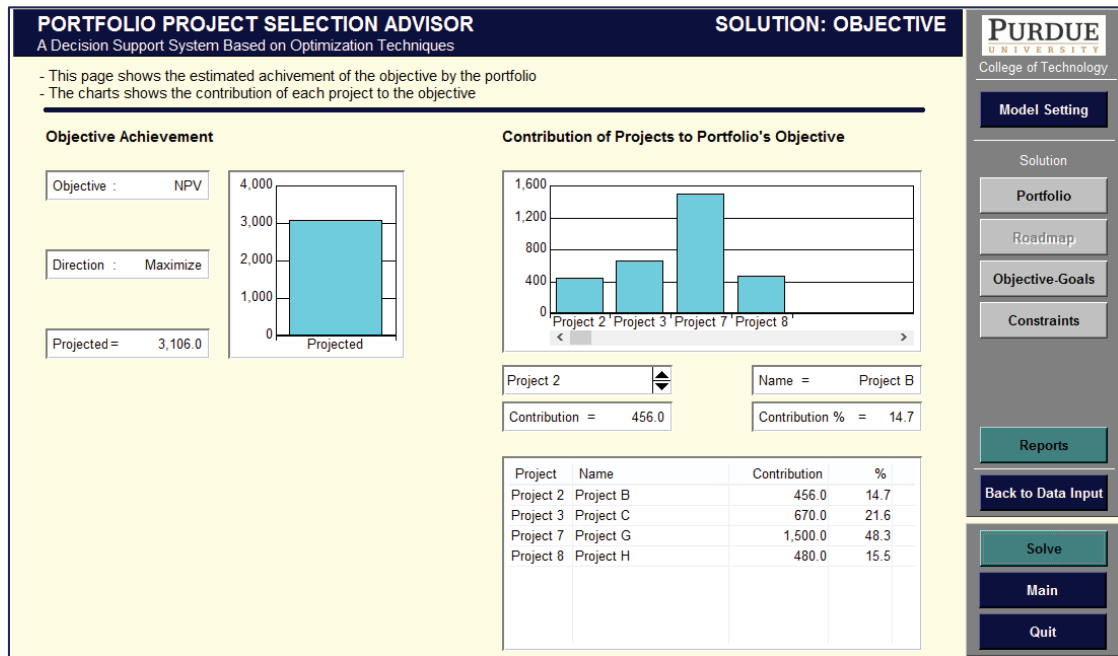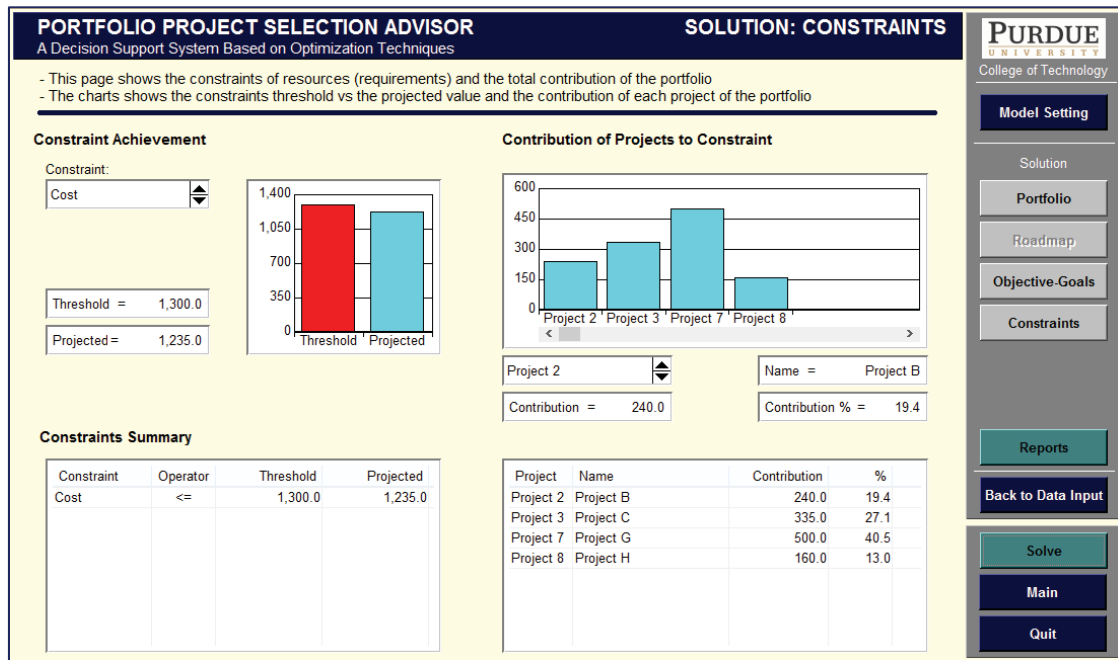
Figure A.7 shows the screenshot of the Solution-Portfolio page.
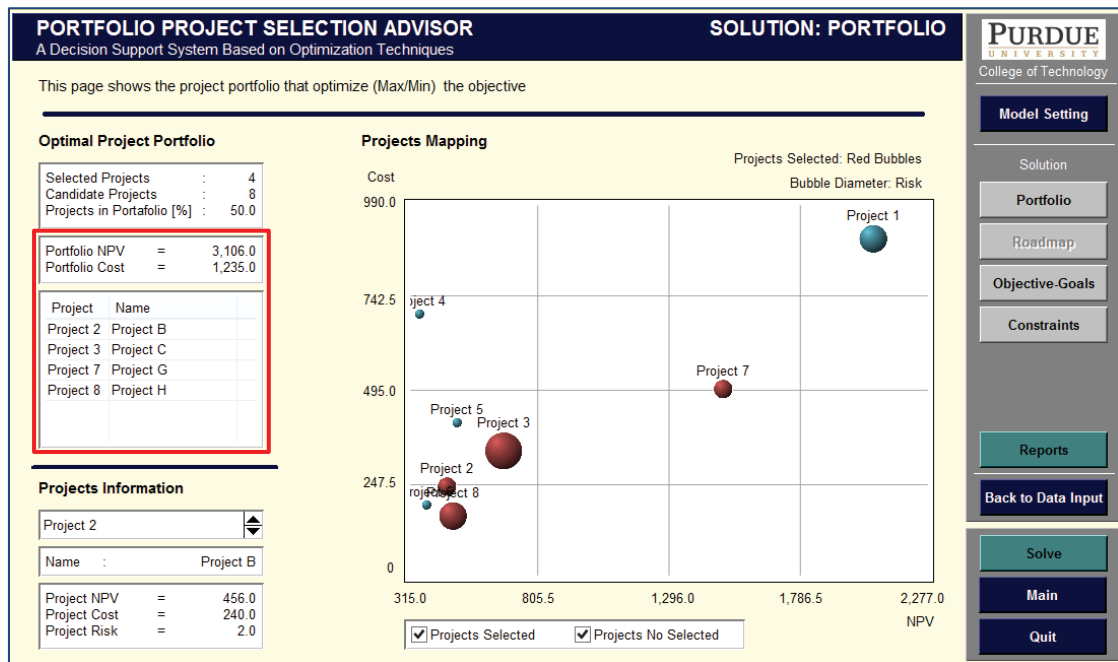
Figure A.7 Screenshot of the Solution Page for Test 1

In the Solution-Portfolio page can be found the following information:

- Number of projects selected: 4

- Number of candidate projects: 8

- % of projects in the portfolio: 50%

- The total NPV of the portfolio: $3,106

- The total cost of the portfolio: $1,235

- Project selected: projects 2, 3, 7 and 8

- A bubble chart that shows in the x-axe the NPV and in the y-axe the cost. The

  projects selected are the red bubbles and the projects not selected are blue

ones. The risk is by default the diameter of the bubble. It is possible display only

the set of projects selected or the set of projects no selected or using the check

box in the lower part of the bubble chart.

- Projects information. You can select any project and the information of the

  project NPV, cost and risk is shown.

Go to the menu bar and press the "Objective-Goals" button

STEP 6: SOLUTION: OBJECTIVE

Figure A.8 shows the screenshot of the Solution-Objective page.

Figure A.8 Screenshot of the Solution-Objective Page for Test 1

In the optimal Solution-Objective page can be found the following information:

- Objective: NPV

- Direction: Maximize

- Estimated value: $3,106

- A bar graph and a table with the contribution of each project to the objective

Go to the menu bar and press "Constraints" button

STEP 7: SOLUTION: CONSTRAINT

Figure A.9 shows the screenshot of the Solution-Constraints page.

Figure A.9 Screenshot of the Solution-Constraint Page for Test 1

In the optimal Solution-Constraints page can be found the following information:

- Constraints: Cost

- Threshold: $1,300

- Estimated value: $1,235

- A bar graph shows the constraint threshold and the estimated value.

- A bar graph and a table with the contribution of each project to the constraints.

Go to the menu bar and press "Reports" button

STEP 8: CHECK REPORTS MENU

Figure A.10 shows the screenshot of the Optimal Portfolio page.

Figure A.10   Screenshot of the Reports Page for Test 1

In the Reports it is possible the following:

- View Report. The report screenshot is shown in Figure A.11

- Print Report. The report can be send to a printer.

- Print and Save Report. The report can be printer and saved as *.ps file

- Export results to Excel: Write the name of the Excel file. The result will be in the directory Results\. The Excel file is shown in Figure A.12
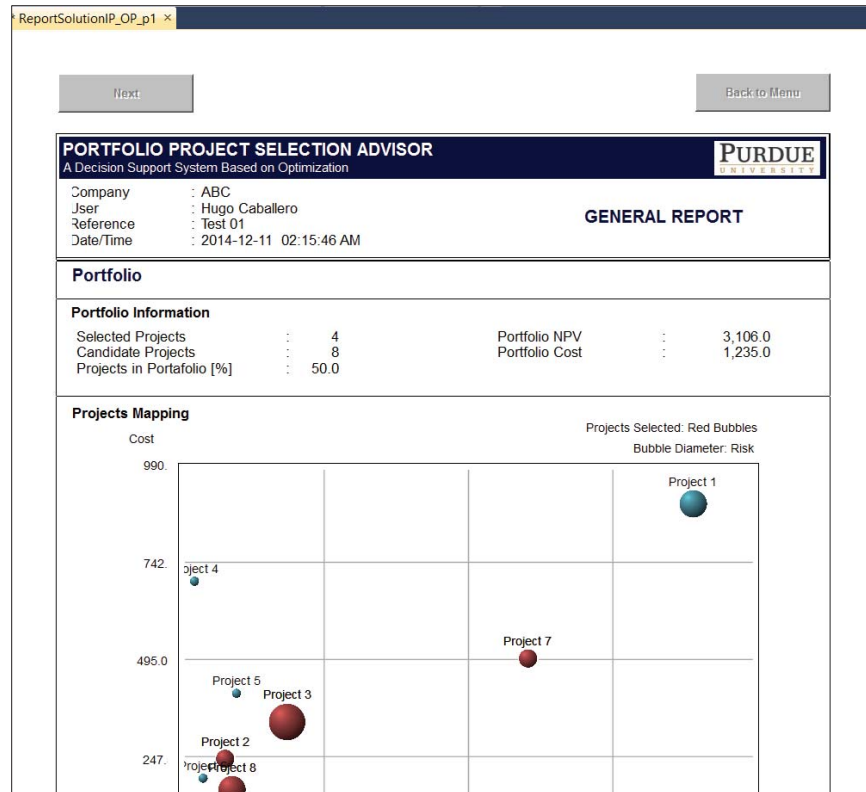
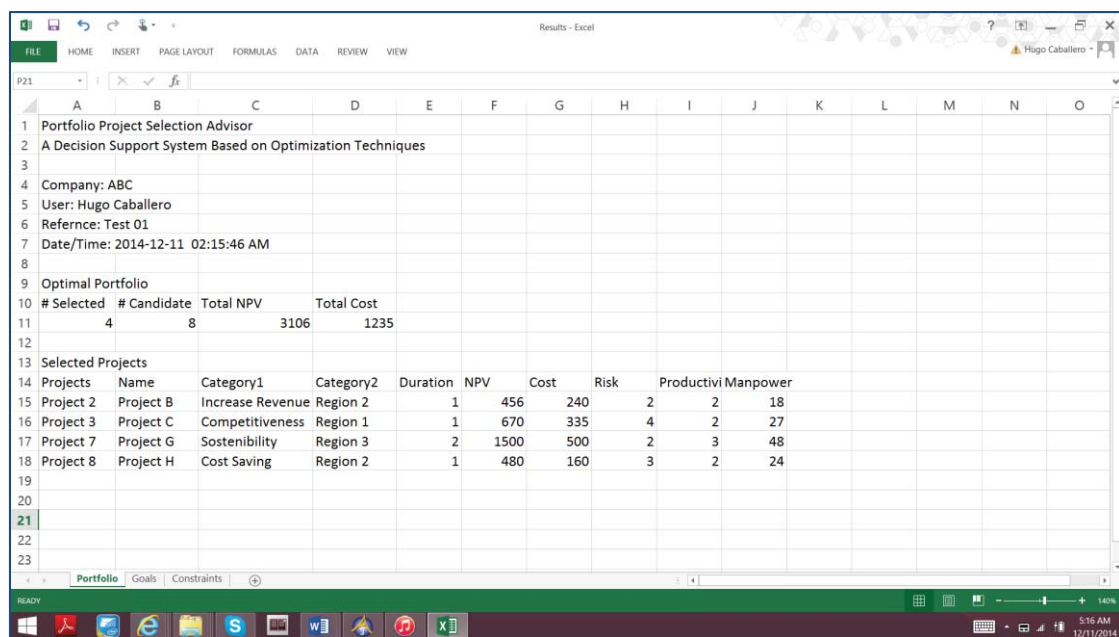*Figure A.11*   Screenshot of the Report for Test 1

Figure A.12   Screenshot of the Excel File for Test 1

VITA

VITA

Hugo was born in 1974 in to Guido and Blanca de Caballero in Barranquilla, Colombia, and has a younger sister, Idania Carolina.

Hugo received his Bachelor of Science degree in Mechanical Engineering from Universidad del Norte in Barranquilla, Colombia. Upon graduation he joined the Cummins distributor in Colombia as service engineer. After a couple years Hugo received his MS in Mechanical Engineering from Universidad de los Andes in Bogota, Colombia and then returned to the Cummins distributor as service manager. After three years Hugo joined to Cementos Argos in Colombia as a project engineer. After six years of experience leading projects in cement industry. This experience led to an interest in the field of project and portfolio management and he applied to a Fulbright scholarship for graduate studies at Purdue University. Hugo got a MS Industrial Engineering focus on Operations Research in 2013 and a Ph.D. in Technology in 2014 working with Dr. Edie Schmidt.

Hugo Caballero is married to Rita Jaramillo, a Ph.D. student in the Mechanical Engineering department of Purdue University. Hugo and Rita are parents to an eight-years-old daughter, Alejandra.