IT PORTFOLIO ATTRIBUTES AND INVESTMENT CHOICES

BY

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DISSERTATION

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ABSTRACT

Many Chief Information Officers (CIOs) and senior executives face the challenge of finding the appropriate IT resource allocation to meet enterprise strategic goals across multi-organizational units. To address this problem, my dissertation opens the black box of enterprise strategic IT resource allocation by examining the prioritization and selection of IT investment choices (i.e., IT initiatives). Since IT Portfolio Management (ITPM) involves making applicable decisions to achieve a firm's strategic objectives by fine-tuning budgeted costs and returns as business conditions change, my dissertation examines an important class of IS decision problems: IT portfolio attributes and investment choices. My research addresses how a firm can systematically profile numerous IT portfolios and provide theoretical insights into the components of the optimal solution. Based on design science, my specialized method incorporates mathematical optimization and computational experiments and combines real-world data using the Monte Carlo approach to simulate the experimental data. Consequently, by combining the suggested IT portfolio attributes while addressing a variety of ITPM-related issues, the main contribution for my research is a new ITPM-related methodology built on three proposed ITPM models/techniques: (1) optimal efficiency across multi-organizational levels/units simultaneously; (2) the most qualified IT portfolio selection that incorporates decision-makers' risk tolerance levels; and (3) accurately estimating the current financial standing of each project in a portfolio of IT projects over the project's full lifecycle. By applying the proposed ITPM-related methodology with illustrative examples, I develop theoretical propositions based on my main findings.

Keywords: IT Portfolio Management (ITPM), efficiency, risk tolerance levels, financial standing

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Chapter 1. Introduction to the Dissertation

In 2014, global information technology (IT) spending grew by 3.2% to total $3.8 trillion U.S. dollars, according to the latest forecast by the research firm Gartner, Inc. (2014). IT budgets reflect the underlying techniques for the production of information services; thus, the analyzing budget data can provide considerable insights into the nature of the production process as well as useful benchmarks for best practice (Gurbaxani et al., 1997). Chan et al. (1997) found that the "fit" between an Information System (IS) and a business's objectives is significantly associated with the firm's performance. Of the three types of proxy logic (Technology as Perception, Technology as Diffusion, and Technology as Capital), my research is mainly built on Technology as Capital, which is also known as the monetary measure of technology (Orlikowski and Iacono, 2001). To improve the performance of IT investments, Maizlish and Handler (2005) indicate that the communication associated with collaboration between IT and business value is the most vital aspect of IT Portfolio Management (ITPM). ITPM aims to manage IT assets as a whole through methods similar to those required for managing financial portfolios (McFarlan, 1982; Bardhan et al., 2004; Weill and Aral, 2006), along with nonfinancial methods of evaluation (Betz, 2007).

In finance literature, portfolios are collections of investments owned by an institution or an individual, and portfolio management is about analyzing different investments as a whole. According to Kumar et al. (2008), financial portfolio management mainly focuses on a variety of asset classes (e.g., stocks, bonds, and cash) to maximize expected returns during a specified period of time for a given risk. Since the market typically determines each financial asset's value, financial assets are more liquid than real assets, and investors can periodically trade financial assets in the market. Specifically, many studies show that the Modern Portfolio Theory (MPT) has had a significant impact on the practice of portfolio management through its wide applicability across many fields. The MPT asserts that the most efficient portfolio choice has the highest portfolio value for a given portfolio risk. Therefore, MPT provides a framework for constructing and selecting portfolios based on the expected performance of the investor's investments and risk appetite (Fabozzi et al., 2002).

Following the implementation of the Sarbanes-Oxley Act, investment issues have become a great concern for many senior executives, and many enterprises are under pressure to implement more effective IT investment controls. My dissertation focuses on IT Investment Planning and Decision Making to address key elements of IT Governance. Many enterprise investment decisions have been strictly scrutinized, and thus my dissertation aims to examine an important class of IS decision problems: IT portfolio attributes and investment choices. The objectives of my ITPM research are to demonstrate how a firm can systematically profile numerous IT portfolios and to provide theoretical insights into the optimal solution's components. By integrating Zhu (2003) and Ray et al.'s (2005) concepts, the IT portfolio level, which is defined as the IT project portfolio in this dissertation, can be seen as a bridge connecting the project level to the firm level in terms of internal IT resource allocation. Hence, I will address ITPM issues related to decision-making in this dissertation's three chapters: (1) Chapter 2: The Effect of Information Technology (IT) Portfolio Composition on Portfolio Efficiency: The Roles of Project Size, Complexity and Strategic Objectives in Identifying IT Portfolio Attributes and Evaluating the Efficiency of Portfolio; (2) Chapter 3: Selecting the Most Qualified IT Portfolio Choice under Various Risk Tolerance Levels; and (3) Chapter 4: Using the Mark-To-Market Valuation Technique to Objectively Measure IT Portfolios.

In addition to proposing a new ITPM methodology, my research uses a large amount of empirical data related to IT investment project portfolios, which facilitates a better understanding of IT project portfolio characteristics across business units. Based on design science, my methodology incorporates mathematical optimization and computational experiments, including the Monte Carlo approach, to simulate the experimental data. Along with combining real-world data using the Monte Carlo approach to simulate a firm's IT portfolios, my contribution to academics and practice is to provide IT portfolio profiles while demonstrating numerous scenarios in the ITPM context. Accordingly, after applying the proposed ITPM methodology to illustrative examples, my research provides numerous theoretical propositions based on my main findings.

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Chapter 2. Effect of Information Technology (IT) Portfolio Composition on Portfolio Efficiency: The Role of Project Size, Complexity and Strategic Objectives

I. INTRODUCTION

With the increasing importance of information technology (IT) in diverse business functions, a growing set of evidence suggests that investment in IT produces value at a variety of organizational levels. At the firm level, research has demonstrated that IT investment translates into profitability (e.g., Melville, Kraemer and Gurbaxani, 2004; Mithas, Tafti, Bardhan and Goh, 2012). At the internal organizational process level, IT is considered to be a critical enabler for transforming IT resources into business value (e.g., Ray, Muhanna and Barney 2005). Thus, an IT portfolio, which is defined as an IT project portfolio in this paper, is an internal bridge connecting the project level allocation of enterprise resources to firm level business results (e.g., Archer and Ghasemzadeh, 1999; De Reyck, Grushka-Cockayne, Martin, Calderini, Moura, and Sloper, 2005).

Moreover, since many Chief Information Officers (CIOs) and senior executives have difficulty appropriately allocating IT resources across multi-organizational units in order to accomplish their enterprise strategic goals, the motivation of this research is to open the black box of enterprise strategic resource allocation in terms of IT-related investments. Although this research recognizes that investment decisions in complex business environments are fraught with political and organizational challenges (Shimizu and Hitt, 2004; Weill and Ross, 2004), modeling these challenges is beyond the scope of this paper. Given that measuring and managing IT investment across organizational levels/units is critical for an enterprise, the research question of this paper is: "How can a senior executive improve the efficiency of IT resource allocation across multi-organizational units?" For these reasons, this paper aims to address this research question using a new IT Portfolio Management (ITPM) model to evaluate the efficiency of business units simultaneously considering the needs of various IT portfolios. Instead of being determined by senior executives' intuition, weight scores generated by the proposed model enable a firm to create a rational viewpoint for better allocating IT resources.

Furthermore, this research examines how an IT portfolio profile that is composed of different IT projects leads to superior portfolio performance. As a result, the three main contributions of this research are as follows: first, the new model is beneficial in the ITPM context because senior executives, primarily IT executives, can use it to better allocate IT resources and thereby accomplish their strategic goals across multiple business units; second, this research finds that IT project portfolios may be defined by the proposed portfolio attributes: benefit, budgeted cost, portfolio distribution, project portfolio diversity following the combination of project types, and project portfolio technical complexity; lastly, the findings of this study indicate that: (1) a firm that concentrates its IT investment on one or a very small number of large IT projects (Dominant IT portfolio) is able to manage technical complexity and take on projects to improve its operating margin with high efficiency; (2) a firm that allocates its IT investments to all of the IT projects within a certain range (an even distribution-based IT portfolio) is able to cope with numerous types of IT projects with low technical complexity, which may contribute to a more balanced utilization of IT resources and thereby yield better operating margins and long-term growth; and (3) a firm that distributes its IT investments to a portfolio composed of diversified IT projects (an uneven distribution-based IT portfolio) is able to deal with projects of higher technical complexity and thereby reach operation efficiency and innovative adaption. Accordingly, this paper proposes three theoretical propositions building from these findings and aims to move toward an ITPM-based theory.

This paper is organized as follows. Section II reviews related theoretical studies. In Section III, this study draws on the DEA/Parallel (DEA/P) model to propose a new ITPM model. In Section IV, the proposed methodology is illustrated with a hypothetical example and also concludes the results, and Section V summarizes the findings while moving toward a theory.

II. THEORETICAL DEVELOPMENT

2.1 IT Portfolio Management (ITPM)

An important managerial principle for increasing productivity is to manage all IT portfolios in a holistic way. According to Jeffery and Leliveld (2004), the definition of IT portfolio management is, first, to manage IT as a portfolio of assets that is similar to a financial portfolio and, second, to strive to improve the performance of the portfolio by balancing risk and return. Additionally, Maizlish and Handler (2005) indicate that the collaboration between IT and business value is the most vital aspect of IT portfolio management. By integrating Zhu (2003) and Ray et al. (2005)'s concepts, an IT portfolio level can be considered a bridge connecting the project level to the firm level in regards to internal strategic resource allocation.

With the increasing influence of IT on all businesses within an enterprise, many firms have greatly increased IT investment in recent years (Kohli and Grover, 2008). In order to establish a good IT Portfolio Management (ITPM) framework, enterprise executives may need to identify measurable strategic objectives embraced by various business units. In response to this need, the central goal of this research is to provide various kinds of business scenarios that illustrate IT resource allocation so that IT executives can select the most appropriate IT portfolio and achieve their enterprise strategic goals.

2.2 IT Project Portfolio Management (IT PPM)

Generally, project management is the application of managerial systems to perform a project from the beginning to end, and it is the primary mechanism for managers to achieve their objectives in terms of schedules, budgets, and revenue (Huang et al., 2013). With reference to Ajjan et al. (2008) and De Reyck et al. (2005), Project Portfolio Management (PPM) is the process of managing a collection of projects to accomplish a firm's strategy. According to the Project Management Institute (PMI), Portfolio Management can be defined as the centralized management of one or more portfolios, which includes identifying, prioritizing, authorizing, managing, and controlling projects, programs, and other related work in order to achieve specific strategic business objectives.

From an enterprise IT point of view, an IT project is the main tactical level through which IT activity translates to business results for the enterprise (e.g., Engwall and Jerbrant, 2003; Chiang and Nunez, 2013). Specifically, since IT projects account for most of the IT spending, IT projects need to be considered on the same enterprise level as business problems because most IT components are customized for an enterprise through project implementation (Cho and Shaw, 2013; Huang et al., 2015). In line with this perspective, the core of IT Project Portfolio Management (IT PPM) is project selection and resource allocation, and Data Envelopment Analysis (DEA) has been shown to be a specific solution approach for giving both subjective and objective evaluations (Chiang and Nunez, 2013).

2.3 IT Portfolio Attributes

Building on Maizlish and Handler (2005)'s IT portfolio concept, function-enabled attributes make a firm quickly recognize which business processes, information types, and related applications will possibly be affected. Regarding technical complexity of IT projects, the technical condition attributes emphasize the need for new technical versions to fulfill standards as well as to specify operational shortcomings. Additionally, variations across business areas or geographies may significantly impact the business process level. Englund, Graham, and Dinsmore (2003) mention that firms may have a large number of different projects within their portfolios in terms of IT project types; the more these projects vary, the more challenging their management process will be. Moreover, according to Prahalad and Bettis (1986), dominant general management logic can be defined as a way in which managers conceptualize the business and make critical resource allocation decisions.

2.4 Productivity Theory and Data Envelopment Analysis (DEA)

Understanding a firm's production is important for efficiently implementing its information systems into business functions, since the principal activity of any firm is to turn inputs to outputs. Prior research indicates that production theory has been widely utilized to uncover how best to combine resource inputs and thereby achieve desired outcomes, including the efficiency of resource allocation based on a firm's input-output relationships (Theodori et. al, 2006). Given a set of inputs that produce outputs, the production function defines an optimum relationship for producing the maximal amount of output. While allocating enterprise resources to address the optimization of production processes, each organizational unit that incorporates inputs (e.g., cost) and outputs (e.g., return) can be seen as a production unit, or a Decision Making Unit (DMU).

With reference to Hitt and Brynjoifsson (1996), production theory can be used to evaluate IT investments concerning IT productivity. Compared to other production models, Data Envelopment Analysis (DEA), which was proposed by Charnes, Cooper and Rhodes (1978), lessens the complexity of analysis by concurrently measuring the relevant attributes of multiple Decision Making Units (DMUs) and then turning out a composite score, referred to as the efficiency (Powers and McMullen, 2000). In other words, since the DEA model is known as a non-parametric approach and a linear fractional programming model, there is no need for the DEA model to include explicit mathematical forms between inputs (e.g., cost) and outputs (e.g., return). The DEA model can be broadly used for efficiency analysis to address the inputs consumed by the outputs produced, and it also can show the tradeoffs in achieving various performance metrics (Banker et al., 2004, 2011). Dia (2009) indicates that maximizing value requires linking the portfolio problem to the challenge of enterprise resource allocation. Hence, when the inputs and outputs of IT investments in a portfolio are considered in the production process, the efficiency scores generated by the DEA model can be used to represent IT portfolio value.

2.5 The Parallel DEA Model and its contributions

The DEA model has been applied in a wide range of applications to measure the relative efficiency of peer DMUs that have multiple inputs and outputs. The assumption of conventional DEA is that organizational units (e.g., firms) are considered to be individual DMUs without connecting them to lower organizational levels when measuring the efficiency of resource allocation. Before the concept of the parallel production model was applied to the DEA model, researchers considered individual organizational units as DMUs without connecting them to lower organizational levels when measuring the efficiency of resource allocation.

To address various modifications of the standard DEA models, research on parallel production systems began with Färe and Primont (1984). The network DEA model, which has linear constraints, was subsequently introduced by Färe and Grosskopf (2000). Following this idea, Kao (2009) applied a theory and models from their earlier work and created the general DEA parallel model. Its fundamental assumption is that a production system with multiple processes operates independently. According to Kao (2012), the parallel DEA model is constructed with the underlying assumption of constant returns to scale, and the parallel DEA model can be modified to a model developed by Banker et al. (1984) to accommodate the variable returns to scale.

In addition, the parallel DEA model can decompose a system into multiple separated processes through the concept of the parallel production system and then can measure both the system and its process efficiencies in one linear fraction model. More constraints are considered in the parallel DEA model due to the logic of multiple parallel processes in linear programing applications. As shown in the following sections, this research extends the parallel DEA model to develop a new model, which is known as DEA/Parallel model.

III. MODEL DEVELOPMENT

3.1 Research Design and Research Approach

The definition of IT Portfolio Management (ITPM) is a firm's total investment in computing and communication technology, or the sum total of all of its IT projects (Weill and Vitale, 2002). Regarding ITPM research, the main focus of this paper is IT project portfolio management. My research team had some opportunities to collaborate with a Fortune 50 firm located in the Midwestern United States; therefore, I had the chance to look into firm's IT project portfolio data. With regard to research design, based on design science, the method section of this paper incorporates mathematical optimization and combines IT project portfolio data with the Monte Carlo approach to simulate its experimental data.

To measure the efficiency of IT portfolios that incorporate key IT portfolio attributes, this research aims to develop a model that includes important parameters that may uniquely characterize the IT portfolio. Moreover, according to Boonstra (2003) and Mintzberg et al. (1976), decision patterns can be identified and analyzed, although organizational decision-making is highly complex and unstructured. The paper's research approach, shown in Figure 2.1, follows this concept, and this paper attempts to identify how an IT portfolio profile (or IT investment decision patterns) composed of various IT portfolio attributes can contribute to portfolio performance. With the proposed ITPM model built on the concept of the DEA/Parallel model in the Section 3.3 and Section 3.4, the objective of this research is to build a systematic approach and drive toward theoretical propositions.

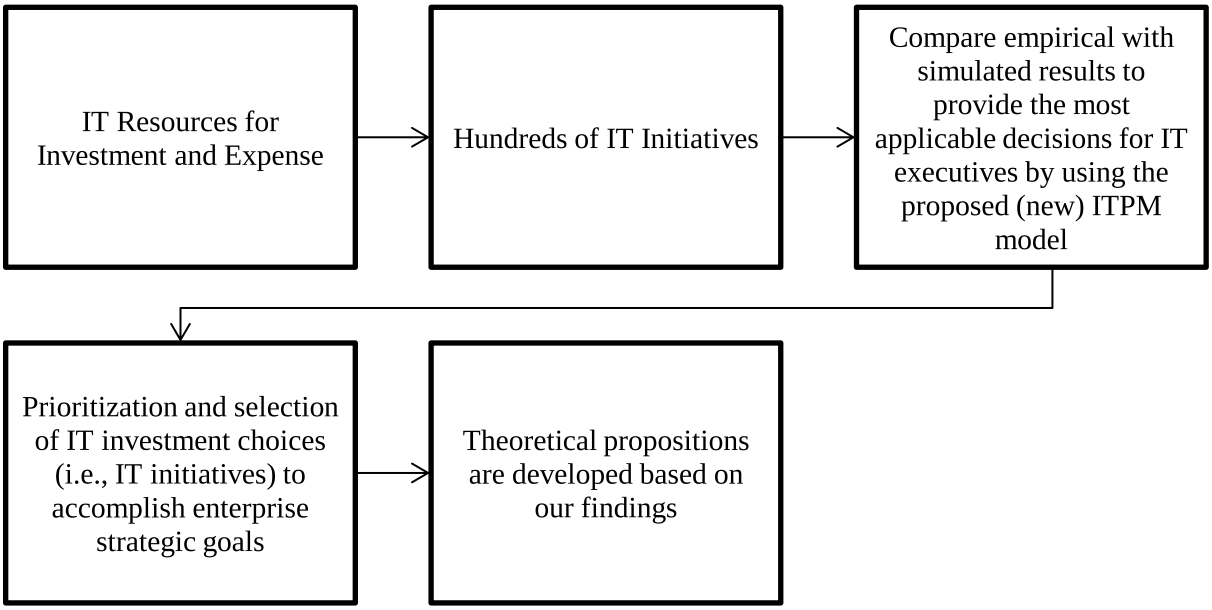

Figure 2.1: Research Approach

3.2 The Data Envelopment Analysis (DEA) Model in the ITPM context

Concerning the optimization of production processes while allocating enterprise resources, each organizational unit that incorporates inputs (e.g., cost) and outputs (e.g., return) can be seen as a production unit, otherwise known as a Decision Making Unit (DMU) (e.g., firms and IT projects). Since organizations intend to minimize inputs and maximize outputs, the Data Envelopment Analysis (DEA) model is a regarded as an appropriate method that calculates the efficiency of DMUs based on the input and output data of individual DMUs and then ranks them (Tanriverdi and Ruefli, 2004; Cho, 2010). With the assumption of constant returns to scale, any proportional change in inputs leads to the same proportional change in outputs, and the DEA-CCR model is appropriate for resource allocation operations under constant returns to scale (Charnes et al., 1978). However, if the assumption of constant returns to scale does not hold, the DEA-BCC model, proposed by Banker et al. (1984), could be used instead. The DEA-BBC model accommodates variable returns to scale.

Regarding IT investments, the relationship between return and risk may be non-linear (Tanriverdi and Ruefli, 2004). Since the DEA model is known as a non-parametric approach and a linear fractional programming model, it can be used with the heterogeneous metrics of inputs and outputs in the ITPM context (Cho, 2010). In other words, the DEA model does not assume a linear relationship between outputs and inputs, and therefore there is no need for the DEA model to include explicit mathematical forms between inputs (e.g., cost) and outputs (e.g., return). Consequently, the DEA model can uncover hidden relationships among multiple inputs and outputs. My research assumes that the overall IT budget of the firm is already allocated to multiple business units/divisions in a way that reflects each business unit/division's strategic goals. This paper aims to develop a new model built on the features of the DEA model that can combine various IT portfolios attributes to address organizational performance in the ITPM domain, as shown in Table 2.1. Motivated by the non-linear relationship between inputs and outputs in IT investment, one of the key features of the DEA model is to produce an optimal combined ratio of all the inputs to outputs and to generate an efficiency score between 0 and 1 as a final outcome. As a result, the efficiency score generated by the DEA model can be considered as the IT portfolio value in this research.

Table 2.1: DEA model applied in the ITPM context

Concept of DEA model →	Mathematical equation
The DEA model will derive an efficiency score between 0 and 1 for each DMU by solving the following question. Maximize score of DMU k Subject to: For every DMU j (including k) $\text{score}_j \leq 1$ Score = $\dfrac{\text{weighted Sum of Outputs}}{\text{weighted Sum of Inputs}}$ Through the normalization process, the weighted sum of inputs can be equal to 1 Then $\text{score}_j \leq 1$ is equivalent to, that is, weighted sum of outputs $\leq$ weighted sum of inputs	For DMU k, the best score can be computed by the following equations. Maximize $E^k = \sum_{r=1}^{s} u_r y_{rk}$ Subject to: $\sum_{i=1}^{m} v_i x_{ik} = 1$ For each DMU j (including k): $\sum_{r=1}^{s} u_r y_{rj} \leq \sum_{j=1}^{m} v_i x_{ij}$ j = number of DMUs m = number of inputs s = number of outputs v_i = weight applied to the i^{th} input u_r = weight applied to the r^{th} output x_{ij} = level of i^{th} input for DMU j y_{rj} = level of r^{th} output for DMU j
Mathematical equation →	ITPM context
For DMU k, the best score can be computed by the following equations. Maximize $E^k = \sum_{r=1}^{s} u_r y_{rk}$ Subject to: $\sum_{i=1}^{m} v_i x_{ik} = 1$ For each DMU j (including k): $\sum_{r=1}^{s} u_r y_{rj} \leq \sum_{j=1}^{m} v_i x_{ij}$	j = number of DMUs ➔ Each DMU is considered to be an organizational unit, such as a business unit, IT project portfolio, and IT project. m = number of inputs ➔ Input(s) in my example includes Capital Expenditure and Operating Expense s = number of outputs ➔ Output(s) in my example includes Expected Return and Cost Saving v_i = weight applied to the i^{th} input u_r = weight applied to the r^{th} output x_{ij} = level of i^{th} input for DMU j y_{rj} = level of r^{th} output for DMU j

3.3 The Data Envelopment Analysis/Parallel (DEA/P) Model in the ITPM context

According to Tanriverdi and Ruefi (2004)'s survey of approaches to IT investments, Milgrom and Roberts (1990; 1995) assume a one-level firm with only resources and activities as its elements. On the other hand, Barua, Lee and Whinston (1996) and Barua and Mukhopadhyay (2000) contend that the firm should be conceptualized in multiple levels because investments in resources and activities are converted into firm level performance outcomes through several intermediate levels. In this regard, IT plays a critical role in all levels of the firm, including intermediate levels, while demonstrating the impact of IT investments on firm performance. By further connecting the ITPM context, an enterprise usually consists of various business units (or organizational departments), and each business unit may have its own strategic priority in terms of enterprise IT-driven strategic goals. These goals can be realized by a set of ongoing IT projects, known as the IT project portfolio. Accordingly, the IT portfolio that performs particular IT-related functions not only links to enterprise strategic goals but also supports the associated business plans of each organizational level.

To address strategic IT resource allocations for a multi-business firm, my new ITPM model is to apply the DEA/Parallel (DEA/P) model to the ITPM context. The proposed model is a centralized approach for allocating IT resources across multi-business units (multi-divisions) within a firm, and all the IT projects are overseen by a firm's CIO office (senior IT executive). Along with ITPM research, this paper conceptually illustrates three main components of the proposed model in Figure 2.2: (1) Business Unit/Organizational Department, (2) Strategic Objectives (Strategic Goals) implemented by the IT Project Portfolio, and (3) IT Projects. By solving the DEA/P's mathematical equations in Figure 2.3, each higher organizational level (e.g., business unit) is able to distribute its strategic IT resources into several lower organizational levels via a parallel approach. In Section IV, this paper will demonstrate the proposed ITPM model with a hypothetical example based on a Fortune 50 firm's IT project portfolio data.

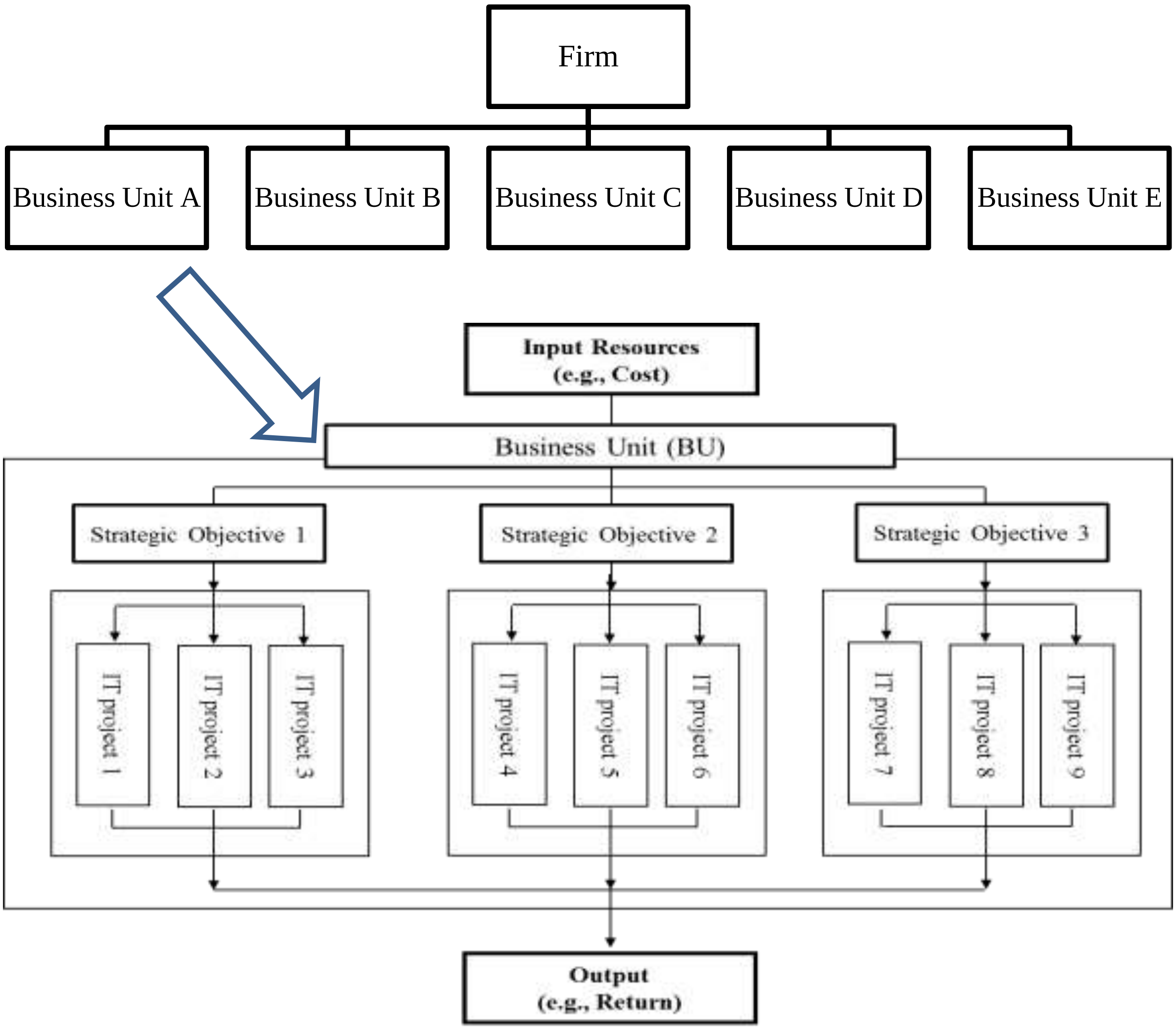

Figure 2.2: A Generic Model built on the concept of the DEA/P model in the ITPM context

Business Unit

$$E^{BU} = \max \sum_{r=1}^{s} u_r Y_{rk}$$

$$\text{s.t.} \sum_{i=1}^{m} v_i X_{ik} = 1$$

$$\sum_{r=1}^{s} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ik} + s_k = 0$$

$$\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, \ \ j = 1, \ldots \ldots n, \ \ j \neq k$$

IT Project Portfolio

$$\sum_{r \in O^{(ITPP)}}^{s} u_r Y_{rk}^{(ITPP)} - \sum_{i = I^{(ITPP)}}^{m} v_i X_{ik}^{(ITPP)} + s_k^{(ITPP)} = 0, \qquad ITPP = 1 \ldots \ldots q$$

$$\sum_{r \in O^{(ITPP)}}^{s} u_r Y_{rj}^{(ITPP)} - \sum_{i = I^{(ITPP)}}^{m} v_i X_{ij}^{(ITPP)} \leq 0, \ \ ITPP = 1 \ldots \ldots q, \ \ j = 1 \ldots \ldots . n, \ \ j \neq k$$

IT Project

$$\sum_{r \in O^{(ITP)}}^{s} u_r Y_{rk}^{(ITP)} - \sum_{i = I^{(ITP)}}^{m} v_i X_{ik}^{(ITP)} + s_k^{(ITP)} = 0, \ \ ITP = 1 \ldots \ldots q$$

$$\sum_{r \in O^{(ITP)}}^{s} u_r Y_{rj}^{(ITP)} - \sum_{i = I^{(ITP)}}^{m} v_i X_{ij}^{(ITP)} \leq 0, \qquad ITP = 1 \ldots \ldots q, \ \ j = 1 \ldots \ldots , n, \ \ \ j \neq k$$

$$u_r, v_i \ \geq \ \varepsilon, \quad r = 1, \ldots \ldots s, \quad i = 1, \ldots \ldots . m$$

$$s_k, \ s_k^{(ITPP)}, s_k^{(ITP)} \ \geq \ 0, \quad \text{ITPP} = 1, \ldots \ldots q, \quad \text{ITP} = 1, \ldots \ldots q$$

Figure 2.3: The DEA/Parallel Model (mathematical formula) in the ITPM context

3.4 Parameter and Variable Definition

The selection of input and output variables plays an essential role in the DEA/P model since these variables reflect variations in IT-related resource utilization across different organizational levels. Along with the DEA/P model components in Figure 2.2 and Figure 2.3, I summarize the DEA/P model's parameters and variables in Table 2.2.

Table 2.2: Parameter & Variable Definition of the DEA/Parallel Model in the ITPM context	
Parameter & Variable	Definition
E^{BU} E^{ITPP} E^{ITP}	Efficiency scores of IT-related resource allocation across multi-organizational levels—that is, firm level, business unit (BU), IT project portfolio (ITPP), and IT project (ITP)—can be generated by the proposed DEA/P model.
v_i	Weight of the ith input (IT resource) variable
u_r	Weight of the rth output (expected return) variable
X_{ik}	A certain amount of the ith input (IT resource) is assigned to the specific Decision Making Unit (DMU) k; therefore, DMU k is considered as a specific business unit k with regard to the business unit (BU) level.
Y_{rk}	The rth output (expected return) is produced by the specific Decision Making Unit (DMU) k; therefore, DMU k is considered as a specific business unit k with regard to the business unit (BU) level.
X_{ij}	A certain amount of the ith input (IT resource) is assigned to the Decision Making Unit (DMU) j; therefore, DMU j is considered as a business unit j with regard to the business unit (BU) level.
Y_{rj}	The rth output (expected return) is produced by the Decision Making Unit (DMU) j; therefore, DMU j is considered as a business unit j with regard to the business unit (BU) level.
s_k	The buffer IT resources related to the specific Decision Making Unit (DMU) k; therefore, DMU k is considered as a specific business unit k with regard to the business unit (BU) level.
$X_{ik}^{(ITPP)}$	Amount of input (resource) i required for the IT project portfolio from the specific Decision Making Unit (DMU) k
$Y_{rk}^{(ITPP)}$	Given certain input-based resource allocations, an amount of output (return) r expected for the IT project portfolio from the specific Decision Making Unit (DMU) k
$X_{ij}^{(ITPP)}$	Amount of input (resource) i required for the IT project portfolio from Decision Making Unit (DMU) j

Table 2.2, continued	
$Y_{rj}^{(ITPP)}$	Given certain input-based resource allocations, an amount of output (return) r expected for the IT project portfolio from Decision Making Unit (DMU) j
$s_k^{(ITPP)}$	The buffer IT resources for the IT project portfolio level under the specific Decision Making Unit (DMU) k
$X_{ik}^{(ITP)}$	Amount of input (resource) i required for the IT project from Decision Making Unit (DMU) k
$Y_{rk}^{(ITP)}$	Given certain input-based resource allocations, an amount of output (return) r expected for the IT project from Decision Making Unit (DMU) k
$X_{ij}^{(ITP)}$	The amount of input (resource) i required for the IT project from Decision Making Units (DMU) j
$Y_{rj}^{(ITP)}$	Given certain input-based resource allocations, an amount of output (return) r expected for the IT project from Decision Making Units (DMU) j
$s_k^{(ITP)}$	The buffer IT resources for the IT project level under the specific Decision Making Unit (DMU) k

Along with the DEA/P model components shown in Figure 2.2 and Figure 2.3, Table 2.3 summarizes the proposed ITPM model's key parameters and variables as well as managerial interpretations.

Table 2.3: Summary of Parameter & Variable with associated Managerial Interpretation		
Parameter & Variable	Range	Managerial Interpretation
E^{BU}: Efficiency score for Business Unit or Org. Dept. E^{ITPP}: Efficiency score for IT project portfolio level E^{ITP}: Efficiency score for IT project level	The range for Efficiency score is between 0 and 1 E = 0 (worst); E = 1 (optimal)	A higher efficiency score can be understood as a better strategic resource allocation in connection with an organizational level, as such; E = 1 means the optimal situation for IT-related strategic resource allocation.

Table 2.3, continued		
S: Slack score	The slack score is associated with E-score	The slack score can be used to indicate Utilized resources; a lower score indicates high utilization and a higher score indicates organizational slack.
W: Weight score (strategic option focus)	The range for weight score is between 0 and 1 W = 0 (worst); W = 1 (optimal)	The weight score is how much to invest in each strategic goal to improve investment efficiency.
X: Input Variable	Each hierarchical organizational level has its amount of resources related to Labor Cost	The needed IT resources to realize IT project portfolios
Y: Output variable	Each hierarchical organizational level has its amount of resources related to Expected Return	The outcomes after utilizing the needed IT resources

Specifically, the efficiency scores for the business unit, IT project portfolio and IT project from the proposed DEA/P Model can be defined as follows:

$$E^{BU} = 1 - s_k$$

$$E^{ITPP} = 1 - s_k^{(ITPP)} / \sum_{i=I^{(ITPP)}}^{m} v_i X_{ik}^{(ITPP)}$$

$$E^{ITP} = 1 - s_k^{(ITP)} / \sum_{i=I^{(ITP)}}^{m} v_i X_{ik}^{(ITP)}$$

To address the strategic priority of each business unit or organizational department in a firm, a weight score derived from the DEA/P model is defined as a percentage of the IT resources assigned to the IT project portfolio in order to realize one of the business unit's specific strategic goals, as shown below.

$$w^{(ITPP)} = \frac{\sum_{i \in I^{(ITPP)}} v_i X_{ik}^{(ITPP)}}{\sum_{i=1}^{m} v_i X_{ik}}$$

According to the emphasis of strategic priorities in the organization, the weight score is how much to invest in each strategic goal to improve the investment efficiency. Therefore, a higher weight score can be considered as a more influential strategic focus connected to a certain organizational level.

IV. HYPOTHETICAL EXAMPLE

4.1 IT Project Portfolio Data Description

This section provides a hypothetical example to articulate IT investment decision-making by utilizing IT portfolio data collected from a Fortune 50 Company. This company is a multinational corporation that produces diversified machinery and also operates as an infrastructure and financial services company. In response to the IT portfolio data, the selection of input and output variables plays an essential role in using the proposed ITPM model to truly reflect variations in IT resource utilization across different organizational units/levels. After looking into the firm's organizational structure, including its IT project portfolio data, the following sections will discuss the selected IT portfolio attributes, respectively. Also, Table 2.4 shows the summary of five main IT portfolio attributes associated with parameters/variables.

4.2 Benefit

In most cases, benefit can be considered as the outputs or impacts after the utilization of the firm's resources. In line with this perspective, this research will mainly address two critical output attributes, as shown below.

4.2.1 Expected Return

With reference to Ilmanen (2011), expected returns are uncertain ex ante but they are also unknowable ex post for most assets. Since my research cannot directly observe the market expectations about returns or rates, it must infer expected returns from a Focal Firm IT Portfolio, including market yields or valuation ratios, past returns, investor surveys, and models. Moreover, Eisfeldt and Papanikolaou (2013) mentioned that the capital asset pricing model does not explain the dispersion in expected returns arising from heterogeneity in the ratio of organization capital to assets. After applying this principle to the IT Portfolio Management (ITPM) context, the definition of expected return in this paper is based on a corresponding ROI.

4.2.2 Cost Saving

Kim and Chhajed (2000) summarized several scholarly journal articles to address methods for cost savings, which are as follows: using a common product module for multiple products to improve economies-of-scale in production, reducing inventory holding costs due to the pooling effect against demand uncertainty, and reducing investments in production equipment. But many practical issues have interdependent properties for criteria or candidate projects; thus, considering these interdependencies offers cost-saving benefits to organizations (Lee and Kim, 2000). Consequently, the definition of cost saving in the ITPM context is the savings from business process improvement, inventory reduction, or payables gathered quickly after implementing IT project(s).

4.3 Budgeted Cost

Generally, budgeted costs are highly related to a firm's invested resource. According to March (1991), both exploration and exploitation are critical for organizations, but each competes for scarce resources. Therefore, obtaining an applicable balance is made especially challenging by the fact that the same issues occur at the levels of a nested system (i.e., at the individual level, the organizational level, and the social system level). This is especially the case when a firm implements process management practices, which involve concerted efforts to map, improve, and adhere to organizational processes. In stable, technologically certain settings, these practices may be productive, while in uncertain or technologically complex contexts, these practices may become unfavorable, according to Benner and Tushman (2003).

4.3.1 Capital Expenditure (utilization of capital expenditure is likely to increase return)

According to Shim et al. (2012), a capital expenditure budget reveals how much is required to invest in capital assets to meet the nonfinancial manager's objectives, so that the division or department can function properly. Moreover, when deriving a stable level of capital expenditures, it is common to express capital expenditures as a percentage of depreciation expense (Bodmer, 2014). In the ITPM context, the definition of Capital Expenditure is funds invested in a firm for the purposes of furthering its business objectives; on the other hand, capital investment refers to a firm's acquisition of capital assets or fixed assets.

4.3.2 Operating Expense (utilization of operating expense may not increase return)

Based on Promislow (2010), there are various expenses that will depend on the amount of benefits. Concerning operating expense, all the money that the system spends turns inventory into throughput, which is the rate at which the system generates money through sales (Rahman, 1998). In the ITPM context, operating expense is defined as what a business accrues as a result of performing its normal business operations.

4.4 Proposed IT Portfolio Attributes

In addition to Benefit and Budgeted Costs, IT project portfolios may be defined by three additional portfolio attributes: project portfolio diversity (following a combination of project types), project portfolio technical complexity, and portfolio distribution.

4.4.1 Project Type

Crawford et al. (2005) distinguished a broad list of features used to classify projects and realized that the potential list was without end. Muller and Turner (2007) extended Crawford et al. (2005)'s research and further summarized project attribute and project type. As such, regarding applications, there are a number of project types: engineering and construction, ICT, or organizational change; regarding contracts, there are fixed price, re-measurement, or alliance. In accordance with the Focal Firm IT portfolio data, this paper intends to express three types of IT projects listed below.

- Must Do (MD): This type of IT project addresses a critical compliance or controllership issue; these IT projects receive first priority in terms of funding or resources.
- Long Term Growth (LTG): This type of IT project usually adds new capabilities to the business; these IT projects have a significant impact on the existing business process.
- Operating Margin (OM): This type of IT project can be considered ROI-driven IT projects that allow the business to do the same processes faster or at lower cost.

4.4.2 Technical Complexity

Tatikonda and Rosenthal (2000) express both technology novelty and project complexity dimensions to better differentiate various project types and to better capture the associated challenges in project execution. Specifically, regarding complexity, there are three project classifications: high, medium and low (Muller and Turner, 2007). Hence, IT projects' technical complexity in this paper is defined as follows:

- Low technical complexity: This category of IT project may include one of the following: simple functionality upgrades with standard technologies, new custom developed applications, or significant capacity/infrastructure expansions.

- Medium technical complexity: This category of IT project may include one of the following: major functionality enhancements, new custom-developed applications using non-standard offerings, new technologies that are not in the standard tech stack but that exist in the current infrastructure, new third-party applications that use standard technologies, or obsolescence programs focused on a sub-business.
- High technical complexity: This category of IT project may include one of the following: extending applications to a customer or vendor for the first time, introduction of new business processes, new technologies that are not in the standard tech stack, new third party applications that use non-standard technologies, or obsolescence programs crossing multiple sub-businesses.

4.4.3 Portfolio Distribution

Project allocations associated with project variation are mainly built on project size; therefore, this paper produces three forms of IT project portfolio distribution to illustrate the differentiation of project portfolio distribution: Even distribution-based IT portfolios, Uneven distribution-based IT portfolios, and Dominant IT portfolios. Even distribution IT portfolios are when the IT projects are assigned certain amounts of IT resources within a portfolio; Uneven distribution IT portfolios are when IT resources are dispersed within a portfolio; and Dominant type IT portfolios are when most IT resources are centralized on a few IT projects within a portfolio.

Table 2.4: Summary of IT Portfolio Attributes associated with Parameter(s) and Variable(s)				
IT Portfolio Attribute	**Parameter/ Variable**	**Description**	**Primary Reference**	**Data Source**
Benefit	Expected Return	The definition of expected return is related to on a corresponding ROI.	Ilmanen, 2011; Eisfeldt and Papanikolaou, 2013	Focal Firm IT portfolio data along with simulated data
	Cost Saving	The savings from a business process improvement, a reduction in inventory, or gathering payables more quickly after implementing IT project(s).	Kim and Chhajed, 2000; Lee and Kim, 2000	
Budgeted Cost	Capital Expenditure	The definition of capital expenditure is funds invested in a firm for the purposes of furthering its business objectives.	Shim et al., 2012; Bodmer, 2014	Focal Firm IT portfolio data along with simulated data
	Operating Expense	Operating expense is defined as what a business incurs as a result of performing its normal business operations.	Rahman, 1998; Promislow, 2010	
Project Type	Must Do	This type of IT project addresses a critical compliance or controllership issue; these IT projects receive first priority in terms of funding or resources.	Ross and Beath, 2002; Crawford et al., 2005; Kumar et al., 2008	Focal Firm IT portfolio data along with simulated data
	Long Term Growth	This type of IT project usually adds new capabilities for the business; these IT projects have a significant impact on the existing business process.		
	Operating Margin	This type of IT project is a ROI-driven IT project that allows the business to do the same process faster or at a lower cost.		

Table 2.4, continued				
Technical Complexity	High Technical Complexity	This category of IT project extends applications to customers or vendors for the first time, or introduces a new business process or new technology that is not in the standard tech stack.	Tatikonda and Rosenthal, 2000; Muller and Turner, 2007	Focal Firm IT portfolio data along with simulated data
	Med Technical Complexity	This category of IT project is related to major functionality enhancement, new custom-developed applications using non-standard offerings, or new technology that is not in the standard tech stack but exists in the current infrastructure.		
	Low Technical Complexity	This category of IT project is simple functionality upgrades with standard technologies, new custom-developed applications, or significant capacity/infrastructure expansion.		
Portfolio Distribution	Dominant IT Portfolio	A Dominant IT portfolio is defined as a firm that concentrates its IT investment on one or a very small number of large IT projects.	Prahalad and Bettis, 1986	Focal Firm IT portfolio data along with simulated data
	Uneven-distribution-based IT Portfolio	An Uneven distribution-based IT portfolio is defined as a firm that allocates its IT investment to a portfolio composed of diversified IT projects (e.g., varying project types and project sizes).		
	Even distribution-based IT Portfolio	An Even distribution-based IT portfolio is defined as a firm that allocates its IT investment to all the IT projects with similar sizes.		

While the diversity of IT project portfolios is regarded as an essential characteristic, this paper incorporates the concept of project type to distinguish various IT portfolios. Concerning project portfolio technical complexity, this research illustrates high, medium and low levels in its latter section. In brief, this paper summarizes a set of IT portfolios based on the parameters from the actual IT portfolio at a Fortune 50 firm in Table 2.5.

Table 2.5: A set of IT portfolios based on the parameters from an actual IT project portfolio at a Fortune 50 firm

Strategic Goal	Project Type	Project Allocation of Business Unit – A (BU-A)	Project Allocation of Business Unit – B (BU-B)	Project Allocation of Business Unit – C (BU-C)
Operation Management	Must Do (MD)	63.0%	31.6%	26.3%
	Long Term Growth (LTG)	18.5%	33.7%	47.4%
	Operating Margin (OM)	18.5%	34.7%	26.3%
Innovation Management	Must Do (MD)	26.9%	33.3%	0.0%
	Long Term Growth (LTG)	57.7%	16.7%	20.0%
	Operating Margin (OM)	15.4%	50.0%	80.0%
Customer Management	Must Do (MD)	50.0%	16.7%	31.3%
	Long Term Growth (LTG)	0.0%	72.2%	18.8%
	Operating Margin (OM)	50.0%	11.1%	50.0%

4.5 Experimental Design with IT Portfolio Simulations

In line with Davis et al. (2007), I found numerous essential strengths (i.e., internal validity and experimentation) and weaknesses (i.e., external validity and overly simplistic) for theory development and simulation. The IT project portfolio data collected from a Fortune 50 company reveals that all IT projects appear as diverse investments and expenses corresponding to different expected returns. The correlation matrix in relation to the IT project portfolio data can be found in Table 2.6, and Table 2.6 shows that the Efficiency Score (generated by the proposed DEA/P model) has a high positive correlation with both Expected Return and Capital Expenditure. While Capital Expenditure has an extremely high positive correlation with Expected Return, it has a low negative correlation with Cost Saving.

Table 2.6: Correlation Matrix corresponding to IT Project Portfolio Data

	Efficiency Score (generated by the DEA/P model)	Expected Return	Cost Saving	Capital Expenditure	Operating Expense
Efficiency Score (generated by the DEA/P model)	1				
Expected Return	0.835403605	1			
Cost Saving	0.346628858	0.195012238	1		
Capital Expenditure	0.759726142	0.9586883	-0.036730071	1	
Operating Expense	0.582824571	0.796388307	0.603015091	0.665300458	1

While looking into the empirical IT portfolio data, including IT portfolio attributes, this research develops a logical experimental design by using the DEA/P model to analyze ITPM for a multi-business unit firm. The research design of this paper demonstrates how to improve the efficiency of IT resource allocation across multi-organizational levels, and the concept of the simulated multi-level organization across business units is shown in Figure 2.2. To elucidate the IT portfolio simulations, this research aims to simulate strategic IT resources by showing numerous scenarios that are composed of three types of portfolio distribution (i.e., the Even distribution IT portfolio, the Uneven distribution IT portfolio, and the Dominant type IT portfolio). With these three types of portfolios related to the IT project portfolio data, there are 27 scenarios (3*3*3; BU1: Even/Uneven/Dominant, BU2: Even/Uneven/Dominant, BU3: Even/Uneven/Dominant) in this paper. While the simulated firm is structured in this way, the findings apply without loss of generality to firms with more than three business units or strategic goals realized by corresponding IT portfolios.

The simulation of this study takes the level of input resources from the parameters of a Fortune 50 firm but then varies the level of other parameters to test their impact on the outcomes for IT investment. More specifically, all the simulated IT project portfolios are included in a range of Uneven Distribution-based IT portfolios, with both the Even Distribution-based IT portfolio and the Dominant IT portfolio serving as two extreme cases of the Uneven Distribution-based IT portfolio to further demonstrate the enterprise IT resource allocations. In addition, this paper incorporates two IT portfolio attributes in each scenario; that is, (1) the composition of IT project types in the portfolio and (2) the level of technical complexity of the projects in the portfolio. Then, comparing the Focal Firm IT Portfolio results by using the DEA/P model in the ITPM context, this paper discovers the most applicable IT portfolio profile among various scenarios for each business unit to meet its strategic goals.

4.6 Analysis and Results

To address how a firm can systematically profile numerous IT portfolios and to provide theoretical insights into the optimal solution, the methodology of this study incorporates mathematical optimization and computational experiments along with real-world data using the Monte Carlo approach to simulate the firm's IT portfolios. Following these premises and employing the proposed DEA/P model from Figure 2.2 and Figure 2.3, this research measures three business units and their associated IT project portfolios' efficiency by using LINDO software.

The results include two parts: empirical results and simulation results, which lead to 27 scenarios. Drawing from the empirical results, this paper aims to discover the most applicable IT portfolio by conducting a number of simulated scenarios to improve the efficiency of IT resource allocation across multi-organizational levels. Thus, along with the empirical results, the analysis from the simulation results may provide a number of rationales for senior executives to make better upcoming investment decisions. The details about the empirical results and simulation results can be found in the Appendix (Table 2.8.a - Table 2.8.c).

Moreover, the Focal Firm IT Portfolio data shows that the Business Unit A (BU-A) gains the best efficiency through the proposed DEA/P model among the three business units in this research. While comparing empirical analysis to the analysis of the 27 simulated scenarios driven by portfolio distributions (Even/Uneven/Dominant), the results indicate that if the BU-A's senior executives allocate IT resources to three strategic goals, from centralized to dispersed, as shown in Table 2.7.a, there would be no significant effect on the efficiency improvement of the BU-A-like business unit within a firm. However, if a firm has a business unit similar to BU-A that is focused on Must Do (MD) IT projects to attain operating margin-oriented business objective(s), it may reach higher efficiency without making significant modification to the current IT resource allocations.

Table 2.7. a. Empirical results & selected simulated IT portfolio profiles in the BU- A

IT portfolio profile	BU-A	Strategic Goal 1 – Operation Mgt.			Strategic Goal 2 – Innovation Mgt.			Strategic Goal 3 – Customer Mgt.		
	Efficiency Score	Efficiency Score	Weight Score	Slack	Efficiency Score	Weight Score	Slack	Efficiency Score	Weight Score	Slack
Focal Firm IT Portfolio	0.448	0.53	75.8%	0.36	0.22	14.3%	0.09	0.15	9.9%	0.19
(Simulated) Dominant type IT portfolio	0.364	0.57	42.7%	0.18	0.22	31.5%	0.24	0.20	25.9%	0.21

Table 2.7. a, continued										
(Simulated) Uneven distribution –based IT portfolio	0.315	0.37	42.8%	0.27	0.35	34.2%	0.22	0.16	22.9%	0.19
(Simulated) Even distribution –based IT portfolio	0.282	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25

Referring to BU-B's strategic focus, as evidenced by the empirical results, the IT resources are largely concentrated on innovative adaptions implemented by the IT project portfolio, which is mostly composed of the Operating Margin type of IT projects with a high technical complexity level and is able to generate high efficiency. Furthermore, based on the analysis of the 27 simulated scenarios driven by portfolio distributions (Even/Uneven/Dominant), the results show that the BU-B may improve its efficiency if its senior executives could reallocate IT resources by embracing the simulated dominant IT portfolio profile in Table 2.7.b. In this regard, if a firm has a similar business unit as BU-B, the firm can allocate its IT investment to a specific enormous IT project or to a very small number of large IT projects to better govern technical complexity and improve the operating margin with high efficiency. Particularly, improvements in cost efficiency across a large scope in terms of enterprise IT investment mean that the firm benefits from economies of scale and scope.

Table 2.7. b. Empirical results & selected simulated IT portfolio profiles in the BU- B										
IT portfolio profile	BU-B	Strategic Goal 1 – Operation Mgt.			Strategic Goal 2 – Innovation Mgt.			Strategic Goal 3 – Customer Mgt.		
	Efficiency Score	Efficiency Score	Weight Score	Slack	Efficiency Score	Weight Score	Slack	Efficiency Score	Weight Score	Slack
Focal Firm IT Portfolio	0.356	0.19	11.5%	0.11	0.40	66%	0.39	0.31	22.5%	0.33
(Simulated) Dominant type IT portfolio	0.360	0.19	12.2%	0.09	0.52	49.6%	0.25	0.21	38.2%	0.30
(Simulated) Uneven distribution –based IT portfolio	0.282	0.26	32.4%	0.24	0.28	23.9%	0.17	0.30	43.7%	0.30
(Simulated) Even distribution –based IT portfolio	0.298	0.25	32.8%	0.25	0.33	35.5%	0.24	0.31	31.8%	0.22

Compared to the empirical results, all the simulated IT portfolio profiles reveal that there might be a substantial impact on the BU-C, as shown in Table 2.7.c. Practically, if a firm has a similar business unit as BU-C (i.e., a concentrated emphasis on long term growth and an operating margin in a collection of diversified IT projects), then it is able to achieve to the business objectives of the firm with high efficiency in terms of operation efficiency and innovative adaption. Put simply, the firm may build on the simulated Uneven distribution-based IT portfolio to modify IT resource allocations and meet its operational business objectives more capably.

Table 2.7. c. Empirical results & selected simulated IT portfolio profiles in the BU – C										
IT portfolio profile	BU-C	Strategic Goal 1 – Operation Mgt.			Strategic Goal 2 – Innovation Mgt.			Strategic Goal 3 – Customer Mgt.		
	Efficiency Score	Efficiency Score	Weight Score	Slack	Efficiency Score	Weight Score	Slack	Efficiency Score	Weight Score	Slack
Focal Firm IT Portfolio	0.26	0.36	30.7%	0.08	0.26	44.4%	0.16	0.13	24.9%	0.22
(Simulated) Dominant type IT portfolio	0.27	0.28	50%	0.36	0.28	43.1%	0.31	0.14	6.9%	0.06
(Simulated) Uneven distribution –based IT portfolio	0.303	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34
(Simulated) Even distribution –based IT portfolio	0.27	0.34	29.5%	0.20	0.31	45%	0.31	0.12	25.5%	0.22

V. MANAGERIAL IMPLICATIONS & SUMMARY OF FINDINGS: MOVING TOWARD A THEORY

5.1 Managerial Implications

My research aims to assist firms in building an IT portfolio with attributes that perform well in the context of the firm to better achieve enterprise business objectives. A new methodology, which is used to demonstrate the optimal efficiency of IT resource allocation, is the main contribution of this research.

To address the limitation of the conventional DEA model, the proposed DEA/P model incorporates all inputs and outputs related to IT investments across connected organizational levels. Specifically, instead of being determined by a senior executive's intuition, the weight scores generated by the proposed DEA/P model are based on data, which enables a firm to create a rational viewpoint of how much to invest in each strategic goal and thereby improve investment its efficiency based on the specific contingencies faced by the organizational unit. Also, the advantage of using the DEA/P model in the ITPM context is DEA/P model's ability to not only to incorporate IT portfolio attributes but also to include the combined economic efficiency of all business units in the firm that pertain to ITPM issues. In future work, I will run additional large-scale simulations incorporating other unique industry and firm-level characteristics to complement the proposed initial illustrative example.

5.2 Summary of Findings: Moving Toward a Theory

Based on the DEA/Parallel model applied to the context of IT Portfolio Management (ITPM), senior executives can track the efficiency of resource allocations for multiple organizational units concurrently. This paper has characterized IT portfolio data as having the following attributes: (1) a project portfolio distribution: Even distribution-based IT Portfolio, Uneven distribution-based IT Portfolio, and Dominant IT Portfolio; (2) one of three project types: Must Do, Long Term Growth, and Operating Margin; and (3) different technical complexity: High, Medium and Low level. In addition to these characterizations of the IT Portfolio, this research takes into account correlations among the variables corresponding to the IT project portfolio data across business units to better identify IT portfolio profiles. Through the following discussion of IT portfolio profiles that may be characterized by the proposed portfolio attributes, senior executives may choose the most appropriate IT portfolio to accomplish specific strategic goal(s) and then deliver business value to the enterprise.

According to Davis et al. (2007), simulation involves creating a computational representation of the underlying theoretical logic that links constructs together within the simplified worlds. While simulation can be used purely for description or exploration, my study focuses on using simulation for theory development. Consequently, this research suggests three theoretical propositions, building from the key findings of this paper, which are explained below.

5.2.1 Finding 1 & Theoretical Proposition 1

The first key finding of the simulated IT project portfolios is that a firm that concentrates its IT investment on one or a very small number of large IT projects (Dominant IT portfolio) is able to manage technical complexity and take on projects specifically to improve its operating margin with high efficiency. A dominant IT portfolio allows the IT organization to focus narrowly on the objectives of a small set of projects and their stakeholders rather than attempting to satisfy the objectives of a wider, more diverse audience. This scenario means that the firm's IT function can specialize in highly technical capabilities that are best suited for its dominant projects. This specialization provides a strong platform for delivering solutions that are particularly responsive to the needs of the business and may also create rare and inimitable resources for the firm. Meanwhile, a strong focus on operating margin in a dominant (i.e. large) project means that whatever outcome is achieved in terms of cost savings applies to a broadly applicable business objective in the firm. Improvements in cost efficiency across a large scope IT projects, frequently in the form of investment in enterprise systems, mean that the firm may benefit from economies of scale and scope across the functional and business units of the firm. Thus, the first theoretical proposition of this paper is as follows:

- **Theoretical Proposition 1**

The IT resource allocation driven by Dominant IT portfolios, which involve high technical complexity associated with high operating expenses, may contribute to superior portfolio

efficiency to achieve business objective(s).

5.2.2 Finding 2 & Theoretical Proposition 2

The second finding of the simulated IT project portfolios shows that a firm that allocates its IT investments to IT projects of similar size (an Even distribution-based IT portfolio) is able to cope with numerous types of IT projects with low technical complexity. This even-distribution IT portfolio may contribute to a more balanced utilization of the IT resources and, in turn, yield operating margins and long term growth objectives. Also, an emphasis on must-do projects related to compliance issues or operational imperatives in a large set of similar size IT projects may lead to better efficiency. Following this observation, the second theoretical proposition of this paper is as follows:

- **Theoretical Proposition 2**

More diversified project types in an Even distribution-based IT portfolio with low technical complexity level may contribute to superior portfolio efficiency to achieve business objective(s).

5.2.3 Finding 3 & Theoretical Proposition 3

The third finding of the simulated IT project portfolios is that a firm that allocates its IT investments to a portfolio composed of diversified IT projects (e.g., varying project types and project sizes), an Uneven distribution-based IT portfolio, is able to deal with projects of higher technical complexity. Specifically, an intensive emphasis on long-term growth and operating margin project types in a collection of diversified IT projects means that operation efficiency and innovation management are achieved. Thus, the third theoretical proposition of this paper is as follows:

- **Theoretical Proposition 3**

More dispersed IT resource allocation in the form of an Uneven distribution-based IT portfolio, comprised of various technical complexity levels and project types, may contribute to superior portfolio efficiency.

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Chapter 3. Selecting the Most Qualified IT Portfolio Choice under Various Risk Tolerance Levels

I. INTRODUCTION

In 2014, global information technology (IT) spending grew by 3.2 % to total $3.8 trillion U.S. dollars, according to the latest forecast by the research firm Gartner, Inc. (2014). Chan et al. (1997) found that the “fit” between IS and business objectives is significantly associated with the performance of a firm. In fact, evidence increasingly shows that investment in IT can produce value for a variety of organizational levels. At the firm level, research has demonstrated that IT investment translates into profitability (e.g. Mithas, Tafti, Bardhan and Goh, 2012), and IT portfolio management is expected to improve the performance of IT investment (Jeffery and Leliveld, 2004). In regard to a firm’s IT resources, IT portfolios can be thought of as a bridge that connects projects to the firm as a whole. For these reasons, several Information Systems (IS) researchers have drawn attention to the concept of IT Portfolio Management (ITPM), a system for managing the total IT-related investments within an enterprise (Weill and Vitale, 2002). The concept of ITPM is similar to the concept of financial portfolio management, but a significant difference is that IT investments are not liquid, as are stocks and bonds in the financial market. Therefore, IT investments may need to incorporate both financial and nonfinancial methods for evaluation (Betz, 2007). Since IT-driven business activities are mainly realized by IT investment projects, this study found there is very limited research addressing IT (project) portfolio selection issues in the ITPM domain. Thus, the motivation of this research is to propose a new decision-making model to assist enterprise executives in selecting the most qualified IT portfolio when dealing with IT investments.

This proposal follows Aral and Weill (2007)'s argument that a firm should determine its IT investment allocation based on its strategic priorities. In line with Bhatt and Grover (2005) and Kohli and Grover (2008), making appropriate strategic IT investment choices is a critical capability for maximizing firm performance in the long run. However, Dewan et al. (2007) indicate that IT investments are much riskier than non-IT capital investments, as measured by their relative contributions to the overall riskiness of the firm. Therefore, this research aims to address the following research question in this paper: "How can a firm select the most qualified IT portfolio choice to improve the efficiency of IT resource allocation under different risk tolerance levels?" The proposed new model (methodology), the IT Portfolio Efficient Frontier model, is composed of concepts from the Data Envelopment Analysis (DEA) and the Markowitz Portfolio Theory (MPT), as well as a risk assessment component, to articulate the decision maker's risk tolerance levels. Specifically, the proposed model is built on portfolio optimization; thus, the experimental design and simulation data of this paper will be able to differentiate all the IT project portfolios into three types of IT portfolio profiles (also known as IT portfolio scenarios): Even distribution-based IT portfolios, Uneven distribution-based IT portfolios, and Dominant IT portfolios. With regard to the findings of this study, the IT portfolio efficient frontiers of both the Even distribution-based IT portfolio and the Uneven distribution-based IT portfolio show that IT portfolio risk has a positive linear relationship with IT portfolio return. Additionally, this study finds that the IT portfolio efficient frontier from the Dominant IT portfolio may be considered as a concave curve. Accordingly, if IT investments resemble the Dominant IT portfolio, senior executives may need to consider a more conservative investment strategy after reaching the turning point of the IT portfolio efficient frontier.

The two main contributions of this paper are as follows: 1) The IT Portfolio Efficient Frontier model may be regarded as a new methodology in ITPM literature and 2) Practitioners may leverage the proposed new approach/model to boost the performance of IT portfolios based on decision-makers' (e.g., senior executives') risk tolerance levels when making IT investment decisions. The sections of this paper are as follows: Section II reviews the related theoretical studies. The proposed IT Portfolio Efficient Frontier model is developed in Section III. In Section IV, the proposed model is illustrated with a hypothetical example and computational analysis. Finally, Section V presents the main findings and future work on this research topic.

II. THEORETICAL BACKGROUND

The Modern Portfolio Theory (Markowitz, 1959) refers to the principles underlying the analysis and evaluation of rational portfolio choices based on trade-offs between risk and return when considering investment decisions. According to this theory, the portfolio choice that involves greater return and less risk is considered to be superior (e.g., more efficient) than the portfolio choices that involves less return and greater risk. In other words, given the same level of risk, the portfolio choice that involves greater return is considered to be superior to the portfolio choice that involves less return. According to Bentley and Davis (2009), IT portfolio management is the application of systematic management to large classes of items managed by enterprise IT groups. Compared to conventional financial investments, IT investments are not liquid, as are stocks and bonds. Thus, it is critical to develop a proper risk assessment method to evaluate IT investment risk and better cope with the relationship between risk and return before making decisions about IT portfolio selections. Furthermore, the following section (Section III) will demonstrate how this research establishes these main theoretical insights to develop the proposed IT Portfolio Efficient Frontier model.

2.1 Portfolio Theory

With reference to finance literature, a basic definition of portfolios is a collection of investments owned by an institution or an individual, and portfolio management is about analyzing different investments as a whole. Though widely applicable across many fields, many studies show that the Modern Portfolio Theory (MPT) has had a significant impact on the practice of portfolio management. In particular, MPT is able to provide a framework for constructing and selecting portfolios based on the expected performance of the investments and the risk appetite of the investor (Fabozzi et al., 2002). In this regard, the MPT could be seen as the only theory pertaining to IT portfolio management in prior IS research, since the portfolio value and risk balance is its centerpiece (Markowitz, 1952).

Along with the portfolio choice built on the MPT, two key fundamental aspects need to be considered: diversification and the trade-off between expected return and risk (Brandt, 2009). Furthermore, the MPT asserts that the balanced portfolio choice is the most efficient portfolio choice because it involves the highest portfolio value for a given portfolio risk. Although these dominant choices might present different values associated with risk, they are equally efficient choices. In accordance with this perspective, rational risk-averse investors should be able to make a portfolio selection from these efficient portfolio choices. Thus, it is important to note that risk aversion is closely related to portfolio diversification in the context of portfolio choice application.

2.2 Information Technology Portfolio Management (ITPM)

Following the implementation of the Sarbanes-Oxley Act, many enterprise investment decisions have been strictly scrutinized; thus, investment issues become a great concern for many senior executives. As a consequence, many enterprises are under pressure to implement more effective IT investment controls. Along with this topic research, enterprise IT should be managed as the Information Capital of an enterprise, and since IT projects account for most IT spending, they need to be considered on the same enterprise level as portfolios. For this reason, IT project selection turns out to be an essential business problem, because most IT components are customized for an enterprise through project implementation (Cho and Shaw, 2013).

According to Jeffery and Leliveld (2004), the definition of ITPM is to manage IT as a portfolio of assets through a method similar to a financial portfolio and also to strive to improve the performance of the portfolio by balancing risk and return. A firm's IT portfolio is its total investment in computing and communication technology (Weill and Vitale, 2002), or the sum total of all its IT projects. In line with this perspective, IT portfolios are a bridge that connects the project level to the firm level in terms of internal strategic resource allocation (Zhu, 2003; Jeffery and Leliveld, 2004; Ray et al., 2005). To improve the performance of IT investments, ITPM aims to manage IT assets as a whole through a method similar to managing financial portfolios (McFarlan, 1982; Bardhan et al., 2004; Weill and Aral, 2006), along with nonfinancial methods for evaluation (Betz, 2007). Hence, the key motivation for many IT executives using ITPM is to select the most qualified IT portfolio to improve firm performance.

2.3 Data Envelopment Analysis (DEA) and IT Portfolio Management

Generally, the Data Envelopment Analysis (DEA) model is known as a non-parametric approach and a linear fractional programming model; thus, the DEA model is able to uncover hidden relationships among multiple inputs and outputs. Also, the DEA model has been widely used as an objective multi-criteria decision-making method (Lawrence and Kleinman, 2010). Additionally, Sowlati et al. (2005) present a model within the DEA framework for prioritizing information system (IS) projects.

The objectives of ITPM are to plan, measure and optimize the business value of enterprise IT. The goal of ITPM is to manage the Information Capital at the individual and the enterprise level. With reference to financial economics literature, the relationship between return and risk is positively linear. However, for IT investments, the relationship between return and risk could be non-linear (Tanriverdi and Ruefli, 2004). In line with Cho (2010), motivated by the potential non-linear relationship between return and risk in IT investments, the DEA model can be seen as an appropriate model for addressing the heterogeneous metrics of inputs and outputs in the ITPM context. To have a comprehensive viewpoint of the DEA method in the ITPM context, this paper summarizes the assumptions and contributions of DEA model in Table 3.1.

Table 3.1: Summary of the assumptions and contributions for the DEA model

Assumptions	Contributions
(1) The proposed DEA model does not assume a linear output (e.g., return) and input (e.g., risk) relationship for IT investments. (2) My research assumes that the overall IT budget of the firm was already allocated to the multiple business units/divisions in a way that reflects each business unit's/division's strategic goals.	(1) The DEA is an analytical tool for determining effective and ineffective performance as the starting point for inducing theories about best-practice behavior (Charnes et al., 1995). (2) The DEA examines the decisions among alternatives that have high uncertainty (Linton et al., 2002).

Table 3.1, continued	
(3) In my research, when the inputs and outputs of IT investments in a portfolio are considered in the production process, the efficiency scores generated by the DEA model can be used to represent IT portfolio value. (4) All observed production possibilities are feasible. (5) With the assumption of constant returns to scale, any proportional change in input leads to the same proportional change in output. The CCR model is only appropriate when assuming constant returns to scale (Charnes et al., 1978). However, if this assumption does not hold, the BCC model proposed by Banker et al. (1984) should be used instead. The BBC model is mainly to accommodate variable returns to scale.	(3) The DEA model is known as a non-parametric approach and a linear fractional programming model that is capable of coping with nonlinear relationships between the inputs and outputs. Therefore, the DEA model can be used with heterogeneous metrics of inputs and outputs in the ITPM context (Cho, 2010). (4) The DEA has been widely used as an objective multi-criteria decision-making method (Lawrence and Kleinman, 2010). (5) Sowlati et al. (2005) present a model within the DEA framework for prioritizing IT projects. (6) There is no need for the DEA model to include explicit mathematical forms between inputs (e.g., cost) and outputs (e.g., return), and this feature of the DEA model will uncover hidden relationships among multiple inputs and outputs.

2.4 Efficient Frontier and IT Portfolio Management

To reduce portfolio risk through diversification, the MPT has been widely used in practice by embracing financial instruments that are not perfectly correlated over the past few decades. With reference to Markowitz (1952), investors consider each balanced portfolio choice and select the highest portfolio return for given portfolios risks. More importantly, a series of balanced portfolio choices, which are known as dominant choices, form the efficient frontier.

The efficient frontier is also recognized as a graphical result that represents the optimal combination of risk and return.

My research assists a firm in building an IT portfolio with relevant attributes that perform well in the context of the firm to better achieve enterprise business objectives. The IT Portfolio Management (ITPM) problem can be seen as an optimization problem concerning IT resource allocation issue. When dealing with ITPM problems, a fundamental question is how to maximize the return and minimize the risk; meanwhile, the decision-maker needs to incorporate all the possible attributes to better address IT portfolios. To properly address ITPM issues, enterprise executives may need to identify measurable strategic objectives embraced by various business units. In response to this need, the central goal of my research is to provide various kinds of business scenarios to illustrate IT resource allocations as references for enterprise executives so they can select the most appropriate IT portfolio to achieve their enterprise strategic goals.

ITPM is widely regarded as a management practice. ITPM aims to manage IT assets as a whole through a method similar to managing financial portfolios (McFarlan, 1982; Bardhan et al., 2004; Weill and Aral, 2006), along with nonfinancial evaluation methods (Betz, 2007). In terms of ITPM, both the DEA and the MPT are applicable to measure the performance of IT project portfolios by taking into account relevant components (e.g., cost, risk and return). Specifically, incorporating risks into the project portfolio management processes gives the senior executive a better understanding of the evaluation and selection of projects, the allocation of resources, and the implementation for projects (Teller et al., 2014). My research finds out how the concept of an efficient frontier, when applied to IT portfolios, demonstrates the optimal combination of selected IT portfolio attributes (e.g., budget cost, risk and expected return). Accordingly, the results will include a series of balanced IT portfolio choices (also known as efficient choices) that form the IT portfolio efficient frontier as the final outcome.

III. MODEL DEVELOPMENT

Along with risk metric development, attaining efficient frontiers from the Data Envelopment Analysis (DEA) and the Markowitz Portfolio Theory (MPT) is a new methodology for firms to identify their most qualified IT portfolio from all the portfolio choices. As a result, rational senior executives can benefit from the proposed model, which is called the IT Portfolio Efficient Frontier model, to make optimal IT investment decisions. This process is outlined in Figure 3.1; this section will provide more details to justify each step of the proposed model.

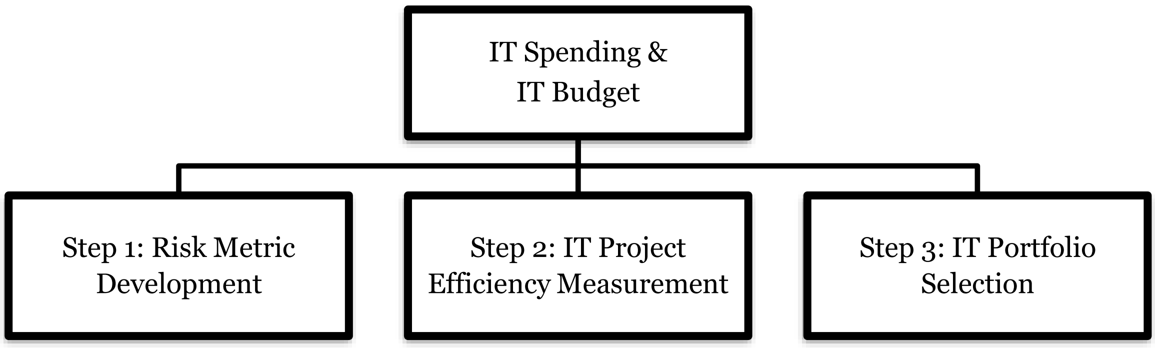


Figure 3.1: IT Portfolio Efficient Frontier Model

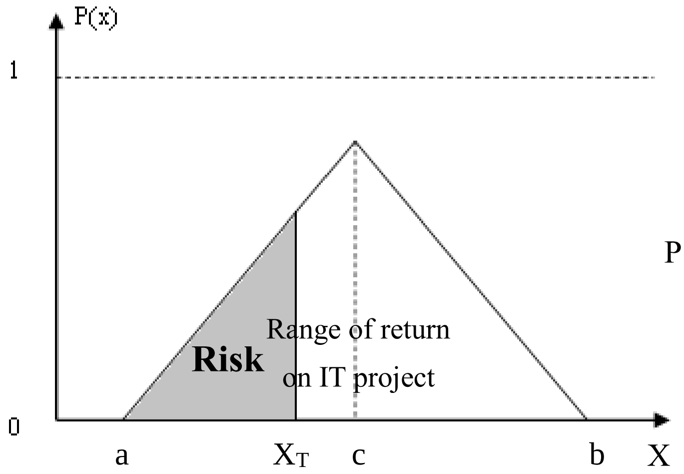
3.1 Step 1: Risk Metric Development

Building from Markowitz (1959), financial literature defines risk as the standard deviation of return and considers a portfolio to be a weighted combination of assets. Since IT investments are more likely to be considered illiquid, Dewan et al. (2007, 2011) indicate that IT investments are much riskier than non-IT capital investments.

From the Management Information Systems (MIS) standpoint, risk is perceived as the possibility of additional cost or loss due to the choice of alternatives; thus, risk can be quantified by assessing the probability of occurrence and a financial consequence for each alternative (Pearlson and Saunders, 2010). According to Lientz and Larssen (2006), IT projects are often distinguished from many non-IT projects on the basis of their high levels of risk; therefore, risk can be viewed as the product of an event's likelihood and the exposure or loss if the event occurs. Project risk, according to the project management body of knowledge (PMBOK) from the Project Management Institute (2000), is "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project objective. A risk has a cause and, if it occurs, a consequence" (p. 127). Further, decision theory defines risk as each action that leads to one of many possible specific outcomes with known probabilities, which are assumed to be known by the decision maker (Hansson, 1994).

In addition, utility theory (Keeney and Raiffa, 1993) is used to represent the preference of a decision maker for various levels of a performance measure. If an appropriate utility is assigned to each possible consequence, and the expected utility of each alternative is calculated, then the most efficient course of action is the alternative with the highest expected utility. According to Clemen and Reilly (2001), risk is defined as an event having a negative impact on project outcomes, and three common risk attitudes, which depend on decision-makers' utility curves, are: (1) Risk-Averse: Concavity in a utility curve implies that an individual has a risk-averse attitude, called a concave (opening downward) Utility Curve, (2) Risk-Seeking: Convexity in a utility curve implies that an individual has a risk-seeking attitude, called a Convex (opening upward) Utility Curve, and (3) Risk-Neutral: Risk neutrality is reflected by a utility curve that is simply a straight line.

The preference for various levels of each performance measure may be different; thus Step 1 of the proposed model presents a risk assessment method that embraces concepts from the Technical Performance Measure (TPM) and utility function to measure risk (Browning et al., 2002). More specifically, risk measurement is the integral of the products of probability P(x) and the loss of each unachieved outcome, which is calculated by $[U(X_T) - U(X)]$. While evaluating the probability of an identified risk and its effects on objectives (Wang et al., 2010), the possible value of a performance measure is represented by a Probability Density Function (PDF). Following these premises, this study presents three different level values: the most likely return, the worst-case return, and the best-case return, by using the triangular probability distribution shown in Figure 3.2.



$$P(x) = \begin{cases} 0 & for\ \ x < a, \\ \frac{2(x-a)}{(b-a)(c-a)} & for\ \ a \le x \le c, \\ \frac{2(b-x)}{(b-a)(c-a)} & for\ \ c < x \le b \\ 0 & for\ \ b < x, \end{cases}$$

Figure 3.2: Triangular Probability Distribution

Hence, the definition of risk value (risk score) in this study is the probability that the return falls under the manager's managerial expectation (X_T) for each IT project associated with its utility function, as shown below.

$$R_i = \sum_i wi * \left\{ k * \int_{-\infty}^{X_T} P(x)[U(X_T - U(X)]dx \right\}$$

Additionally, details about the proposed risk assessment method, including its relevant variables and definitions, can be found in Table 3.2.

Table 3.2: Variables and Definitions for Risk Assessment Method	
Variable	Definition
a	Worst-case return for an IT project
b	Best-case return for an IT project
c	Most-likely return for an IT project
X	Actual return on an IT project
X_T	Managerial expectation for an IT project
P(x)	Likelihood of achieving the return on an IT project

Table 3.2, continued	
U (X_T)	The utility value of managerial expectation for an IT project
U(x)	The utility value of actual return on an IT project
k	A normalization constant
w_i	The percentage of budget spending over total budget cost on an IT project
R_i	Risk (value)

3.2 Step 2: IT Project Efficiency Measurement

Tanriverdi and Ruefli (2004) and Dewan and Ren (2011) discuss the importance of incorporating risk into the IT business performance analysis and emphasize the impact of IT investments on the risk-return relations of firms. Based on the concept built from the DEA model while measuring the efficiency of the Decision Making Unit (DMU), the DEA model's unique feature can transform the ratio of multiple inputs and outputs into an equivalent linear program with a scalar measurement ranging between 0 (the worst) and 1 (the best) (Tone, 2001).

By taking into account the nature and complexity of the relation, the Data Envelopment Analysis (DEA) model is regarded as a proper multi-attribute model for estimating IT risks as inputs and returns as outputs. Since an IT project is the main level through which IT activity translates to business results, an IT project portfolio can be thought of as a pool of heterogeneous IT projects within a firm. In this respect, Step 2 will prioritize the IT projects by considering each IT project as a DMU. The quantitative model for IT project efficiency measurement is shown below:

$$\text{Max } E_j = \frac{uy_j - u_0}{v_1x_{1j} + v_2x_{2j}}$$

$$\text{Subject to } \frac{uy_j - u_0}{v_1x_{1j} + v_2x_{2j}} \leq 1$$

j = 1… n

$u, v_1, v_2 \geq \varepsilon$

The variables and definitions for the proposed model can be found in Table 3.3. The variable u_0 is a free variable that is defined with DEA, particularly in the Variable Returns to Scale (VRS) DEA model. However, if u_0 is zero, the model above will be considered an application of the Constant Return to Scale (CRS) DEA model.

Table 3.3: Variables and Definitions for IT project efficiency measurement model

Variable	Definition
x_{1j}	Estimated cost of IT project j or IT portfolio j
x_{2j}	Estimated risk of IT project j or IT portfolio j
y_j	Estimated return of IT project j or IT portfolio j
E_j	The efficiency of IT project j or IT portfolio j
u	The weight on the return
u_0	Free-in-sign variable
$v1$	The weight on the cost
$v2$	The weight on the risk

3.3 Step 3: IT Portfolio Selection

To select the most applicable IT portfolio choice, this paper aims to develop a quantitative model to address the IT portfolio selection, as shown below. In most cases, when decision criteria are outlined in Markowitz's portfolio theory (Markowitz, 1959), the selection rationale is grounded in the portfolio balancing various decision components, including cost (C), risk (R), and return (V). In line with Markowitz's portfolio theory, the selected IT portfolio choices will be able to provide the highest return corresponding to the decision-maker's risk tolerance level. According to Dia (2009), the generation of a portfolio performed by a mathematical model optimizes the weighted sum of the DMUs' efficiency ratios, which can produce an optimal value of selected choices that reflect the decision-maker's preferences. Furthermore, the variables and definitions for the proposed model are shown in Table 3.4, and π is defined as a vector representing a set of selected IT projects, also known as an IT project portfolio in this paper.

$$\text{Max } I(\pi) = \sum_{j=1}^{n} E_j S_j$$

Subject to

$$uy_j - v_1 x_{1j} - v_2 x_{2j} \leq 0$$

$$\sum_{j=1}^{n} uy_j \geq E_j$$

$$\sum_{j=1}^{n} S_j x_{ij} \leq X_i$$

$$\sum_{j=1}^{n} S_j y_{ij} \leq Y_i$$

$\sum_{j=1}^{n} S_j \leq n$

$S_j = 0$ or 1

i = 1… t

j = 1… n

$u, v_1, v_2 \geq \varepsilon$

Table 3.4: Variables and Definitions for IT portfolio selection model	
Variable	Definition
I	Optimal score of a selected IT portfolio
S_j	The selected IT project(s) in the portfolio
X_i	The maximal amount of inputs to be considered in the IT portfolio
Y_i	The minimal amount of outputs to be considered in the IT portfolio
E_j	The efficiency of IT project j
x_{1j}	Estimated cost of IT project j
x_{2j}	Estimated risk of IT project j
y_j	Estimated return of IT project j
u	The weight on the return
$v1$	The weight on the cost
$v2$	The weight on the risk

IV. HYPOTHETICAL EXAMPLE & COMPUTATIONAL ANALYSIS

4.1 Hypothetical Example and Experiment Design

This paper responds to the challenge of IT project portfolio selection at a firm. An illustration of this challenge follows.

ABC is a Fortune-500 enterprise where IT investment governance has been listed among the top management issues. To prepare a short list of the "most qualified" IT project portfolio choice, ABC's C-level managers are going to have an evidence-based meeting to determine the best investment allocation strategy from those qualified IT project portfolio choices.

This illustration could happen at almost any enterprise. There is a set of i qualified IT projects from x1, x2, to xi for the portfolio selection. Based on the hypothetical data in Table 3.5, there are three main IT project types: (1) Operating Margin; i.e., this type of IT project is expected to generate a certain portion of marginal financial return after implementation, (2) IT Infrastructure; i.e., this type of IT project may have low financial return but significant impact on business process, and (3) Long Term Growth; i.e., this type of IT project is expected to generate high financial return with longer completion process. Beyond these options, any combination of IT projects could be the portfolio choice. The two most extreme instances are portfolios composed of none of the IT projects ({}) or composed of all of the IT projects ({x1, x2,… xi}). For example, if 30 IT projects are to be selected, there could be more than 1,000,000,000 portfolio choices (2^30). Finally, by evaluating return, risk, and cost, the n IT portfolio choices ($n \leq m$) can be selected as the "candidates" for the IT portfolio choices.

This research only uses a small data set in this hypothetical example in order to facilitate the understanding of the model's use, and the numbers used in this example are disguised because of the investment information protection agreement with a Fortune 500 company.

Table 3.5: Hypothetical IT project data			
Id.	IT Project Name	Project Type	Return on investment (ROI)
#1	J2EE platform migration	Operating Margin	4.7%
#2	Mobile payment plan	Operating Margin	4.5%
#3	Contract management system upgrade	Operating Margin	2.7%
#4	Operating system upgrades	IT Infrastructure	-3.8%
#5	Underwriting system upgrade	Operating Margin	2.2%
#6	Life and auto policy web interface	Long Term Growth	10.0%
#7	Installations of a new database system	IT Infrastructure	-5.4%
#8	Client e-notice system	Operating Margin	8.0%
#9	Partnership e-credit plan	Operating Margin	9.9%
#10	Deployment of new computers and memory upgrades of servers	IT Infrastructure	-7.9%
#11	Debt/lending data analysis plan (BI)	Long term Growth	11.1%

This research demonstrates three scenarios for IT project portfolios by using the proposed IT Portfolio Efficient Frontier model to address IT resource allocation. The characteristics of these three scenarios, as well as descriptive statistics for the simulated IT portfolio data, can be found in Table 3.6. The assumptions of this paper's hypothetical example are as follows: (1) the three scenarios (i.e., Even distribution-based IT portfolio, Uneven distribution-based IT portfolio, and Dominant IT portfolio) each have the same budget for IT investment projects and (2) each specific IT investment project will apply the same utility function across the three scenarios.

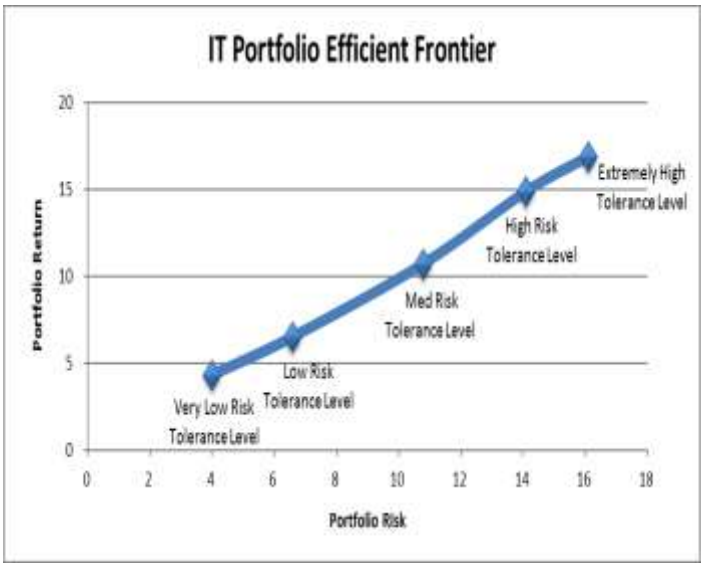
Table 3.6: Characteristics and Descriptive statistics of the simulated IT portfolio data			
Scenario 1	Variable	Average	Std. Dev.
Even Distribution-based IT Portfolio (All IT project sizes are included between one Std. Dev of the Mean value)	Cost ($ Million)	$ 2	$ 0.05
	Return ($ Million)	$ 2.06	$ 0.13
Scenario 2	Variable	Average	Std. Dev.
Uneven Distribution-based IT Portfolio (Around half of the IT project sizes are out of the range of one Std. Dev of the Mean value)	Cost ($ Million)	$ 2	$ 0.58
	Return ($ Million)	$ 1.95	$ 0.74
Scenario 3	Variable	Average	Std. Dev.
Dominant IT Portfolio (Along with multiple small project sizes in an IT portfolio, there is at least one IT project size that is larger than two Std.	Cost ($ Million)	$ 2	$ 2.94
	Return ($ Million)	$ 2.11	$ 3.19

4.2 Results from Computational Analysis

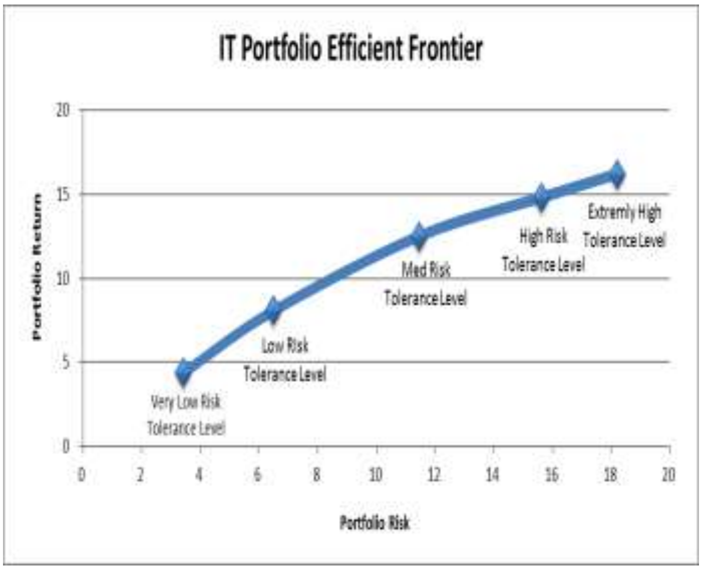
To determine the optimal decision in regards to the decision-maker's risk tolerance level, this paper illustrates three scenarios using the proposed IT Portfolio Efficient Frontier model to address the qualified IT portfolio choices from an extremely high risk tolerance level (aggressive) to a very low risk tolerance level (conservative). Additionally, based on the experimental setting of this study, the risk tolerance levels are set from 0.2 to 0.8. Specifically, the derived aggressive portfolio choice's risk will be no more than 80% of the original overall IT project risk, while the derived conservative portfolio choice's risk will be no less than 20% of the original overall IT project risk. This setting follows heuristics, and the exact settings in the enterprise are very contingent. More details about the computational results can be found in Table 3.7, Table 3.8 and Table 3.9 as shown below.

Referring to the results in Table 3.7, the IT portfolio efficient frontier generated from the Even distribution-based IT portfolio scenario appears as a slight upward curve, which shows that the IT portfolio risk has a positive linear relationship with the IT portfolio return. Along with the decision-maker's extremely high risk tolerance level, if a firm's IT investment projects are similar to the Even distribution-based IT portfolio scenario, the firm will be able to gain its optimal portfolio value via the proposed IT Portfolio Efficient Frontier model.

Table 3.7: IT Portfolio Selection under different risk tolerance levels in Even Distribution

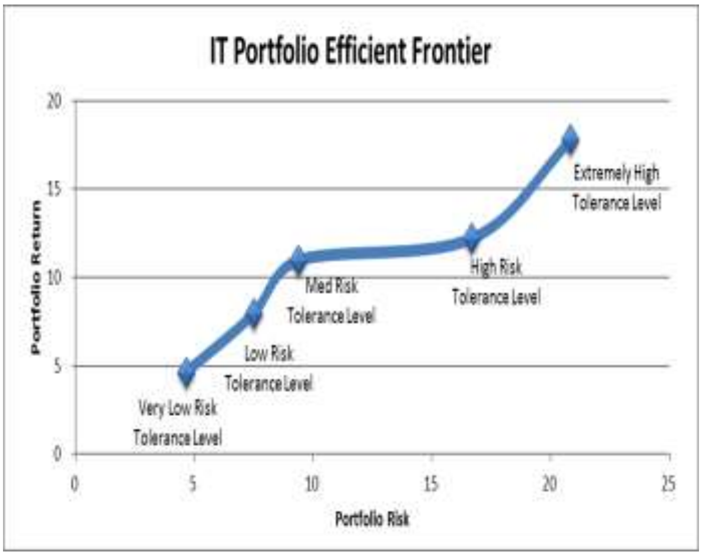
The IT efficient frontier is derived by maximum return in a given risk limit	Risk Tolerance Levels	The selected # IT project(s) in the qualified IT portfolio
	Extremely High 0.8	{1, 2, 3, 5, 6, 7, 8, 9}
	High 0.65	{1, 2, 3, 5, 6, 9, 11}
	Med 0.5	{1, 2, 6, 9, 11}
	Low 0.35	{1, 6, 9}
	Very Low 0.2	{1, 9}

Based on the results in Table 3.8 as shown below, the IT portfolio efficient frontier is able to resemble a slight downward curve; that is, IT portfolio risk has a positive linear relationship with IT portfolio return. Consequently, along with decision-maker’s extreme risk tolerance levels, if a firm’s IT investment projects are comparable to the Uneven distribution-based IT portfolio scenario, this firm will be able to achieve its optimal IT portfolio value via the proposed IT Portfolio Efficient Frontier model.

<table>
<tr><th colspan="3">Table 3.8: IT Portfolio Selection under different risk tolerance levels
in Uneven Distribution</th></tr>
<tr><th>The IT efficient frontier is derived by maximum return in a given risk limit</th><th>Risk Tolerance Levels</th><th>The selected # IT project(s) in the qualified IT portfolio</th></tr>
<tr><td rowspan="5">
</td><td>Extremely High
0.8</td><td>{1, 2, 3, 4, 5, 6, 9, 10, 11}</td></tr>
<tr><td>High
0.65</td><td>{1, 2, 3, 5, 6, 9, 11}</td></tr>
<tr><td>Med
0.5</td><td>{1, 2, 3, 5, 9, 11}</td></tr>
<tr><td>Low
0.35</td><td>{1, 2, 3, 5, 9}</td></tr>
<tr><td>Very Low
0.2</td><td>{1, 2, 5}</td></tr>
</table>

In this study, the Dominant IT portfolio is considered to be an extreme case of the Uneven distribution-based IT portfolio. The results in Table 3.9 show that if IT investment projects resemble the Dominant IT portfolio scenario, an inflection point of the IT portfolio efficient frontier appears under the decision-maker's medium risk tolerance level. In particular, before reaching the decision-maker's medium risk tolerance level, the results show an extreme downward curve, which may appear to be a concave curve. Further, after reaching the decision-maker's medium risk tolerance level, the results of this study indicate an extreme upward curve, which may appear to be a convex curve. Regarding the Dominant IT portfolio scenario, the most qualified IT portfolio can be generated with the decision-maker's medium risk tolerance level. This is because the most qualified IT portfolio includes almost all the IT projects except the largest IT investment project. Accordingly, if IT investments are similar to the Dominant IT portfolio, the senior executives may need to consider a conservative investment strategy after reaching the inflection point of IT efficient frontier.

Table 3.9: IT Portfolio Selection under different risk tolerance levels in Dominant IT portfolio

The IT efficient frontier is derived by maximum return in a given risk limit	Risk Tolerance Levels	The selected # IT project(s) in the qualified IT portfolio
	Extremely High 0.8	{1, 4, 5, 7, 8, 10}
	High 0.65	{8}
	Med 0.5	{1, 2, 3, 4, 5, 6, 7, 9, 10, 11}
	Low 0.35	{1, 4, 5, 6, 7, 9, 11}
	Very Low 0.2	{1, 5, 9, 11}

V. CONCLUSION AND FUTURE RESEARCH

Based on the experimental design and simulation data, this paper demonstrates three scenarios for tackling IT investment decisions: Even distribution-based IT portfolio, Uneven distribution-based IT portfolio, and Dominant IT portfolio. In each case, this study assumes that these three scenarios utilize the same IT budget and IT spending to realize their IT project portfolios. More importantly, this study assumes that senior executives will have consistent risk tolerance levels to deal with all the IT investment projects; meanwhile, each specific IT investment project across the three types of IT portfolio scenarios is assigned the same utility function in the hypothetical example of this paper. In addition, the results of this paper show that if IT investments are similar to the Even distribution-based IT portfolio, then IT portfolio efficient frontiers may resemble a slight upward curve. On the other hand, if IT investments are comparable to the Uneven distribution-based IT Portfolio, the IT portfolio efficient frontiers may appear as a slight downward curve. Furthermore, the Dominant IT portfolio is considered to be an extreme case of the Uneven distribution-based IT Portfolio in this study. If IT investment projects resemble the Dominant IT portfolio scenario, an inflection point appears in the IT portfolio efficient frontier under the decision-maker's medium risk tolerance level.

For managerial interpretation, the IT portfolio efficient frontiers of both the Even distribution-based IT Portfolio and the Uneven distribution-based IT Portfolio indicate that IT portfolio risk has a positive linear relationship with IT portfolio return. In this regard, the results may match the fundamental concept of financial investment; that is, low risk investment yields low return, while high risk investment yields high return. In particular, a senior executive who has a high risk tolerance level with the same IT budget and IT spending across the three types of IT portfolio scenarios (i.e., Even, Uneven and Dominant) may get the most qualified IT portfolio choice from the Even distribution-based IT portfolio. Alternatively, a firm may benefit most from a Dominant IT portfolio if a senior executive has a medium or lower risk tolerance level with the same IT budget and IT spending across the three types of IT portfolio. Regarding all the portfolio choices in the Dominant IT portfolio, the results of this paper show that the most qualified IT portfolio choice could be generated with the senior executive's medium risk tolerance level. This is because this most qualified IT portfolio includes almost all the IT projects except for the largest IT investment project in the Dominant IT portfolio. To put it briefly, if IT investments are similar to the Dominant IT portfolio, it would be good for senior executives to consider a conservative investment strategy after reaching the inflection point of the IT efficient frontier.

In terms of future work in this topic, I will run a large-scale simulation including interactions with the three steps to complement the initial illustrative example, and I also intend to collect more empirical data related to IT project portfolios. Consequently, the results of the simulated data may serve as strong references when applying the proposed IT Portfolio Efficient Frontier model to better analyze empirical data.

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Chapter 4: Using a Mark-To-Market Valuation Technique to Objectively Measure IT Portfolio

I. INTRODUCTION

There has been significant debate on whether investment in information technology (IT) leads to improved productivity and/or competitive advantage (e.g. Carr, 2003; McFarlan and Nolan, 2003). However, there is also a growing set of evidence showing that investment in information technology does produce value. Such research considers investment and returns at different levels. Researchers have found that overall economic productivity may be attributed to investment in IT through substitution of labor, basic automation and improved process, or multi-factor productivity (Brynjolfsson and Hitt, 1995; Dewan and Min, 1997; Jorgenson, 2001). Country-level returns on IT investment also suggest that countries that invest in IT infrastructure and have higher overall IT investments consequently have improved productivity (Dewan and Kraemer, 2000). Productivity has been linked to investment in IT across industries, with IT-intensive industries experiencing gains in the value of complementary non-IT assets while less IT-intensive industries experience improvements via basic automation (Mittal and Nault, 2009). Finally, at the firm level, there is additional evidence that IT investment translates into profitability (e.g. Bharadwaj, Bharadwaj, and Konsynski, 1999; Melville, Kraemer, and Gurbaxani, 2004; Mithas, Tafti, Bardhan, and Goh 2012).

This study complements the aforementioned research at the economy, country, industry, and firm levels by examining the process or mechanism at the root of this value creation: the IT project and the associated IT portfolio. Evaluating the process level (i.e. the within-firm mechanism) is an important aspect of understanding how investment in IT resources translates to business value (Ray, Muhanna, and Barney, 2005). The IT project is the main tactical level through which IT activity translates to business results for the enterprise. As such, understanding investments in IT projects and the associated IT portfolio is of high importance to IT managers, general managers and the overall firm. Additionally, this approach leverages Mark-To-Market valuation, a financial measurement technique often used by commodity traders to dynamically assess the market value of a given asset, and modern portfolio theory (Markowitz, 1952) to develop a technique that provides a relatively objective means for quantifying and monitoring value creation at the level in which is created.

This research specifically utilizes the Mark-To-Market concept to allow managers to evaluate an IT project's attractiveness before, during and after the project. This paper has three main contributions. First, Mark-To-Market concepts are shown to be useful in the context of IT projects in order to provide objective measures of IT success. Second, while many valuation techniques related to IT projects consider the forecasted return on a given investment (cost/benefit, ROI, Internal Rate of Return), this technique proves useful beyond the project lifecycle by including returns that occur after the work of an IT project is complete (i.e. long-term investments are common, especially in IT infrastructure projects). Third and finally, this research allows all IT projects, regardless of their potentially heterogeneous nature, to be treated equivalently in terms of evaluating value creation and applying financial portfolio management techniques (Markowitz, 1952).

II. THEORETICAL DEVELOPMENT

2.1 Mark-To-Market

Mark-To-Market (MTM) is a technique that values an asset at its fair market value. The technique has been used to assess realized and unrealized gains and losses for stocks and commodities since the 1950s. Accountants began utilizing the valuation mechanism to recognize unrealized gains and losses of certain assets with the advent of FAS115 (Financial Accounting Standards Board 1993). The accounting practice became especially prevalent as regulatory agencies sought to provide more transparency for a firm's financial standing in the wake of the collapse of the energy trading firm Enron (e.g. FAS133). The premise of Mark-To-Market accounting is that an unrealized gain or loss may be measured as the difference between the purchase price of the asset and its fair market price. One key benefit of Mark-To-Market valuation is that assets are constantly assessed in a longitudinal way based on their value relative to the current market value of similar assets. This provides real-time valuation that is not possible with traditional valuation methods, such as NPV, ROI and Cost-Benefit analysis, which tend to focus on the initiation phase of IT projects.

However, one of the disadvantages of Mark-To-Market accounting is that the external market may overemphasize the volatility in value, especially in illiquid markets undergoing a crisis (Allen and Carletti, 2008). In the case of the IT portfolio, there is no market in which a firm can trade its existing or future IT projects, so it is problematic to establish a fair market value for a portfolio of IT projects. To address this issue, the MTM technique establishes a model for each project as a proxy for the fair market value. The proposed MTM model is intended for internal management of the IT project portfolio, not for the consumption of the external market. To put is simply, the proposed MTM model focuses on the expected return of the project based on all discounted cash flows as of the initiation phase of the IT project, and the model articulates the difference between all anticipated future revenues and budgeted future costs known at the beginning of the project. In other words, the MTM technique utilizes the benefit of marking the current financial standing of an IT project versus a model created for internal use by the firm, but avoids the challenges when the valuation's source is external to the firm (i.e. stock market). As a result, the technique avoids the downside of external fluctuation normally associated with Mark-To-Market accounting valuation.

Because IT-related projects are almost 100% illiquid (i.e. the firm is not generally able to sell an IT project to a buyer before, during or after its completion in any type of marketplace), there is no true Mark-To-Market valuation. Instead, this study applies the same basic principles of Mark-To-Market, but "mark" or compare the current value of the IT project against the projected value of the IT project at its inception (the model). The model serves as a substitute for a market valuation in this scenario of illiquidity. The result is a systematic and relatively objective way to measure IT project and portfolio success that is applicable across a diverse set of IT projects. While this study is not proposing that any such valuation of IT projects be recognized in the financial reporting of the company in a true Mark-To-Market accounting sense, the technique of determining fair value estimates from a Mark-To-Model approach has been shown to be highly correlated to firm value (Kolev, 2008).

2.2 The Black-Scholes Model and Real Option Analysis

The fundamental assumption of the Black-Scholes model is that the risk-free rate and volatility of the underlying are known and constant, and market movements cannot be predicted in an efficient market. According to Burke (2012), the Black-Scholes model, which was the first widely used option model, uses stochastic calculus to obtain a value for an investment, assuming costs are fixed. Another important assumption of the Black-Scholes model is that revenues follow a log-normal distribution for investment returns; thus, the value generated by the Black-Sholes model is between zero and infinite. Compared with financial derivatives (which have a minimum value of zero), IT projects may have negative values and often use up a substantial amount of money. While the essential feature of the Black-Scholes model is to assume that correlation between costs and revenues is symmetric, the Black-Scholes model may suffice in assessing simple investments (Black and Sholes, 1973). In line with this perspective, the Black-Scholes option model is understood as the foundation for real options-based approaches, as real option thinking incorporates in the valuation of a firm's portfolio of assets the choices that it may have (Trigeorgis, 1993; Copeland and Antikarov, 2001; Mun, 2002; Mahoney, 2004).

An increasing number of practitioners and researchers has started to evaluate financial portfolios by measuring the Greeks, which are built on the Black-Scholes option-based model. Accordingly, Benaroch & Kaufman (1999) developed a bridge to transfer the use of the Greeks from traditional financial assets (Black-Scholes model) to IT projects. Along with Benaroch & Kaufman (1999)'s method, the proposed MTM Valuation approach is used to measure and keep track of IT portfolios over different time periods (i.e., relevant information associated with project portfolios may be updated during the whole project lifecycle). Since Mark-To-Market value is a single metric that assesses project success, the measurement of value at every stage of the project, during the whole project lifecycle, allows aggregated reporting across the IT portfolio. As a result, the top management will be able to monitor project completeness and its cash flow process in terms of change in real dollars.

2.3 IT Portfolio Management (ITPM)

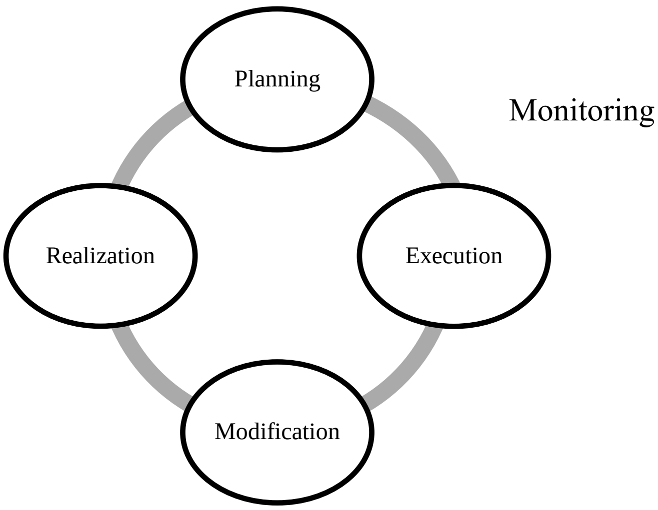
Briefly, project management is the application of managerial systems to perform a project from the beginning to end, and, as mentioned earlier, it is the primary mechanism for managers to achieve their objectives in terms of schedule, budget, and revenue. The IT portfolio of a firm is regarded as its total investment in computing and communication technology (Weill and Vitale, 2002), or the sum total of all IT projects. Concerning the application of portfolio management to the IT portfolio, both academic and industrial researchers refer to Markowitz's modern portfolio theory (Markowitz, 1952) and apply it to this context (e.g. Tu and Shaw, 2011). In fact, the primary decision model in ITPM is frequently the financial portfolio model, which is used to evaluate investments according to a balance of return and risk.

The increasing embeddedness of IT investment and its integral role in the creation of value for firms (Davern and Kauffman, 2000; Kohli and Grover, 2008) has led to increasing levels of IT investment and additional scrutiny of the overall IT portfolio in delivering value (Maizlish and Handler, 2005). Additionally, with the increasing influence of IT to all businesses within an enterprise, many firms have largely increased IT investments in recent years (Kohli and Grover, 2008). Due to the changing nature of a project's financial position, many IT projects cannot easily be measured by traditional financial methods (e.g. NPV). The main reason for this is that assessment of financial success rarely includes the associated cash flows that occur after an IT project is closed. More importantly, since financial position is rarely assessed after the completion phase of the project, one major gap in the IT project financial assessment is that IT projects typically lack a standard, numeric valuation approach. In addition, IT projects are illiquid: there is no market for buying and selling said projects (as compared to stocks for example) since they are firm-specific assets. The illiquidity of IT projects means that assessments are appropriate for internal measurements by the firm, but they do not have the same market characteristics required for many of the portfolio management tools. Consequently, assessment techniques common for commodities and available using modern portfolio theory may not be fully leveraged in the management of the IT portfolio.

Option thinking is a useful technique for assessing the value of flexibility in the context of the IT portfolio (Benaroch and Kauffman, 1999; Benaroch, Shah, and Jeffery, 2005), especially given the value inherent in a multiple stage investment decision (Copeland and Tufano, 2004), which is typical with IT projects. Valuation that leverages a combination of discounted cash flows and real option thinking presents the most realistic assessment of an asset's true value (Putten and MacMillan, 2004). The common choices available to managers in IT project and portfolio management include staging, abandoning, deferring, scaling and switching to an alternative use (Fichman, Keil, and Tiwana, 2005). The credibility of using options thinking to evaluate IT portfolio is well established. This study does not preclude the use of real options thinking; instead, it proposes that real options valuation may serve as a useful input to the proposed valuation technique.

2.4 Valuing IT Projects throughout the Project Lifecycle

According to the Project Management Body of Knowledge (PMBOK), there are five relevant phases of project management, as shown in Figure 4.1: Planning, Execution, Modification, Realization and Monitoring. Other frameworks may vary, but IT projects are generally conceptualized as occurring in phases with a monitoring aspect as part of the overall process. Unlike many IT valuation techniques, the Mark-To-Market technique addresses projects throughout their lifecycle in a consistent manner. This technique attributes a specific dollar value to the project at every time period of its lifecycle. The technique is also useful beyond the phases of the project in which the costs are incurred to include those phases (especially realization) where actual returns are earned.



Phase
Planning
Execution
Modification
Realization
Monitoring

Figure 4.1: Phases of the IT Project

As for the comprehensive definition for IT portfolio management, Maizlish and Handler (2005) classify the IT portfolio management problem into three phases of IT life cycle: the IT discovery portfolio, the IT project portfolio, and the IT asset portfolio. As such, any technique that is proposed to value an IT portfolio must account for these three phases and must also address a diverse set of initiatives that are nearly certain to occur in most organizations. The approach of this paper differs from many of the IT project justification techniques such as cost/benefit analysis, NPV and ROI, especially regarding their use in practice. In practice, the financial attractiveness of a project is almost always evaluated prior to its approval and initiation. However, financial attractiveness is often not measured on an ongoing basis, especially beyond the duration of the IT project itself to incorporate cash flows attributable to the project. By contrast, this valuation technique includes the continuous assessment of the financial health of a project before, during and well beyond the implementation of the information technology or system to capture the realized return when it occurs. Since valuing IT investments, especially in an IT infrastructure, requires understanding their use value within the organization (Kumar, 2004), a complete IT portfolio management tool should incorporate the value realization that frequently occurs after the IT project is completed.

There are three main components in the research framework of this paper: (1) Mark-To-Market, (2) IT Portfolio Management (ITPM) and (3) Valuing IT Projects throughout the Project Lifecycle. After applying MTM Valuation technique to evaluate IT portfolios throughout the project lifecycle, (Realized Return – Realized Cost) + (Unrealized Return – Unrealized Cost) is considered as a cash flow process that is connected to the project execution phase, the modification phase and the realization phase. Along with the proposed research framework, (Expected Return – Original Cost) is regarded as the planning phase. Greeks can be used to manage the IT portfolio throughout the planning, monitoring and realization phases.

The details about IT project phases relating to MTM Valuation technique are summarized in Table 4.1.

Table 4.1: MTM Valuation technique associated with IT Project Phase and Managerial Demonstration		
MTM Valuation technique	Phase of the IT Project	Managerial Demonstration
(Expected Revenue – Original Cost)	Planning phase	In connection with IT portfolio plan
(Realized Return – Realized Cost) + (Unrealized Return – Unrealized Cost)	Execution phase, Modification phase and Realization phase	Cash flow process
Whole MTM Valuation	Monitoring phase	Greeks measurement

III. MODEL DEVELOPMENT

3.1 Basic Assumptions of the Mark-To-Market Valuation Technique

Each project is measured in the same terms, just as a stock or commodity trader would value each of their assets. Mark-To-Market Valuation is a single metric that measures project success. Additionally, the measurement of value at every stage of the project allows aggregated reporting across the IT portfolio, and reports to top management will be in terms of change in real dollars instead of "75% of the selected projects are green," for example.

Benaroch & Kaufman (1999) presented the real options pricing analysis method to evaluate IT project investment, and their contribution is to apply real options in IT project investments domain. In this regard, my research extends Benaroch & Kaufman's (1999) real options pricing analysis method to further propose a Mark-To-Market (MTM) Valuation approach to measure IT portfolio, which incorporates revenue realization in order to accurately measure the value and the performance of IT portfolio. In particular, my proposed MTM valuation model assumes that the IT managers will reassess value of IT portfolio based on current conditions rather than assuming success, and all the IT investment decisions are rational. With regard to the limitation, this study does not include the IT managers' learning curves over time. Moreover, the difference in parameters between the Black-Scholes option model and Benaroch & Kaufman (1999) approach can be found in Table 4.2.

<table>
<tr><td colspan="4">Table 4.2: Parameters for Black-Scholes Model and Banaroch and Kauffman (1999)</td></tr>
<tr><td colspan="2">Black-Scholes Model</td><td colspan="2">Benaroch and Kauffman (1999)</td></tr>
<tr><td colspan="2">$C = SN(d_1) - Ee^{-rt}N(d_2)$
$d_1 = \left[\ln(\frac{S}{E}) + \left(r + \frac{1}{2\sigma^2}\right)t\right] / \sqrt{\sigma^2 t}$
$d_2 = d_1 - \sqrt{\sigma^2 t}$</td><td colspan="2">$C = AN(d_1) - e^{-r_f t}XN(d_2)$
$d_1 = \ln(\frac{A}{X})\, r_f T / \sigma\sqrt{T} + \frac{1}{2}\sigma\sqrt{T}$
$d_2 = d_1 - \sigma\sqrt{T}$</td></tr>
<tr><td>Parameter/variable</td><td>Managerial interpretation</td><td>Parameter/variable</td><td>Managerial interpretation</td></tr>
<tr><td>C</td><td>Value of a call option</td><td>C</td><td>Value of a call option to defer the investment</td></tr>
<tr><td>S</td><td>Current stock price</td><td>A</td><td>Present value of expected revenues from the operational project</td></tr>
</table>

Table 4.2, continued			
E	Exercise price of call	X	Cost of converting the investment opportunity into an operational project
r	Annual risk-free rate of return	r_f	Annual risk-free interest rate
σ^2	Variance (per year) of the continuous return on the stock	σ	Volatility of expected revenues
t	Time (in years) to expiration date	T	Maximum time to defer conversation of the investment opportunity into an operational project
N(d)	Probability that a standardized, normally distributed, random variable will be less than or equal to d	N(d)	Probability that a standardized, normally distributed, random variable will be less than or equal to d

All projects can be monitored periodically via the proposed MTM Valuation approach, and relevant information associated with project portfolio may be updated during the entire project lifecycle. Therefore, IT managers are able to keep track of both project completeness and its cash flow process simultaneously. Additionally, the main features of Benaroch & Kaufman (1999) and the proposed MTM Valuation approach are described in Table 4.3 as shown below.

Table 4.3: MTM Valuation Extends from Option Approach		
Methodology	Benaroch and Kauffman (1999)	MTM Valuation approach
Greeks are associated with project phase	Benaroah and Kaufman's Greeks are mainly focused on project planning phase.	New Greeks based on MTM approach are connected with both cash flow process and project planning phase.
Monitoring mechanism	Assess the value of deferring project for different deferral period	Dynamically update Revenue associated with Cost During project and After project
Project value	V is regarded as Call option value, according to Benaroch and Kauffman (1999).	This study uses MTM value for V in Greeks' measurement in the paper
Greeks measurement	Greeks from Benaroch and Kauffman (1999) = f (project size) Project size can be regarded as project cost here.	New Greeks = f (departure A-X from both cash flow process and planning phase) Departure can be included realized revenues and costs vs. planned revenues and costs. (Difference between planned and realized)

The longitudinal reassessment of the value of each project as if each project was a commodity allows the application of many portfolio risk management tools, including the "Greeks" – Delta (price), Theta (time), and Vega (volatility). Furthermore, the ability to apply common financial tools introduces the idea of hedging into the management of the IT Portfolio in order to reduce overall portfolio risk. This model enables the monitoring of projects beyond cost realization (which normally stops at project closure) and into the revenue realization that is likely to occur after project closure. To clarify the Greeks definition for the three methods in this paper, I summarize their basic mathematical definitions in Table 4.4.

Table 4.4: Greeks definition among three methods			
Greeks	Greeks from Black-Scholes Model	Greeks from Banaroch and Kauffman (1999)	Greeks from MTM Valuation
Delta (Δ)	Delta = $\frac{\partial C}{\partial S}$	Delta = $\frac{\partial C}{\partial A}$	Delta = $\frac{\partial V \text{ of MTM}}{\partial A}$
Vega (Λ)	Vega = $\frac{\partial C}{\partial \sigma}$	Vega = $\frac{\partial C}{\partial \sigma}$	Vega = $\frac{\partial V \text{ of MTM}}{\partial \sigma}$
Gamma (Γ)	Gamma = $\frac{\partial^2 C}{\partial S^2}$	Gamma = $\frac{\partial^2 C}{\partial A^2}$	Gamma = $\frac{\partial^2 V \text{ of MTM}}{\partial A^2}$

3.2 Quantitative Component – Mark-To-Market Valuation

The Mark-To-Market valuation is simply the best available information on revenues less cost associated with the project (realized and unrealized) as compared to the "mark", or the revenue less cost as estimated at project initiation. Therefore, it is a comparison of the current financial position at a given time period compared to the originally estimated financial position of the project. It can be written as:

Mark-To-Market Valuation, V = (Realized Revenue – Realized Cost) + (Unrealized Revenue – Unrealized Cost) – (Estimated Revenue – Original Cost)

$$\underbrace{V_{i,j,k}}_{\text{Mark-to-Model Valuation}} = \left(\underbrace{\sum_{j=0}^{j<k;\ i,j,k\geq 0,} R_j - \sum_{j=0}^{j<k;\ i,j,k\geq 0,} C_j}_{\text{Realized Revenue} - \text{Realized Cost}}\right) + \left(\underbrace{\sum_{j=k}^{j=T;\ i,j,k\geq 0} R_{j\geq k} - \sum_{j=k}^{j=T;\ i,j,k\geq 0} C_{j\geq k}}_{\text{Unrealized Revenue} - \text{Unrealized Cost}}\right)$$

$$- \left(\underbrace{\sum_{j=0}^{j=T;\ i,j,k\geq 0} R_{i,0} - \sum_{j=0}^{j=T;\ i,j,k\geq 0} C_{i,0}}_{\text{Estimated Revenue} - \text{Original Cost}}\right),$$

where R = revenue attributed to each project, C = cost attributed to each project, i = time period for the overall portfolio, j = time period for each project, with T as the last period where the project realizes costs or revenues, and k = current date.

3.3 Methodology and Simulated Data

Ultimately, the objective of this research is to demonstrate the usefulness of the valuation technique with real-world IT portfolio data. Currently, this study has developed a simulated IT portfolio to demonstrate the valuation technique and to pilot test the empirical model. The simulated IT portfolio is constructed to represent the IT investments of a company with revenues at the median size, which is just over $10 billion in revenue, of a Fortune 500 company (CNN Money 2012). An average enterprise IT investment is assumed to be 3.5% of revenue, matching Gartner's estimate of average IT spending in 2012 and their forecasted metric for 2013 (McGittigan et al., 2013). This means that the simulated portfolio is roughly based on a total enterprise annual IT investment of $369 million. Projects are constructed based on an average project size of $4.1million but are drawn randomly from an F-distribution (df_1=3, df_2=6) to provide the expected skewed distribution associated with many relatively small projects and a few very large projects. This assumption regarding project size is consistent with the notion that about one quarter of human resources on IT projects work on "business transformation projects" (PMI, Inc. 2012). Based on these assumptions, 90 IT projects formed the simulated IT portfolio.

This study then developed scenarios to represent the environmental shocks and operational uncertainty inherent in project financials over time. For example, this paper assumes a 12% standard deviation in actual project costs and actual revenues as compared to forecast, consistent with PMI's estimate of project dollars at risk (PMI, Inc. 2012). Therefore, descriptive statistics for the Simulated IT Portfolio is shown in Table 4.5. The consequence is that the simulated scenarios realistically depict project cost overruns, late project deliveries and failure to achieve estimated project revenues. Scenarios are constructed such that IT project costs and associated returns are quantified over time. The IT portfolio includes projects that start and finish at varying times and have different project durations. In this way, the simulated portfolio mirrors the complexity of an enterprise's IT portfolio.

Using these scenarios, this study applies the proposed Mark-To-Market valuation technique to the simulated portfolio. For each project and time period (assumed to be by the month to enable monthly assessment and reporting), the Mark-To-Market value is calculated as described in the previous section. Furthermore, MTM Valuation approach enables the organization to apply one metric to reflect the current financial standing of the project, and this allows the application of common financial tools to understand performance and assess risk in the overall portfolio.

Table 4.5: Descriptive Statistics for the Simulated IT Portfolio

Variable	Mean	Median	Std Dev.
Budget Cost	$11,764,184	$3,557,709	$41,143,429
Project Duration	11.1 months	9.0 months	6.9 months

IV. RESULTS

This simulation affords three main results: demonstration of the Mark-To-Market valuation, calculation of the "Greeks"; Delta(Δ), Vega (Λ) and Gamma(Γ), for the IT portfolio, and determination of a new proposed metric for IT portfolio risk management.

First, the simulation allows the determination of the net Mark-To-Market valuation of a portfolio of IT projects. The simulated IT portfolio was monitored for a period of three years, with projects starting and ending at various time periods. Two metrics are reported related to the Mark-To-Market valuation. The first is the Mark-To-Market valuation in total dollars. This metric captures the net difference in dollars between the current financial standing of the project and the financial standing of the project as estimated during the initiation phase. It allows an organization to observe, monitor and quantify the net departure of its portfolio of IT projects from the planned financial estimates. Mark-To-Market valuation is reported in Figure 4.2 for the three-year period. This result may be subject to dramatic differences depending on the size of the IT investment. A large company that invests a significant dollar figure in IT can expect that its Mark-To-Market net valuation to be higher than a smaller company with a lower IT budget. The Mark-To-Market valuation can be scaled as a ratio of the Mark-To-Market net / estimated budget cost. This second metric means that departures from estimates may be compared on equal footing regardless of the size of the project. The second metric is reported in Figure 4.3.

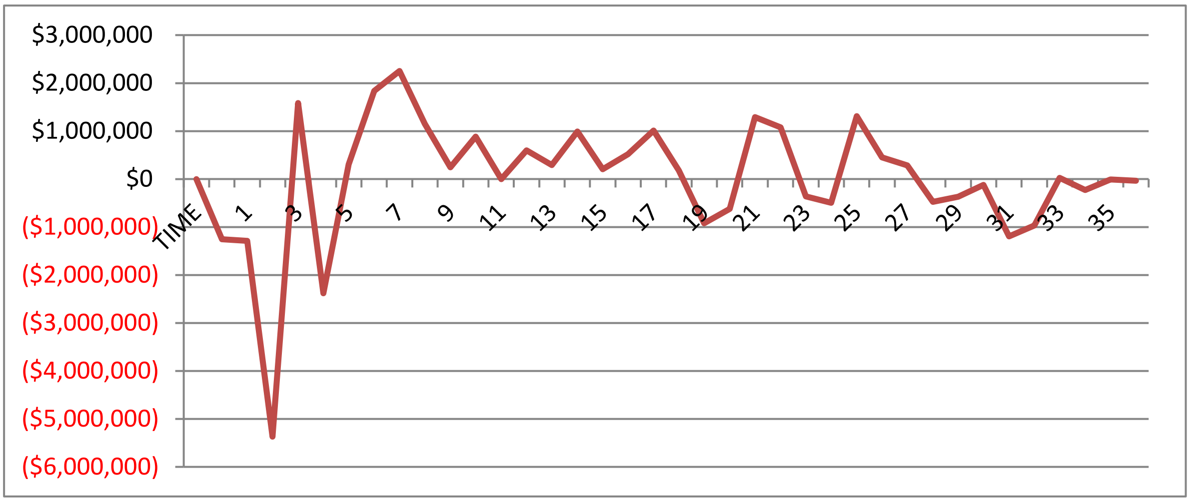


Figure 4.2: Simulated Mark-To-Market Valuation ($) at different time periods (36 months)

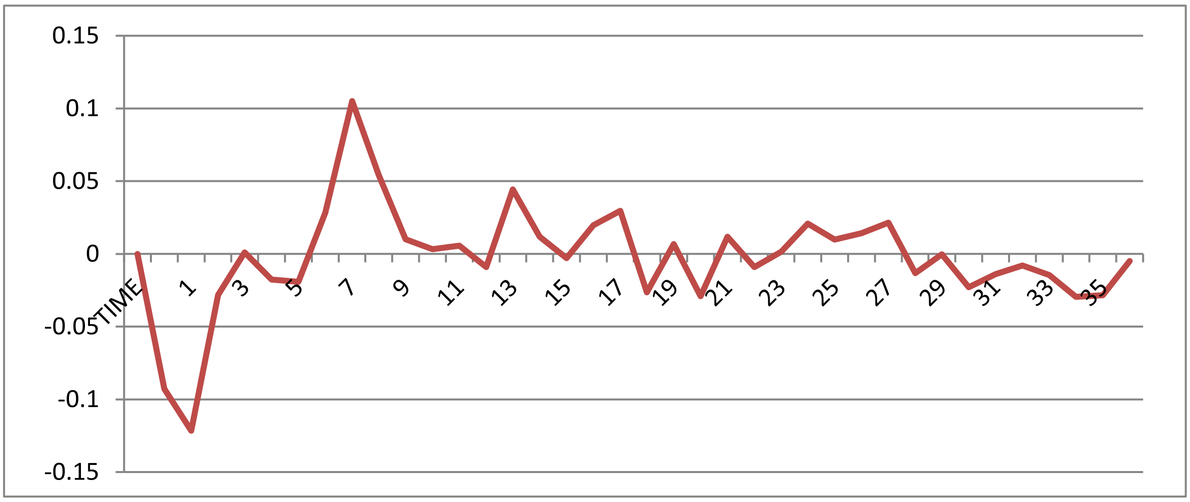


Figure 4.3: Mark-To-Market Valuation Scaled by Estimated Project Cost at different time periods (36 months)

Second, this study follows the approach of Benaroch and Kauffman (1999) customized for an IT portfolio in calculating the "Greeks"; Delta (Δ), Vega (Λ) and Gamma (Γ). The results for Delta, Vega and Gamma by time period regarding the simulated IT portfolio are reported in Figure 4.4, Figure 4.5, and Figure 4.6 respectively. Through the Delta calculation, a firm's executives are able to understand the rate of change of MTM value related to changes in expected revenues of IT portfolio. Through the Vega calculation, a firm's executives can find out how to assess the rate of change of MTM value in connection with the sensitivity to volatility in IT portfolio. Through the Gamma calculation, a firm's executives can apply Gamma to evaluating the rate of change in Delta associated with changes in expected revenues of IT portfolio. In this research, the results themselves depend on the nature of the IT portfolio and are only intended to serve as an example. However, the benefit of the proposed Mark-To-Market valuation technique is that project status is reported in dollars and may be treated as a commodity asset, affording assessment using additional financial techniques.

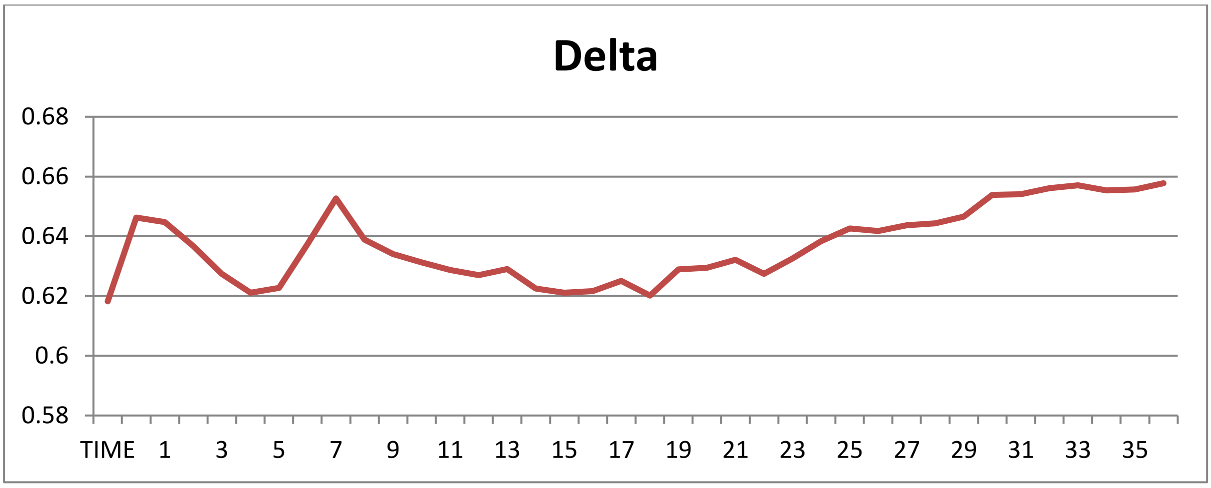


Figure 4.4: IT Portfolio Average Delta at different time periods (36 months)

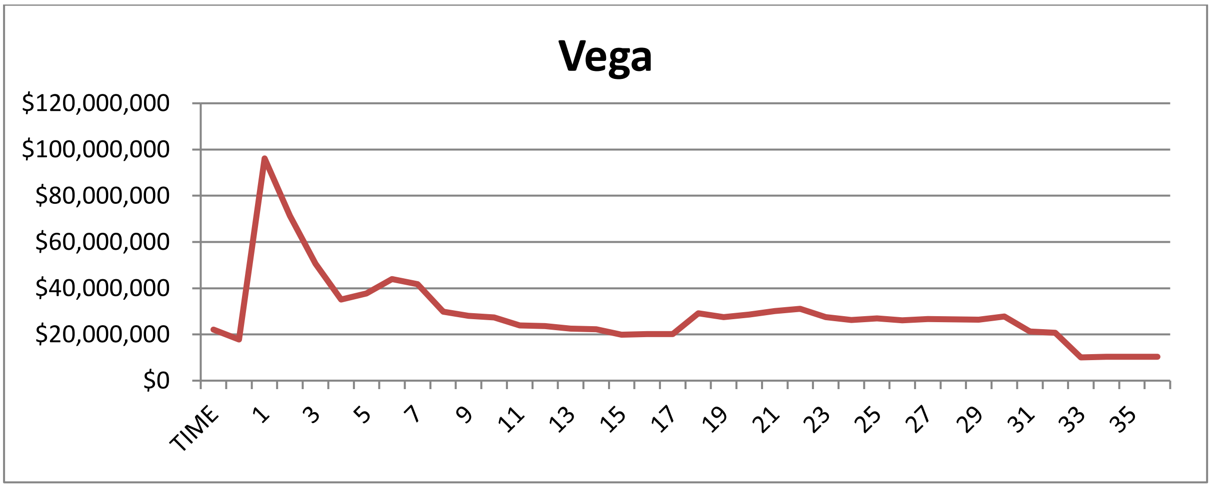


Figure 4.5: IT Portfolio Average Vega at different time periods (36 months)

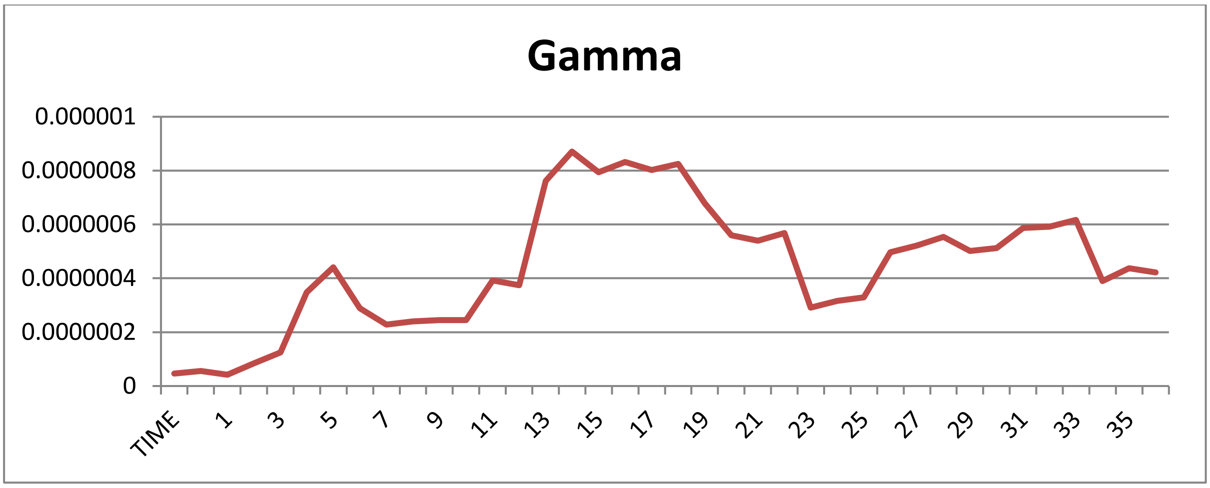


Figure 4.6: IT Portfolio Average Gamma at different time periods (36 months)

Additionally, this paper suggests an additional parameter to complement the "Greeks" in assessment of the IT portfolio. The benefit of using the Greek letter, Iota (I), is to reflect the trajectory of IT portfolio with respect to its financial health as compared to its estimated financial payoff at the beginning of the project, where M is the scaled Mark-To-Market value and t is the time period. Iota is the average slope or change in the Mark-To-Market value for the projects over time, represented by the partial derivative of the Mark-To-Market value with respect to time, a regression coefficient of the Mark-To-Market valuation as follows:

$$I = \frac{\partial M}{\partial t},$$

Finally, Iota is similar in most respects to the Greek theta (which is the change in value with respect to time or the time decay); however, there is one difference. The new measure, Iota, reflects the change in value with respect to the original budgeted financial standing. Therefore, it is particularly relevant to practitioners trying to keep IT projects on track vs. original estimates. It may be used to identify concerning trends in the financial performance of the IT portfolio. For example, a manager may observe Iota for a window of time and detect an alarming negative trend in value. Figure 4.7 provides one example of such a trend associated with the simulated data. In particular, the utility of this new measure is that it reflects a relevant portfolio attribute that may enable portfolio and project managers to monitor and address problems related how the firm's IT portfolio is tracking vs. estimates.

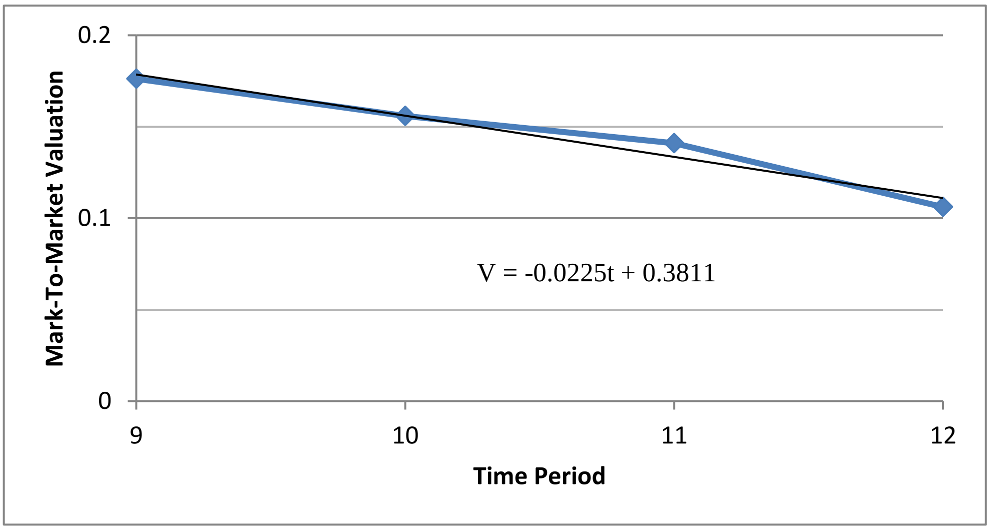


Figure 4.7: Evaluating Trends in Portfolio Financial Performance Using Iota

V. CONCLUSION AND FUTURE RESEARCH

This study suggests a Mark-To-Market valuation technique for IT portfolio management to assist an enterprise's decision-makers in monitoring an IT portfolio's real value over multiple time periods, especially beyond cost realization to include revenue realization. This paper provides a demonstration of the Mark-To-Market valuation, a calculation of relevant "Greeks" that may be used to manage risk of the IT portfolio, and the introduction of a new metric to understand the trend in financial performance for an IT portfolio.

This research serves as a starting point for other potentially fruitful research avenues. There are opportunities to enhance the existing simulation to include the complementarity, or synergy, that is common among IT projects (Jeffery and Leliveld, 2004; Tu and Shaw, 2011). In the current implementation, projects are treated independently. Additional scenarios may be executed via the simulation platform in order to provide sensitivity analysis to the results. Following this concept, this study is able to allow for project costs and revenues to vary randomly based on an average assessment of value at risk (PMI, Inc. 2012); however, some firms are better or worse at managing their IT projects. A simulated IT portfolio representing a firm with a tendency to exceed project budgets on most of their IT projects may provide new and interesting insights. As mentioned above, the ultimate interest with this work is to demonstrate the use of the Mark-To-Market valuation with real IT portfolios and validate that the Mark-To-Market valuation provides a measure that is correlated with project success. Furthermore, since the Greeks are designed to measure the performance and risk of a commodity portfolio, the proposed MTM valuation technique does allow for a consistent metric and enables the use of the Greeks as a tool to manage the IT portfolio. Thus, there is an opportunity to develop additional measures to further complement the "Greeks" and provide specific metrics that are useful in the context of an IT portfolio.

In the following research progress, this research aims to include the interdependence of IT projects in the paper. In addition to the simulated data, I have collected very granular data for a large firm's entire IT portfolio over the course of multiple years, and I intend to leverage real enterprise data to demonstrate the proposed MTM valuation.

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Chapter 5: Discussion

A basic definition of portfolios is a collection of investments owned by an institution or an individual. Financial portfolio management, meanwhile, mainly focuses on a variety of asset classes to maximize expected return during some specified period of time for a given portfolio risk. Since the value of each financial asset is typically determined by the markets, investors will be able to periodically trade the financial assets in the market. After the implementation of the Sarbanes-Oxley Act, an increasing number of enterprises is under pressure to realize more effective IT investment controls. The ideas in my dissertation were developed through engaging with practitioners to understand their challenges in managing IT functions. To address IT Portfolio Management (ITPM) issues based on design science, my specialized method incorporates mathematical optimization and computational experiments. With regard to IT investment decisions, my proposed ITPM models include common important parameters/variables that may uniquely characterize suggested IT portfolio attributes.

My ITPM research seeks to discover the patterns of IT portfolios that lead to most applicable decisions, which can in turn significantly impact a firm's investment performance. Specifically, my dissertation examines an important class of IS decision problems: IT portfolio attributes and investment choices. Thus, the expected contributions of my ITPM research include a standardized approach for managing diversified IT portfolios, and this approach illustrates several ITPM profiles by using the proposed ITPM models/techniques. Following these proposals, decision-makers (e.g., senior executives) will be able to prioritize and select the most qualified IT portfolio choice to meet their organizational business objectives.

The aim of my ITPM research is to reveal how a firm can systematically profile numerous IT portfolios and to provide theoretical insights into the components of the optimal solution. The findings from Chapter 2 are as follows: Firstly, a firm that concentrates its IT investment on one or a very small number of large IT projects (a Dominant IT portfolio) is able to manage technical complexity and take on projects specifically to improve its operating margin with high efficiency; secondly, to meet a firm's business objectives with high efficiency, the firm's IT function can be comprised of a variety of project types implemented by a large set of similar size IT projects (an Even distribution-based IT portfolio) in low technical capabilities; thirdly, a firm that has an intensive emphasis on long term growth and operating margin project types in a collection of diversified IT projects (an Uneven distribution-based IT portfolio) means that operation efficiency and innovation management are achieved. Moreover, in line with findings from Chapter 3, the IT portfolio efficient frontiers from both the Even distribution-based IT Portfolio and the Uneven distribution-based IT Portfolio indicate that IT portfolio risk has a positive linear relationship with IT portfolio return; that is, low risk investment yields low return, while high risk investment yields high return. However, if IT investments are similar to the Dominant IT portfolio, executives may consider a conservative investment strategy after reaching the turning point of the IT efficient frontier. Lastly, the findings from Chapter 4 suggest a Mark-To-Market valuation technique applied to IT portfolio management to assist an enterprise's decision-makers in monitoring an IT portfolio's real value over multiple time periods, especially beyond cost realization to include revenue realization. By providing a demonstration of the Mark-To-Market valuation, a calculation of relevant "Greeks" may be used to manage IT portfolio risk and introduce a new metric for understanding the trends in an IT portfolio's financial performance.

According to Davis et al. (2007), the underlying theory of the research model is that simulation involves creating a computational representation of the underlying theoretical logic that links constructs together within simplified worlds. While simulation can be used purely for description or exploration, my main focus is on using simulation for theory development when only theory exists. Hence, I suggest the following theoretical propositions, which are based on my findings. On the other hand, detailed qualitative field work will be necessary to understand the decision-making processes of executives and top managers in terms of IT investments and IT portfolio. Face-to-face conversations with decision-makers would likely expose the level(s) of management responsible for structuring the IT portfolio. Analyzing complex negotiations as they unfold among a diverse set of stakeholders might prove fruitful for validating and extending the results of this research.

In follow-up studies, I will investigate other ways of characterizing the IT portfolio to provide additional ITPM profiles as a reference for IT executives and general managers to make better investment decisions concerning IT resource allocation. Meanwhile, additional IT portfolio data would allow further empirical testing of these findings and other combinations of attributes. A fuller appreciation of the relationships among key variables will enable better and more transparent choices by management and ultimately drive the development of ITPM-related theory.

Appendix

Table 2.8. a. Summary of empirical results and simulated IT portfolio profiles in the BU-A												
Focal Firm IT Portfolio (Empirical Data)			Business Unit (BU)-A	Strategic Goal 1 - Operation Mgt			Strategic Goal 2 - Innovation Mgt			Strategic Goal 3 - Customer Mgt		
			Efficiency score	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack
			0.448	0.53	75.8%	0.36	0.22	14.3%	0.09	0.15	9.9%	0.19
D: Dominant IT Portfolio, U: Uneven distribution-based IT portfolio, E: Even distribution-based IT portfolio												
Simulated Data			Business Unit (BU)-A	Strategic Goal 1 - Operation Mgt			Strategic Goal 2 - Innovation Mgt			Strategic Goal 3 - Customer Mgt		
BU -A	BU -B	BU -C	Efficiency score	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack
D	D	D	0.371	0.58	42.6%	0.18	0.23	31.5%	0.24	0.21	25.9%	0.20
D	D	U	0.364	0.57	42.7%	0.19	0.22	31.5%	0.24	0.20	25.9%	0.21
D	D	E	0.368	0.57	42.6%	0.18	0.22	31.5%	0.24	0.21	25.9%	0.20
D	U	U	0.364	0.57	42.7%	0.19	0.22	31.5%	0.24	0.20	25.9%	0.21
D	U	D	0.371	0.58	42.6%	0.18	0.23	31.5%	0.24	0.21	25.9%	0.20
D	U	E	0.368	0.57	42.6%	0.18	0.22	31.5%	0.24	0.21	25.9%	0.20
D	E	U	0.364	0.57	42.7%	0.19	0.22	31.5%	0.24	0.20	25.9%	0.21
D	E	D	0.371	0.58	42.6%	0.18	0.23	31.5%	0.24	0.21	25.9%	0.20
D	E	E	0.368	0.57	42.6%	0.18	0.22	31.5%	0.24	0.21	25.9%	0.20
E	D	D	0.280	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25
E	D	E	0.275	0.31	36.7%	0.25	0.29	31.6%	0.22	0.22	31.7%	0.25
E	D	U	0.283	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25
E	E	D	0.280	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25
E	E	E	0.275	0.31	36.7%	0.25	0.29	31.6%	0.22	0.22	31.7%	0.25
E	E	U	0.283	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25
E	U	D	0.280	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25
E	U	E	0.275	0.31	36.7%	0.25	0.29	31.6%	0.22	0.22	31.7%	0.25
E	U	U	0.283	0.32	36.7%	0.25	0.30	31.6%	0.22	0.22	31.7%	0.25
U	D	E	0.309	0.36	42.7%	0.27	0.34	34.0%	0.22	0.16	23.3%	0.20
U	D	U	0.315	0.37	42.8%	0.27	0.35	34.2%	0.22	0.16	22.9%	0.19
U	D	D	0.316	0.37	42.7%	0.27	0.35	34.0%	0.22	0.16	23.3%	0.20
U	E	D	0.316	0.37	42.7%	0.27	0.35	34.0%	0.22	0.16	23.3%	0.20
U	E	E	0.309	0.36	42.7%	0.27	0.34	34.0%	0.22	0.16	23.3%	0.20
U	E	U	0.315	0.37	42.8%	0.27	0.35	34.2%	0.22	0.16	22.9%	0.19
U	U	D	0.316	0.37	42.7%	0.27	0.35	34.0%	0.22	0.16	23.3%	0.20
U	U	E	0.309	0.36	42.7%	0.27	0.34	34.0%	0.22	0.16	23.3%	0.20
U	U	U	0.315	0.37	42.8%	0.27	0.35	34.2%	0.22	0.16	22.9%	0.19

Table 2.8. b. Summary of empirical results and simulated IT portfolio profiles in the BU-B												
Focal Firm IT Portfolio (Empirical Data)			Business Unit (BU)-B	Strategic Goal 1 - Operation Mgt			Strategic Goal 2 - Innovation Mgt			Strategic Goal 3 - Customer Mgt		
			Efficiency score	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack
			0.356	0.19	11.5%	0.11	0.40	66%	0.39	0.31	22.5%	0.33
D: Dominant IT Portfolio, U: Uneven distribution-based IT portfolio, E: Even distribution-based IT portfolio												
Simulated Data			Business Unit (BU)-B	Strategic Goal 1 - Operation Mgt			Strategic Goal 2 - Innovation Mgt			Strategic Goal 3 - Customer Mgt		
BU -A	BU -B	BU -C	Efficiency score	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack
D	D	D	0.352	0.19	12.2%	0.10	0.50	49.6%	0.25	0.21	38.2%	0.30
D	D	U	0.359	0.19	12.1%	0.10	0.52	49.6%	0.24	0.20	38.3%	0.30
D	D	E	0.339	0.19	12.2%	0.10	0.48	49.6%	0.26	0.21	38.2%	0.30
D	U	U	0.286	0.26	32.4%	0.24	0.28	23.9%	0.17	0.31	43.7%	0.30
D	U	D	0.287	0.26	32.3%	0.24	0.28	24.1%	0.17	0.31	43.6%	0.30
D	U	E	0.286	0.26	32.3%	0.24	0.27	24.1%	0.18	0.31	43.6%	0.30
D	E	U	0.296	0.25	32.8%	0.25	0.33	35.5%	0.24	0.31	31.8%	0.22
D	E	D	0.296	0.25	32.6%	0.24	0.32	35.7%	0.24	0.31	31.7%	0.22
D	E	E	0.293	0.25	32.6%	0.24	0.31	35.7%	0.25	0.31	31.7%	0.22
E	D	D	0.342	0.19	11.9%	0.10	0.49	49.8%	0.25	0.20	38.3%	0.31
E	D	E	0.331	0.19	11.9%	0.10	0.47	49.8%	0.26	0.20	38.3%	0.31
E	D	U	0.350	0.19	11.9%	0.10	0.51	49.8%	0.25	0.20	38.3%	0.31
E	E	D	0.284	0.24	33.3%	0.25	0.32	34.6%	0.24	0.30	32.1%	0.23
E	E	E	0.282	0.24	33.3%	0.25	0.31	34.6%	0.24	0.30	32.1%	0.23
E	E	U	0.286	0.24	33.3%	0.25	0.32	34.6%	0.23	0.30	32.1%	0.23
E	U	D	0.275	0.25	32.8%	0.25	0.28	23.2%	0.17	0.30	44.1%	0.31
E	U	E	0.274	0.25	32.8%	0.25	0.27	23.2%	0.17	0.30	44.1%	0.31
E	U	U	0.276	0.25	32.8%	0.25	0.28	23.2%	0.17	0.30	44.1%	0.31
U	D	E	0.339	0.19	12.2%	0.10	0.48	49.6%	0.26	0.21	38.2%	0.30
U	D	U	0.359	0.19	12.1%	0.10	0.52	49.6%	0.24	0.20	38.3%	0.30
U	D	D	0.352	0.19	12.2%	0.10	0.50	49.6%	0.25	0.21	38.2%	0.30
U	E	D	0.296	0.25	32.6%	0.24	0.32	35.7%	0.24	0.31	31.7%	0.22
U	E	E	0.293	0.25	32.6%	0.24	0.31	35.7%	0.25	0.31	31.7%	0.22
U	E	U	0.296	0.25	32.8%	0.25	0.33	35.5%	0.24	0.31	31.8%	0.22
U	U	D	0.287	0.26	32.3%	0.24	0.28	24.1%	0.17	0.31	43.6%	0.30
U	U	E	0.286	0.26	32.3%	0.24	0.27	24.1%	0.18	0.31	43.6%	0.30
U	U	U	0.286	0.26	32.4%	0.24	0.28	23.9%	0.17	0.31	43.7%	0.30

Table 2.8. c. Summary of empirical results and simulated IT portfolio profiles in the BU-C

Focal Firm IT Portfolio (Empirical Data)	Business Unit (BU)-C	Strategic Goal 1 - Operation Mgt			Strategic Goal 2 - Innovation Mgt			Strategic Goal 3 - Customer Mgt		
	Efficiency score	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack
	0.26	0.36	30.7%	0.08	0.26	44.4%	0.16	0.13	24.9%	0.22

D: Dominant IT Portfolio, U: Uneven distribution-based IT portfolio, E: Even distribution-based IT portfolio

Simulated Data			Business Unit (BU)-C	Strategic Goal 1 - Operation Mgt			Strategic Goal 2 - Innovation Mgt			Strategic Goal 3 - Customer Mgt		
BU -A	BU -B	BU -C	Efficiency score	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack	Efficiency score	Weight Score	Slack
D	D	D	0.275	0.28	49.9%	0.36	0.29	42.8%	0.30	0.14	7.3%	0.06
D	D	U	0.302	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34
D	D	E	0.271	0.34	29.5%	0.20	0.31	45.0%	0.31	0.12	25.5%	0.22
D	U	U	0.302	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34
D	U	D	0.275	0.28	49.9%	0.36	0.29	42.8%	0.30	0.14	7.3%	0.06
D	U	E	0.271	0.34	29.5%	0.20	0.31	45.0%	0.31	0.12	25.5%	0.22
D	E	U	0.302	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34
D	E	D	0.275	0.28	49.9%	0.36	0.29	42.8%	0.30	0.14	7.3%	0.06
D	E	E	0.271	0.34	29.5%	0.20	0.31	45.0%	0.31	0.12	25.5%	0.22
E	D	D	0.269	0.28	50.0%	0.36	0.27	43.1%	0.31	0.14	6.9%	0.06
E	D	E	0.263	0.33	29.9%	0.20	0.29	45.8%	0.32	0.12	24.3%	0.21
E	D	U	0.295	0.58	21.1%	0.09	0.29	41.0%	0.29	0.14	37.9%	0.33
E	E	D	0.269	0.28	50.0%	0.36	0.27	43.1%	0.31	0.14	6.9%	0.06
E	E	E	0.263	0.33	29.9%	0.20	0.29	45.8%	0.32	0.12	24.3%	0.21
E	E	U	0.295	0.58	21.1%	0.09	0.29	41.0%	0.29	0.14	37.9%	0.33
E	U	D	0.269	0.28	50.0%	0.36	0.27	43.1%	0.31	0.14	6.9%	0.06
E	U	E	0.263	0.33	29.9%	0.20	0.29	45.8%	0.32	0.12	24.3%	0.21
E	U	U	0.295	0.58	21.1%	0.09	0.29	41.0%	0.29	0.14	37.9%	0.33
U	D	E	0.271	0.34	29.5%	0.20	0.31	45.0%	0.31	0.12	25.5%	0.22
U	D	U	0.302	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34
U	D	D	0.275	0.28	49.9%	0.36	0.29	42.8%	0.30	0.14	7.3%	0.06
U	E	D	0.275	0.28	49.9%	0.36	0.29	42.8%	0.30	0.14	7.3%	0.06
U	E	E	0.271	0.34	29.5%	0.20	0.31	45.0%	0.31	0.12	25.5%	0.22
U	E	U	0.302	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34
U	U	D	0.275	0.28	49.9%	0.36	0.29	42.8%	0.30	0.14	7.3%	0.06
U	U	E	0.271	0.34	29.5%	0.20	0.31	45.0%	0.31	0.12	25.5%	0.22
U	U	U	0.302	0.60	20.7%	0.08	0.31	39.9%	0.28	0.14	39.4%	0.34