How do you invest in IT to create Business Value?

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ABSTRACT

Since information technology (IT) projects are connected with IT-related resource allocation to drive organizational performance, IT projects across the portfolio become critical for enterprise executives to address business value creation. Briefly, IT (Project) Portfolio Management (ITPM) is to manage a firm's total investment in computing and communication technology. We propose a new production model (DEA/Parallel-based, or DEA/P) that aligns ITPM with enterprise strategic goals. Also, we conduct a computational experiment and simulation in this paper. Two main contributions may be drawn from this study. 1) Methodology: Measuring and managing IT investment across different organizational levels is a critical capability for an enterprise; therefore, optimality could be considered as the main focus to characterize IT portfolio performance here. In this respect, the DEA/P model is to articulate each organizational level's performance in connection with ITPM versus strategic goal through a parallel approach. 2) Business Value Creation: The preliminary results show that three profiles of IT Portfolios (Even distribution-based IT Portfolio, Uneven distribution-based IT Portfolio, and Dominant set of IT Portfolio) are associated with relevant Efficient Frontiers, which can demonstrate the optimal combination of strategic resource allocation across hierarchical organizational levels. Further,

corresponding to enterprise strategy maps, IT executives are able to select the most appropriate IT portfolio profile that fit with specific strategic goals to create IT-driven business value.

Keywords: Data Envelopment Analysis (DEA), IT Portfolio Management (ITPM), Production Parallel System, Strategic Resource Allocation

I. INTRODUCTION

Many IT executives are interested in managing enterprise resources from a top-down perspective while investing firm resources in IT. With the increasing importance of IT to diverse business functions, there is a growing set of evidence that investment in IT can produce value related to a variety of organizational levels. On 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). From internal organizational level, the process level within the firm is seen as a critical viewpoint of understanding how investment in IT resources translates to business value (e.g. Ray, Muhanna and Barney 2005). In addition to process level, the IT project is the main tactical level through which IT activity translates to business results for the enterprise. Briefly, both process level and project level are internal pathways for IT value creation. With this thinking, an IT portfolio can be regarded as a process level, a critical bridge connecting firm (enterprise) level and project level to efficiently allocate enterprise resources.

The ability to measure and manage IT investment across different organizational levels is a critical capability for an enterprise. Though the value creation does aggregate from lower to higher levels, the executives could optimize their investments at different organizational levels. In line with this perspective, we propose a new production modeling approach to address our research question: "How do managers optimize enterprise resource allocation in an IT portfolio creating business value and connecting with enterprise strategic goals?"

The motivation of this research is to open the black box of enterprise internal strategic resource allocation and further assist enterprise executives in creating business value when dealing with IT-related investments. Thus, optimality is our main focus for the IT portfolio selection to characterize IT portfolio performance. Regarding the research purpose in this paper, we aim to examine how an IT portfolio profile that is composed of different IT projects leads to portfolio performance. First, we define IT portfolio profile variations that drive IT value creation. Second, we propose a new production model (DEA/Parallel-based, or DEA/P) to distribute enterprise strategic resources from the top level to lower organizational levels: the organizational department, the IT portfolios and IT projects. Finally, we conduct a computational experiment and simulation to demonstrate the usefulness of our approach.

We suggest that there are two main contributions of this research. First, the DEA/P model is shown to be helpful in ITPM context that enterprise executives, primarily IT executives, can gain a more precise understanding of IT-related resources required to improve organizational performance. Second, from preliminary simulation outcomes, we find the following three main ITPM profiles associated with relevant Efficient Frontiers: (1) Even distribution-based IT Portfolio, (2) Uneven distribution-based IT Portfolio, and (3) Dominant set of IT Portfolio. According to these three ITPM profiles tied with different enterprise strategic goals, IT executives are able to improve decision making process through the optimal IT portfolio profile that fits with the enterprise strategy maps to create business value. This paper is organized as follows. Section II reviews the related theoretical studies. The proposed DEA/Parallel-based model is developed in Section III. In Section IV, the proposed methodology is illustrated with a hypothetical IT project. Section V concludes the results, and Section VI summarizes the findings of the paper.

II. THEORETICAL FRAMEWORK

Strategic Resource Allocation, Performance Measurement and Business Value of IT

According to Resrouce-Based View (RBV), a firm's resources play a critical role in enabling a firm to achieve a competitive advantage and also lead to the long-term performance (Penrose 1959; Wernerfelt 1984). Hence, referring to four indicators of strategic resources in RBV – valuable, rare, imperfectly-imitable, and non-substitutable (Barney, 1991), we could build on it to address IT executives' main mission, which is to make strategic IT resources valuable, rare, in-imitable, and non-substitutable from IT-related investment. Then, the firm will be able to achieve maximum value of the IT resources when the IT resources of the firm fit well with unique needs of each organization level.

In addition, both Balanced Scorecard (BSC) and Strategy Maps proposed by Kaplan and Norton (1992, 2004) have evolved into a strategic management system that not only measures performance but also aligns different aspects of organizational levels with enterprise strategic goals. According to Ray, Muhanna and Barney (2005), evaluating the process level (the within-firm mechanism) is an important aspect of understanding how investment in IT resources translates to business value. Briefly, leveraging IT and complementarities can help a firm to create resources and capabilities that are heterogeneous and imperfectly mobile and to create differential value (Kohli and Grover, 2008).

Data Envelopment Analysis (DEA) and Parallel Production System

Data Envelopment Analysis (DEA) was introduced by Charnes, Cooper and Rhodes (CCR) in 1978, and DEA has been applied in a wide range of applications to measure the relative efficiency of peer decision making units (DMUs) that have multiple inputs and outputs. Notably, Banker et al.

(2004, 2011) points out that DEA has been widely used to estimate production analysis in connection with the inputs consumed to the outputs produced and also shows the tradeoffs in achieving various performance metrics. Additionally, research on parallel production systems began with Färe and Primont (1984), and Kao (2009, 2012) applied theory and model from the earlier work. Kao proposes the general parallel production system with multiple processes operating independently. Before the concept of parallel production model applied to DEA model, researchers considered either a firm level or an organizational department level to be an individual DMU without connecting with lower organizational levels when measuring efficiency of resource allocation.

IT Portfolio Management (ITPM)

Regarding enterprise IT point of view, an IT project is the main tactical level through which IT activity translates to business results for the enterprise. IT project selection is an essential business problem because most IT components are customized for an enterprise through project implementation (Cho and Shaw 2013). Integrating Zhu (2003) and Ray et al. (2005)'s concepts, an IT portfolio level can be considered a bridge to connect with project level to the firm level regarding internal strategic resource allocation. The IT portfolio of a firm is understood as its total investment in computing and communication technology (Weill and Vitale 2002), or the sum total of all IT projects. According to Jeffery and Leliveld (2004), the definition of IT portfolio management is to manage IT as a portfolio of assets similar to a financial portfolio and then strive to improve the performance of the portfolio by balancing risk and return. The key motivation for many IT executives doing ITPM is to select the optimal IT portfolio to create business value.

How Data Envelopment Analysis (DEA) can be used in IT Portfolio Management (ITPM)?

Most performance measurement methods do not have an overview on different hierarchical organizational level's performance indicators. After considering IT a production unit, we found that Data Envelopment Analysis (DEA) model's unique feature can provide a standard transformation for different performance indicators and units to solve this problem appropriately. IT function-based strategic goals can be implemented by a set of IT-related projects, called an IT Portfolio. Through the DEA-based approach, we are able to utilize common inputs and outputs across all IT projects when measuring organizational performance.

III. MODEL DEVELOPMENT

Main components of DEA/Parallel (DEA/P) Model

An enterprise usually consists of various types of departments, and each department can be connected with the enterprise through strategic goals, which are implemented by a set of ongoing IT projects, known as the IT portfolio. In order to demonstrate the strategic position of each organizational level, we illustrate three main components of the DEA/P model as shown in Figure 1: (1) Organizational Department, (2) IT Portfolio, and (3) IT Project. According to the DEA/P model, the IT portfolio will be understood as the Decision Making Unit (DMU) when working on performance measurement. In other words, the IT portfolio that performs the particular IT-related functions not only links to strategic goals but also supports the associated strategic goals in hierarchical organizational levels.

Additionally, DEA/P model is mainly based on the concept of Linear Programming (LP), and the three main components associated with their mathematical equations for DEA/P model could be found in Figure 2. Referring to DEA/P's mathematical equations, each higher organizational level can distribute its strategic IT resources into multiple lower organizational levels via a parallel approach. Besides, the sum of weight scores at the same organizational level is equal to 1, which is a key constraint in DEA/P model. Weight scores are assigned to random IT portfolios based on the emphasis of the organization on specific strategic goals. In practice, many enterprise executives would like to figure out how to improve the performance at each of their related strategic goals, so we will present our DEA/P model with simulated data in section IV.

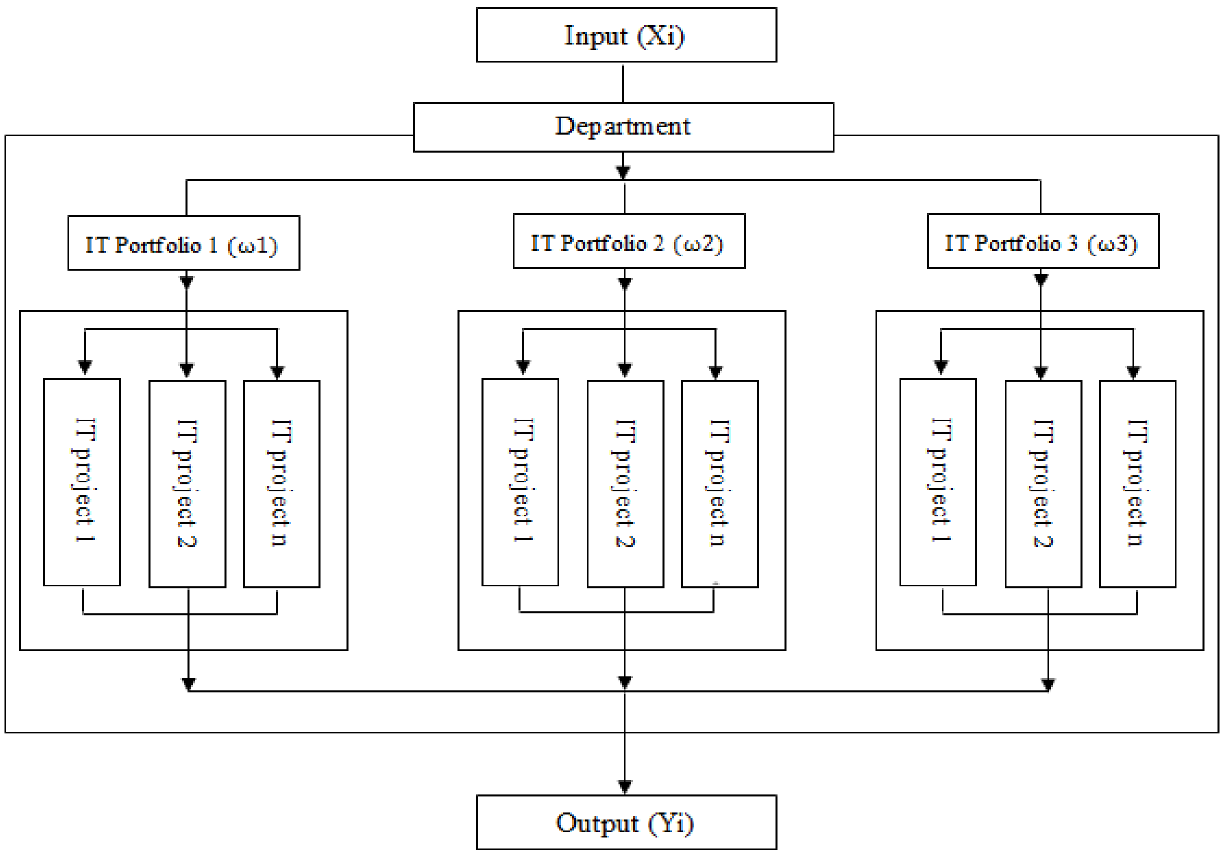


Figure 1 – DEA/Parallel Model Design in ITPM context

$$E^{DEA/P} = \max \sum_{r=1}^{s} u_r Y_{rk}$$

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

Organizational Department

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

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

IT Portfolio

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

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

IT Project

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

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

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

$$S_k, S_k^{(ITPM)}, S_k^{(ITP)} \geq 0, \quad p = 1, \ldots\ldots q$$

Figure 2 – DEA/Parallel Model (mathematical formula) in ITPM context

Parameter/Variable Definition and Managerial Interpretation

The selection of input and output variables plays an essential role in DEA/P model since these variables are able to truly reflect variations in IT-related resource utilization across different organizational levels. Along with DEA/P model components in Figure 1 and Figure 2, we summarize DEA/P model's parameters and variables and show related managerial interpretations in Table 1. Also, an efficiency score is generated by the DEA-based model for each DMU.

Table 1 – Parameter & Variable definition and relevant Managerial Interpretation

Parameter & Variable	Range	Managerial Interpretation
Efficiency score (E-score) E-Dept.: E-score for Department level E-ITPM: E-score for IT portfolio level E-ITP: E-score for IT project level	E = 0 (worst) ~ E = 1 (optimal)	The 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.
Slack Variable score	The slack variable is associated with E-score	Utilized resources – lower score indicates high utilization and higher score indicates organizational slack.
Weight score (strategic resource focus)	W = 0 (worst) ~ W = 1 (optimal)	The higher weight score can be considered a more influential strategic focus connected to a certain organizational level.
Input Variable 1 (X1)	Each hierarchical organizational level has its amount of resources related to Labor Cost	Labor Cost
Input Variable 2 (X2)	Each hierarchical organizational level has its amount of resources related to General Spending	General Spending (capital investment)
Output variable (Y)	Each hierarchical organizational level has its amount of resources related to Revenue	Revenue

The unique advantage of DEA/Parallel (DEA/P) Model

Measuring and managing IT investment across different organizational levels is a critical capability for the organization. However, based on Zhu (2003), the value-added systems or processes have been treated as a black-box, particularly when examining the resources available to the systems or processes and monitoring the "conversions" of these resources (inputs) into the desired outputs. In order to open the black-box regarding strategic IT resource allocations, our proposed DEA/P model's top-down parallel approach enables enterprises (firms) to allocate resources corresponding to enterprise strategic priorities, and this concept can make IT-related functions tie with different strategic goals to deliver IT-driven business capabilities benefiting the entire enterprise. To put it simply, optimality can be seen as the main focus to characterize IT portfolio performance here. In this respect, the DEA/P model is to articulate each organizational level's performance in connection with ITPM versus strategic goal through a parallel approach.

IV. EXAMPLE WITH SIMULATED DATA

Simulation Data description

We have developed a simulated IT portfolio to demonstrate DEA/P model. Referring to a Fortune 500 company (CNN Money 2012), our simulated IT portfolio is constructed to represent the IT investments of a company with revenues at the median size, which is over $10 billion in revenue. Moreover, according to Gartner's estimate of average IT spending in 2012 and their forecasted metric for 2013 (McGittigan et al. 2013), the average enterprise IT investment is assumed to be 3.5% of revenue. In addition, projects are constructed based on an average project size of $4 million, but drawn randomly from an F-distribution (df1 = 4, df2 = 6) to provide the expected skewed distribution. Based on these assumptions, the descriptive statistics for the simulated IT portfolio is in Table 2.

Table 2 – Descriptive Statistics for the Simulated IT Portfolio

Variable	Mean	Std. Dev.
Budget Cost 1 – Labor Cost	$2.96 Million	$12.22 Million
Budget Cost 2 – General Spending	$8.8 Million	$28.72 Million
Revenue	$12.38 Million	$42 Million

The hierarchal organizational levels in our research design are shown in Figure 3, while cost allocation and revenue allocation for hierarchical organizational levels (organizational department, IT portfolio and IT project) are shown in Figure 4, Figure 5 and Figure 6. Our simulated enterprise is composed of 3 organizational departments, each organizational department has 3 IT portfolios, and each IT portfolio is comprised of 10 IT projects. Through strategy maps, the enterprise can connect with organizational departments via 3 strategic goals, and each strategic goal is implemented by an IT portfolio. Our DEA/P will produce the efficiency score to demonstrate each organizational level's resource allocation variation. Weight score can represent the importance of each strategic goal that is implemented by an IT portfolio. Detailed computational results are shown in Appendix I.

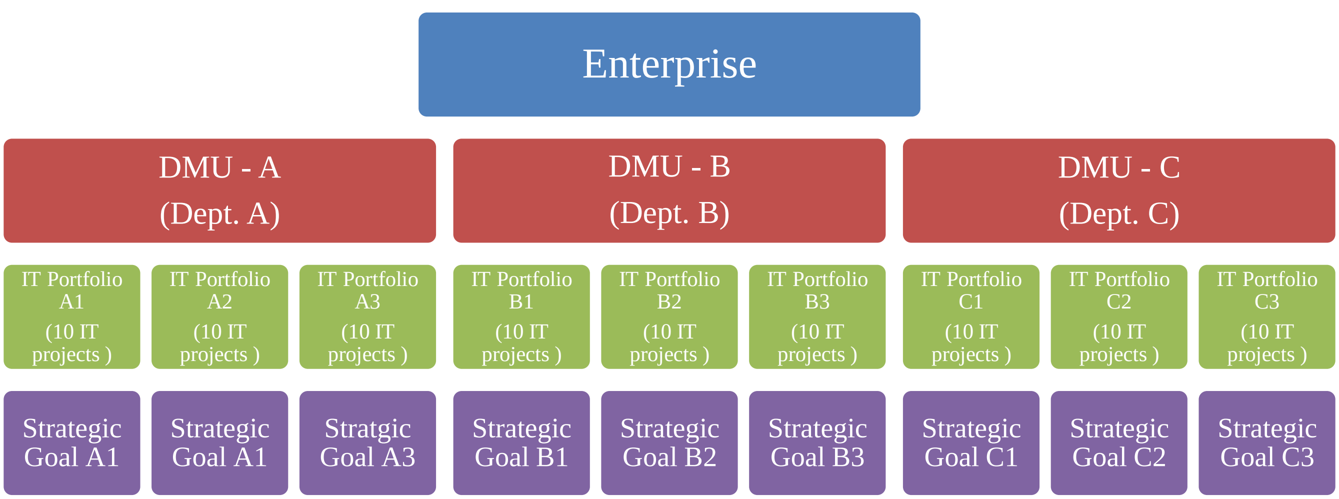


Figure 3 – Research Design

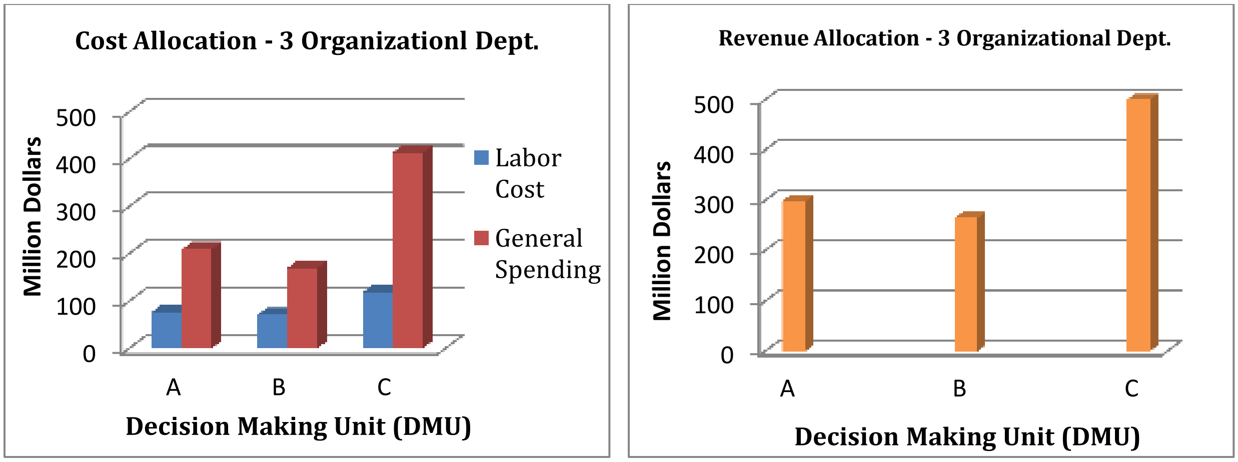


Figure 4 – Cost & Revenue Allocation for 3 Organizational Dept.

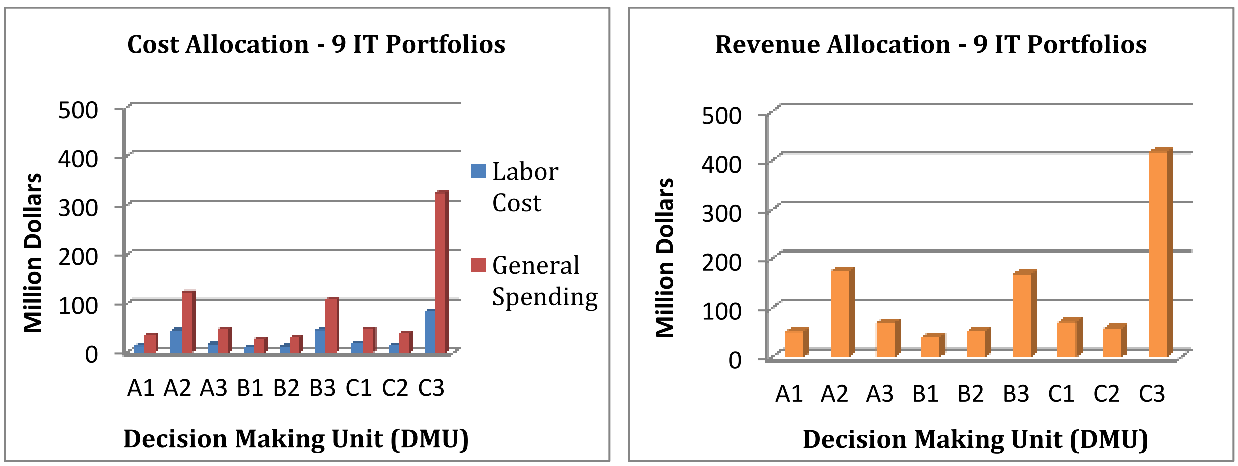


Figure 5 – Cost & Revenue Allocation for 9 IT Portfolios

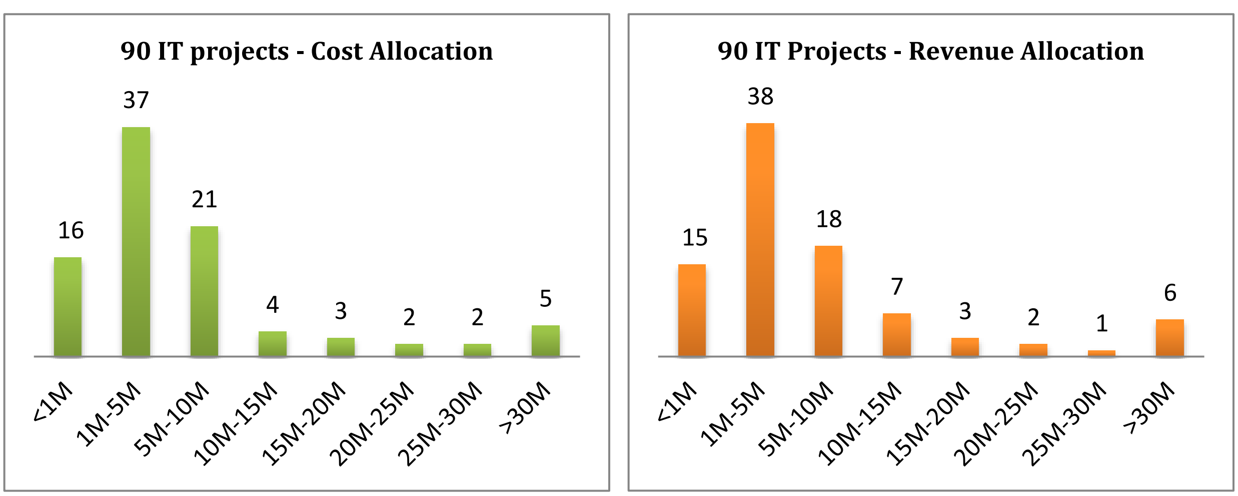
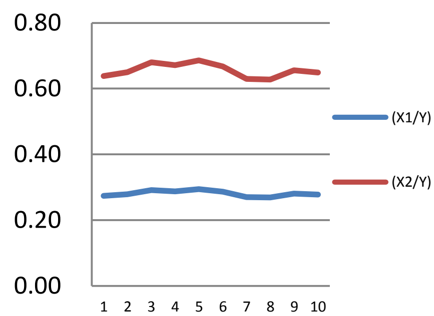


Figure 6 – Cost and Revenue Allocation for 90 IT Projects

V. SIMULATION RESULTS

Simulation results enable us to identify various IT portfolio profiles that may be of use to manage IT investments. Based on our example with simulation data, we can classify all our IT portfolios into three main profiles in this study: Even distribution-based IT (Project) Portfolio, Uneven distribution-based IT (Project) Portfolio and Dominant set of IT (Project) Portfolio. Furthermore, these three IT portfolio profiles associated with Efficient Frontiers can demonstrate the optimal combination of budget cost and expected revenue across hierarchical organizational levels. Also, the three IT portfolio profiles along with their relevant characteristics are shown in Table 3, Table 4 and Table 5, respectively.

Table 3 – Even distribution-based IT (Project) Portfolio along with relevant Efficient Frontier

<table>
<tr>
<td>Even distribution-based
IT portfolio</td>
<td>
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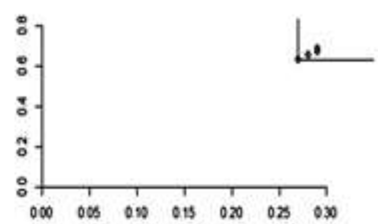
<td>

Horizontal axis: X1/Y, $\frac{\text{Labor}}{\text{Revenue}}$
Vertical axis: X2/Y, $\frac{\text{General Spending}}{\text{Revenue}}$</td>
</tr>
<tr>
<td colspan="3">I . Efficient frontier description: The strategic resources are dispersed on different IT projects.
II. Efficient frontier properties:
(1) Shape: small right angle
(2) Curvature: 90 degree
(3) Distance: Compared to the other two IT portfolio profiles, this efficient frontier is far way from the origin point.</td>
</tr>
</table>

Table 4 – Uneven distribution-based IT (Project) Portfolio along with relevant Efficient Frontier

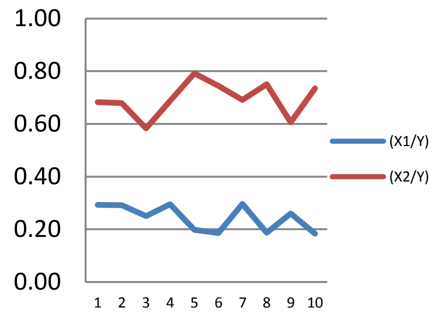
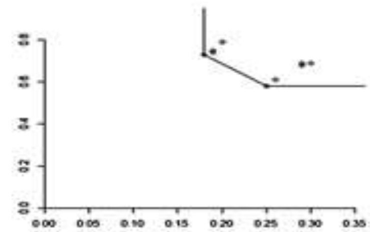
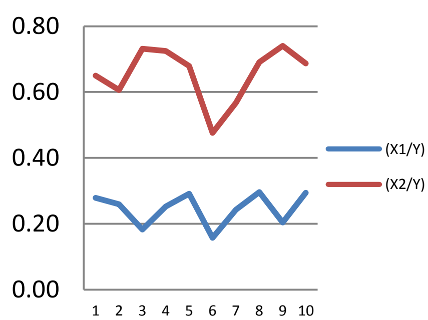
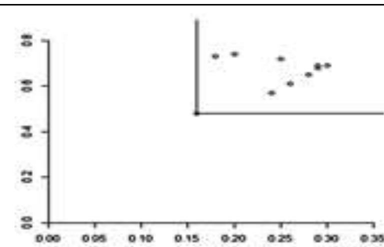
Uneven distribution-based IT portfolio		 Horizontal axis: X1/Y, $\frac{\text{Labor}}{\text{Revenue}}$ Vertical axis: X2/Y, $\frac{\text{General Spending}}{\text{Revenue}}$
I . Efficient frontier description: The strategic resources are centralized on some IT projects in this portoflio. II. Effiecient frontier properties: (1) Shape: Convex (2) Curvature: over 90 degree (3) Distance: Compared to the other two IT portfolio profiles, this efficient frontier belongs to medium distance from the origin point.		

Table 5 – Dominant set of IT (Project) Portfolio along with relevant Efficient Frontier

Dominant set of IT portfolio		 Horizontal axis: X1/Y, $\frac{\text{Labor}}{\text{Revenue}}$ Vertical axis: X2/Y, $\frac{\text{General Spending}}{\text{Revenue}}$
I . Efficient frontier description: The strategic resources are concentrated on few dominant IT projects in this IT portoflio. II. Efficient frontier properties: (1) Shape: large right angle (2) Curvature: 90 degree (3) Distance: This efficient frontier is relatively close to the origin point.		

VI. SUMMARY OF FINDINGS

Different IT portfolios may have various profiles related to resources allocations. According to our DEA/P model, IT executives can keep track of hierarchical organizational levels' efficiency of resource allocations concurrently. As a result, IT executives are able to find the most appropriate IT portfolio for each individual strategic goal to generate the optimal business value for the whole enterprise. We summarize our findings connected with the three IT portfolio profiles as follows.

(1) Even distribution-based IT Portfolio: Strategic IT resources are dispersed on IT projects in an IT portfolio and then each individual IT project of this IT portfolio has a similar ratio of costs to revenue. Since most IT projects within this portfolio present the average level for efficiency score, and with regard to the characteristics of this IT portfolio, the IT executives may apply it to a Low Risk (IT investment projects) IT portfolio concerning the strategic IT-related resource allocations.

(2) Uneven distribution-based IT Portfolio: Strategic IT resources are centralized on some IT projects, and almost every IT project has a different ratio of costs to revenue. Generally speaking, this type of IT portfolio is quite common in IT investments. In this regard, some of the Decision Making Units (DMUs) could reach the efficient frontier line (optimal combination of strategic resource allocations). Thus, the IT executive may apply Medium Risk (IT investment projects) to manage this IT portfolio pattern.

(3) Dominant set of IT Portfolio: Strategic IT resources are concentrated on few dominant IT projects, and the rest of the IT projects are small size projects. Briefly, since the dominant IT projects in a portfolio consume a lot more strategic IT-related resources, they could be easily understood as critical investment projects for the enterprise. Therefore, IT executives may

apply this profile to a High Risk (IT investment projects) IT portfolio. Additionally, according to our DEA/P model, the IT executive will have a better understanding of finding the most applicable IT portfolio to fit with enterprise strategic goals.

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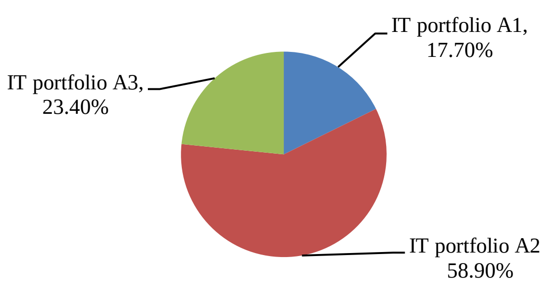
APPENDIX I – COMPUTATIONAL RESULTS

According to our simulated data, different types of IT Portfolio can come up with relevant Efficient Frontiers related strategic resource allocation in this section. Both efficiency score and slack score of DMU-A (organizational department level) including three associated IT Portfolios are shown in Table 6-1, and IT Portfolio – A3 has highest efficiency score, E_{A3} = 0.69, among three IT portfolios from DMU-A. However, IT portfolio – A2 is considered as the most critical one because it have the highest multiplier score, E_{A2} * W (0.68*0.589), in Table 6-1.

Table 6-1 DMU – A is associated with three IT portfolios

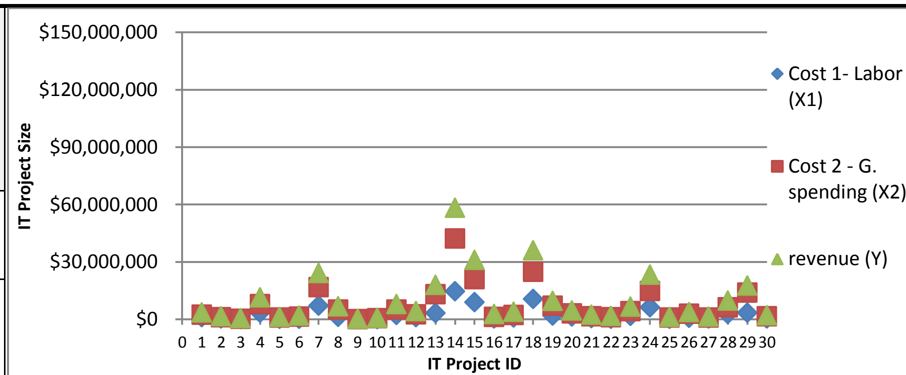
<table>
<tr><td rowspan="2">IT portfolio
Department A: DMU-A</td><td>IT portfolio - A1</td><td>IT portfolio - A2</td><td>IT portfolio - A3</td></tr>
<tr><td>E_{A1} = 0.68, S = 0.0567
W = 0.177 (17.7%)</td><td>E_{A2} = 0.68, S = 0.187,
W = 0.589 (58.9%)</td><td>E_{A3} = 0.69, S = 0.074
W = 0.234 (23.4%)</td></tr>
<tr><td>E_A = 0.682
S = 0.317</td><td colspan="3">IT portfolio A1, A2 and A3 is assigned certain amount of resources from Department (DMU-A) level, and we use weight score (W) to demonstrate this top-down resource allocation viewpoint.


Therefore, department's E-score is connected with related IT portfolios' E-score associated with their weight (W) score as follows: E = 0.682 (Department level) = 0.68*17.7% (IT portfolio A1) + 0.68*58.9% (IT portfolio A2) + 0.69*23.4% (IT portfolio A3).</td></tr>
</table>

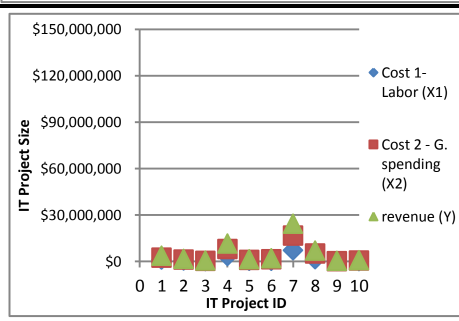
In Table 6-2, we can find that IT Project Portfolio distribution with relevant Efficient Frontier for DMU-A; meanwhile, Strategic Goal 2 is implemented by IT Portfolio - A2 that has the feature of a dominant set of IT Portfolio.

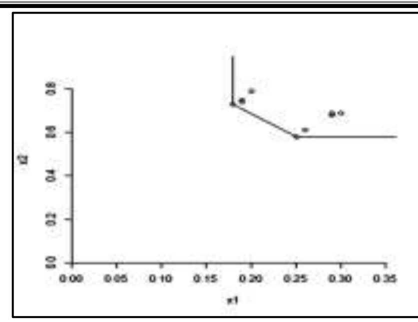
Table 6-2 DMU – A is associated with three IT portfolios related to Efficiency Frontier

Organizational Department Level is Decision Making Unit (DMU) including three IT Portfolios.		
DMU – A	E – Dept.	S - Dept.
	0.683	0.317

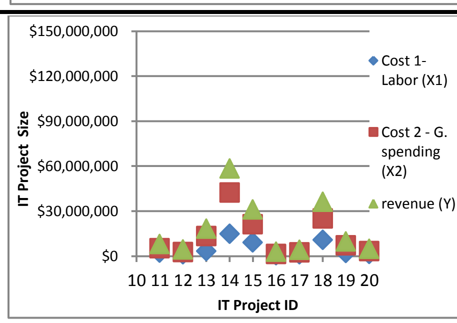


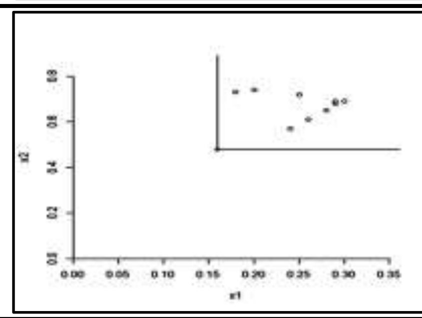
Strategic Goal 1 is implemented by IT Portfolio A1 – ITP #1 ~ #10		
E - A1	W - A1	S - A1
0.68	0.177	0.0567



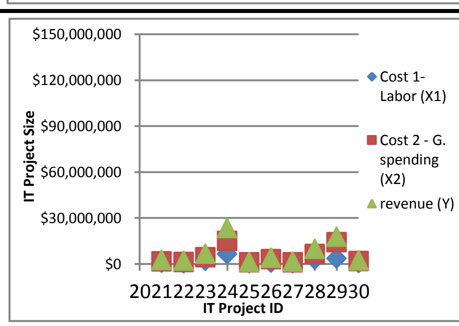


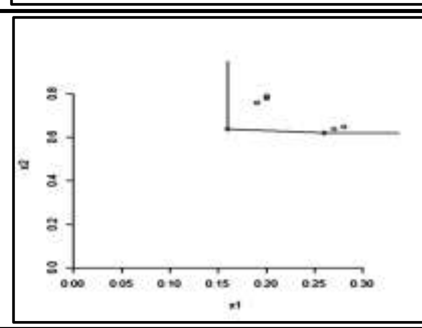
Strategic Goal 2 is implemented by IT Portfolio A2 – ITP #11 ~ #20		
E - A2	W - A2	S - A2
0.68	**0.589**	**0.187**





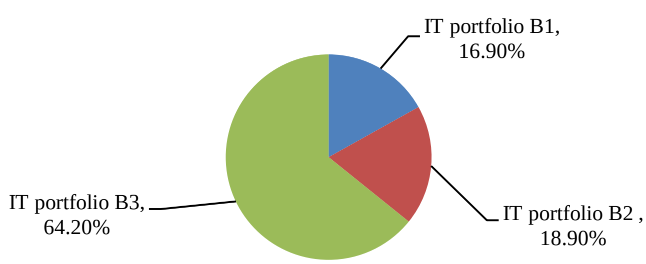
Strategic Goal 3 is implemented by IT Portfolio A3 – ITP #21 ~ #30		
E - A3	W - A3	S - A3
0.69	0.234	0.074





According to our simulated data, different types of IT Portfolio can come up with relevant Efficient Frontiers related strategic resource allocation in this section. Both efficiency score and slack score of DMU-B (organizational department level) including three associated IT Portfolios are shown in Table 7-1, and IT Portfolio – B2 has highest efficiency score, E_{B2} = 0.80, among three IT portfolios from DMU-B. However, IT portfolio – B3 is considered as the most critical one because it have the highest multiplier score, E_{B3} * W (0.74*0.642), in Table 7-1.

Table 7-1 DMU – B is associated with three IT portfolios

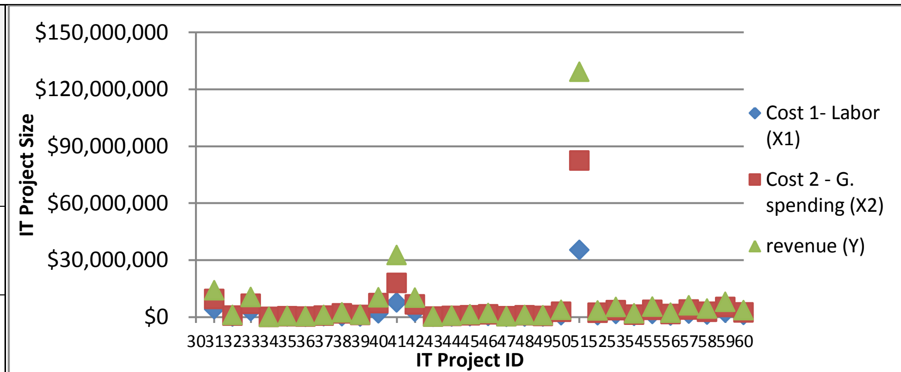
<table>
<tr><td rowspan="2">IT portfolio
Department B: DMU-B</td><td>IT portfolio – B1</td><td>IT portfolio – B2</td><td>IT portfolio – B3</td></tr>
<tr><td>E_{B1} = 0.69, S = 0.0524
W = 0.169 (16.9%),</td><td>E_{B2} = 0.80, S = 0.039
W = 0.188 (18.8%),</td><td>E_{B3} = 0.74, S = 0.167
W = 0.642 (62.4%),</td></tr>
<tr><td>E_B= 0.743
S = 0.258</td><td colspan="3">Regarding top-down resource allocation viewpoint, IT portfolio B1, B2 and B3 is assigned certain amount of resources from Department (DMU-B) level.


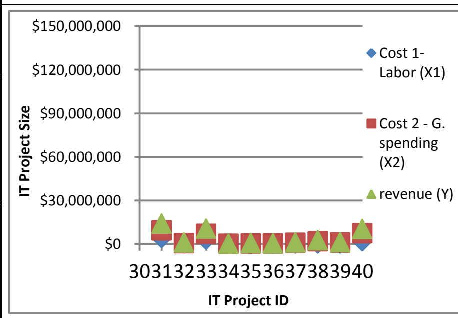
Therefore, department’s E-score is connected with related IT portfolios’ E-score associated with their weight (W) score as follows: E = 0.743 (Department level) = 0.69*16.9% (IT portfolio B1) + 0.80*18.8% (IT portfolio B2) + 0.74*62.4% (IT portfolio B3).</td></tr>
</table>

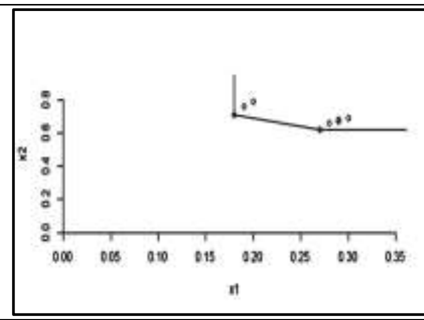
In Table 7-2, we can find that IT Project Portfolio distribution with relevant Efficient Frontier for DMU-B; meanwhile, Strategic Goal 3 is implemented by IT Project Portfolio that has the feature of even distribution-based IT Portfolio.

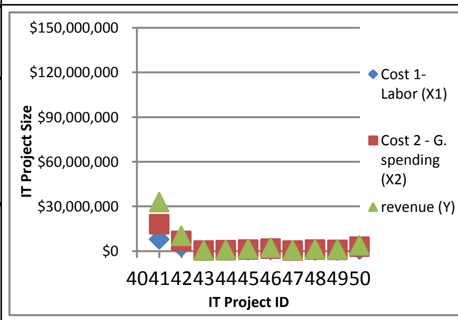
Table 7-2 DMU – B is associated with three IT portfolios related to Efficiency Frontier

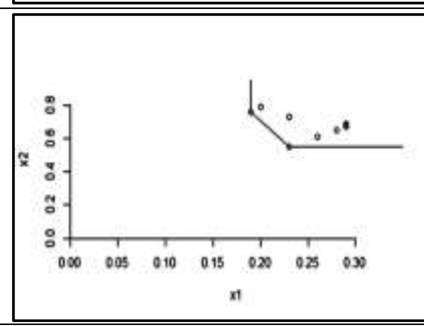
Organizational Department Level (Decision Making Unit: DMU)		
DMU	E – Dept.	S - Dept.
	0.743	0.258
Strategic Goal 1 is implemented by IT Portfolio B1 (ITP #31 ~ #40)		
E - SG1	W - SG1	S - SG1
0.69	0.169	0.0524
Strategic Goal 2 is implemented by IT Portfolio B2 (ITP #41 ~ #50)		
E - SG2	W - SG2	S - SG2
0.80	0.188	0.039
Strategic Goal 3 is implemented by IT Portfolio B3 (ITP #51 ~ #60)		
E - SG3	W - SG3	S - SG3
0.74	**0.642**	**0.167**

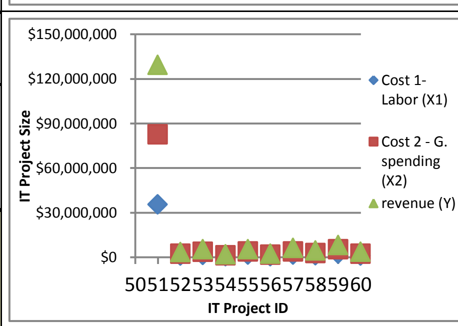


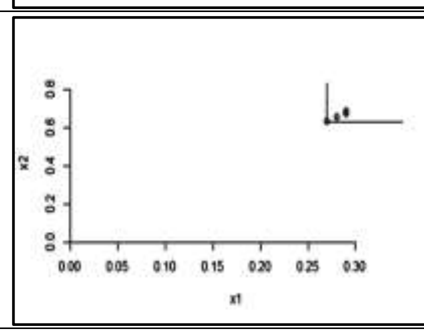






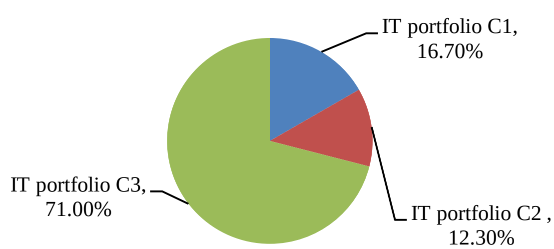






According to our simulated data, different types of IT Portfolio can come up with relevant Efficient Frontiers related strategic resource allocation in this section. Both efficiency score and slack score of DMU-C (organizational department level) including three associated IT Portfolios are shown in Table 8-1, and IT Portfolio – C3 has highest efficiency score, E_{C3} = 0.78, among three IT portfolios from DMU-C. Also, IT portfolio – C3 is considered as the most critical one because it have the highest multiplier score, E_{C3} * W (0.78*0.71), in Table 8-1.

Table 8-1 DMU – C is associated with three IT portfolios

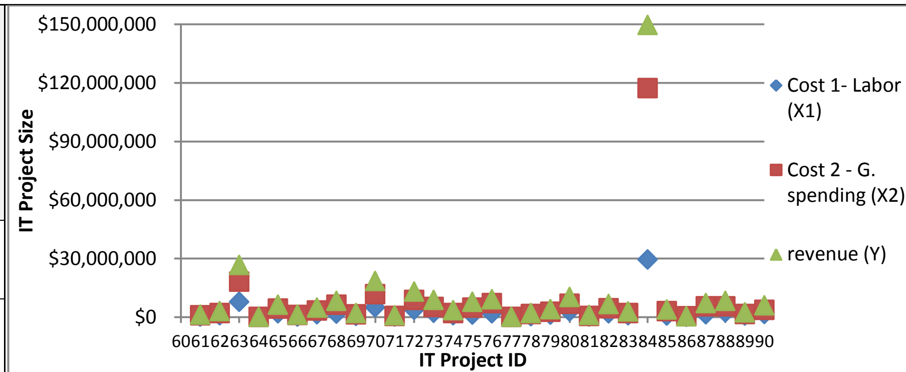
<table>
<tr><td rowspan="2">IT portfolio
Department C:
DMU-C</td><td>IT portfolio – C1</td><td>IT portfolio – C2</td><td>IT portfolio – C3</td></tr>
<tr><td>E_{C1} = 0.57, S = 0.0712
W = 0.167 (16.7%),</td><td>E_{C2} = 0.64, S = 0.044
W = 0.123 (12.3%),</td><td>E_{C3} = 0.78, S = 0.157
W = 0.71 (71%),</td></tr>
<tr><td>E_C = 0.728
S = 0.273</td><td colspan="3">Regarding top-down resource allocation viewpoint, IT portfolio C1, C2 and C3 is assigned certain amount of resources from Department (DMU-C) level.


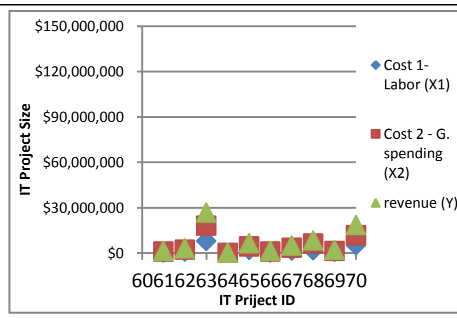
Therefore, department's E-score is connected with related IT portfolios' E-score associated with their weight (W) score as follows: E = 0.728 (Department level) = 0.57*16.7% (IT portfolio C1) + 0.64*12.3% (IT portfolio C2) + 0.78*71% (IT portfolio C3).</td></tr>
</table>

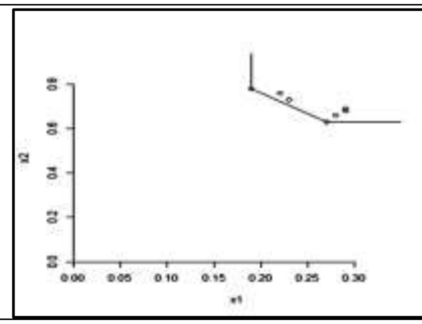
In Table 8-2, we can find that IT Project Portfolio distribution with relevant Efficient Frontier for DMU-C; meanwhile, Strategic Goal 3 is implemented by IT Portfolio – C3 that has the feature of uneven distribution-based IT Portfolio.

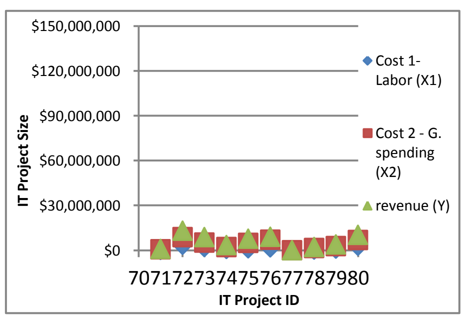
Table 8-2 DMU – C is associated with three IT portfolios related to Efficiency Frontier

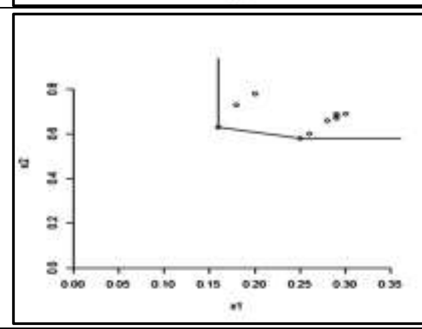
Organizational Department Level (Decision Making Unit: DMU)		
DMU	E – Dept.	S - Dept.
	0.728	0.273
Strategic Goal 1 is implemented by IT Portfolio C1 (ITP #61 ~ #70)		
E - SG1	W - SG1	S - SG1
0.57	0.167	0.0712
Strategic Goal 2 is implemented by IT Portfolio C2 (ITP #71 ~ #80)		
E - SG2	W - SG2	S - SG2
0.64	0.123	0.044
Strategic Goal 3 is implemented by IT Portfolio C3 (ITP #81 ~ #90)		
E - SG3	W - SG3	S - SG3
0.78	**0.71**	**0.157**

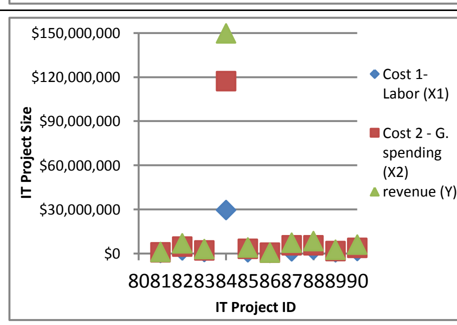


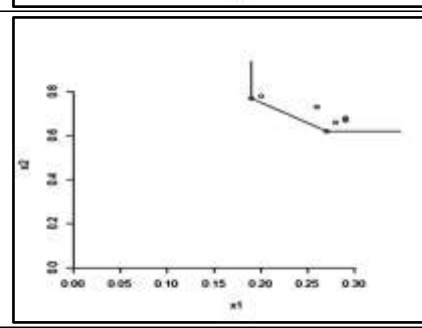












APPENDIX II – DATA ENVELOPMENT ANALYSIS MODLE (MATH EUQATION)

A. Conventional DEA model is proposed by Charnes, Cooper & Rhodes

Primal form	Dual form
$\mathrm{E} = \max. \sum_{r=1}^{S} u_r \, Y_{rk}$ $\mathrm{s.t.} \quad \sum_{i=1}^{m} v_i X_{ik} = 1$ $\sum_{r=1}^{s} u_r Y_{rj} - \sum_{i=1}^{m} v_i X_{ij} \leq 0,$ $\mathrm{j = 1, \ldots \ldots . n}$ $\mathrm{u_r, v_i} \geq \varepsilon,$ $\mathrm{r = 1, \ldots \ldots s,}$ $\mathrm{i = 1, \ldots \ldots . m}$	$\mathrm{E} = \min \theta - \varepsilon \, (\sum_{i=1}^{m} S_i^- + \sum_{r=1}^{S} S_r^+)$ $\mathrm{s.t.} \quad \sum_{j=1}^{n} \lambda_j \, X_{ij} + S_i^- = \theta X_{ik},$ $\sum_{j=1}^{n} \lambda_j \, Y_{rj} - S_r^+ = Y_{rk},$ $\lambda_j, S_i^-, S_r^+ \geq 0,$ $i = 1, \ldots \ldots, m,$ $j = 1, \ldots \ldots n,$ $r = 1, \ldots \ldots, s$ θ unrestricted in sign

B. DEA-based Parallel Production system is proposed by Kao Chiang

Primal form	Dual form
$\mathrm{E} = \max. \sum_{r=1}^{S} u_r Y_{rk}$ $\mathrm{s.t.} \sum_{i=1}^{m} v_i X_{ik} = 1$ $\sum_{r=1}^{S} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ik} + s_k = 0$ $\sum_{r=1}^{S} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ij} \leq 0,$ $\mathrm{j} = 1, \ldots \ldots \mathrm{n}, \mathrm{j} \neq \mathrm{k}$ $\sum_{r \in O^{(p)}}^{S} u_r Y_{rk}^{(P)} - \sum_{i=I^{(p)}}^{m} v_i X_{ik}^{(P)} + S_k^{(p)} = 0$ $P = 1 \ldots \ldots q$ $\sum_{r \in O^{(p)}}^{S} u_r Y_{rj}^{(P)} - \sum_{i=I^{(p)}}^{m} v_i X_{ij}^{(P)} \leq 0,$ $P = 1 \ldots \ldots q, j = 1 \ldots \ldots., n, j \neq k$ $\mathrm{u_r}, \mathrm{v_i} \geq \varepsilon, \; r = 1, \ldots \ldots s, i = 1, \ldots \ldots. m$ $S_k, S_k^{(P)} \geq 0, p = 1, \ldots \ldots q$	$\mathrm{E} = \min \theta - \varepsilon \sum_{p=1}^{q} (\sum_{i \in I^{(p)}} S_i^{-(p)} + \sum_{r \in O^{(p)}} S_r^{+(p)})$ $\mathrm{s.t.} \; \sum_{p=1}^{q} \left(\sum_{j=1}^{n} \lambda_j^{(p)} X_{ij}^{(p)} + S_i^{-(p)} \right) = \theta X_{ik},$ $i = 1, \ldots \ldots, m$ $\sum_{p=1}^{q} \left(\sum_{j=1}^{n} \lambda_j^{(p)} Y_{rj}^{(p)} - S_r^{+(p)} \right) = Y_{rk},$ $r = 1, \ldots \ldots, s$ $\lambda_j^{(p)}, S_i^{-(p)}, S_r^{+(p)} \geq 0, p = 1, \ldots \ldots q,$ $j = 1, \ldots \ldots, n, i = 1 \ldots \ldots m, r = 1, \ldots \ldots., s$ θ unrestricted in sign

C. DEA/P model (A new model) is proposed by this paper

Primal form	Dual form
$\mathbf{E}^{\mathbf{DEA/P}} = \max \sum_{r=1}^{s} u_r Y_{rk}$ $\text{s.t.} \sum_{i=1}^{m} v_i X_{ik} = 1$ $\sum_{r=1}^{s} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ik} + s_k = 0$ $\sum_{r=1}^{s} u_r Y_{rk} - \sum_{i=1}^{m} v_i X_{ij} \leq 0, \text{j} = 1, \ldots \ldots \text{n}, \text{j} \neq \text{k}$ $\sum_{r \in O^{(ITPM)}}^{S} u_r Y_{rk}^{(ITPM)} - \sum_{i=I^{(ITPM)}}^{m} v_i X_{ik}^{(ITPM)} + S_k^{(ITPM)} = 0,$ $ITPM = 1 \ldots \ldots q$ $\sum_{r \in O^{(ITPM)}}^{S} u_r Y_{rj}^{(ITPM)} - \sum_{i=I^{(ITPM)}}^{m} v_i X_{ij}^{(ITPM)} \leq 0,$ $ITPM = 1 \ldots \ldots q, \quad j = 1 \ldots \ldots . n, \quad j \neq k$ $\sum_{O^{(ITP)}}^{S} u_r Y_{rk}^{(ITP)} - \sum_{i=I^{(ITP)}}^{m} v_i X_{ik}^{(ITP)} + S_k^{(ITP)} = 0,$ $ITP = 1 \ldots \ldots q$ $\sum_{r \in O^{(ITP)}}^{S} u_r Y_{rj}^{(ITP)} - \sum_{i=I^{(ITP)}}^{m} v_i X_{ij}^{(ITP)} \leq 0,$ $ITP = 1 \ldots \ldots q, \quad j = 1 \ldots \ldots , n, \quad j \neq k$ $u_r, v_i \geq \varepsilon, \quad r = 1, \ldots \ldots s, \quad i = 1, \ldots \ldots . m$ $S_k, S_k^{(ITPM)}, S_k^{(ITP)} \geq 0, \quad p = 1, \ldots \ldots q$	$E^{DEA/P} = \min \theta - \Phi$ $s.t. \sum_{ITPM} \sum_{p=1}^{q} (\sum_{j=1}^{n} \lambda_j^{(ITPM)} X_{ij}^{(ITPM)} + s_i^{-(ITPM)}) = \theta X_{ik}$ $\sum_{ITPM} \sum_{p=1}^{q} (\sum_{j=1}^{n} \lambda_j^{(ITPM)} Y_{rj}^{(ITPM)} - s_r^{+(ITPM)}) = Y_{rk}$ $\lambda_j^{(ITPM)}, s_i^{-(ITPM)}, s_r^{+(ITPM)} \geq 0$ $\Phi = \varepsilon \sum_{ITPM} \sum_{p=1}^{q} (\sum_{i \epsilon I^{(ITPM)}} s_i^{-(ITPM)} + \sum_{i \epsilon O^{(ITPM)}} s_r^{+(ITPM)})$