Evaluating the Efficiency in which Risk is Managed in a Portfolio of IT Projects: A Data Envelopment Analysis Approach

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Abstract— This paper presents a method that allows managers and information technology professionals to better evaluate how efficiently risk is being managed within the confines of a portfolio of software projects. The method, which is based upon optimization and risk modeling, favors actions that increase the efficiency of risk management and, as a result, the likelihood of projects being delivered on time, within budget and in accordance with the requirements they were intended to be satisfied.

Index Terms—Risk analysis, software project management, software engineering economics and data envelopment analysis.

I. INTRODUCTION

Since F. L. Bauer coined the term "software crisis" in the late 1960's [1] to refer to the difficulty of writing correct, understandable, and verifiable computer programs within a specific time frame. Both industry and academia have made a tremendous effort to provide developers with concepts, methods and tools aimed at bringing reliability to the software development practice [2]. However, even today, forty years after the term "software crisis" was used for the first time in a NATO conference in Germany, an astonishing number of software development initiatives still fail miserably to deliver as promised [3].

For example, the tenth issue of the Standish Report, published in 2004, shows that out of the 50 thousand information technology (IT) projects examined by the Standish Group¹ only 29% were considered a success. Of the projects surveyed, 58% were developed in the US, 27% in Europe and 15% in the rest of the world, which gives an international perspective to the findings of the report. A full 45% of the projects surveyed were in Fortune 1000 companies [4]. Moreover, this report indicates that an excess of \$50 billion was wasted in unsuccessful IT-related projects in the US alone [5].

Despite criticism from some authors who dispute the accuracy of the Standish Report [6], [7] there is enough evidence in the literature to support the claim that a persistent, although less dramatic, trend of failure in software projects is still in place and that the 1960's software crisis is still very much alive today [8].

Advocates of risk management argue that the success of a project does not depend exclusively on concepts, methods and tools, but also on a multitude of different business, psychological and technical elements [9]. In addition, they rightfully claim that the identification and analysis of the threats posed by these elements do change the risk perception of software project managers, favoring actions that substantially reduce the chances of failure [10]. In computer technical jargon these elements, which consist of events and conditions in a universe of interest, are frequently referred to as *software project risks* [11].

As organizations keep investing in software development as a means of enhancing competitiveness, the events and conditions that can pose a major threat to the successful completion of software projects becomes an area of great concern for management [12]. Despite the vast literature on risk analysis that has been produced over the years, little has been said on how efficiently software risk is being managed. This work is a step towards filing this gap [13].

This article introduces a method that not only allows managers to evaluate the efficiency with which the risks of a portfolio of software projects are being managed, but also suggests the actions to be taken with the intention of increasing the efficiency of risk management. The method, which is based upon optimization techniques and quantitative risk modeling, favors projects that are delivered in accordance with a widely used set of performance metrics, such as time, cost and requirement compliance.

The remainder of this paper is organized as follows. Section II contains the conceptual framework that the paper is based upon. Section III introduces the method

¹An American IT consulting firm.

with the help of a real-world inspired example. In Section IV the method is summarized. Finally, Section V presents the conclusions of this paper.

II. CONCEPTUAL FRAMEWORK

A. Risk Management

When managers try to deal with the risks to which a software project is subjected, they seek to influence the project's surrounding environment with the intention of reducing the chances of a negative outcome. Because this environment is usually complex, full of uncertainties and open to an infinite number of possibilities, models have been devised to make it easier for managers to identify the risks that would most strongly affect the chances of a project being completed successfully.

In risk analysis modeling the relevant risk-related information is most frequently captured by a finite set of variables, called risk factors, which increase the chances of a negative outcome when taking value in a set of undesirable values [14].

Consistent with this perspective, in the course of time, several lists of IT-related risk factors have been proposed [11]. Besides helping IT managers to better identify risks, by and large, these models also provide means to connect risk factors to project performance factors such as time and cost compliancy, and meeting user functional requirements, allowing managers to reason about the best course of action to be taken in each situation, through a process of trial and error.

For example, Wallace *et al.* [11] explore the connection between risk factors and project performance factors using a questionnaire based upon a seven-point Likert scale [15] to collect data from software projects in the US and elsewhere. Initially Wallace *et al.* selected risk and performance factors most commonly cited in the risk literature. Next, they use exploratory factor analysis to elicit risk and project performance constructors. Finally, the connection between risk factors and project performance factors is established with the support of the K-means clustering algorithm [16]. Figure 4 presents the questionnaire used by Wallace *et al.*

By improving certain project elements that are present in Wallace *et al.*'s questionnaire, such as team interpersonal relationships, user involvement and better planning and control mechanisms among others, the project manager may try to influence the likelihood of the occurrence of one or more risk factors, and, as a result, the outcome of project performance factors.

Over the course of time Wallace *et al.*'s [11] ideas and results have become highly influential, serving as the basis for the work of many other researchers and practicioners² including [17]–[19].

However, despite all the progress that software risk analysis has experienced in the last decade and the positive effects that it has had on the management of large and complex software projects, little attempt has been made to develop models that clearly indicate the actions that management should take and the consequences of these actions in improving the chances of finishing a project successfully [20].

B. Data Envelopment Analysis

Data Envelopment Analysis (DEA), due to Charnes *et al.* [21], is a non-parametric linear programming method for the estimation of the relative efficiency of multiple decision making units (DMUs) such as the branches of the same chain of furniture stores; companies doing business in the same market; and departments of the same university. DEA is especially useful when the production process of a set of DMUs presents a structure of multiple inputs and outputs and the most efficient structure cannot be realistically determined in absolute terms.

To estimate the relative efficiency DEA requires that a relevant set of measurements is collected about the DMUs one wants to analyze. For example, the number of employees working in each DMU, the amount of energy consumed by the unit, its floor area, the number of products yielded within a time frame, the percentage of defective products, etc.

Next, the most efficient DMUs are identified, being those that have the highest ratio between products yielded and the resources used to make them. The most efficient units are then connected by a hyperplane in the n-dimensional space defined by the set of relevant measurements. This hyperplane defines an *efficient frontier*, against which the other DMUs are analyzed. If only two measures are used in the analysis, then the hyperplanes become a straight line in a two-dimensional space.

For example, consider a chain of orthopedic clinics in which one is interested in improving the overall efficiency. Figure 1 presents the data that has been collected on each clinic. Initially, one should only take into consideration the data displayed in gray background. Note that the turnover of each clinic is presented millions of American dollars.

Matuia	Branch Id								
Metric	А	В	С	D	E				
Turnover (T)	3	7	6	4	2				
# of nurses	49	81	30	67	70				
# of doctors	1	19	30	13	10				
# of Employees(#E)	50	100	60	80	80				
T / #E	0,06	0,07	0,1	0,05	0,025				

Figure 1. Data on a chain of orthopedic clinics.

According to the information shown in Figure 1 in gray background, clinic B has 100 employees and a turnover

²A search at Google scholar does support this claim.

of US\$ 7 million, which is the highest among all the clinics. On the other hand, clinic E, which employees 80 people, has a turnover of just US\$ 2 million, which is the smallest turn over. It should be noted that clinic C has the best ratio between turnover and number of employees, i.e. 0.1. Hence, it is the clinic that best employs the resources at its disposal to produce the intended results.

If clinic C can reach this degree of efficiency, then the other clinics may very well follow through by either increasing their turnover while keeping the same number of employees or diminishing the number of employees while keeping the same turnover. Consistent with these ideas, in formal terms, *DMU efficiency* is defined as

$$Efficiency_{DMU} = \frac{Output_{DMU}}{Input_{DMU}}$$
(1)

where Input_{DMU} and Output_{DMU} are linear combinations of the measurement of the resources consumed by the DMU and the measurement of the products and services yielded by the unit respectively. Note that in the case of the chain of orthopedic clinics the input is the number of employees and the output is the clinic turnover. Figure 2 shows the data presented in Figure 1 in the form of a two-dimensional graphic.



Figure 2. Graphic display of the data on the chain of orthopedic clinics.

It is important to note that the slope of the straight line connecting each clinic in the graphic to the point of origin (intersection of the vertical and horizontal axis) corresponds to the turnover per employee of that particular clinic. Also, the straight line connecting the point of origin to clinic C is the one with the highest slope. Clinics over this line are the most efficient ones. Hence this particular line is called the *efficient frontier*.

Because one is obviously interested in improving the efficiency of inefficient branches, it is important to provide a metric that measures the relative efficiency of each branch in regards to the one that is the most efficient. This relationship is given by

A	Turnover per employee of clinic x	(2)
$\theta =$	Turnover per employee of C	(2)

where $x \in \{A, B, C, D, E\}$. Table I presents the relative efficiency of each clinic in respect of clinic *C* calculated according to Equation 2.

TABLE I. The relative efficiency of each clinic

Metric	Clinic Id							
	A	B	С	D	E			
θ	0,60	0,70	1	0,50	0,25			

Therefore, clinic D is half as efficient as clinic C and clinic E is a quarter as efficient. Moreover, once the relative efficiency has been calculated, there is a question that unveils quite naturally: *what steps should be taken to make inefficient branches more efficient?*

Equation 1 shows that there are just three ways of improving efficiency: decreasing the input, increasing the output or performing a calculated combination of both. For instance, if one manages to double the turnover of D or to decrease its workforce by half, D becomes as efficient as C. Obviously, one could reach the same degree of efficiency by decreasing the workforce by 20 employees and increasing the turnover by 2 million dollars.

The dashed arrows in Figure 2 show five different ways of moving D to the efficient frontier (out of an infinite number of possibilities) and, as a result, allowing it to become an efficient branch. In technical jargon, both the amount of output one has to add to and the amount of input that one has to subtract from a DMU to move it to the efficient frontier are called *slacks*. If a slack concerns changes in the inputs of a DMU, it is called *input slack* or s^- , otherwise it is called *output slack* or s^+ .

Surely the problem of increasing branch efficiency in the real world is often much more complex, involving the analysis of several different inputs and outputs. For example, Figure 1 reveals further details on how the total number of employees in each clinic is figured out. The numbers presented in white background indicate the quantity of doctors and nurses in each clinic, whose sum yields the number of employees.

Based on the data presented in Figure 1 one could rightfully argue that the way the number of employees is calculated distorts the fairness of the analysis. While the percentage of doctors in clinic A is quite low, in clinic C it reaches 50% of its professional staff.

To make the analysis of the productivity of each clinic fairer one would have to take into account that doctors have to undergo a lengthy theoretical and practical training before they are allowed to practice. Because doctors (especially orthopedists) are highly demanded professionals who are hard to come by, they are often very expensive. Therefore, when analyzing the efficiency of the chain of orthopedic clinics, doctors should not weigh the same as nurses who are a bit easier to find, require less training to practice and earn a lot less.

Hence, to approach the analysis of efficiency properly one has to create an index that weighs the number of orthopedists and nurses in the different branches of the chain of orthopedic clinics. Figure 3 presents such an index where the number of doctors is arbitrarily multiplied by five before being added to the number of nurses.

Matula	Branch Id									
Metric	А	В	с	D	E					
Turnover (T)	3	7	6	4	2					
# of nurses	49	81	30	67	70					
# of doctors	1	19	30	13	10					
Weighted Index (WI)	54	176	180	132	120					
T / WI	0,06	0,04	0,03	0,03	0,02					

Figure 3. Using a weighted index to analyze efficiency.

It should be noted that when considering the weighted sum of doctors and nurses the most efficient unit shifts to A (previously C was the most efficient unit). Therefore, determining the most efficient unit depends on how the input and output variables are combined.

The problem of figuring the relative efficiency of n decision making units with multiple inputs and outputs has been generalized by Charnes, Cooper and Rhodes [21] with the following optimization model:

$$\max_{u,v} \theta = \frac{u_1 y_{1o} + u_2 y_{2o} + \dots + u_s y_{so}}{v_1 x_{1o} + v_2 x_{2o} + \dots + v_m x_{mo}}$$
(3)

subjected to

$$\begin{aligned} \frac{u_1y_{1j} + u_2y_{2j} + \dots + u_sy_{sj}}{v_1x_{1j} + v_2x_{2j} + \dots + v_mx_{mj}} &\leq 1, \text{ for } j = 1, \dots, n, \\ v_1, v_2, \dots, v_m \geq 0, \text{ and} \\ u_1, u_2, \dots, u_s \geq 0 \end{aligned}$$

where $1 \leq o \leq n, x_{1o}, \dots, x_{mo}$ and y_{1o}, \dots, y_{so} are respectively the measurements of the inputs and outputs of a given DMU_o, and u_1, \dots, u_s and v_1, \dots, v_m are weights whose value one is interested in determining.

According to Charnes, Cooper and Rhodes once the values of v_1, \dots, v_m and u_1, \dots, u_s have been obtained, the performance of DMU_o is compared to the performance of the most efficient DMU among the decision making units, allowing for the calculation of DMU_o's input and output slacks.

Note that in Charnes, Cooper and Rhodes's model n optimizations are performed, one for each unit whose efficiency one wants to evaluate. In each optimization the DMU under analysis (i.e. DMU_o) is allowed to display its best possible performance, before being compared to the other DMUs, restricted to the condition that the ratio between any two DMUs are always less than or equal

to one. See [22] for a thorough introduction to DEAmodeling.

III. AN EXAMPLE

According to Seneca (5BC - 65AD), the Roman philosopher: "The path of precept is long, that of example, short and effectual." Hence the method proposed in this paper is introduced step-by-step with the support of a real world inspired example.

Step 1: Context Information

Consider an information technology service organization such as Accenture, Tata, Unisys, IBM, HP-EDS, InfoSys and many others, which runs tens of thousands of software projects every year for clients worldwide. For the purpose of this paper this organization is named Worldwide IT Consultancy Services, or WITCS³.

Because today's competition in the IT service market is tougher than ever, WITCS' Board of Directors has become increasingly concerned that, in some operations, the projects the company runs are not being properly managed according to required market standards. For example, over the past twelve months client satisfaction with the software that WITCS produces in its South American operation has been lower than it should, while project cost and duration have been higher than they should be.

An inquiry made among the executives and client companies in WITCS South America revealed that poor risk management is to blame. As the complexity of the projects run by the company increased over the years, project managers became less able to anticipate problems and take corrective actions beforehand.

To get a hold of the situation as fast as possible, WITCS decided to analyze the projects run in its South America operation, with the idea of taking actions that could help its project managers to better deal with the risk that IT projects are naturally exposed to. Table II shows the list of projects to be analyzed by WITCS' appointed group of auditor-analysts.

Fourteen project managers currently work in WITCS' South America operation. Each manager contributed to the list with the projects they were responsible for over the period the company's performance was lower than expected, i.e. the last twelve month. Table III shows the number of projets contributed to the list by each project manager. It is worth keeping in mind that in WITCS the work project managers are expected to do is made easier by the help provided by a team of project leaders.

³The data used to obtain the results presented in this paper are based upon real data provided by the South America operation of a major player in the IT service business. Because the data partly reflects the current state of affairs of this company, the authors are not at liberty to disclose its name.

Therefore, WITCS' project managers are used to running quite a large number of different projects yearly.

Step 2: The Auditing Mechanism

Following the advice of its auditors, WITCS decided to use Wallace *et al.*'s questionnaire to properly audit the risk the projects in Table II were exposed to, together with the projects' outcome.

To ensure that the auditing process remained unbiased, for each project the first part of the Wallace *et al.*'s questionnaire was answered by the project team with the help of a facilitator, while the second part of the questionnaire was answered by users, managers and technicians from the client side of the same project, i.e. from the company that footed the bill of the project. Table IV presents the data collected by WITCS.

Step 3: Choosing the Mathematical Model

When questioned how the data collected from WITCS's project managers and clients should be analyzed, the team of auditors pointed out that the situation WITCS's is going

 TABLE II.

 PROJECTS RUN BY WITCS IN SOUTH AMERICA

Prj.	Mngr.	Industry	Project Name and
Id	Id		Description
P ₁	M ₅	Oil & Gas	Contract management - allows prices to be prop- erly and timely adjusted
P ₂	M ₈	Industrial Gases	Cylinder bar coding - makes it easier to know where industrial-gas cylin- ders are and where they are heading by tracking them with bar codes
:	:	:	· · · ·
P ₄₉₁	M ₁₁	Tyre Making	<i>Fiscal automation</i> - pro- vide the inland revenue service with fiscal in- formation by electronic means

TABLE III. NUMBER OF PROJECTS PER PROJECT MANAGER

 M_2

32

 M_{13}

35

 M_{14}

37

 M_1

36

TABLE 1	V.
DATA COLLECTED FROM WITCS'	S PROJECT MANAGERS AND
CLIENTS	.

Prj.	Mngr.	Risk Factors			Perf. Factors			
Id	Id	\mathbf{RF}_1		RF ₄₄	\mathbf{PPF}_1		PPF ₉	
P ₁	M ₅	4		3	1		2	
P ₂	M ₈	6	•••	5	2		3	
· ·	·	•	· ·	•	·	·	•	
P ₄₉₁	M ₁₁	5		2	3		1	

through is very similar to the one faced by the chain of orthopedic clinics. While not all branches of the chain

- have the same number of doctors and nurses,
- are all in easily accessible locations,
- have the same floor area,
- offer exactly the same variety of services, etc.,

some have a relatively bigger turn over than others.

As data envelopment analysis has been extensively used to analyze DMUs in the health care business [23], WITCS considered using a similar approach to deal with the efficiency with which its software projects are being managed.

Step 4: Selecting a DEA Solver

Because only very simple DEA problems can be solved by analytical means, WITCS has to resort to a computer tool to evaluate how efficiently risk is being managed in its South America operation⁴. A comprehensive list of DEA solvers can be found in [24].

Step 5: Preparing the data for analysis

Table V shows the data required by the DEA solver selected by WITCS.

TABLE V. DEA-SOLVER REQUIRED DATA.

Prj. Id	Mngr. Id	Risk Dimension			Performance Dimension		
		\mathbf{RD}_1	•••	\mathbf{RD}_6	\mathbf{PD}_1	•••	PD_9
P1	M_5	(8 - 4.3)		(8 - 3.1)	1		2
P_2	M8	(8 - 6.0)		(8 - 5.4)	2		3
	•	:	•••	•••		•••	:
P ₄₉₁	M ₁₁	(8 - 5.1)		(8 - 2.7)	3		1

It should be noted that the risk-factor grades have been grouped into risk dimensions, with the view of not only reducing the effort required to compute the solution of the corresponding DEA-model, but also avoiding to request the model no deal with large groups of highly correlated variables. As suggested by Wallace *et al.* [11], each dimension is the result of the average value of the risk factors it is comprised of.

It should be also noted that the data used by the solver consists of the first and second part of Wallace *et al.*'s questionnaire, where the data concerning the first part has been adjusted to be in the same scale as the data concerning the second part.

Although one may not realize at first, input and output variables in Wallace *et al.*'s questionnaire take value in a slightly different scale. While 7 is an excellent mark for an output variable, showing that clients are thrilled

Mngr. Id

of Projects

⁴The DEA problems presented throughout this paper were solved with the help of an optimization solver developed by the authors of this paper specifically to tackle this problem.

with some particular aspect of project performance, the same mark indicates that a project performs miserably in a given risk dimension.

Step 5: Adjusting the DEA-Model

However, before a DEA-model can be built and analyzed, the Charnes, Coopers and Rhodes' model introduced in Equation 3 has to be modified to properly accommodate risk and perform dimension constraints. If additional variables constraints are not added to the model, then using the slacks it provides may not lead to the optimum value that risk dimension variables should take, leaving the modeler with the unpleasant task of figuring out how far from the optimum solution those slacks suggest one may take the variables.

For example, adding a slack to an input variable has to lead to a value that belongs to the real-number set $\{1, \dots, 7\}$, as according to Wallace *et al.*'s questionnaire this is the interval from which input variables (i.e. risk dimensions) are allowed to take value.

In formal terms, when using Wallace *et al.*'s questionnaire to evaluate the efficiency with which risk is being managed in a profolio of n IT projects, one is interested in

$$\max_{u,v} \theta = \frac{u_1 \times PD_{1,o} + \dots + u_4 \times PD_{4,o}}{v_1 \times RD_{1,o} + \dots + v_6 \times RD_{6,o}}$$
(4)

subjected to

$$\frac{u_1 \times PD_{1,j} + \dots + u_4 \times PD_{4,j}}{v_1 \times RD_{1,j} + \dots + v_6 \times RD_{6,j}} \le 1,$$
$$u_1, \dots, u_4 \ge 0,$$
$$v_1, \dots, v_6 \ge 0,$$
$$PD_{1,j}, \dots, PD_{4,j},$$
$$RD_{1,j}, \dots, RD_{6,j}, \text{ and}$$

$$s_{RD_{1,j}}^+ + RD_{1,j}, \cdots, s_{RD_{6,j}}^+ + RD_{6,j} \in \{1, \cdots, 7\},$$

where $1 \le j \le n, 1 \le o \le n, u_{1j}, \dots, u_{4j}$ and v_{1j}, \dots, u_{6j} are weights whose values have to be determined, and $s_{RD_{1,j}}^+, \dots, s_{RD_{6,j}}^+$ are the input slacks generated by the DEA model.

Step 7: Identifying the relative efficiency of the projects run by WITCS

Table VI shows the outputs provided by the DEA solver, comprised of the project Id, the manager Id, the relative efficiency with which each project was run, and the value of the slacks that should be added to each input (i.e. to each risk dimension), if one wants to move a project to the efficient frontier.

Alternatively one could consider moving a project to the efficient frontier by adding output slacks to the performance dimension variables. However, in order to obtain the results WITCS needs, these slacks were set to remain at zero, as project managers are not supposed to directly influence the value of those variables.

TABLE VI. DEA-SOLVER OUTPUT.

Proj.	Mngr.	Relative	Slack					
Id	Id	Effcy	$s^+_{RD_1}$	$s^+_{RD_2}$		$^{s}\mathbf{R}\mathbf{D}_{6}$		
P ₁	M ₅	83.0%	1.2	1.5		2.1		
P ₂	M ₈	35.6%	3.7	2.4		4.1		
:	•		:	:	÷	:		
P ₄₉₁	M ₁₁	39.9%	4.6	5.3		0		

Step 8: Identifying the most efficient manager

Table VII shows the WITCS' project managers ordered by the median of the relative efficiency of the projects they have run.

TABLE VII. Managers ordered by their average efficiency.

Mngr.	Median of the
Id	Relative Efficiency
M9	91.7
M_2	86.9
M_7	83.3
M_1	81.1
M ₁₀	77.1
M_4	69.0
M_{11}	67.3
M_5	58.1
M_{14}	57.2
M_3	55.7
M ₁₃	48.4
M ₆	46.8
M8	39.2
M_{12}	30.5

According to the information presented in Table VII, M_9 and M_2 are respectively the most and second most efficient project managers from the risk management perspective, while M_8 and M_{12} are the worst. As each project manager has been in change of a different number of projects (see Table III), these claims are supported by the unilateral Fisher's median nonparametric test (Fisher Exact Test) with a 90% degree of confidence. See [25] for a discussion on nonparametric hypothesis testing.

A nonparametric test has been used in this case because the distribution of the project managers' relative efficiency is unknown and the plot of a simple histogram has revealed that this distribution is far from being a normal distribution. The degree of confidence has been set to 90% because the usage given to this information does not require more precision, as it becomes evident in Step 9. See [25], [26] for a discussion on how to choose the right degree of confidence.

Step 9: Considering the actions to be taken

192

Based on the information presented in Table VII it is possible that WITCS decides to partly renovate its team of project managers in South America. Rationally, such a decision depends upon the cost of the theoretical and practical training that project managers would have to undergo in order to bring risk management to an acceptable level of performance, and the cost of opportunity, which reflects the cost of keeping a new professional in one's payroll until they are ready to fully perform their duties.

Although possible, it is unlikely that project managers perform poorly in all risk management dimensions. Most often it is the case that there is one or two areas in which they tend to excel [27]. In these circumstances, for those who remain with the company, the slacks provided by the DEA-solver may be used to indicate in which risk factor dimensions project managers need to improve their performance more strongly. Table VIII relates project managers to the average slacks per risk dimension of the projects they have run.

TABLE VIII. Slack medians of the projects run by each project manager.

Id	Slack (Median)									
	$s^+_{RD_1}$	$s^+_{RD_2}$	$s^+_{RD_3}$	$s^+_{RD_4}$	$^{s}\mathbf{R}\mathbf{D}_{5}$	$s^+_{RD_6}$				
M ₉	0.7	1.3	0.4	0.2	0.5	0.6				
M_2	0.8	0.4	2.1	0.3	2.3	0.7				
:	:	•	:		:	:				
M ₁₂	4.8	1.1	5.3	4.3	4.0	5.4				

For example, $s_{RD_6}^+$ bears the highest value among all project manager M_{12} slacks, indicating that managing requirement risks is an area in which project manager M_{12} 's skills need to improve most firmly. In addition, $s_{RD_3}^+$ bears the second highest value among all M_{12} slacks, therefore user risk management is another important area in which the skills of M_{12} need to improve, and so on and so forth. Because the distribution of slacks are unknown these claims are supported by the nonparametric unilateral Arbuthnot signal test with a 90% degree of confidence.

Step 10: Taking action

After conferring with its team of auditor-analysts, WITCS decided that, at this time, it will not be necessary to provide any further risk management training for those who have reached a relative efficiency level of at least 60% on average. The project managers that have either equaled or excelled this threshold are to continue performing their duties as they were. Project manager M_9 , M_2 , M_7 , M_1 , M_{10} , M_4 and M_{11} fall into this category. This claim is supported by the non-parametric unilateral Arbuthnot signal test with a 90% degree of confidence. Project managers that fail to reach the 60% threshold are required to undergo further risk management training in specific areas. Project managers M_5 , M_{14} , M_3 , M_{13} , M_6 , M_8 and M_{12} are the ones who fall into this category. Again, this claim is supported by the non-parametric unilateral Arbuthnot signal test with a 90% degree of confidence.

To make it easier to access the risk management areas in which managers are required to polish up their knowledge, WITCS established a threshold of 60% of the slack six point interval scale, i.e. from 1 to 7. Therefore, according to WITCS's slack policy, project managers who have performed poorly are required to further develop their risk management skills in the areas where the average slacks of the projects they have run equal or exceed $3.4 = 7 - \frac{60}{100} \times (7 - 1)$.

In these circumstances, project manager M_{12} is required to further develop his risks management skills in the following risk dimensions: team building, requirements, planning and control, user involvement and system complexity. This claim is supported by the non-parametric unilateral Arbuthnot signal test with a 90% degree of confidence.

IV. THE METHOD

Organizations interested in increasing the efficiency with which risk is being managed in a portfolio of IT projects may benefit from taking the following steps:

- Identify the project managers whose risk management effectiveness one wants to analyze and select a time frame. Subsequently, create a portfolio of IT projects that these managers have completed within the selected time frame;
- 2) Have the project team of each project in the portfolio fill in the first part of Wallace *et al.*'s questionnaire, while the users, managers and technicians from the client side of each project fill in the second part of the questionnaire;
- Choose the mathematical model to analyzed the data collected from the project team and the client side of each project;
- 4) Select a DEA solver to help with the efficiency analysis⁵;
- Adjust the DEA model so that the restrictions imposed by the variables in Wallace *et al.*'s questionnaire are properly considered;
- Prepare the data required by the DEA solver, comprising of the project Id, manager Id, and the risk and performance dimension variables of Wallace *et al.*'s questionnaire;
- Run the DEA-solver, making sure that the output slacks remain at zero. Identify the relative efficiency of each project, together with their input slacks;
- Calculate the average efficiency of the projects each project manager has run together with the average slack for each risk dimension;

⁵Alternatively one may consider building one's own DEA-solver. It is actually easier than it may seem at first.

- 9) Consider partly or completely renovating the team of project managers. For those who remain with the company use the average slacks as an indicator of the areas in which management skills need to improve;
- 10) Finally, take action.

V. CONCLUSIONS

According to DeMarco and Lister [28], almost no IT project ever runs exactly to plan. Note that this assertion can be easily tested by considering the IT projects that are run in the organization one works for. Ask yourself, of those projects that were recently run, how many were canceled? Of those projects that succeeded in delivering anything useful, how many were late? Of those that were on time, how many maintained their schedule by getting rid of required functionality? At best one should be able to name a few that actually came in on time and with all their planned features. The Standish Report estimates that no more than 28% of all IT projects that are run in the USA and elsewhere in the world can be considered successful [4].

Eventually many authors came to believe that risk management were greatly responsible for the poor successful completion record of IT projects [11]. As a result a myriad of risk analysis models have been proposed to identify the risk that software project are exposed to. Although none of them can claim completeness, as the number of risk factors a software project is exposed to is infinite, some models have been built upon more solid ground than others [29].

Therefore, even the model developed by Wallace *et. al.* falls short of containing all the risk factors and dimensions that can affect the successful conclusion of a software project, despite its relative comprehensiveness and solid scientific basis [11].

Nevertheless, it is the case that not every project manager shares the same risk management skills. While some excel in specific aspects of risk management, others perform poorly. Therefore, the way risk is managed in IT projects varies considerably [27].

This paper presents a method based upon data envelopment analysis (an optimization technique) and risk modeling that allows organizations not only to identify their most efficient managers from the risk management perspective, but also to pinpoint the areas in which the management skills of each manager should be further developed. So far, the model presented in this paper is the first to propose efficiency as a dimension worth taking into consideration in the software-project riskmanagement realm.

All of this helps companies to set standards in the crucial area of IT management (i.e. how risks are being managed in IT projects), where practically no standards have been set so far. Furthermore, it makes it easier

to identify where and when new investments in risk management are necessary. Hence favoring the taking of corrective actions that help projects to be delivered on time, within budget and according to the requirements they were set to satisfy.

Interviews done later on with WITCS' high management did reveal a considerable increase in performance regarding the management of the risks that software projects are naturally subjected to. Furthermore, this increase in performance was largely led by those project managers who were subjected to the selective training necessary to bring their risk management skills up to date with both WITCS and market standards.

REFERENCES

- F. L. Bauer, "Software engineering," in *Report on the NATO Software Engineering Conference 1968*, P. Naur and B. Randell, Eds., North Atlantic Treaty Organization (NATO). Garmisch, Germany: NATO Scientific Affairs Division, 7th to 11th October 1968.
- [2] R. Pressman, Software Engineering: A Practitioner's Approach, 7th ed. McGraw-Hill, 2009.
- [3] R. N. Charette, "Why software fails," *IEEE Spectrum On Line*, September 2005.
- [4] S. P. Masticola, "A simple estimate of the cost of software project failures and the break even effectiveness of project risk management," in *Proceedings of the First International Workshop on The Economics of Software and Computation*. Minneapolis, MN, USA: IEEE Computer Society, May 20th, 2007, pp. 6–9.
- [5] S. Beer, "IT project failures up sharply according to US report," *ITWire*, November 26th 2004.
- [6] R. L. Glass, "The standish report: does it really describe a software crisis?" *Communications of the ACM*, vol. 49, no. 8, pp. 15th-16th, August 2006.
- [7] W. Harrison, "Managing uncertainty," *IEEE Software*, pp. 8–12, September / October 2005.
- [8] K. Moløkken and M. Jørgensen, "A review of software surveys on software effort estimation," in *Proceedings* of the International Symposium on Empirical Software Engineering (ISESE). Roman Castles (Rome), Italy: IEEE Press, September 29th - October 4th 2003, pp. 223–230.
- [9] Y. H. Kwak and J. Stoddardb, "Project risk management: lessons learned from software development environment," *Technovation*, vol. 24, no. 11, pp. 915–920, 2004.
- [10] P. K. Dey, J. Kinch, and S. O. Ogunlana, "Managing risk in software development projects: a case study," *Industrial Management & Data Systems*, vol. 107, no. 2, pp. 284– 303, 2007.
- [11] L. Wallace, M. Keil, and A. Rai, "Understanding software project risk: a cluster analysis," *Information & Management*, vol. 42, no. 1, pp. 115–125, December 2004.
- [12] D. Baccarini, G. Salm, and P. E. Love, "Management of risks in information technology projects," *Industrial Management & Data Systems*, vol. 104, no. 4, pp. 286– 295, 2004.
- [13] L. Jingyue, O. P. N. Slyngstad, M. Torchiano, M. Morisio, and C. Bunse, "A state-of-the-practice survey of risk management in development with off-the-shelf software components," *IEEE Transactions on Software Engineering*, vol. 34, no. 2, pp. 271 – 286, 2008.

- [14] G. Westerman and R. Hunter, *IT Risk: Turning Business Threats into Competitive Advantage*. Harvard Business School Press, August 2007.
- [15] R. Likert, "A technique for the measurement of attitudes," *Archives of Psychology*, vol. 140, pp. 1 – 55, 1932.
- [16] R. Xu and D. Wunsch, Clustering. Wiley, 2008.
- [17] A. Gemino, B. H. Reich, and C. Sauer, "A temporal model of information technology project performance," *Journal* of Management Information Systems, vol. 24, no. 3, pp. 9 – 44, 2007.
- [18] T. Chena, J. Zhangb, and K.-K. Laic, "An integrated real options evaluating model for information technology projects under multiple risks," *International Journal of Project Managemen*, February 2009.
- [19] S.-J. Huang and W.-M. Hana, "Exploring the relationship between software project duration and risk exposure: A cluster analysis," *Information & Management*, vol. 45, no. 3, pp. 175–182, April 2008.
- [20] A. J. Alencar, G. G. Rodrigues, E. A. Schmitz, and A. L. Ferreira, "Combining decorated classification trees with RCPS stochastic models to gain new valuable insights into software project management," in *Proceedings of the* 19th International Conference on Software Engineering & Knowledge Engineering (SEKE), Boston, MA, USA, July 9th-11th 2007, pp. 151–155.
- [21] A. Charnes, W. W. Cooper, and E. Rhodes, "Measuring the efficiency of decision making units," *European Journal of Operational Research*, vol. 2, no. 6, pp. 429–444, 1978.
- [22] W. W. Cooper, L. M. Seiford, and K. Tone, *Introdution to Data Envelopment Analysis and Its Uses*. Springer, 2005.
- [23] Y. A. Ozcan, Health Care Benchmarking and Performance Evaluation: An Assessment using Data Envelopment Analysis. Springer, 2007.
- [24] R. Ramanathan, An Introduction to Data Evelopment Analysis. Sage Publications, 2003.
- [25] D. Israel, Data Analysis in Business Research: A Step-By-Step Nonparametric Approach. Thousand Oaks, CA, USA: Sage Publications, 2009.
- [26] S. T. Ziliak and D. N. McCloskey, *The Cult of Statistical Significance*. Ann Arbor, MI, USA: University of Michigan Press, 2008.
- [27] S. El-Sabaa, "The skills and career path of an effective project manager," *International Journal of Project Man*agement, vol. 19, no. 1, pp. 1–7, January 2001.
- [28] T. DeMarco and T. Lister, *Waltzing With Bears: Managing Risk on Software Projects*. Dorset House, 2003.
- [29] W.-M. Hana and S.-J. Huang, "An empirical analysis of risk components and performance on software projects," *Journal of Systems and Software*, vol. 80, no. 1, pp. 42– 50, 2007.

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#	Risk	#	Risk Factor	Evaluation Scale						
	Dimension			↓ <i>S</i>	trongly	disagre	e	stron	gly agr	ee \downarrow
				1	2	3	4	5	6	7
		RF ₁	Frequent conflicts between development team members	0	0	0	0	0	0	0
		RF ₂	Frequent turnover within the project team	Ŏ	Õ	Õ	Õ	Õ	Õ	Õ
		RF ₃	Team members not familiar with the task(s) being automated	Ō	0	0	0	0	0	0
RD ₁	Team	RF ₄	Team members lack specialized skills required by the project	Õ	Õ	Õ	Õ	Õ	Õ	Õ
		RF ₅	Inadequately trained development team members	Õ	Õ	Õ	Õ	Õ	Õ	Õ
		RF ₆	Team members lack commitment to the project	Õ	Õ	Õ	Õ	Õ	Õ	Õ
		RF ₇	Inexperienced team members	Õ	Õ	Õ	Õ	Õ	Õ	Ō
		RF ₈	Lack of top management support for the project	0	0	0	0	0	0	0
		RF ₉	Change in organizational management during the project	0	0	0	0	0	0	0
RD_2	Organizational	RF ₁₀	Organization undergoing restructuring during the project	Õ	Õ	Õ	Õ	Õ	Õ	Ō
	Environment	RF11	Unstable organizational environment	0	0	0	0	0	0	0
		RF12	Corporate politics with negative effect on project	0	0	0	0	0	0	0
		RF13	Changes in priorities shift resources away from the project	0	0	0	0	0	0	0
		RF14	Incorrect system requirements	0	0	0	0	0	0	0
		RF15	Users lack understanding of system capabilities and limitations	Õ	Õ	Õ	Õ	Õ	Õ	Ō
		RF16	Undefined project success criteria	Ō	0	0	0	0	0	0
RD ₃	Requirements	RF ₁₇	Conflicting system requirements	Õ	Õ	Õ	Õ	Õ	Õ	Õ
		RF ₁₈	Difficulty in defining the inputs and outputs of the system	0	0	0	0	0	0	0
		RF19	Unclear system requirements	0	0	0	0	0	0	0
		RF20	System requirements not adequately identified	0	0	0	0	0	0	0
		RF21	Continually changing system requirements	0	0	0	0	0	0	0
		RF22	Project milestones not clearly defined	0	0	0	0	0	0	0
		RF23	Project progress not monitored closely enough	Ō	0	Õ	0	Ō	0	0
		RF_{24}	Lack of an effective project management methodology	Õ	0	Õ	0	Ō	0	0
RD_4	Planing and	RF ₂₅	Inexperienced project manager	Õ	Ō	Õ	0	Ō	0	0
	Control	RF26	Poor project planning	0	0	0	0	0	0	0
		RF27	Lack of people skills in project leadership	0	0	0	0	0	0	0
		RF28	Ineffective communication	0	0	0	0	0	0	0
		RF ₂₉	Inadequate estimation of required resources	0	0	0	0	0	0	0
		RF ₃₀	Inadequate estimation of project schedule	0	0	0	0	0	0	0
		RF31	Lack of cooperation from users	0	0	0	0	0	0	0
		RF32	Users resistant to change	0	0	0	0	0	0	0
		RF ₃₃	Users not committed to the project	0	0	0	0	0	0	0
RD ₅	User	RF34	Lack of user participation	0	0	0	0	0	0	0
		RF35	Conflict between users	0	0	0	0	0	0	0
		RF36	Users with negative attitudes toward the project	0	0	0	0	0	0	0
		RF37	Project uses technology that has not been used in prior projects	0	0	0	0	0	0	0
		RF38	Large number of links to other systems required	Õ	Õ	Õ	Õ	Õ	Ŏ	Õ
		RF39	High level of technical complexity	Õ	Õ	Õ	Õ	Õ	Ŏ	Õ
RD_6	Complexity	RF_{40}	One of the largest projects attempted by the organization	Ŏ	Ŏ	Ő	Ó	Ő	Ő	Ő
		RF41	Project involved the use of new technology	Ō	Ō	Õ	Ō	Ō	Ō	Ō
		RF42	Many external suppliers involved in the development project	Ō	Õ	Õ	Õ	Õ	Õ	Õ
		RF43	Immature technology	Ō	Ō	Õ	Ó	Ó	Ó	Ō
		RF44	Highly complex task being automated	0	0	0	0	0	0	0

Part I: Risk Perception

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Part II: Project Performance Perception

#	Performance	#	Project Performance Factor	Evaluation Scale						
	Dimension			↓ strongly disagree			strongly agree \downarrow			
				1	2	3	4	5	6	7
PD ₁	Technical	PPF ₁	The application developed is reliable	0	0	0	0	0	0	0
		PPF_2	The application developed is easy to maintain	0	0	0	0	0	0	0
		PPF ₃	The system meets intended functional requirements	0	0	0	0	0	0	0
		PPF ₄	The users are satisfied with the developed application	0	0	0	0	0	0	0
PD_2	User	PPF ₅	The system meets user response-time expectations	0	0	0	0	0	0	0
		PPF ₆	The system meets user ease-of-use expectations	0	0	0	0	0	0	0
		PPF ₇	The overall quality of the developed application is high	0	0	0	0	0	0	0
PD_3	Cost	PPF ₈	The system was completed within budget	0	0	0	0	0	0	0
PD_4	Time	PPF ₉	The system was completed within schedule	0	0	0	0	0	0	0

Figure 4. Risk Evaluation Questionnaire.