Analysing IT Investments in the Public Sector: A Project Portfolio Approach

Rigel Procópio Fernandes, Antonio Juarez Alencar, Eber Assis Schmitz, and Alexandre Luis Correa
Email: rigelfernandes@gmail.com, juarezalencar@nce.ufrj.br, eber@nce.ufrj.br, and alexcorr@yahoo.com

***Abstract*— Since the first electronic computers hit the market in the 1950's, governments have been amongst the biggest users of Information Technology (IT) worldwide. Therefore, it is in the general public's best interests that government officials are provided with concepts, methods and tools that help them to optimise the results yielded by IT investments. This paper presents a method that identifies the best implementation order for a portfolio of IT projects that has been broken down into a large number of subprojects. The method builds on previous proposals by providing a framework that properly considers the intangible benefits that are a matter of common concern in the public sector.**

I. Introduction

Because free elections have to be carried out from time to time in democratic nations, the government in power is likely to be sensitive to people's wishes and desires [1]. Also, as "having more for less" seems to be a common desire amount voters, government officials and representatives are often under considerable pressure to reduce spending and yet provide quality services for all [2].

Moreover, since the first commercial electronic computers became available in 1950s, information technology (IT) has been successfully used to reduce costs and increase efficiency in organizations of all kinds and sizes. Therefore, it should come as no surprise that democratic governments are consistently ranked amongst the biggest users of IT worldwide [3], [4].

Note that the IT budget tends to be substancial when compared with those of other organizational functions [5]. Therefore, in the last few decades researchers and practitioners have provided a considerable body of proposals on how to maximize the returns yielded by IT investments [6]. Nevertheless, the majority of these studies have targeted companies and corporations in the private sector and, in a few cases, a mix of public and private enterprises [7], [8].

Clearly public and private organizations have distinct differences in terms of objectives, management structure and governance [9]. It would be ingenuous to blindly apply the concepts, methods and techniques developed to better manage IT investments in the private sector to the public sector [10].

This paper presents a method that identifies the best implementation order for a portfolio of IT projects that has been divided into a large number of subprojects. The method considers the intangible benefits yielded by IT, which are a matter of common concern in the public sector. At the same time it does not disregard the financial aspects of investments made at the taxpayer's expense.

The remainder of this paper is organized as follows. Section II presents a review of the principal concepts and techniques used in the subsequent sections. Section III introduces the method with the help of an example inspired on real life. Section IV formalizes the method presented in this paper. Section V compares the method with other possible alternatives. Finally, Section VI presents the conclusions of this paper.

II. Conceptual Framework

A. Decisions Based upon Intangibles

An asset is frequently defined as something of value that can be owned or controlled. For example, cars, buildings, parking spaces, patents, machinery and club memberships [11].

Moreover, the value of an asset proceeds from the benefits that it yields to its owner or controller. A car, for example, can be sold, leased or rented and the resulting capital can be used to buy other products and services. The same general line of thinking can be applied to houses, parking spaces, patents, machinery and club memberships [12].

Nevertheless, some of the benefits proceeding from an asset are intangibles, i.e. they are the result of subjective perceptions of reality that do not have a physical or easily identifiable financial embodiment. Strong motivation, boosted employee moral, engagement, trust in management and confidence in the future of a company are common examples of intangible benefits, which usually proceed from good management practices and well conceived strategies [13].

According to Saaty [14], although intangible benefits are difficult to quantify in financial terms, they can be more easily dealt with when compared to each other in pairs. Given a set $A = \{A_1, A_2, \cdots, A_n\}$ of elements that can be compared with each other using a criterion $\mathcal{C}$, Saaty's pairwise comparison strategy leads to the construction of a valuation matrix $V_{n\times n}$ as shown in Table I.

Each component $a_{i,j}$ in $V_{n\times n}$ is the result of a direct comparison between two elements in regard to criterion $\mathcal{C}$, using the scale described in Table II. Therefore, if experience and judgement slightly favour A_2 over A_1 regarding $\mathcal{C}$, then $a_{2,1} = 3$ and, as a consequence, the opposite also holds true, implying that $a_{1,2} = \frac{1}{3}$. On

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TABLE I.
SAATY'S SQUARED VALUATION MATRIX

$$\begin{array}{cc} & \begin{array}{ccccc} A_1 & A_2 & A_3 & \cdots & A_n \\ \downarrow & \downarrow & \downarrow & & \downarrow \end{array} \\ \begin{array}{cc} A_1 & \rightarrow \\ A_2 & \rightarrow \\ A_3 & \rightarrow \\ \vdots & \\ A_n & \rightarrow \end{array} & \left[\begin{array}{ccccc} 1 & \frac{1}{a_{2,1}} & \frac{1}{a_{3,1}} & \cdots & \frac{1}{a_{n,1}} \\ a_{2,1} & 1 & \frac{1}{a_{3,2}} & \cdots & \frac{1}{a_{n,2}} \\ a_{3,1} & a_{3,2} & 1 & \cdots & \frac{1}{a_{n,3}} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{n,1} & a_{n,2} & a_{n,3} & \cdots & 1 \end{array} \right] \end{array}$$

TABLE II.
SCALE OF PAIRWISE COMPARISON

Strength	Definition	Explanation
1	Equal importance	The two elements are equally important when compared to each other
3	Moderate importance	Experience and judgement slightly favour one element over another
5	Strong importance	Experience and judgement strongly favour one element over another
7	Very strong	An element is favoured very strongly over another
9	Extreme importance	The evidence favouring one element over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	Should be used when compromise is needed

the other hand, if it is A_1 that is slightly favored over A_2 regarding $\mathcal{C}$, then $a_{2,1} = \frac{1}{3}$ and, as a consequence, $a_{1,2} = 3$.

All of this leads to the construction of a matrix in which all of its main diagonal entries are 1s, because when compared to itself every element A_i is always equally important. Also, every component $a_{i,j}$ in the off-diagonal lower and upper triangular parts of $V_{n\times n}$ is either drawn from the scale introduced in Table II or is the inverse of $a_{i,j}$.

According to [14] the importance of each element A_i, when compared to the other elements under analysis, is given by the component e_i of the normalized principal eigenvector $E = (e_1, \cdots, e_i, \cdots, e_n)^T$ of the valuation matrix $V_{n\times n}$. By normalized it is meant that $\sum_{i=1}^{n} e_i = 1$.

As e_i is actually an indicator of the importance of A_i, for the remainder of this paper e_i is referred to as the *relative importance index* of A_i or *RII*(A_i). See Larson [15] for a comprehensive introduction to eigenvalues and eigenvetors.

Because Saaty's valuation method frequently relies upon perceptions of reality, it is not unusual that some valuation matrices present inconsistencies. For example, consider that A_i is strongly favored over A_j, which in turn is strongly favored over A_k. Nevertheless, inadvertently let A_k be strongly favored over A_i. As this contradicts the usual notion of transitivity, the previous statement actually introduces an inconsistency in the evaluation of A_i, A_j and A_k.

Inconsistencies in valuation matrices can be detected with the consistency ratio (CR). For a given valuation matrix $V_{n\times n}$ that has λ_{max} as its main eigenvalue

$$CR = \frac{CI}{RI}, \qquad (1)$$

where *CI*, the consistency index, is given by $\frac{\lambda_{max}-n}{n-1}$, and RI, the random index, is drawn from Table III in accordance with n.

According to [16], for 3×3 matrices if $CR \geq 5\%$, then the inconsistencies should be resolved. For 4×4 matrices the threshold is 9%, and for 5×5 and larger matrices the threshold is 10%,

B. The Method's Statistical Foundation

Let n be the number of subprojects that a portfolio of IT projects has been divided into. In these circumstances the number of different possible implementation sequences for the subprojects in the portfolio tends to grow exponentially with n. Therefore, as n grows larger, one will inevitably find oneself in a difficult position to determine the implementation sequence that maximizes a given performance indicator $\mathcal{N}$ [17].

Nevertheless, according to Kolmogoroff [18], [19] it is possible to establish a confidence interval around the empirical density function (edf) of any continuous random variable, with an arbitrary degree of confidence. In this section, Kolmogorov's ideas along with related results obtained by others [20], [21] are used to lay down the statistical foundations of an approximation method that identifies that best implementation order of a portfolio of IT projects that has been divided into a large number of subprojects. First, Kolmogorov's result is presented in a formal manner. Next, Kolmogorov's ideas are used to lay down the statistical foundations of the approximation method.

1) The Kolmogorov Confidence Contours: In formal terms, for a continuous random variable x let $F(x) = P(X \leq x)$ be its cumulative density function, or cdf. Also, let X_1, X_2, $\cdots$, X_n be a random sample of x and

$$S_n(x) = P_n(X \leq x) = \frac{1}{n}\sum_{i=1}^{n} \begin{cases} 1 & \text{if } X_i \leq x \\ 0 & \text{otherwise} \end{cases}$$

be the corresponding empirical density function, or edf.

In addition, let $D_n = sup \mid F(x) - S_n(x) \mid$, where sup stands for the supreme (least upper bound) of a set of ordinal-scale values. According to Glivenko [22] and Cantelli [23]

$$\lim_{n\to\infty} D_n = \lim_{n\to\infty} sup \mid F(x) - S_n(x) \mid \to 0,$$

i.e. as the size of the sample increases, the distance between the cdf and the edf tends toward zero.

A result obtained by Kolmogorov [18], [19] in the 1930s not only shows that the statistic D_n does not

TABLE III.
THE RANDOM INDEX

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45

depend on $F(x)$, but also states that the probability α of D_n not exceeding an arbitrary value in the form of $\frac{\lambda}{\sqrt{n}}$ is given by

$$P(D_n \leq \frac{\lambda}{\sqrt{n}}) = \alpha\,.$$

Moreover, according to Walsh [20] and Connover [21], when applied to discrete variables the values derived from Kolmogorov's work lead to a safely conservative estimate of $\frac{\lambda}{\sqrt{k}}$, which does not depend on the underlying cumulative density function (cdf).

In the course of time λ has been tabulated for different values of n (the sample size) and α (the level of confidence). Table IV presents some of these values. Tables containing a more detailed list of values of λ can be found in [24]–[27] and many other statistics texts.

TABLE IV.
THE VALUE OF λ FOR DIFFERENT VALUES OF n AND α

n	α		
	0.90	**0.95**	**0.99**
10	0.323	0.369	0.457
20	0.232	0.265	0.329
30	0.190	0.218	0.270
40	0.165	0.189	0.235
$n > 40$	$\frac{1.07}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.52}{\sqrt{n}}$

As a result, if one takes k random observations of a continuous random variable x, where k is greater than 40, the probability that the distance between x's cdf and its edf is smaller than $\frac{1.22}{\sqrt{k}}$ is 0.95, i.e. $P(D_k \leq \frac{1.22}{\sqrt{k}}) = 0.95$.

2) The Basis of the Approximation Algorithm: If the random sample that is used to build an edf is comprised of the net present values (NPVs) of implementation sequences of subprojects, then the corresponding confidence interval bears a special meaning. When applied to the highest NPV in the sample, the confidence interval indicates how close to the actual absolute-maximum NPV that particular value is, in relative terms. See Baker [28] for an introduction to the financial meaning of the net present value.

For instance, consider a random sample containing 2,000 possible implementation sequences of a portfolio of IT projets, together with their respective NPVs. Also, let h be the highest NPV in that sample. In these circumstances, as the estimations are conservative

$$P(D_{2,000} \leq \frac{1.22}{\sqrt{2,000}}) \geq 0.95$$
$$\Downarrow$$
$$P(\mid F(h) - S_{2,000}(h) \mid \leq \frac{1.22}{\sqrt{2,000}}) \geq 0.95\,.$$

Because h is the highest value in the sample, $S_{2,000}(h)$ is necessarily 1. As a result,

$$P(\mid F(h) - 1 \mid \leq 0.0273) \geq 0.95$$
$$\Downarrow$$
$$P(-0.0273 \leq F(h) - 1 \leq 0.0273) \geq 0.95$$
$$\Downarrow$$
$$P(0.9727 \leq F(h) \leq 1.0273) \geq 0.95\,.$$

As by definition $F(h)$ cannot exceed 1,

$$P(0.9727 \leq F(h) \leq 1) \geq 0.95\,.$$

Therefore, the probability that all the other NPVs in the set of all possible NPVs are smaller than or equal to h is 0.9727 in the worse case, with a level of confidence that equals or exceeds 95%.

Hence, h may be considered a good approximation to the highest possible NPV, and the implementation sequence that has h as its NPV is the one to be followed during the development of the corresponding IT project. Note that if one is not satisfied with the results provided by a certain sample size, one may randomly increase the number of observations in the sample and improve the results until one is fully satisfied with them.

III. AN EXAMPLE

As rightfully stated by Edmund Burke (1729-1797), the Irish philosopher, "Example is the school of mankind, and they will learn at no other."

As a result, the method proposed in this paper is introduced step-by-step with the support of an example inspired on real life, which describes the decision making process adopted by the Navy of a fictitious country and how they identify the best implementation order for a portfolio of IT projects. For the purpose of this paper this country is named *The Barkov Republic*[1].

Step 1 - Context information: like many other government organizations throughout the world, the Barkovian Navy is required by law to provide a certain range of services to both the general public and companies doing business in the Barkov Republic. For example,

- *Maritime vessel ownership registration* - allows organizations and people to rightfully own maritime vessels, and buy, lease and sell them as a result;
- *Maritime vessel structural and personnel safety evaluation* - ensures that maritime vessels are fit for navigation and able to be properly handled by qualified personnel;

[1] A fictitious country name has been used throughout this example to preserve the anonymity of the real country and its naval force.

TABLE V.
NAVY'S PORTFOLIO OF IT PROJECTS

Prj.	Project Name and Description
NVA	*Mary Rose, the navy virtual assistant* - offers fast and accurate answers to questions about maritime law and Navy procedures posed by the general public, maritime professionals and organizations
VLE	*Virtual learning environment* - provides candidates for different types of maritime vessel permits with an environment in which they can more easily master the skills they are required to have
VIS	*Vessel identification system* - allows watercrafts within visual range to be properly identified
EFS	*Electronic fining system* - makes it easier for Navy personal to fine and arrest maritime vessels that have broken navigation laws

- *Cartographic mapping* - allows the ever changing Barkovian territorial waters and coastline to be kept properly mapped, making navigation easier and safer as a result; and
- *Maritime salvage and rescue* - provides immediate help to maritime vessels and people in distress along Barkovian territorial waters;

According to Milton Friedman, the laureate American economist, none of these services is free. All of them require investment and demand a constant flow of financial and non-financial resources to be properly maintained. Ultimately, it is the Barkovian taxpayers who have to settle the bill of those services [29].

Nevertheless, as in many other nations in which free elections are held form time to time, the executive branch of the Barkovian Government is frequently under considerable pressure to provide a wide range of quality services within a tight budget [30], [31].

The scenario is no different for the Barkovian Navy, especially over the last decades in which the maritime business has been expanding in Barkov as a result of increasing oil exploitation and import and export of goods.

The more maritime business there is, the greater the demand for services from the Barkovian Navy. This is despite the fact that the Navy's discounted annual budget has remained almost unchanged over the same period.

In addition, in recent years the news media has reported an alarming number of high-profile incidents involving maritime vessels in Barkov, prompting the Barkovian Navy to take action. As a result, the Navy has been working hard on tightening up procedures that ensure the security of waterways, and vessel's structural safety and proper handling.

Among the actions that are scheduled to take place in the immediate future, the Barkovian Navy has decided to develop the portfolio of IT projects introduced in Table V.

Because maritime law covers many different aspects of commerce, including navigation, transportation of goods and passengers, and handling of hazardous items and livestock, it is extensive and complex [32].

As a result maritime vessels can break the law in many different ways, including some that may pose serious risks for Navy personnel, such as weapons and explosives trafficking, inadequate handling of chemicals, failure to prevent the spread of contagious diseases, sheltering dangerous fugitives from justice, etc. [33], [34].

Nevertheless, it is largely accepted that these risks can be considerably reduced by requiring Navy personnel and vessel crew members to follow procedure when interacting with each other and the public. By avoiding the misinterpretation of unexpected behavior by crew members, these procedures help not only to prevent injuries, but also to avoid casualties in extreme cases [35].

Consistent with these ideas, the NVA project aims at increasing Navy procedure and regulation awareness. This is accomplished by presenting direct and easy to understand answers to questions posed by the general public and maritime professionals, on a 24 / 7 basis.

In addition, the VLE project makes it easier to master the proper handling of maritime vessels in a large variety of different situations. It is expected that the VLE will help accredited navigation schools to deliver better prepared officers and sailors, by providing them with experience that otherwise could only be obtained at sea, at a much higher cost.

Moreover, by making maritime vessels identifiable at a distance with the help of the VIS project, the Barkovian Navy expects to make their owners more easily accountable for their proper use. This will reduce the use of unseaworthy maritime vessels, their handling by unqualified personnel and the improper use of restricted waters.

Finally, the EFS project allows maritime vessels to be penalized whenever they break the law and, in extreme circumstances, bans their use. Hence, it not only improves safety in Barkovian territorial waters, but it also helps to make maritime professionals more aware of the consequences of their wrongdoings.

Step 2 - Project planning overview: the Secretary of the Navy changes every four years at the most. Furthermore, the new secretary almost always re-evaluates the need for ongoing projects and the propriety of their ranked priorities. Therefore, it is advisable to run the projects in Table V within a specific *makespan*, or MkSp for short. In this circumstance MkSp refers to the time from the beginning of the development of a project until the point at which its final products are available for use.

Nevertheless, due to budget restrictions, only one project can be run at a time, and financial and non-financial resources have to be used efficiently.

Therefore, it might be the case that not every project in Table V is going to be run. So, a priority criteria should be devised to indicate the order in which those projects should be implemented.

The committee of senior officers who have been appointed to oversee the execution of the projects in Table V has decided to adopt the criteria presented in Table VI to prioritise those projects.

Step 3 - Evaluation criteria priorization: because all the criteria introduced in Table VI describe intangible

TABLE VI.
THE EVALUATION CRITERIA

Criterion	Description	Explanation
MS	Maritime safety	The more an IT project reduces the likelihood of an accident the better
PS	Public support	The more support an IT project is expected to gather from the general public the better
PT	Procedure and regulation transparency	The more an IT project makes naval procedures and regulations open to public scrutiny the better

TABLE VII.
THE INITIAL VALUATION MATRIX

$$\begin{array}{c} \\ \\ MS \rightarrow \\ PS \rightarrow \\ PT \rightarrow \end{array} \begin{array}{ccc} MS & PS & PT \\ \downarrow & \downarrow & \downarrow \end{array} \quad \begin{bmatrix} 1 & 2 & 3 \\ \frac{1}{2} & 1 & 1 \\ \frac{1}{3} & 1 & 1 \end{bmatrix} \quad \begin{array}{c} E \\ \downarrow \end{array} \begin{bmatrix} 54.8 \\ 24.1 \\ 21.1 \end{bmatrix}$$

CR = 2.1%

benefits, the overseeing committee has decided to use Saaty's ideas on decision making [14] to prioritize the developments of the projects in Table V.

The valuation matrix presented in Table VII captures the perception of the overseeing committee on the relative importance of each criterion.

Hence, according to the overseeing committee point of view PS is slightly less important than MS, and PT is moderately less important than MS. Also, PS and PT are equally important when compared to each other.

The normalized main eigenvector of the valuation matrix presented in Table VII is $(54.8\%, 24.1\%, 21.1\%)^{\mathrm{T}}$, which indicates the relative importance of each criterion. Therefore, MS is approximately $\frac{54.8\%}{24.1\%} = 2.3$ times more important than PS and $\frac{54.8\%}{21.1\%} = 2.6$ times more important that PT.

Step 4 - Project performance: it should be noted that the projects in Table V are likely to perform differently when subjected to the different criteria established by the steering committee.

For example, while the EFS project may make an outstanding contribution to improve maritime safety and may gather considerable support from the general public, it is unlikely to add much to making naval procedures and regulations more open to public scrutiny.

As a result the committee decided to keep following Saaty's ideas on decision making and generate an index that combines the performance of each project in all criteria.

For a certain project P_j, this is accomplished by a *weighted relative importance index*, or *WRII*(P_j), which is given by

$$\sum_{i=1}^{n} \mathit{RII}(\mathcal{C}_i) \times \mathit{RII}_{\mathcal{C}_i}(P_j), \tag{2}$$

where $\mathit{RII}(\mathcal{C}_i)$ is the relative importance index of criterion $\mathcal{C}_i$ and $\mathit{RII}_{\mathcal{C}_i}(P_j)$ is the relative importance index of project P_j when subject to criterion $\mathcal{C}_i$.

TABLE XI.
THE PROJECTS' WEIGHTED RELATIVE IMPORTANCE INDEXES

Proj.	WRII (%)
VIS	$54.8 \times 8.3 + 24.1 \times 7.2 + 21.1 \times 7.2 = 7.8$
EFS	$54.8 \times 55.0 + 24.1 \times 57.6 + 21.1 \times 11.2 = 46.4$
VLE	$54.8 \times 24.9 + 24.1 \times 11.2 + 21.1 \times 24.0 = 21.4$
NVA	$54.8 \times 11.8 + 24.1 \times 24.0 + 21.1 \times 57.6 = 24.4$
Total	100.0

Tables VIII, IX and X capture the perception of the steering committee on the relative importance of the projects introduced in Table V when subject to the criteria presented in Table VI.

Table XI presents the *WRII* of the projects introduced introduced in Table V.

It is important to notice that according to the perception of the steering committee the benefits yielded by the EFS project as a whole surpasses the benefits yielded by any of the other projects introduced in Table V.

In this respect, the benefits yielded by the EFS project are respectively $6.0 = \frac{46.4}{7.8}$, $2.2 = \frac{46.4}{21.4}$ and $1.9 = \frac{46.4}{24.4}$ times more important than the benefits yielded by the VIS, VLE and NVA projects.

Step 5 - Project dependency relations: when dealing with a portfolio of IT projects it is not unusual that dependency relations are required to hold true among the projects in the portfolio. In this respect, Figure 1 introduces the dependency relations that are expected to hold true among the units in the Navy's portfolio of IT projects.

In the diagram presented in Figure 1 *Begin* and *End* are dummy projects, which require no capital investment and take no time to be run. They indicate respectively the beginning and end of the development of the IT projects introduced in Table V.

An arrow going from one project to another, e.g. VIS $\rightarrow$ EFS, indicates that the development of the former (VIS) must precede the development of the latter (EFS). In these circumstances, VIS is called a predecessor of EFS. It should be noted that predecessor is a transitive relation. Therefore, as VIS $\rightarrow$ EFS and EFS $\rightarrow$ *End*, then necessarily VIS $\rightarrow$ *End*. Frequently transitive relations are not made explicit in precedence diagrams in order to keep them simple.

Step 6 - Splitting up projects into subprojects: in order to reduce the complexity of dealing with the many tasks that make up large projects, modern project management principles advocate the splitting up of these projects into subprojects with high internal cohesion and loose coupling among themselves [36].

As a result, the projects presented in Table V have been split up into the subprojects introduced in Tables XII, XIII, XIV and XV.

TABLE VIII.
MARITIME SAFETY

	VIS	EFS	VLE	NVA	E
VIS	1	$\frac{1}{5}$	$\frac{1}{3}$	$\frac{1}{2}$	8.3
EFS	5	1	3	5	55.0
VLE	3	$\frac{1}{3}$	1	3	24.9
NVA	2	$\frac{1}{5}$	$\frac{1}{3}$	1	11.8

CR = 5.6%

TABLE IX.
PUBLIC SUPPORT

	VIS	EFS	VLE	NVA	E
VIS	1	$\frac{1}{7}$	$\frac{1}{2}$	$\frac{1}{3}$	7.2
EFS	7	1	5	3	57.6
VLE	2	$\frac{1}{5}$	1	$\frac{1}{3}$	11.2
NVA	3	$\frac{1}{3}$	3	1	24.0

CR = 3.1%

TABLE X.
PROCEDURE AND REGULATION TRANSPARENCY

	VIS	EFS	VLE	NVA	E
VIS	1	$\frac{1}{2}$	$\frac{1}{3}$	$\frac{1}{7}$	7.2
EFS	2	1	$\frac{1}{3}$	$\frac{1}{5}$	11.2
VLE	3	3	1	$\frac{1}{3}$	24.0
NVA	7	5	3	1	57.6

CR = 3.1%

Step 7 - Subproject dependency relations: if an IT project is spilt up into sub-projects, it is frequently the case that some dependency relations are also required to hold true among these smaller project units. Figures 2 to 5 introduce the dependency relations that have to hold true among the subprojects in the Navy's portfolio of IT projects.

Observe that the subprojects in the diagrams introduced in Figures 2 to 5 have been assigned with percentages. In addition, some of the subprojects are presented with a gray background, while others are presented with a white background. The reason for this additional notation is included in the next two steps.

Step 8 - Subproject evaluation: in a similar way to their source projects, subprojects also perform differently when subjected to different criteria. For example, Tables XVI, XVII and XVIII show the evaluation of the subprojects comprising the NVA project when subjected to the criteria introduced in Table VI.

The middle column of Table XIX presents the *WRII* of each NVA subproject calculated in accordance with Equation 2. Because the NVA project has a *WRII* of 24.4% (See Table XI), the *WRII* of its subprojects have

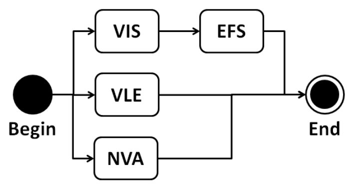

Figure 1. The general precedence diagram for the IT projects in the Navy's portfolio

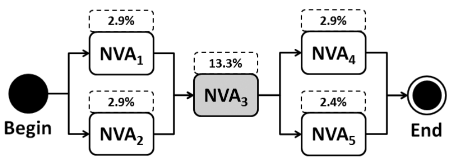

Figure 2. Navy's virtual assistant precedence diagram

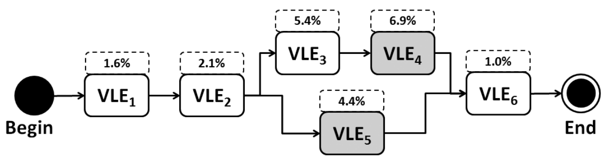

Figure 3. Virtual learning environment precedence diagram

TABLE XVI.
NVA'S SUBPROJECT EVALUATION ACCORDING TO THE MARITIME SAFETY CRITERION

	NVA_1	NVA_2	NVA_3	NVA_4	NVA_5	E
NVA_1 →	1	1	$\frac{1}{5}$	1	1	10.8
NVA_2 →	1	1	$\frac{1}{5}$	1	1	10.8
NVA_3 →	5	5	1	5	7	57.5
NVA_4 →	1	1	$\frac{1}{5}$	1	1	10.8
NVA_5 →	1	1	$\frac{1}{7}$	1	1	10.1

CR = 0.6%

TABLE XVII.
NVA'S SUBPROJECT EVALUATION ACCORDING TO THE PUBLIC SUPPORT CRITERION

	NVA_1	NVA_2	NVA_3	NVA_4	NVA_5	E
NVA_1 →	1	1	$\frac{1}{3}$	1	1	13.8
NVA_2 →	1	1	$\frac{1}{3}$	1	1	13.8
NVA_3 →	3	3	1	3	5	45.9
NVA_4 →	1	1	$\frac{1}{3}$	1	1	13.8
NVA_5 →	1	1	$\frac{1}{5}$	1	1	12.6

CR = 1.1%

TABLE XVIII.
NVA'S SUBPROJECTS EVALUATION ACCORDING TO THE PROCEDURE AND REGULATION TRANSPARENCY CRITERION

	NVA_1	NVA_2	NVA_3	NVA_4	NVA_5	E
NVA_1 →	1	1	$\frac{1}{6}$	1	1	9.8
NVA_2 →	1	1	$\frac{1}{6}$	1	1	9.8
NVA_3 →	6	6	1	6	7	60.9
NVA_4 →	1	1	$\frac{1}{6}$	1	1	9.8
NVA_5 →	1	1	$\frac{1}{7}$	1	1	9.6

CR = 0.1%

TABLE XIX.
THE NVA'S ADJUSTED WEIGHTED RELATIVE IMPORTANCE INDEXES

Sub-Proj.	**WRII (%)**	**AWRI (%)**
NVA_1	$54.8 \times 10.8 + 24.1 \times 13.8 + 21.1 \times 9.8 = 11.3$	$11.2 \times 24.4 = 2.8$
NVA_2	$54.8 \times 10.8 + 24.1 \times 13.8 + 21.1 \times 9.8 = 11.3$	$11.2 \times 24.4 = 2.8$
NVA_3	$54.8 \times 57.5 + 24.1 \times 15.9 + 21.1 \times 60.9 = 55.4$	$55.4 \times 24.4 = 13.5$
NVA_4	$54.8 \times 10.8 + 24.1 \times 13.8 + 21.1 \times 9.8 = 11.3$	$11.3 \times 24.4 = 2.8$
NVA_5	$54.8 \times 10.1 + 24.1 \times 12.6 + 21.1 \times 9.6 = 10.6$	$10.6 \times 24.4 = 2.5$
Total	100.0	24.4

TABLE XII.
MARY ROSE - THE NAVY VIRTUAL ASSISTANT SUBPROJECTS

Id	Description
NVA_1	*Software selection and acquisition* - selects and acquires the virtual assistance software to be used by the Barkovian Navy
NVA_2	*Knowledge base building* - builds the knowledge base to be used by the Navy's virtual assistant to answer questions posed by the general public and maritime professionals
NVA_3	*Virtual assistant customization and deployment* - configures the virtual assistance software with the view to fulfill Navy requirements and make it attractive to the general public
NVA_4	*NVA monitoring* - selects and hires a third party to monitor the NVA performance, making the necessary adjustments whenever they become necessary
NVA_5	*Foreign language interaction* - enables the virtual assistant to interact with its users in widely used foreign languages

TABLE XIII.
VIRTUAL LEARNING ENVIRONMENT SUBPROJECTS

Id	Description
VLE_1	*VLE registration module* - allows people to register with the Barkovian Navy so that they can be granted access to the Navy's virtual learning environment
VLE_2	*Simulation module* - allows users to master the necessary skills to navigate a maritime vessel by providing a realistic simulation of a large variety of navigation conditions
VLE_3	*User's simulation interface module* - allows the virtual learning environment to be adjusted to user requests. For example, preferred level of difficulty, class of vessel to be used in the simulations, atmospheric and traffic conditions, navigation equipment available on board, navigation routes, etc.
VLE_4	*Dynamic scoring module* - allows users to have their navigation skills evaluated while navigating a maritime vessel
VLE_5	*Static scoring module* - allows users to have their navigation skills evaluated using multiple choice tests
VLE_6	*VLE monitoring module* - monitors system use, providing statistical reports upon request

TABLE XIV.
MARITIME VESSEL IDENTIFICATION SYSTEM SUBPROJECTS

Id	Description
VIS_1	*Officer registration module* - records and updates relevant information about officers who are entitled to register and update information regarding vessel identification and ownership
VIS_2	*Vessel registration module* - captures and updates information about vessels' main characteristics (class, size, weight, propulsion system, etc.) and their rightful owners (names, addresses, phone numbers, etc.)
VIS_3	*Unique id code registration module* - generates a unique id code for each vessel that is required to be broadcast by the vessel's on-board transmitter
VIS_4	*Ownership certificate module* - issues upon request an ownership certificate that allows vessels to be bought, sold and leased
VIS_5	*Vessel information module* - gives authorities and the general public access to vessels' characteristics and ownership information using a variety of search fields, such as vessels' name, unique id code, owner name, etc.
VIS_6	*VIS monitoring module* - monitors system use, providing statistical reports upon request

TABLE XV.
ELECTRONIC FINING SYSTEM SUBPROJECTS

Id	Description
EFS_1	*Picture registration module* - allows officers to capture the images of vessels that are breaking the law, with the support of the built-in cameras of mobile devices
EFS_2	*Mobile id code capturing module* - allows mobile devices such as notebooks, tablets and smartphones to use a USB receiver to capture a vessel's unique identification code
EFS_3	*Officer registration module* - records and updates relevant information about the officers who are authorised to impose fines on maritime vessels
EFS_4	*Fine registration module* - registers a fine. Requires the unique vessel id code to register law infringement details, such as the id of the officer responsible for the registration, date and place of occurrence, type of infringement, vessel's pictures when breaking the law, etc.
EFS_5	*Fine issue module* - sends electronic fine tickets to the owners of vessels that are caught breaking the law
EFS_6	*Fine payment registration module* - records the payment of fines issued by the Barkovian Navy
EFS_7	*Fine cancelation module* - records the cancelation of fines issued by the Barkovian Navy whenever this is required by procedures and regulations
EFS_8	*System monitoring module* - monitors system use, providing statistical reports upon request

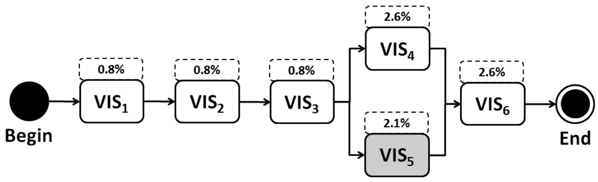

Figure 4. Maritime vessel identification system precedence diagram

to de adjusted accordingly.

In this respect, the adjusted *WRII* of a subproject P_i in regard to its source project *P*, or *AWRII(P_i)*, is given by

$$AWRII(P_i) = WRII(P_i) \times WRII(P) \quad (3)$$

The right column of Table XIX introduces the *AWRII* of each NVA subproject.

The *AWRII* of the remaining subprojects in the Navy's portfolio are the percentages assigned to the subprojects in the diagrams introduced in Figures 2 to 5. For example, according to the information presented in Figure 3, the *AWRII* of the VLE_1, VLE_2 and VLE_3 subprojects are respectively 1.6%, 2.1% and 5.4%.

Step 9 - Catalyst and non-catalyst subprojects: when dealing with software projects in the public sector one

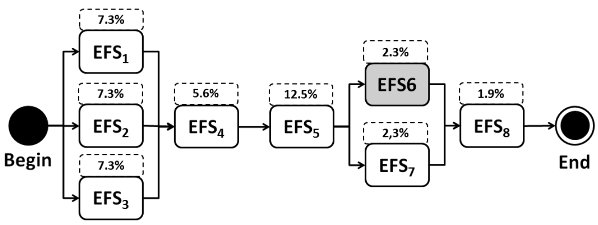

Figure 5. Electronic fining system precedence diagram

should be aware that not all subprojects are likely to be implemented. Moreover, in the general case, the set of subprojects that can be made available to end users within an allowed makespan may deliver no benefits at all [37].

For example, consider the NVA project (see Table V). Concede that only the subprojects NVA_1 (knowledge base building) and NVA_2 (virtual assistant customization) can be completed within the allowed makespan (see Table XII).

Observe that the products delivered by these two subprojects do not allow users to interact with the Navy's virtual assistant. Therefore, by relying solely on NVA_1 and NVA_2 they cannot have their questions resolved with Mary Rose's help. As a result, $\text{NVA}_1 \rightarrow \text{NVA}_2$ is just a "half-baked" computer system that, depite requiring capital investment to be built, delivers no benefits to its users.

However, if NAV_3 (virtual assistant deployment) can be completed within the allowed makespan, then interactions between Mary Rose and its users can take place (see Figure 2), and one can collect whatever intangible benefits are yielded by NAV_1, NAV_2 and NAV_3 (see Table XIX).

Subprojects like NAV_3 act as a catalyst, allowing the intangible benefits yielded by its predecessor and itself to be collected when they are completed. The catalyst subprojects in the Navy portfolio of IT projects are presented with a gray background in Figures 2 to 5.

Note that *End* is always a catalyst subproject. Also, in those diagrams if a P_1 is a predecessor of catalyst subproject P_2, then the intangible benefits yielded by P_1 can only be collected when P_2 is completed. However, if P_1 is not a predecessor of a catalyst subproject, then its benefits can be collected immediately after its completion.

Moreover, observe that the intangible benefits yielded by a project can only be fully appropriated if all its subprojects are implemented. If only a subset of its subprojects are run, then the appropriation of benefits is partial. For example, consider the following partial implementation S of the NVA project:

$$\text{NAV}_1 \rightarrow \text{NAV}_2 \rightarrow \text{NAV}_3$$

The amount of benefits that are appropriated by S is given by its *AWRII(S)*, which is the sum of the *AWRII* of its components, i.e.

$$\textit{AWRII}(\text{NAV}_1 \rightarrow \text{NAV}_2 \rightarrow \text{NAV}_3) =$$

$$\textit{AWRII}(\text{NVA}_1) + \textit{AWRII}(\text{NVA}_2) + \textit{AWRII}(\text{NVA}_3) =$$

$$2.8 + 2.8 + 13.5 = 19.1$$

Therefore, S allows for the appropriation of $78.1\% = \frac{19.1}{24.4}$ of the total benefits that the NVA project can yield.

Step 10 - Portfolio financial planning: No project can actually be run for free. One has to consider the finance of each subproject in the portfolio introduced in Table V before determining the order in which these subprojects are going to be developed.

Some projects in the public sector do improve tax collection, providing financial return on the investment they require. Others however have to rely solely on existing taxpayer's money from the very beginning of their development until the point at which their final product is replaced by a more suitable alternative. This period is often referred to as the project's *window of opportunity*.

Therefore, using the revenue generated by one project to fund the development of others not only reduces the need for capital investment, but also diminishes the financial risk every project is naturally exposed to [38].

For example, the EFS project is certain to generate some revenue as a result of issuing electronic fines against law-breaking vessels. Nevertheless, the NVA project has to rely solely on taxpayer's money during its whole window of opportunity.

Note that if a project generates financial returns, so do some of its subprojects. Also, if a project does not generate any revenue, nor do its subprojects.

Therefore, if the development of the EFS subprojects precedes the development of the NVA subprojects, the revenue generated by the former may be used to fund the development of the latter.

Table XX presents the cash-flow elements of each subproject in the Navy's portfolio of IT projects in thousands of monetary units.

According to the information presented in Table XX, EFS_6 requires an initial investment of \$15,000 (fifteen thousand monetary units), or \$15K for short. Once its development is completed at the end of the first period, it provides a series of positive returns until the 24^{th} period, when the subproject as a whole becomes obsolete and has to be replaced by a new and more suitable tool. Subprojects that follow a similar path are called *cash generating subprojects*.

On the other hand, despite requiring a relatively small investment of \$5K, NAV_1 does not provide any positive financial return throughout its life cycle. Subprojects that follow a similar path are called *non cash generating subprojects*.

It is a well established principle that one cannot perform financial mathematical operations without taking a discount rate into consideration. Therefore, in order to compare the financial value of different subprojects one has to consider their discounted cash-flow. The sum of all discounted cash-flow elements of a subproject is its net present value (NPV) [39].

Table XXI introduces the NPV of each subproject in the Navy's portfolio in accordance with the period in which it

TABLE XX.
THE CASH-FLOW ELEMENTS OF THE SUBPROJECTS IN THE NAVY'S PORTFOLIO OF IT PROJECTS

Sub-Proj.	**Period**							
	1	**2**	**3**	**4**	**5**	**6**	···	**24**
NVA_1	-20	0	0	0	0	0	···	0
NVA_2	-15	-10	0	0	0	0	···	0
NVA_3	-25	0	0	0	0	0	···	0
⋮	⋮	⋮	⋮	⋮	⋮	⋮	...	⋮
EFS_6	-15	60	80	80	80	80	···	80
EFS_7	-29	0	0	0	0	0	···	0
EFS_8	-20	0	0	0	0	0	···	0

development starts. For example, considering a discount rate rate of 0.8% per period, if EFS_6 is developed in the first period it yields an NPV of

$$\frac{-15}{(1+0.8\%)^1}+\frac{60}{(1+0.8\%)^2}+\cdots+\frac{60}{(1+0.8\%)^18}=\$1,193\text{K}$$

Instead, if EFS_6 is developed in the second period it yields an NPV of $1,115K, in the third it yields $1,037K and so forth. Clearly not every subproject can be developed in the first period. The dependency diagrams presented in Figures 1 to 5 illustrate this.

Moreover, the NPV of a particular implementation sequence is given by the NPV of its components. For example, consider that during the allowed makespan only the sequence S described in Step 6 is going to be implemented. In these circumstances,

$$\begin{aligned}\text{NPV}(S) &= \text{NPV}_1(\text{NAV}_1)+\text{NPV}_2(\text{NVA}_2)+\text{NPV}_4(\text{NVA}_3)\\ &= -\$20\text{K} - \$25\text{K} - \$24\text{K}\\ &= -\$69\text{K}\end{aligned}$$

where $\text{NPV}_t(\text{P}_i)$ is the NPV of subproject P_i considering that its development starts in period t.

Step 11 - Capital investment, window of opportunity and allowed makespan identification: considering the pressure the Barkovian Navy is under to increase maritime safety, the steering committee has identified that the capital investment, window of opportunity and makespan to implement the subprojects presented in Tables XII, XIII, XIV and XV are respectively $200K, 12 periods and 24 periods.

Step 12 - The confidence contour, level of confidante and sample size selection: since the total number of subprojects in the Barkovian Navy's portfolio of IT projects is large (see Tables XII, XIII, XIV and XV), the number of possible implementation sequences is certain to be exponentially high.

In these circumstances one may find oneself a position in which it is not feasible to identify the best implementation sequence within a reasonable amount of time. Therefore, one has to resort to the use a random sample to identify a sequence that yields benefits that are close enough to the benefits yielded by the best possible sequence (see Section II-B in this respect). As a result, the steering committee decided to use a random sample containing 2,000 possible implementation sequences to identify such a sequence.

Let h be the highest AWRII that sample. According to the results presented in Section II-B, h may be considered a good approximation to the highest possible AWRII, and the sequence that has h as its AWRII can be safely chosen to implement the projects in Bakovian Navy's portfolio of IT projects.

Step 13 - Sampling the set of all possible implementations sequences: Table XXII presents a random sample of 2,000 possible implementation sequences for the Navy portfolio of IT projects that comply with the allowed portfolio makespan, window of opportunity and CI.

Step 14 - Performance indicators: since the decision making process presented in the next step rely on performance indicators, the AWRII, ROI, CI and MkSp of each possible implementation sequence have been added to the data presented in Table XXII. It might be relevant mention that the ROI of a sequence S is given by the ratio between its NPV and CI, i.e. $\text{ROI}(S)=\frac{\text{NPV}(S)}{\text{CI}(S)}$. See [39] for a discussion of financial performance indicators, which includes ROI.

Note that the sequences in Table XXII have been ranked firstly by their required *AWRII* and secondly by their respective ROI.

Step 15 - Choosing the best implementation sequence: any implementation sequence presented in Table XXII could be selected to partly implement the Navy portfolio of IT projects. However, the highest ranked, along with those sequences that bear the same *AWRII*, are those that yield the highest benefit from intangibles considering the CI available.

Moreover, the AWRII of 97.27% of all possible implementation sequences that comply with the CI, MkSp and window of opportunity established by the Navy are smaller than or equal to the AWRII of the topmost sequence. See Section II-B.

Among the sequences that share the highest AWRII,

TABLE XXI.
NPV ACCORDING TO THE PERIOD IN WHICH THE DEVELOPMENT OF EACH SUBPROJET STARTS

Sub-Proj.	Period							
	1	2	3	4	5	6	···	24
NVA_1	-20	-20	-20	-19	-19	-19	···	-17
NVA_2	-25	-25	-24	-24	-24	-24	···	-13
NVA_3	-25	-25	-24	-24	-24	-24	···	-22
⋮	⋮	⋮	⋮	⋮	⋮	⋮	...	⋮
EFS_6	1,193	1,115	1,037	960	884	808	···	733
EFS_7	-20	-20	-20	-19	-19	-19	···	-17
EFS_8	-20	-20	-20	-19	-19	-19	···	-17

TABLE XXII.
RANDOM SAMPLE OF POSSIBLE DEVELOPMENT SEQUENCES FOR THE SUBPROJECTS IN THE PORTFOLIO OF IT PROJECTS

#	Subproject Implementation Sequences	AWRII (%)	ROI (%)	CI ($1K)	MkSp
1	$VIS_1 \rightarrow VIS_2 \rightarrow VIS_3 \rightarrow VIS_4 \rightarrow VIS_5 \rightarrow VIS_6 \rightarrow EFS_1 \rightarrow EFS_2 \rightarrow EFS_3 \rightarrow EFS_4 \rightarrow EFS_5 \rightarrow EFS_6$	52.0	66	195	12
2	$VIS_1 \rightarrow VIS_2 \rightarrow VIS_3 \rightarrow VIS_4 \rightarrow VIS_5 \rightarrow VIS_6 \rightarrow EFS_2 \rightarrow EFS_1 \rightarrow EFS_3 \rightarrow EFS_4 \rightarrow EFS_5 \rightarrow EFS_6$	52.0	65	195	12
3	$VLE_1 \rightarrow VIS_1 \rightarrow VIS_2 \rightarrow VIS_3 \rightarrow VIS_4 \rightarrow VLE_2 \rightarrow VLE_5 \rightarrow VLE_3 \rightarrow VIS_5 \rightarrow VIS_6 \rightarrow VLE_4$	27.5	12	200	11
⋮	⋮	⋮	⋮	⋮	⋮
2,000	$VIS_1 \rightarrow VLE_1 \rightarrow VIS_2 \rightarrow VIS_3 \rightarrow VIS_4 \rightarrow NVA_2 \rightarrow VIS_5$	7.1	205	87	7

the logical choice to implement the Navy portfolio of IT projects is the one that yields the highest ROI. If two or more sequences yield the same ROI, any of them can be safely chosen.

In these circumstances, the committee of senior officers has chosen the highest ranked sequence in Table XXII to partly implement the Navy portfolio of IT projects.

Alternatively, decision makers can use other financial performance indicators (such as payback time, point of break even, internal rate of return, etc.) to refine the selection criteria even further. See [39] for an introduction to the use of these financial performance indicators.

IV. THE METHOD

Based on the ideas presented in Section III, government bodies, organizations and agencies are expected to benefit from taking the following steps:

1) Select a portfolio of IT projects that could be run;
2) Establish the appropriate evaluation criteria to which each project is going to be subjected;
3) Use Saaty's valuation matrix to prioritize the evaluation criteria, i.e. to find out the RII of each criterion;
4) Evaluate the WRII of each project;
5) Identify the dependency relations that are expected to hold true among the projects in the portfolio of IT projects;
6) Partition each project in the portfolio into smaller subprojects to facilitate understanding, planning and maintenance;
7) Capture the dependency relations that hold true among the subprojects;
8) Calculate the AWRII of each subproject;
9) Identify the catalyst and non-catalyst subprojects;
10) Estimate the cost of developing each subproject, together with the returns they are expected to provide;
11) Identify the available capital investment, the window of opportunity and the allowed makespan;
12) Select the appropriate confidence contour size, level of confidence and sample size;
13) Take a random sample of adequate size from the set of all possible implementation sequences;
14) Calculate the AWRII, ROI, CI and MkSp of each possible implementation sequence in that sample;
15) Identify the affordable implementation sequence that provides the highest AWRII within the allowed makespan. If more than one sequence satisfies this condition, select the one that provides the highest ROI;

V. RELATED WORK AND DISCUSSION

In the last decade many meritorious proposals have been made to advance the coverage and accuracy of IT evaluation methods in the public sector.

For instance, Over [40] suggests the adoption of an IT investment management model to more easily identify where IT investments should be made and how these investments can be appraised, compared and controlled.

Raus et al. [41] introduces an IT investment appraisal framework that brings together the value-creation perspectives of both the public and private sectors. The framework acknowledges the needs and requirements of several stakeholders, facilitating the assessment of IT innovations.

Neuroni et al. [42] argue that the use of real options theory can better capture the flexibility built into IT projects in the public sector. Consistent with this view, the authors present a real option model that can be used to evaluate e-government initiatives. The model takes into account the perspectives of different stakeholders and various aspects of cost and value creation.

Srivastava [43] suggests the use of a framework that brings together eight areas in which IT can provide a positive impact on government initiatives. The framework lays down a basis for analysing e-government projects and assessing their respective return on investment.

Guclu and Bilgen [44] recommend the use of a model that amalgamates public value, strategic goals, the service delivery value chain, performance indicators, continuous monitoring, constant evaluation, and asset management concepts. According to the authors, the model can be used to appraise more easily the effectiveness of investments being made in the development of government information systems.

A review of the existing literature on return on investments made in IT in the public sector, and of general approaches to the measurement of such returns is presented in [45].

Although IT investment is often comprised of one or more projects, none of the proposals presented so far take into account that these projects are often divided into smaller subprojects. Also, the number of subprojects tends to be quite considerable, making it difficult to consider all possible implementation sequences [46].

By not taking into account these particular aspects of IT investments, they have failed to acknowledge that the order in which these subprojects are implemented can have a positive effect on the value of IT investments [47]. Moreover, in the general case, approximation methods have to be used to select the best possible implementation sequence [48].

Furthermore, these proposals fall short of fully combining both the tangible and the intangibles aspects of investments made in IT. Therefore, they make it hard to appropriate intangible benefits with less capital investment. Finally, they tend to ignore either the investment's makespan or window of opportunity, or even both.

Nevertheless, there is an exception worth mentioning. Alencar et al. [49] put forward a proposal that do take into consideration the tangible and the intangibles aspects of IT investments. Also, that proposal takes into account that the order in which subprojects are implemented can change the value of the investments made in IT.

However, if the project makespan is short, Alencar et al. (op. cit.) allow the selection of implementation sequences that not necessarily yield any benefit to the general public. See Step 9 of Section III for further discussion on this subject. Moreover, the method presented by Alencar et al. (op. cit.) cannot easily cope with portfolios containing large numbers of subprojects, as the complexity of the sequencing algorithm they use grows exponentially with the that number.

VI. Conclusions

These days IT exerts an important influence on the application of taxpayers' money in democratic nations. By making information more easily accessible and widely available, IT enables more transparency and accountability in respect to public actions and policy making. Moreover, IT makes it easier for governments to be in touch with people's wishes and desires [50].

Nevertheless, there are many significant differences between public and private sector organizations in terms of their structuring and governance, the part played by intangibles in decision making being one of the most important. Since projects in the public sector do not generally aim to make a profit, the intangible benefits yielded by these projects tend to be at the core of the government decision making process [10].

This paper presents a method that allows the financial aspects of IT projects in the public sector to be properly weighed against the intangible benefits they provide. As a result, government officials can take advantage of the intangibles that are provided by IT projects more efficiently, without losing sight of the financial aspects of initiatives that are run at the taxpayer's expense.

Moreover, the method helps to reduce the capital required to run IT projects in the public sector, as it prompts decisions makers to use the revenue yielded by tax-generating projects to fund the development of others.

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Rigel Procópio Fernandes is an M.Sc. student with the Federal University of Rio de Janeiro (UFRJ), Brazil. His research interests include software development methodologies and economics of software engineering.

Antonio Juarez Alencar is a researcher with the Federal University of Rio de Janeiro (UFRJ), Brazil. He received his B.Sc. in Mathematics and M.Sc. in System Engineering and Computer Science from UFRJ. He holds a D.Phil. in Computer Science from Oxford University, England. His research interests include economics of software engineering, IT strategy and risk analysis.

Eber Assis Schmitz is a Professor of Computer Science with the Federal University of Rio de Janeiro (UFRJ). He holds a B.Sc. in Electrical Engineering from the Federal University of Rio Grande do Sul (UFRGS), an M.Sc. in Electrical Engineering from the Federal University of Rio de Janeiro and a Ph.D. in Computer Science and Control from the Imperial College of Science Technology and Medicine, London, England. His research interests include software development modeling tools, business process modeling and stochastic modeling.

Alexandre Luis Correa is a Professor of Computer Science with the State of Rio de Janeiro Federal University (UNIRIO). He holds a B.Sc. in Mathematics and an M.Sc. and a D.Sc. in System Engineering and Computer Science from the Federal University of Rio de Janeiro. His research interests include reverse engineering, system validation and software development modeling tools.