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Best practice project management: an analysis of the front end of the innovation process in the medical technology industry

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Michael A. Chilton

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Editorial

It is our great pleasure to bring you the seventh number of IJISPM - International Journal of Information Systems and Project Management. The mission of the IJISPM is the dissemination of new scientific knowledge on information systems management and project management, encouraging further progress in theory and practice.

In this issue readers will find important contributions on information systems outsourcing risks, project management best practice, and on resource allocation in information technology projects.

As Tracey Giles and Kathryn Cormican state in the first article of this issue, "Best practice project management: an analysis of the front end of the innovation process in the medical technology industry", there are strong motivating factors for more effective project management practices at the front end of the innovation (FEI) process. Shrewd management of these pre-development activities has proven to be one of the greatest differentials for success. This article presents findings from an empirical case study analysis of a large organization operating in the medical technology industry in Ireland. The authors synthesized the literature to identify five critical success factors (CSFs) known to be effective in the successful management of the FEI process. From this analysis an instrument to assess best practices was developed. Data was collected from 66 engineers in the R&D discipline. The findings of the study show that the organization's FEI phase aligns well with best practice. However, a difference between the level of agreement about the extent to which the critical success factors are in place in the organization and the level of importance placed on these practices emerged.

The second article, "A catalog of information systems outsourcing risks", is authored by Filipe de Sá-Soares, Delfina Soares and José Arnaud. Information systems outsourcing risks are a vital component in the decision and management process associated to the provision of information systems and technology services by a provider to a customer. Although there is a rich literature on information systems outsourcing risks, the accumulated knowledge on this area is fragmented. In view of this situation, an argument is put forward on the usefulness of having a theory that integrates the various constructs related to information systems outsourcing risks. This article aims to contribute towards the synthesis of that theory, by proposing a conceptual framework for interpreting the literature and presenting a catalog of information systems outsourcing risks. The conceptual framework articulates together six key risk elements, namely dangers, negative outcomes, undesirable consequences, factors and mitigation actions. The catalog condenses and categorizes the information systems outsourcing risk elements found on the literature reviewed, both from the perspective of the outsourcing customer and from the perspective of the outsourcing provider.

Resource allocation is the process of assigning resources to tasks throughout the life of a project. Despite sophisticated software packages devoted to keeping track of tasks, resources and resource assignments, it is often the case that project managers find some resources over-allocated and therefore unable to complete the assigned work in the allotted amount of time. Most scheduling software has provisions for levelling resources, but the techniques for doing so simply add time to the schedule and may cause delays in tasks that are critical to the project in meeting deadlines. The third article, "Resource allocation in IT projects: using schedule optimization", by Michael A. Chilton, presents a software application that aims to ensure that resources are properly balanced at the beginning of the project and eliminates the situation in which resources become over-allocated. It can be used in a multi-project environment and reused throughout the project as tasks, resource assignments and availability, and the project scope change. The application utilizes the bounded enumeration technique to formulate an optimal schedule for which both the task sequence and resource availability are taken into account.

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We would like to take this opportunity to express our gratitude to the distinguished members of the Editorial Board, for their commitment and for sharing their knowledge and experience in supporting the IJISPM.

Finally, we would like to express our gratitude to all the authors who submitted their work, for their insightful visions and valuable contributions.

We hope that you, the readers, find the International Journal of Information Systems and Project Management an interesting and valuable source of information for your continued work.

The Editor-in-Chief,

João Varajão

University of Minho

Portugal

João Varajão is currently professor of information systems and project management at the *University of Minho*. He is also a researcher of the *Centro Algoritmi* at the *University of Minho*. Born and raised in Portugal, he attended the *University of Minho*, earning his Undergraduate (1995), Masters (1997) and Doctorate (2003) degrees in Technologies and Information Systems. In 2012, he received his Habilitation degree from the *University of Trás-os-Montes e Alto Douro*. His current main research interests are in Information Systems Management and Project Management. Before joining academia, he worked as an IT/IS consultant, project manager, information systems analyst and software developer, for private companies and public institutions. He has supervised more than 50 Masters and Doctoral dissertations in the Information Systems field. He has published over 250 works, including refereed publications, authored books, edited books, as well as book chapters and communications at international conferences. He serves as editor-in-chief, associate editor and member of the editorial board for international journals and has served in numerous committees of international conferences and workshops. He is co-founder of CENTERIS – Conference on ENTERprise Information Systems and of ProjMAN – International Conference on Project MANagement.

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Best practice project management: an analysis of the front end of the innovation process in the medical technology industry

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Best practice project management: an analysis of the front end of the innovation process in the medical technology industry

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Abstract:
There are strong motivating factors for more effective project management practices at the front end of the innovation (FEI) process. Shrewd management of these pre-development activities has proven to be one of the greatest differentials for success. This study presents findings from an empirical case study analysis of a large organization operating in the medical technology industry in Ireland. We synthesized the literature to identify five critical success factors (CSFs) known to be effective in the successful management of the FEI process. From this analysis an instrument to assess best practices was developed. Data was collected from 66 engineers in the R&D discipline. The findings of the study show that the organization's FEI phase aligns well with best practice. However, a difference between the level of agreement about the extent to which the critical success factors are in place in the organization and the level of importance placed on these practices emerged. This paper contributes to knowledge by (a) assessing the relative importance of critical success factors for the FEI in the medical technology industry, (b) examining whether these initiatives are implemented in practice and, if so, to what extent, and (c) providing a series of recommendations to help bridge the gap from theory to practice.

Keywords:
critical success factors; best practice; empirical analysis, medical technology industry.

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1. Introduction

The early stage of the innovation process has many synonyms. It is also known as "*phase 0*" or "*stage 0*" and lauded to incorporate all pre-project activities but it is probably best known as the fuzzy front end [1]. According to Koen et al. [2] the front end of the innovation process (FEI) is the stage that includes all of the activities that come before the more formal new product development (NPD) phase. Kim and Wilemon [3] define the FEI as the period from when an opportunity is first considered to when it is deemed ready to enter the formal development process. Griffin et al. [4], on the other hand, found that successful serial innovators focus on finding the 'right problem' at the beginning of the process rather than an 'opportunity'. Russell and Tippett [5] believe that there are three distinct phases in the FEI including (a) idea collection, (b) idea screening and (c) project selection. Khurana and Rosenthal [6] state that the FEI is complete when the company decides to either finance and initiate the NPD process or call a halt to the project.

The literature notes that the FEI is poorly managed in practice. In fact, it is seen as the greatest weakness in the innovation process [3], [6], [7]. Perhaps this is because the work is unstructured and experimental, revenue expectations are difficult to gauge, and the output does not meet a planned milestone but rather reinforces a concept. There is also a dearth of investment at this stage of the innovation process. According to Barczak et al. [8] this has caused firms to "*become more conservative in their portfolio of projects*". It seems that because of this an increasing number of development portfolios focus on incremental projects rather than on radical innovation and consequently we are witnessing a reduction in rate of innovation. However literature suggests that the FEI has the greatest potential to impact on and improve the overall innovation process. Koen et al. [2] posit that a "*lack of research into best practices (has) made the FEI one of the most promising ways to improve the innovation process*".

There is a clear need for a better approach to managing the front end of the innovation process. This paper attempts to address this deficit and expand the discussion on innovation management practices at the FEI. The purpose of the study is to identify critical success factors (CSFs) that are known to improve management practices in this area and to assess the level of absorbance and acceptance in the medical technology industry. The case organization targeted in this study designs, develops and delivers complex medical device products. The findings of our work are based on quantitative analysis. 66 engineers working in the R&D department were surveyed in the Spring of 2013. The goal of the survey was to gain a deep insight into the level of importance of known critical success factors as well as the degree of implementation of these factors in a real world setting. The remainder of this paper is organized as follows. The next section identifies, categorizes and discusses critical success factors found to be effective in the management of the FEI. Section 3 presents the research methodology employed in this study. Section 4 summaries some of the key findings from our analysis, section 5 analyses the instrument used and section 6 provides some recommendations to practitioners based on our analysis.

2. Critical success factors for effective management at the FEI

A review of the FEI literature reveals different reasons that distinguish innovative companies from non-innovative companies. In essence it is shown that innovative companies are those that adopt best practice critical success factors (CSFs) whereas non-innovative companies do not. CSFs can be defined as explicit statements of the key performance areas of an organization. Cooper and Kleinschmidt's [9] research has shown that certain best practices set top performing companies apart from the others. This is substantiated by Barczak et al., [8] who found that the best companies did not succeed by implementing just one factor but rather by integrating a number of them simultaneously and more effectively. Yet Boeddrich [10] has noted that companies still neglect to pay attention to many of these CSFs. An analysis of the literature revealed that five affinity groups can be used to categorize the majority of best practice criteria [5], [8], [9], [11], [12]. These are (a) strategy, (b) resources, (c) process (d) climate and (e) tools. It is important to add that no singular group contributes to innovation success; rather it is imperative to adopt elements from all of the groups to provide a balanced approach towards effective innovation management.

2.1 Strategy

According to Barczak et al. [8], the best firms emphasize and integrate their innovation strategy across all levels of the firm. Furthermore, they have well-defined objectives and goals that align with the company's strategy. Russell and Tippett [5] note that a clearly defined and well-publicized new product strategy must be in place at the FEI for an organization to be successful. In order for the strategy to be clearly defined, Cooper [13] suggests that the strategy should focus on strategic arenas that will help propel the business's new product effort. Khurana and Rosenthal [6] second this as they believe that a company should have a clear view of the types of product lines and potential platforms that they want to aim at specific markets. Furthermore, a company's innovation strategy at the FEI should also adopt a "*connect & develop*" strategy [9]. This involves partnering with external organizations in order to develop new products. Cormican and O'Sullivan [11] see the value in this as they too have found that external alliances can be mutually beneficial. One of the most pivotal aspects of the strategy employed at the FEI is that it needs to be flexible. Based on the current economic climate it is also vital that a company's innovation strategy is adaptable so that it can be executed if the environment changes [7].

2.2 Resources

Another common denominator or critical success factor that is synonymous with top-performing companies is the devotion of required and dedicated resources to the innovation process [9]. In terms of impact, R&D expenditure was found to be the most influential factor on product development measured as a percentage of sales. Proper resource management is essential to transforming promising ideas into successful products. One common problem at the FEI is that there may be numerous new product ideas circulating but not enough resources to develop them [11]. It has been shown that the best firms support their people by dedicating resources to the innovation effort [8]. According to Koen et al. [2], permanent support from senior management can be considered essential for product innovation success. It is not enough, however, for this to be just apparent through words; this commitment must be demonstrated through actions such as committing the necessary resources [9]. It is evident that without management's clear commitment of resources in the FEI and subsequent effective portfolio management that a company will flounder.

2.3 Process

According to Boeddrich [10], the absence of a structured process at the FEI has a detrimental effect on a company's innovation management. In fact Cooper and Kleinschmidt [9] have found that the most effective driver, in terms of profitability, is the "*existence of a high-quality, rigorous new product process*" that places a large emphasizes on the FEI. Russell and Tippett [5] also advise that a company should have a process or system in place before commencing the formal part of the innovation process. Barczak et al. [8] concur that a formal process should be in place. However, a crucial finding of Cooper and Kleinschmidt's [9] research is that it is not enough to just have a process in place in the company to deal with the FEI and NPD; instead what is important is the "*quality and nature of that process*". They propose an Idea-to-Launch system which is based on the Stage-Gate process. Although Stage-Gate has some positive attributes like aligning gate review and milestones with the natural stages of development [13] there are many who criticize this highly structured process at the FEI. Other models proposed include Khurana and Rosenthal's [6] model which is quite similar to Cooper's [13] as it has a linear layout where each stage helps the company progress through the sequence. This model concentrates on incremental innovations and there does not appear to be any iterative process allowing for feedback. Koen et al.'s [7] model shows the FEI as a cyclical process or relationship model rather than a sequential process. It comprises three distinctive parts including (a) the internal area which consists of five important elements in the FEI, (b) the engine that propels the front end elements, and (c) the external influencing factors. Griffin et al.'s [4] hourglass model purports to focus on implementation and attempts to address how to implement innovation at this stage in the process.

2.4 Climate

The fourth CSF focuses on people. Although it is labelled climate, it is also an umbrella for culture, teams and leadership. If the correct culture of innovation is developed in a company it will generate a self-sustaining engine for innovation. This corroborates Koen et al.'s [7] reasoning for putting the engine as the driving force in their new concept development model. Cormican and O'Sullivan [11] posit that culture and innovation are intrinsically connected. In other words, innovation will not thrive if the proper culture is not there to support it. In contrast Koen et al. [7] state that in all their research, they have never found a link between culture and success at the FEI. Johannessen et al. [14], posit that innovative companies are those that foster a climate of risk-taking, take the initiative and establish commitment. In the best performing companies there is a climate for innovation that is spearheaded by the company's leaders through their actions and their commitment of resources [7, 9]. Koen et al. [7] also believe that the leadership at the FEI is a vital part of this phase. According to Cormican and O'Sullivan [11] leaders help generate and translate the vision of a company so that what is strategized at a high level is actually being implemented at the operational level. Cooper et al. [15] discovered that the highest performing organizations in innovation encourage their creative personnel to take time out from their official work in order to spend time on informal projects. Barczak et al. [8] found that the implementation of cross-functional development teams is highly associated with the best performing companies. Terziovski et al. [16] also found in their research that this is one of the most important success factors and it needs to be implemented at the early stage of innovation. It is not just sufficient, however, to have a cross-functional team, the team must also communicate effectively in order to bring about success at the FEI [17].

2.5 Tools

Many authors have found that one factor that separates the best from the rest is that progressive companies utilize an abundance of tools and techniques at the FEI. For example, Herstatt et al.'s [18] research investigated activities and tools that are useful in the FEI. Cooper [19] examined eighteen tools that are used by companies when trying to create new product ideas. Koen et al. [2] also recommended some tools that would best complement each element of their new concept development model. One of the most prominent tools cited for the FEI is the lead user method proposed by von Hippel [20] who purports that the initial user of a product creates over 75% of breakthrough inventions. Lead Users are people considered to face needs well in advance of the general marketplace and who stand to benefit from the needs being met. While many authors [2], [8], [18], [19] have also found this method to be one of the well-established market research tools, others such as Soukhoroukova et al. [21] argue that it is very challenging to determine potential lead users for the different markets. Another commonly discussed tool is TRIZ (The Theory of Inventive Problem Solving). The literature suggests that it is a highly effective tool that can be used not only to discover problems and but to solve them as well [2], [18], [19]. Idea banks is another tool used to select ideas. This is similar to the Internal Idea Capture system that Cooper [19] evaluated in his study. A notion similar to Idea Banks is the relatively new concept of Idea Markets [21],[22]. Koen et al. [2] concede that Idea Banks have some merit but they suggest that there is a tendency to not follow-up on the ideas submitted to the bank and the negative impact of this is that those who were initially submitting ideas tend to lose interest. In contrast, Idea Markets engages the employee as their ideas are bought and sold on the virtual market and their fluctuating prices act as a measure of their possible merit [21],[22]. One incentive for using a method like this, that generates a lot of ideas, is that there is a positive correlation between the number of new ideas and their value. It is clear that there are many tools that can prove useful at the FEI, however, experts have different views about which tools are appropriate and which are not. Consequently every company must ascertain for themselves what tools best align with the business they are in.

3. Research methodology

A detailed case study was employed in a leading medical technology organization in Ireland to assess the level of best project management practice at the FEI. This organization was selected as it is a leader in medical device design and development with a proven track record in product innovation. According to Hildreth [23] users of a system are the best evaluators of that system, therefore only R&D engineers involved in the product innovation process was targeted in this study. Cooper and Kleinschmidt [9] advise that there is often a difference between business unit level success and project level success. Consequently the survey was distributed to all 96 engineers in the R&D department who were capable of commenting on FEI management practices. Data was collected between March 2013 and April 2013 using a quantitative approach was used. According to Creswell [24], quantitative research methods are used to test theories. This method is lauded to be effective when empirically measuring people's feelings, beliefs and behaviors. This method was chosen for this study as it is a good mechanism to test theories, it is easy to repeat and findings can be generalized to the greater population [24], [25].

A comprehensive survey was designed, developed and tested. 90 explicit statements were formed based on a detailed synthesis of the literature relating to management practices in the FEI namely (a) strategy, (b) resources, (c) process and (d) climate (see Appendix A). Each category represents an aspect of the business that, according to the literature, is significant to product innovation success. The survey was designed to ask two key questions. First we wanted to learn the extent to which each of the best practice statements was implemented in the organizations. To this end respondents were asked to document whether they agreed or disagreed with the implementation of each of the statements using a five-point Likert scale, i.e., strongly agree, agree, neutral, disagree and strongly disagree. We also wanted to understand how important respondents felt each of the statements was. Therefore respondents were asked to rate the level of importance of each statement on a five-point scale, i.e., critical, very important, important, slightly important or unimportant. In order to identify and prioritize what tools are important at the FEI a list of 40 tools was generated from a synthesis of the literature. Respondents were asked how often they use each of the forty tools in their FEI phase. From here they were asked to rank, in order of their importance, the top five tools from the list of forty tools. Following that they were invited to note any tools that were overlooked in the survey but that are used in their FEI stage. The survey was piloted to establish if there is any ambiguity in the line of questioning and whether any of the questions could be misinterpreted. Amendments were made based on this feedback. Data collected was analyzed numerically using statistical analysis software (SPSS).

4. Analysis of findings

66 people responded to the survey. The majority of the respondents to the survey were either R&D engineers or associate R&D engineers. The majority of respondents are aged between 25 and 34 years old and a chi-squared test was determined that there is a significant association between respondents age and role held within the company ($\chi^2 = 80.228$, $p = .000$, $df = 39$, $n = 66$). Therefore it is likely that the R&D engineers and the associate R&D engineers are mainly made up of people in the younger age categories.

Participants were asked to disclose how many years they have worked in the medical technology industry, the number of years they have worked in R&D and the number of years they have been employed in the company. This information was sought to discern the level of experience the respondents have working at the FEI in the organization. The number of years the respondents worked in the medical device industry ranges from 0 to 28 years (mean $\bar{x}= 8$, standard deviation SD = 6.78). The numbers of years the respondents have worked in R&D range from 0 to 22 years ($\bar{x}= 6.37$, SD = 5.14). Finally the numbers of years the respondents have worked in Company X ranges from 0 to 27 years ($\bar{x} = 6.36$, SD = 6.12).

There was no significant difference between the opinions held by the respondents in the different age categories. This allowed the sample to be considered as a whole and the statistics did not have to be segregated according to the different age groups.

4.1 Strategy

Our results indicate that responding engineers in the R&D department agree that best practice critical success factors relating to strategy are in place at the FEI in the organization studied (i.e. degree of implementation). The employees also consider that critical success factors relating to strategy are important (i.e. level of importance). A Spearman's Rho test was carried out to see whether there was an association between the degree of implementation and the level of importance attached to the strategy related CSFs. We found that there is a weak correlation between respondents' degree of implementation and the level of importance associated with this category and so the relationship is not statistically significant ($r = .186$ $p = .174$). This means that the relationship is so low that it can be considered random.

As there was no significant association between the degree of implementation regarding strategy oriented CSFs in place and the level of importance attached to these CSFs it was decided to carry out a Wilcoxon test to see whether there was a significant difference between them. The results indicate that there is a significant statistical difference between the two (Wilcoxon, $Z = -2.419$, n – Ties = 50, $p = .016$). This means that despite the fact that respondents believe that the organization is good at implementing strategy oriented CSFs, the level of importance assigned to these CSF is rated higher. In other words, respondents believe that CSF in the area of strategy is rated higher than what is practiced in reality and so this imbalance needs to be addressed.

4.2 Resources

Respondents believe that CSFs relating to resources are in place at the front end of the innovation process in their company. Furthermore the employees also consider that CSFs relating to resources are important. These findings suggest that resources in the FEI of the organization are managed in accordance with best practice.

A Spearman's Rho test was carried out to see whether there is an association between respondents' attitude towards the degree of implementation regarding whether CSFs for resources in the FEI (i.e. degree of implementation) and the level of importance attached to these CSFs (i.e. level of importance). It was discovered that there is a statistically significant relationship between implementation and importance in this category ($r = .289$, $p = .042$). As $p < .05$ the relationship can be considered genuine and not a result of chance. Therefore we can deduce that the more the resource related CSFs align with best practice in the FEI, the greater the importance placed on this CSF. Alternatively, if high importance is put on CSFs resource, they are more likely going to be incorporated into the company.

A Wilcoxon test was carried out to see whether there was a significant difference between the degree of implementation and the level of importance attached to the resources related CSFs. The results indicate that there is a significant statistical difference between both measures of attitude (Wilcoxon, $Z = -5.280$, n – Ties = 46, $p = .000$). It seems that a larger number of respondents rated the importance of the resource related CSFs greater than their level of agreement about them being in place in the organization.

4.3 Process

Unlike the previous categories, respondent's scores are concentrated on the lower values of the scale when asked about whether they believe that best practices process oriented CSFs were in place. However, the median score is high which implies that the employees are more in agreement than disagreement about process related CSFs being in place in their company. Respondents also believe that CSFs relating process are more important than unimportant.

A Spearman's Rho test was carried out to see whether there was an association between the level of agreement regarding whether the organization implements process related CSFs and the level of importance attached to these factors. We found a strong correlation between implementation and importance in this category and consequently that the relationship is statistically significant at the 0.01 level ($r = .493$, $p = .001$). This means that the higher level of agreement that the CSF is in place in the organization the higher the level of importance is placed on the CSFs.

A Wilcoxon test was subsequently carried out to see whether there was a significant difference between the level of agreement that these factors are in place and the level of importance attached to these factors. Based on the results, there is no significant statistical difference between both measures of attitude (Wilcoxon, $Z = -1.850$, n – Ties = 37, $p = .064$). This implies that the level of agreement about the level of implementation of CSFs relating to the organizations process is more in line with the level of importance attached to these CSFs.

The findings indicate that organizations FEI process is effective as the high agreement scores indicate that organizations' process compares favorably with the process related CSFs.

4.4 Climate

The majority of respondents believe that CSF relating to the organizations climate is in place. They also believe that these CSF are important.

A Spearman's Rho test was carried out to see whether there is an association between the level of implementation and the level of importance attached to the climate CSFs. It was established that there is a strong correlation between agreement and importance in this relationship is statistically significant ($r = .484$, $p = .003$).

A Wilcoxon test was also conducted to see whether here was a significant difference between the level of implementation and the level of importance attached to the climate related CSFs. According to the results, there is no statistical significant difference between both measures of attitude (Wilcoxon, $Z = -1.287$, n – Ties = 28, $p = .198$). Our findings show that respondents rated the level of importance and level of implementation of climate CSFs is similar.

4.5 Tools

Table 1 summarizes our findings regarding the perceived importance of tools in the FEI. More specifically, the top 10 most important tools, the top 10 least important tools and the top 10 most unknown tools are presented.

Table 1. Perceived importance of tools in the FEI

Most important tools	**Least important tools**	**Most unknown tools**
Brainstorming	Scenario planning	Idea banks
Rapid prototyping	Unfocused groups	Unfocused groups
Customer visit teams	Customer designs	Peripheral visioning
Design for six sigma	Peripheral visioning	Morphologies
Market research	Partners and vendors	Commercial success probability
Focus groups	External product designs	Strategic buckets
Internal idea capture	External submission of ideas	Lead user analysis
Customer advisory board	External idea contest	Community of enthusiasts
User centric design	Idea banks	TRIZ
Intellectual property activity watch	Evaluation criteria matrix	Technical success probability

Table 2 summarizes our findings regarding the use of tools in the FEI. More specifically, the top 10 most frequently used tools and the top 10 least frequently used tools are presented.

Brainstorming and rapid prototyping are the most popular tools used. However, we found that this organization does not appear to use a great variety of tools at the FEI which is contrary to Barczak et al.'s [8] finding that the best companies use a multitude of tools during this phase. Focus groups were found to be in the top 10 most used tools despite the literature showing that group methods are not effective at the FEI [26]. Design for Six Sigma is a tool that is typically employed during the development phase of the innovation process was found to be regularly used and also quite important at the FEI. Interestingly, market research is only considered the fifth most used tool. This is despite it being the deemed the second most important tool by the employees. The usage result is unexpected as one would have thought it is essential to be market aware when trying to generate ideas for new products.

Table 2. Use of tools in the FEI

Most frequently used tools	Least frequently used tools
Brainstorming	Idea banks
Rapid prototyping	Community of enthusiasts
Customer visit teams	Unfocused groups
Design for six sigma	Peripheral visioning
Market research	Morphologies
Focus groups	External idea contest
Internal idea capture	TRIZ
Customer advisory board	Strategic buckets
User centric design	Technical success probability
Intellectual property activity watch	Commercial success probability

Some of the most common tools and techniques that were highlighted in the literature review scored very low usage scores in the survey such as idea banks and TRIZ. Surprisingly, a high proportion of the sample that completed this question was unfamiliar with several of the tools that were collected from the literature. Furthermore two of the tools in the top 10 most unknown tools are lead user analysis and TRIZ despite both tools being highly recommended in the literature.

5. Analysis of the instrument

It is essential to determine the internal reliability of the instrument using a statistic known as Cronbach's Alpha. As this is a developmental scale, the individual Cronbach's Alphas were calculated for each of the subscales on the instrument. The overall Cronbach's Alphas for the combined subscales was also calculated. All of the results are > 0.8 which is deemed as "*highly acceptable for assuming homogeneity of items*" [27]. Therefore the items in this scale can be considered to have a high level of internal consistency.

A Spearman's Rho test was carried out to see whether there are associations between subscales measuring the level of implementation relating to the strategy, resources, process and climate CSFs. The results of the test show that there are strong positive correlations between all of these scales and each of these relationships are statistically significant. This means that as agreement about one CSF increases agreement about resources and other sub scales increase. This relationship reaffirms what was suggested in the literature which is that the four factors are linked.

A Spearman's Rho test was then carried out to see whether there are associations between the subscales measuring the level of importance for each of the CSFs. The results of the test show that there are strong positive correlations between all of the importance subscales and each of these relationships are statistically significant. Based on these results, one can deduce that as the importance placed on the strategy CSFs increases, the importance levels attributed to the other CSFs are likely to increase and so forth. These correlations mean that there is a significant relationship between the four variables and that as the literature suggests, they are linked and cannot be treated independently.

6. Recommendations

Based on our analysis the following is a tentative list of recommendations that the organization studied should take on board so that their FEI phases aligns better with established best practices.

- Focus on new strategic arenas: According to Cooper [19] a company should focus "*R&D efforts on more fertile strategic arenas with extreme opportunities*" as they will help a company to grow and prosper. The organization should consider targeting new strategic arenas that will demand the creation of breakthrough ideas and big concepts.
- Adopt a "*connect & develop*" strategy [9]: It is clear from the findings that the organization studied does not adopt a collaborative innovation strategy. There is evidence to show that many companies have benefited from adopting more open innovation policies [28].
- Deploy more suitable staff at the FEI: The findings of our study show that only a small percentage of employees work full time at the FEI. Furthermore we learned that employees' strengths are not taken into account when assigned to innovation projects. It is imperative to ensure that suitable resources are assigned to the right projects so that there is a well-balanced and effective portfolio of projects.
- Invest more money at the FEI: The organization studied devotes on average 4.2% of turnover to R&D but only 0.2% of this figure is dedicated to the FEI phase. These percentages are considerably less than international expenditure on R&D. We would recommend that the organization should increase their spending at the FEI as it has been found that when the allocation of money (and staff) doubles at the FEI it correlates significantly to product innovation success [13].
- Align innovation metrics to management's personal performance objectives: In order to ensure that management commit the adequate amount of resources to where they are needed at the FEI, new product performance metrics should be integrated into management's personal performance objectives [7]. This link guarantees that management cannot overlook the FEI phase if they want to meet their performance objectives.
- Improve idea management: It is clear that a greater emphasis should be placed on the management of ideas. By incorporating the philosophy of idea banks or idea markets, which allow all employees to contribute and evaluate ideas, would permit a more collaborative effort for determining the value of an idea.
- Evaluate leadership: Stevens et al. [29] found in their research that a leader's personality can greatly affect the FEI. They discovered that a person who demonstrates high tendencies for intuition will select better projects and as a result will generate more profit in comparison to someone who scores low on this psychometric test for intuition. Therefore if leadership is so integral to success in the FEI, companies like the one studied here should consider whether their leaders are effective by carrying out this psychometric evaluation.
- Diversify the tools used at the FEI: There are many idea generating techniques that can provide a rich supply of ideas e.g. idea markets. Organizations should try and familiarize themselves more with the unknown tools, in particular those that are highly referenced in the literature such as TRIZ and lead user analysis. TRIZ is a methodical technique that can be used to solve problems and to generate numerous correct solutions. The benefit of this tool is that it encourages creativity as users must go beyond their own experience and recycle solutions from other scientific fields [2]. The Lead User method involves communicating with people who are likely to face needs sooner than the general marketplace and so will consequently gain from having those needs met.

7. Conclusions

This paper focuses on management practices at the front end of the innovation process in a large organization operating in the medical technology industry. The aim of this research is to provide insights into the level of implementation of known best practices as well as the level of importance assigned to these best practices in a real world setting. The research is important because management practices at the FEI have a significant impact on the performance of the product innovation process. We found that the FEI audit used in this study is internally reliable. The questionnaire, which is based on existing literature relating to the FEI is an effective instrument for gauging the level of best practice in place in a company's FEI. The tool can help practitioners to assess themselves relative to best practice. By analyzing an organization's activities and by quantifying the impacts of these activities the organization can respond in a planned and coordinated way and customized solutions can be implemented.

The findings of our study revealed that CSFs relating to strategy, resources, process and climate are very important at the FEI in the medical technology industry. However these CSFs are not implemented to the extent to which they should be in practice. Our study revealed that if a CSF is considered important by employees it is more likely going to be enforced. In addition, if a CSF is implemented it is also more likely to be considered important. If an organization wants to ensure that they have an effective and efficient FEI phase, it is clear that they must adopt these best practices in these areas uniformly. By incorporating and improving the presence of the CSFs medical technology companies will create FEI phases that align more with best practice.

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Appendix A. Variables used to measure key constructs

Table 1. Variables used to measure strategy

Strategy	
1.	Management have produced a clear well-communicated NPD strategy
2.	There is a defined new product strategy for the R&D unit
3.	The business strategy is active at the start of projects
4.	The business strategy clearly communicates the financial objectives
5.	The business/innovation strategy focuses on attractive strategic arenas, i.e., growth engines
6.	The clearly defined strategic arenas help give direction to the business total new product effort
7.	The business's new product effort has a long term focus – it includes long term projects as well as short term incremental projects
8.	There is a clear vision of product lines and platforms for specific markets
9.	There are clearly defined product innovation goals for the business
10.	Innovations role in achieving business goals is clearly defined
11.	There are goals or objectives for the business total new product effort
12.	The role of new products in achieving business goals is clearly communicated to all
13.	The company has a 'connect & develop' strategy – it works with partners to develop new products outside the organisation
14.	The company often forms alliances with other organisations for mutual benefit
15.	There are people in the organisation to continually scan the external environment
16.	The company looks for opportunities through external analysis – markets industries and sectors
17.	The company looks for opportunities by identifying the unique capabilities of the business in order to leverage them in other markets applications and sectors
18.	The company tries to identify major problems or problem arenas so that it can apply its competencies to solve those problems
19.	The company has the ability to execute the innovation strategy when the environment changes due to its flexibility
20.	If there is uncertainty on any dimensions (e.g. technology or markets) the organisation has a carefully planned alternative approach

Table 2. Variables used to measure resources

Resources	
1.	There is continuous senior management support for innovation and new product development
2.	The company's management enforce company values for the duration of the project
3.	The necessary resources are devoted by senior management to achieve the firm's new product objectives
4.	R&D budgets are adequate to achieve the businesses new product objectives
5.	Priority projects receive the resources they need for execution
6.	New product performance is part of senior management's personal performance objectives
7.	The performance results of the new product programme are measured (e.g. % of annual sales generated by new products, etc.)

8.	The right people are active in the right projects at the time during the innovation process
9.	Staffing policies and project specific staffing are consistent with the new product strategy
10.	The resources needed to meet the projects performance requirements are clearly documented
11.	Project personnel have been tested or trained to develop raw ideas into potential projects
12.	Appropriate “starter” personnel are selected to staff the early stages of the innovation process
13.	The company supports staff learning about other areas of the business e.g. marketing, manufacturing finance etc.
14.	The company encourages job rotation to encourage knowledge sharing
15.	The company urges employees to interact closely with the customers
16.	The company has an effective portfolio management system that aligns well with the business’s strategy
17.	The portfolio of projects are well balanced between risk versus return, maintenance versus growth and short term versus long term projects
18.	There is a good balance between the number of projects and resources
19.	There is a continuous pipeline of new products that are of value to the company
20.	The company does a good job in ranking/prioritising projects so that they are consistent with the new product strategy

Table 3. Variables used to measure process

	Process
1.	The innovation process is a high quality process that aligns with the business strategy
2.	The front end of the innovation process is a complete and thorough process where every necessary activity is carried out without hasty corner cutting
3.	The front end of the innovation process is flexible as stages can be skipped or combined depending on the nature of the project
4.	The module/process used in this company is non-sequential, i.e., iteration is part of the process
5.	Established criteria are used at review points to promote or kill a project
6.	Project targets (time, cost, quality) and relative priorities are clear
7.	The company uses metrics to track idea generation, e.g. % of ideas that entered the new product development process, % of ideas commercialised, etc.
8.	There is an emphasis on up front homework i.e. market and technical assessments before projects move into the development phase in order to build a robust business case
9.	Early concepts and other feasibility prototypes are planned tested and completed at the front end so that there are no surprises later
10.	The process includes sharp, early product definition that is well documented before development work begins
11.	The search for opportunities begins with search for customers’ problems and/or their unarticulated needs
12.	Customers and suppliers are involved throughout the product innovation process
13.	The company carries out concept testing with users to determine the value to the customers
14.	The company encourages customer and marketplace contact
15.	Customer and market information is used early on to set the scope for a project (e.g. target markets, customer segments, features, price, etc.)

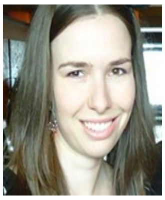
16.	A projected project outcomes' ability to meet the customer need is clearly documented
17.	Major supplier and tooling considerations, manufacturing, logistics and distribution requirements are explicit at the front end of the innovation process
18.	The company has an active formal opportunity identification process that allows fair identification of radical ideas
19.	The company approaches funding problems/opportunities from a strategic perspective
20.	The company has an active idea collection system to support internal and external ideas
21.	Core team members jointly review product concepts using pre-defined and explicit criteria
22.	Idea selection is done through a formal process where prompt feedback is provided to the idea generators
23.	The company has a rapid process in place to screen ideas or concepts for a project
24.	The competitive advantage potential for a project is clearly identified for each new project
25.	Information on ideas generated, problems raised and project status is accessible to all the unit

Table 4. Variables used to measure climate

	Climate
1.	Senior management support innovation by approving projects, securing necessary finance and resources etc
2.	The company has created an environment that is conducive to creativity and knowledge creation
3.	The whole organisation is aware that innovation is fundamental to bringing value to customers
4.	There is a sense of trust and openness that allow people to speak their minds and offer differing opinions
5.	Powerful stories are communicated to staff that reinforce the principles and practices of innovation
6.	The company sets compelling challenges that allow employees to become emotionally committed to the project
7.	There is a dedicated innovation group within the R&D department
8.	Innovation results are one of the key performance metrics/indicators
9.	The organisation permits the emergence of intrapreneurs or product champions by allowing people time to work on projects of their own choice
10.	The company recognises that they need to pay people to be innovative and to also give them the time to be innovative
11.	The company uses incentives or rewards to stimulate the generation and enrichment of ideas
12.	There is a new product idea scheme within the R&D unit which solicits ideas from all employees
13.	Idea screening is done in a way that encourages creativity rather than stifling new ideas
14.	Someone in the company has the formal role of coordinating ideas from generation to assessment
15.	There is sufficient time given for people to think ideas through before having to act
16.	There are funding resources available for new ideas
17.	The company is willing to invest in high risk projects
18.	The project has an assigned team of players that are accountable for the end result
19.	Projects are developed using effective cross functional teams
20.	The project team interact and communicate well through frequent project update meetings
21.	Roles and responsibilities for the core team are clear and well defined

22.	A project team has the ability to get news from outside the company
23.	Partners, suppliers and vendors are integrated into a project team
24.	The company's leaders demonstrate in every decision and action that innovation is important to the company
25.	All projects have a defined team leader who is responsible for advancing the project from start to end

Biographical notes



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A catalog of information systems outsourcing risks

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Abstract:
Information systems outsourcing risks are a vital component in the decision and management process associated to the provision of information systems and technology services by a provider to a customer. Although there is a rich literature on information systems outsourcing risks, the accumulated knowledge on this area is fragmented. In view of this situation, an argument is put forward on the usefulness of having a theory that integrates the various constructs related to information systems outsourcing risks. This study aims to contribute towards the synthesis of that theory, by proposing a conceptual framework for interpreting the literature and presenting a catalog of information systems outsourcing risks. The conceptual framework articulates together six key risk elements, namely dangers, negative outcomes, undesirable consequences, factors and mitigation actions. The catalog condenses and categorizes the information systems outsourcing risk elements found on the literature reviewed, both from the perspective of the outsourcing customer and from the perspective of the outsourcing provider. Proposals for subsequent work towards the generation of the theory of information systems outsourcing risk are suggested.

Keywords:
information systems outsourcing; risk; theory.

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1. Introduction

The survivability and prosperity of any organization depends crucially on its capability to perform a set of activities that result in the delivery of a valuable product or service for the market. In order to enhance their value chain, organizations use various technological and managerial solutions to support their business processes. These solutions may be developed internally or procured externally to the organization, configuring the two main ways to obtain any type of resources – insourcing and outsourcing. Confronted with fierce competition in the context of global economic and financial crises, companies strive for greater efficiency and reduced costs, while at the same time try to increase their specialization in a limited number of key areas. This state of affairs may tip organizations to the outsourcing side of the sourcing binomial, transforming the outsourcing option in a critical strategic decision [1].

In the realm of information systems (IS), outsourcing involves making arrangements with an external party for the partial or total provision of the management and operation of an organization's information technology (IT) assets or activities [2]. These arrangements take the form of contracts that state the agreement between two entities: the customer of the outsourcing services and the provider (or providers) of those services.

The relevance of IS outsourcing is evidenced by Gartner's forecasts of a worldwide market reaching $288 billion in 2013 [3] and of a growth rate of 5.2% in 2014 [4]. It may also be appreciated by considering the accumulated knowledge produced on the area (cf. [5,6]).

Prior to embark upon an IS outsourcing project, an organization should ponder the expected costs and benefits of the outsourcing option. If the organization decides to proceed with the outsourcing, the consideration of the cost-benefit relationship should persist, in order to take into account the benefits really achieved and the costs incurred. Similarly, an outsourcing provider needs to consider the costs and benefits of starting an outsourcing transaction with a potential customer, as well as to track the evolution of the costs and benefits of an ongoing outsourcing contract. Associated with benefits and costs of an outsourcing deal there is a set of risks. These risks need to be managed if the transaction between an outsourcing customer and one or more outsourcing providers is to be successful.

Various studies have been conducted on IS outsourcing risks, addressing issues such as sources of risks, profiling and prioritization of risks, and actions to reduce the impact of risks. To some extent, that collection of works forms a fragmented, although extremely valuable, set of contributions. This interpretation motivated us to seek an integrated view of IS outsourcing risks. In fact, some authors have already made efforts to that end, such as Bahli and Rivard [7] who extended the risk assessment framework used in engineering to analyze IS outsourcing risks, suggesting the need to combine risk scenarios, risk factors, consequences and mitigation mechanisms. This paper builds upon that collection of studies and integrative efforts. Our goal is to contribute towards the synthesis of a theory of IS outsourcing risk by compiling a catalog of IS outsourcing risks. We believe that a theory of IS outsourcing risk may prove particularly useful to practitioners analyzing the feasibility of an IS outsourcing project or steering ongoing IS outsourcing transactions and to researchers deepening our understanding of the IS outsourcing risk management process.

The paper is structured as follows. After this introduction, a conceptual framework for interpreting the literature on IS outsourcing risks is proposed, followed by the description of the work undertook. Next, the catalog of IS outsourcing risks derived from the classification of the literature is presented and discussed. Finally, conclusions are drawn, limitations of the study are acknowledged and future work is suggested.

2. Conceptual framework

The aim of this study is to make a contribution in the domain of IS outsourcing that may assist in the near future in the creation of a theory of IS outsourcing risk. As formulated, this ultimate objective builds on three main concepts: IS outsourcing, theory and risk. As a first step towards that research goal, we will briefly discuss each of these three concepts in order to develop a conceptual framework on which to base the generation of such theory.

Information systems outsourcing is not a new phenomenon. Since its emergence in the 1960s, it has undergone several changes: from an emphasis on time-sharing services, it evolved to the application service provision (ASP) model in the late 90s, and then to service-oriented computing (SOC) and on-demand/utility computing in the beginning of this century [8]. Also, from a geographical point of view, it has diversified from domestic provision of services by third parties to offshore outsourcing, where the responsibility for management and delivery of IT services is located in a different country from that of the customer [9].

Whether the purpose for outsourcing is the externalization of IT infrastructure, application development, or IS management responsibilities, just to name a few, it is possible to conceive IS outsourcing as a process composed of two main phases: the decision process and the implementation [5]. The decision process phase encompasses three stages, in which organizations weight up the advantages and disadvantages of IS outsourcing, address alternative outsourcing arrangements and finally make the decision after comparing the various outsourcing options. The implementation phase is organized by Dibbern et al. [5] in two stages: how and outcome. The 'how' stage includes the selection of the provider and the customer-provider relationship related activities, namely relationship structuring (contractual process), relationship building (strengthening the relationship between customer and provider) and relationship management (driving the relationship in the right direction). The 'outcome' stage reflects the consequences of the outsourcing choice that was made, the degree of success of the arrangement and lessons from the outsourcing. It should be noticed that underlying this organization of the outsourcing process is a customer centric view, especially in what concerns the decision process phase. Although part of the stages may be easily applicable from the perspective of the outsourcing providers, these agents have to conceive the preliminary phases to the contractual process from an offer point of view, in the sense of responding to a market demand originating from potential customers.

The literature on IS outsourcing is significant and diverse. Lacity et al. [6] classified 191 papers on IS outsourcing published between 1990 and 2008 into six topics relevant to practice. The set of topics and the associated questions addressed by researchers are the following:

- Determinants of IS outsourcing – Which types of firms are more likely to outsource IS?
- IS outsourcing strategy – What is the strategic intent behind IS outsourcing decisions? What are the strategic effects of IS outsourcing decisions?
- IS outsourcing risks – What are the risks of IS outsourcing? How are IS outsourcing risks mitigated?
- Determinants of IS outsourcing success – Which practices increase the likelihood that a customer's outsourcing decision will be successful?
- Customer and provider capabilities – Which capabilities do customer firms need to develop to successfully engage IS outsourcing providers? Which capabilities do customer firms seek in an IS outsourcing provider?
- Sourcing varietals – How do practices differ when pursuing different types of outsourcing such as offshore outsourcing, application service provision, and business process outsourcing?

From that review of IS outsourcing literature, it was possible to conclude that the most researched topics have been the determinants of IS outsourcing success and the determinants of IS outsourcing, followed by customer and provider capabilities. In what concerns IS outsourcing risks, those authors note that the corresponding body of literature encompasses a "quite intimidating" number of risks. To a certain extent this reinforces the need to revisit the accumulated knowledge on IS outsourcing risks, with the aim of providing an integrative interpretation for that richness of contributions.

The second fundamental concept we review is theory. A theory is a set of defined and interrelated constructs that presents a systematic view of phenomena [10]. In order to be considered a theory, a conceptual artifact must identify the constructs that compose it, specify the relationships among these constructs, and be formulated so that these relationships are able to be tested, i.e., are falsifiable [11].

The importance of theory may be appreciated by considering its primary goals: analysis and description (description of the phenomenon of interest and analysis of the relationships among constructs), explanation (how, why, and when things happen), prediction (what will happen if certain preconditions hold) and prescription (provision of a recipe to the construction of an artifact) [12]. In this study we are interested in the IS outsourcing phenomenon from the perspective of risk, our third fundamental concept to discuss.

Risk is a word with multiple meanings. Recognizing the incoherent use of the concept, Slovic [13] identified four main conceptions for risk: a dangerous activity ("Where is in the list the risk of flying by plane?"); a probability ("What is the annual risk of death at eighty?"); a consequence ("What is the risk of letting the parking meter expire? Answer: be fined!"); and a danger or threat associated to an activity or technology ("How big is the risk of smoking cigars?").

In the literature it is possible to find these different conceptions of risk. Aubert et al. [14] argue that risk encompasses the meaning of negative outcome, such as shortfalls in systems performance, disruption of service to customer, and loss in innovative capacity, and the meaning of factors leading to negative outcomes, such as a continuing stream of requirement changes or personnel shortfalls, lack of upper management commitment, and business uncertainty. Similarly, in ISO 31000 standard is observed that risk is often characterized by reference to potential events, consequences, or a combination of these, being often expressed in terms of a combination of the consequences of an event and the associated likelihood of occurrence [15]. Willcocks and Lacity [16] view risk as a negative outcome that has a known or estimated probability of occurrence. Bahli and Rivard [7] perceive risk as a danger or hazard. Lacity et al. [6] define risk as the probability of an action adversely affecting an organization.

Despite the diversity of meanings of the term risk, Renn [17] isolated a common element among all definitions, namely the distinction between reality and possibility. Under this assumption, that author defined risk as the possibility that human actions or events lead to consequences that have an impact on what people value [17]. In a similar vein, the standard ISO 31000 defines risk as the effect (positive and/or negative) of uncertainty on objectives [15]. At this point a distinction between risk and uncertainty is needed. As soon as 1921, Knight contrasted between the concepts of uncertainty and risk, noting that the former is present when the likelihood of future events is indefinite or incalculable, while the latter is present when future events occur with measurable probability [18]. This distinction contributes to correctly place the role of likelihood (probability) in risk related constructs. A final important derivation from the conception of risk by Renn [17] is that risks may be conceived as mental representations of threats capable of causing losses or as opportunities that can produce gains. This last alternative view of the concept of risk is in sharp contrast with the common view that associates risk to hazard. In this study we adopted the former view of risk, focusing our attention on the possibility of some unfavorable event or outcome occur in the realm of IS outsourcing. Nevertheless, we will address the usefulness of the alternative view of risk for the management of IS outsourcing in the conclusion section of this paper.

Given the aim of this study, the review of literature on the concepts of theory and risk prompted us to develop a conceptual framework that could provide a basis for constructing a theory of IS outsourcing risk, by shaping and organizing our interpretation of the findings in IS outsourcing literature. To this end, we propose the conceptual framework illustrated in Figure 1.

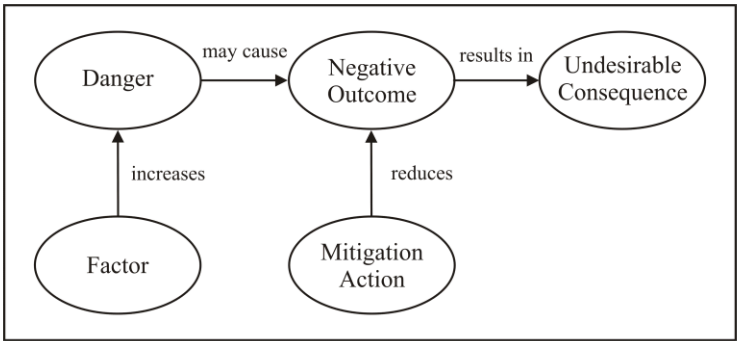

Fig. 1. Conceptual framework

A danger is a potential cause of a negative outcome; it is not, by itself, a realized damage. A negative outcome is an adverse result from which derives an undesirable consequence. An undesirable consequence configures an explicit loss to the entity (in this case the organization), in terms of tangible or intangible assets or opportunities to reap future benefits. Both dangers and negative outcomes are possibilities that may culminate in undesirable consequences. A negative outcome and the originating danger are of interest to an organization due to the undesirable consequences that may entail for the organization. Associated with a danger and a negative outcome there is a likelihood of occurrence. Different dangers and negative outcomes may present distinct levels of severity. In contrast, a factor is an attribute of some entity or situation that increases the exposure of the organization to a danger. Contrary to dangers and negative outcomes, at a given time a factor has a well determined non-probabilistic value. Finally, a mitigation action consists in an act, usually performed by the entity that may suffer the undesirable consequence, expected to lessen the intensity of a negative outcome, eventually nullifying it.

3. Study description

Having defined the conceptual framework, we proceeded to review literature that explicitly addressed IS outsourcing risks. In order to pursue the goal of generating a theory of IS outsourcing risk, it is essential to take into account the wealth of studies conducted in the area. Our purpose was to interpret the findings in the literature in light of the proposed conceptual framework. We began by doing a literature search in the main scientific indexing platforms and repositories, such as ISI Web of Knowledge, SCOPUS, Google Scholar, b-on, and AIS Electronic Library. The search criteria involved looking for expressions “IS outsourcing”, “IT outsourcing” and “risk” in the title or abstract of papers. The results were screened for relevance, yielding a list of 34 papers. The next step was to characterize the IS outsourcing risks discussed in those studies. For that matter, we built a repository of IS outsourcing risk related elements. These elements were diverse in nature and in designation. Among the risk elements we found denominations such as risk factors, risks, consequences, adverse events, risk mitigation mechanisms, risk management strategies, risk management practices, and risk profiles. From this recollection exercise we got 727 risk related elements (corresponding to an average of 22 risk elements per paper, with a minimum of 1 element and a maximum of 131 elements). To make sense of this set of issues we classified them according to the constructs found on our conceptual framework. In addition, we also classified each issue according to the party involved, namely IS outsourcing customer or IS outsourcing provider.

After classifying the issues, we aggregated them, by condensing issues presenting similar formulations. Special care was placed in the naming of the condensed issues, in order to remain faithful to the ideas underlying the original formulations and to minimize phrasing ambiguity. Besides the classification of each risk element, we also characterized them. For that end, we located each of the condensed issues in the IS outsourcing process, by asking the following questions in accordance to the construct category under examination: “When is this undesirable consequence felt more strongly?”, “At what stages this negative outcome may result?”, “At what stages this danger can be experienced more severely?”, “At what stages this factor has its major impact?” and “When does this mitigation action take place?”. For the undesirable consequences we used the following scale: pre-contract (Pre), execution of the contract (Exec) and post-contract (Post). For the other four constructs we resorted to Dibbern et al. [5] stage framework, locating the risk elements in the following IS outsourcing stages: Decision (D); Provider Selection (PS); Relationship Structuring (RS); Relationship Building (RB); Relationship Management (RM); and Outcomes (O). As previously noted, this stage organization of the IS outsourcing process has a fundamental customer centric nature. For that matter, and for those risk elements related to providers, we adapted it, discarding the first stage (Decision) and maintaining the other five, but with a slight modification of the meaning of stage Provider Selection. Instead of reflecting the issues regarding the selection of an IS outsourcing provider by a customer, it has come to mean the issues regarding the attractiveness of a provider himself for being selected by a potential customer.

The nature of the risk elements was also considered by identifying for each undesirable consequence the corresponding type of loss and for each negative outcome, danger, factor and mitigation action their respective foci, i.e., the target object of the element. For each negative outcome and factor we also determined their loci – for the negative outcomes according to the emphasis of the risk element, and for the factors if they concerned the customer (Cust), the provider (Prov) or the transaction (Tran) that takes place between those two parties. The identification of the foci and the determination of the loci was an inductive process, *a la* grounded theory, where categories were formed based on the concepts covered in each of the risk elements.

From this classification and characterization process resulted an artifact in the form of a catalog of IS outsourcing risks which is presented in the next section. The catalog is organized in two parts, accordingly to the perspective of the outsourcing customer and from the perspective of the outsourcing provider. For each party, the risk elements composing the conceptual framework – undesirable consequences, negative outcomes, dangers, factors, and mitigation actions – are listed and discussed.

4. Catalog of information systems outsourcing risks

4.1 Customer side view

The undesirable consequences for the IS outsourcing customer condensed from literature are shown in Table 1. Of the 17 issues, the loss of critical skills and competences by the customer on the domain of the services outsourced is the most referenced (14 authors), followed by unexpected transition costs of IS services and loss of control over IS decisions. The type of loss most often cited is financial, usually expressing situations where the customer incurs additional costs not expected or not anticipated. The group of undesirable consequences concentrates on the execution phase of the contract and on the post-contract phase. This set of issues suggests that practitioners may find useful to consider the overall risk of an outsourcing transaction according to six types of potential losses, namely in terms of capability and internal control, image and morale, and strategy and finance.

Table 1. Customer-side undesirable consequences

Phase			Type of Loss	Item	Authors
Pre	Exec	Post			
		×	Capability	Loss of capability to change	[19]
	×	×	Capability	Loss of in-house critical skills and competences on the domain of the services outsourced	[6,14,16,19,20,21,22,23, 24,25,26,27,28,29]
		×	Capability	Loss of IS innovative capacity	[30]
	×		Financial	Additional financial costs	[21,22,23,31]
	×		Financial	Costs of services outsourced higher than planned	[14,32]
	×	×	Financial	Excessive switching costs	[21,22,23,27,33]
×	×		Financial	Excessive transaction costs	[6,19,22,32]
×			Financial	High costs of locating providers and communication infrastructure	[32]
	×	×	Financial	Loss in future revenue	[23]
		×	Financial	No overall cost savings	[6]
	×		Financial	Unexpected transition costs of IS services	[6,7,14,21,22,23,27,34]
		×	Financial	Unwinding equity to cancel outsourcing contract	[22]
	×	×	Image	Negative impact on image of organization	[19,21,35]
	×	×	Internal control	Loss of control over IS decisions	[6,19,20,21,22,23,26,32]
	×		Internal control	Loss of control over services outsourced data	[6,19,21,22,23,26,32]
×	×	×	Morale	Negative impact on employees' morale	[35,36]
		×	Strategic	Loss of strategic alignment between business and IT	[20]

Table 2 groups the issues classified as negative outcomes. The most reported negative outcome relates to the general nature of the previous discussed financial undesirable consequences, namely the failure by the customer team responsible for the governance of the transaction to consider all the costs associated with the provision of IS outsourcing services. Of all 44 issues, 59% were classified in the Service category, with the outcomes regarding non-delivery or delayed delivery of services, unsatisfactory quality of services and security breaches in services concentrating the largest number of references. The second most represented category is Organizational, which includes the second most cited negative outcome, namely Provider lock-in. As it might be expected, the outsourcing stage that by far brings together more aspects is Outcomes (38 in 44). The stages Decision and Relationship Building have no issues, suggesting the need for more research on the adverse results that an organization may face during the crucial periods of deciding on outsourcing and laying the foundations for a smooth relationship with the provider.

Table 2. Customer-side negative outcomes

Stage						Locus	Focus	Item	Authors
D	PS	RS	RB	RM	O				
		×			×	Contract	Changeability	Inflexible outsourcing contracts regarding changes	[37]
					×	Contract	Financial	Contractual amendments in favor of provider	[7,14,23,37]
					×	Contract	Financial	Uncontrollable outsourcing contract growth	[6,21,26]
	×					Organizational	Governance	Failure to assess all provider search costs	[27]
					×	Organizational	Governance	Failure to consider all outsourcing costs	[6,19,21,23,24, 25,26,28,30,35]
					×	Organizational	Learning	Lack of organizational learning about the capabilities of the services outsourced	[30]
					×	Organizational	Strategy	Excessive dependence on the provider	[19,22,24,25]
					×	Organizational	Strategy	Irreversibility of the outsourcing decision	[21,24,25,26]
					×	Organizational	Strategy	IT becomes undifferentiated commodity	[37]
					×	Organizational	Strategy	Provider lock-in	[6,7,14,22,23,26,28]
					×	Personnel	Conflicts	Conflicts between users of the services outsourced	[38]
					×	Personnel	Impact	Large number of users affected by outsourcing	[22,38]
				×		Relational	Accountability	Unaccountability of actions performed in the realm of the services outsourced	[37]
				×		Relational	Dispute resolution	Involvement in the resolution of issues between the prime provider and its subcontractors	[22]
					×	Relational	Infringement	Infringement of Intellectual Property Rights	[6,20,32,36,37,39]
				×		Relational	Litigation	Disputes and litigation over the services outsourced	[7,14,21,23,32]
				×		Relational	Ownership	Undefined ownership of outsourced data	[37]
				×		Relational	Withdrawal	Disengagement turmoil	[22]
					×	Service	Adaptability	Inability to adapt services outsourced to new IT	[20,24,27]
					×	Service	Changeability	Inflexible services outsourced regarding business change	[20,37]
					×	Service	Changeability	Inflexible services outsourced regarding technological change	[37]
					×	Service	Compatibility	Incompatible systems, software and procedures	[37]
					×	Service	Functionality	Non-delivery or delayed delivery by provider of services outsourced	[23,26,32,36,37,38]
					×	Service	Functionality	Services outsourced do not perfectly fit customer’s needs	[37]
					×	Service	Functionality	Services outsourced wrongly developed	[38]
					×	Service	Integration	Lack of integration of customer’s processes and outcomes	[22]
					×	Service	Integration	Lack of services outsourced integration between different units of customer	[22]
					×	Service	Integration	Lack of services outsourced integration between regional units of customer	[22]
					×	Service	Maintenance	Poor maintenance of services outsourced	[32,37]
					×	Service	Performance	Slow response time of services outsourced	[34,37]
					×	Service	Performance	Underperformance of services outsourced	[36,37,38]
					×	Service	Price	Unique needs of customer not met cost-effectively	[22]

					×	Service	Privacy	Privacy breach on the services outsourced	[6]
					×	Service	Quality	Debasement of services outsourced	[19,37,39]
					×	Service	Quality	Unsatisfactory quality of services outsourced	[19,22,23,32,36,37]
					×	Service	Reliability	Lack of reliability of services outsourced	[23,37]
					×	Service	Scalability	Limited scalability of services outsourced	[37]
					×	Service	Security	Disclosure of data handled by services outsourced	[19,37,39]
					×	Service	Security	Lack of awareness regarding location where services outsourced data is held	[37]
					×	Service	Security	Security breach on the services outsourced	[6,23,24,34,35,37]
					×	Service	Security	Unauthorized access to services outsourced	[37]
					×	Service	Security	Unavailability of services outsourced	[23,34,37]
					×	Service	Security	Violation of integrity of data handled by services outsourced	[37]
					×	Service	Workload	Workload below contracted base	[22]

The construct with the second largest number of issues is Danger, with a total of 104, as depicted in Table 3. Although the range of issues is very broad, three foci stand out: Governance (26 issues), Provider behavior (19 issues) and Contract (13 issues). This stresses the challenges customers face in terms of directing and managing the transaction, the potential hazardous relationship with a third party and the central role of the outsourcing contract as the fundamental instrument that structures and ultimately arbitrates the transaction. Concerning the stages of the outsourcing process we find a more balanced distribution, although jointly the relational categories gather the largest number of references, indicating that part of the negative outcomes may be traced to relational issues.

A complementary analysis of the customer-side dangers is to sort the issues by stage of the IS outsourcing process. Based on the risk elements found in literature, this reveals a dominance of governance focus issues during the decision, relationship building, and relationship management stages; a conjunction of capability, governance, and provider behavior issues during the provider selection stage; the relevance of provider capability during relationship structuring; and the impact of provider behavior issues, closely followed by contract and governance related issues on the outcomes of an IS outsourcing process for the customer.

Table 3. Customer-side dangers

Stage						**Focus**	**Item**	**Authors**
D	**PS**	**RS**	**RB**	**RM**	**O**			
	×					Capability	Difficulty in attracting providers	[22]
	×					Capability	Difficulty in attracting providers to perform small slices of IS services	[22]
					×	Capability	Inability to respond to changes	[19,36]
				×	×	Capability	Insufficient knowledge transfer between customer and provider	[40]
			×	×		Communication	Communication difficulties between customer and provider	[6,32,38]
			×	×		Communication	Ineffective liaison elements between customer's managers and provider's IT specialists	[30]
			×	×		Communication	Insufficient interactions across outsourcing team members	[35]
				×		Communication	Logistical complications between customer and provider	[38]
	×	×		×	×	Communication	Miscommunication of services requirements	[35]
					×	Contract	Breach of contract by the provider	[6,24,25,26,37]
			×	×	×	Contract	Contract in favor of provider	[38]
				×		Contract	Difficulty in adapting outsourcing contracts in the face of business or technical change	[16,29]
		×		×		Contract	Difficulty in changing outsourcing panel of providers	[22]
				×		Contract	Difficulty in reducing costs when lesser volumes of outsourced services are required	[22]
					×	Contract	Exceeding budget in unit pricing outsourcing contracts	[22]
			×	×	×	Contract	Incomplete outsourcing contract	[16,29,34,37]

			×	×	×	Contract	Inflexible outsourcing contract	[6,34]
					×	Contract	Lack of competition on outsourcing contract rollovers	[22]
					×	Contract	No reflection of technical costs deflation in outsourcing contract	[19]
				×	×	Contract	Obstacles to the use of alternative providers	[22]
		×			×	Contract	Portion of outsourcing contract price devoted to accommodate the volatility of provider's cost to supply	[22]
					×	Contract	Inflexible outsourcing contract terms	[27]
			×	×		Culture	Poor cultural fit between customer and provider	[6]
×					×	Environment	Business uncertainty	[23,30]
					×	Environment	Currency fluctuations	[35,41]
					×	Environment	Environmental disaster	[20,39]
			×	×	×	Environment	Geopolitical instability	[35,40,41]
×					×	Environment	Legal environment uncertainty	[38,42]
					×	Governance	Awareness of the outsourcing costs incurred only allows to correct future behavior, precluding the recoup of past losses	[22]
				×		Governance	Differences in methodologies/processes used by distinct members of outsourcing provider team	[35]
			×	×		Governance	Difficulty in managing remote teams	[6]
					×	Governance	Failure to specify appropriate measures for service	[38]
				×		Governance	High number of small outsourcing contracts to manage	[22]
				×	×	Governance	Inability to know state of the outsourcing service	[38]
×	×	×			×	Governance	Inadequate requirements or strategy for outsourcing	[21,38]
	×					Governance	Inappropriate provider selected	[36]
	×				×	Governance	Incorrect outsourcing project planning	[32]
			×	×		Governance	Ineffective coordination between customer and provider	[42]
×						Governance	Lack of consideration of the merits of internal IT team to deliver services in-house	[27]
			×	×	×	Governance	Lack of establishment of risk/reward sharing of potential initiatives between customer and provider	[22]
				×		Governance	Loss of track of individual cost drivers	[22]
			×	×		Governance	Low visibility of outsourcing project processes	[35]
				×		Governance	Misinterpretation over outsourcing scope	[22]
					×	Governance	Outsourcing costs in the control of the provider	[22]
				×	×	Governance	Overlook of post-outsourcing	[27]
			×	×	×	Governance	Poor audit, quality assurance and control of outsourced services by customer	[38]
				×		Governance	Poor location of outsourcing contract management responsibility	[22]
					×	Governance	Poor management of change	[35,38]
				×	×	Governance	Poor management of users' expectations	[35,38]
				×	×	Governance	Poor project management by provider	[38]
				×		Governance	Poor relationship management by provider	[16,29]
			×	×		Governance	Poor relationship management of multiple providers	[22]
×	×				×	Governance	Unclear outsourcing cost-benefit relationship	[24]
					×	Governance	Unrealistic estimation of schedule and required resources	[38]
			×	×	×	Parties behavior	Complacency in customer and/or provider	[22]
			×	×		Parties behavior	Conflict between customer and provider	[19,38]
			×	×		Parties behavior	Lack of cooperation between customer and provider	[32]
			×	×	×	Personnel behavior	Lack of cooperation by customer IT team	[38]
×			×	×	×	Personnel behavior	Opposition from internal IT staff	[6,25]
				×		Power	Power asymmetries developing in favor of the provider	[6,16,29,34]
					×	Privacy	Insufficient privacy of data handle by IS services outsourced	[37,40]
			×	×		Provider behavior	Adversarial relationship between multiple contracted providers	[19,22]
	×	×				Provider behavior	Biased portrayal by providers	[6,26,34,38]

					×	Provider behavior	Delivery of outsourced services restricted to core contract discarding value-added component	[22]
				×		Provider behavior	Encroachment of areas of activity among providers	[22]
				×		Provider behavior	Exploitation of customer's expertise by provider	[34]
					×	Provider behavior	Lack of motivation of provider to reduce costs	[22]
			×	×		Provider behavior	Lack of trust on provider	[6,23,26]
					×	Provider behavior	Misplacement of focus on outsourcing service provided (how vs. what)	[30]
				×	×	Provider behavior	Monopolistic provider's behaviors	[22]
				×		Provider behavior	Non-compliance with specified methodologies for developing or providing services	[38]
				×	×	Provider behavior	Opportunistic bargaining by provider	[19,23,41]
					×	Provider behavior	Poaching	[41]
				×		Provider behavior	Provider limits its accountability to specification meeting	[22]
					×	Provider behavior	Provider with superior experience takes advantage of inexperienced customer	[22]
					×	Provider behavior	Shirking (deliberate underperformance by provider while claiming full payment)	[23,41]
	×					Provider behavior	Too low outsourcing bidding to make a profit	[22]
			×	×	×	Provider behavior	Unethical behavior of provider	[38]
				×		Provider behavior	Unexpected subcontracting of IS services outsourced by provider	[19,22,34]
				×		Provider behavior	Use of hidden subcontractors by provider	[37]
					×	Provider capability	Difficulty in incorporating existing data into outsourcing services to provide	[37]
		×	×	×	×	Provider capability	Lack of experience of provider	[6,30]
		×	×	×	×	Provider capability	Lack of expertise of provider	[6,22,25,30,35, 38]
					×	Provider capability	Loss of provider's key employees	[38]
				×		Provider capability	Reduced provider's teamwork effectiveness	[32]
		×				Provider capability	Underestimation of the resources required to run the customer's systems by provider	[31]
					×	Provider capability	Unsuitability of technical methodologies applied by provider	[32]
					×	Provider infrastructure	Instability of provider's infrastructure	[40]
					×	Provider infrastructure	Technological platform of services outsourced restricted to vanilla solutions	[22]
					×	Provider infrastructure	Technical problems with telecommunications or infrastructure	[22,35]
			×	×	×	Provider personnel	High turnover/burnout of provider's staff	[6,35,40]
			×	×	×	Provider personnel	Unreliability of provider	[42]
					×	Provider service	Insufficient support or maintenance by provider	[22,35,37]
					×	Provider service	Poor provider service	[6]
					×	Provider viability	Poor provider's financial stability	[6,19,28]
					×	Provider viability	Provider goes out of business	[6,34]
					×	Regulatory	Non-compliance with regulations	[36,37]
				×	×	Requirements	Conflicting requirements	[38]
				×		Requirements	Difficulty in negotiating requirements changes	[22]
×	×	×			×	Requirements	Inconsistent, missing, or incorrect IS requirements for services to outsource	[32]
				×	×	Requirements	Requirements instability	[38,42]
			×	×		Security	Accommodation of services outsourced infrastructure and granting access to provider's staff	[22]
					×	Security	IS security issues	[25,37,39,40]
×					×	Uncertainty	Endemic uncertainty	[30,43]

The fifty five factors that have resulted from the interpretation of the reviewed literature on IS outsourcing risks are presented in Table 4. This is the construct category where the issues have distributed more evenly over the six outsourcing process stages. Two factors – experience and expertise with IS outsourcing – are present throughout the lifecycle of outsourcing, with customer's expertise being the most cited factor. The majority of the factors (30) have locus on the customer, followed by 20 factors related to the transaction and five factors being attributes of the provider. Concerning the issues with customer locus, the two major focus categories are Governance (14 factors), comprising a set of issues that shapes the perspective customers hold on outsourcing, followed by Capability (11 factors), as measures of the customer's skills and competences on IS outsourcing.

To a certain extent, this list of factors provides a means for a customer to evaluate its current stand with respect to the fulfillment of the conditions for enabling a successful IS outsourcing transaction. Indeed, by self-diagnosing itself in the majority of the factors, and by judging provider related characteristics and outsourcing transaction features, the customer may get a better understanding of the present weaknesses and be in a better position to decide if meets the conditions to go ahead with the outsourcing or if is able to improve certain attributes in order to compensate some imbalance both in terms of know-how or power in relation to the provider.

Table 4. Customer-side factors

Stage						Locus	Focus	Item	Authors
D	**PS**	**RS**	**RB**	**RM**	**O**				
×	×					Cust	Capability	Capability to attract providers	[22]
				×		Cust	Capability	Capability to manage outsourcing contract scope changes	[40]
				×		Cust	Capability	Capability to measure services outsourced	[21,27,43]
			×	×		Cust	Capability	Capability to trace accountability in outsourcing services outsourced	[22,44]
					×	Cust	Capability	Change management capability	[3,8]
×	×	×	×	×	×	Cust	Capability	Experience with IS outsourcing	[16,29,34]
×	×	×	×	×	×	Cust	Capability	Expertise with IS outsourcing	[6,21,22,27,30,34,35,38,42,43,44]
		×				Cust	Capability	Familiarity with international and foreign contract law	[35]
			×	×		Cust	Capability	Reliability of mechanisms to audit and control outsourcing service	[21,27]
	×	×				Cust	Capability	Sourcing and contracting capability	[16,29]
		×	×	×	×	Cust	Capability	Variation of available technical expertise	[27]
			×	×	×	Cust	Environment	Stability of business and organizational environment	[38]
×						Cust	Financial	Availability of funds	[38]
		×				Cust	Governance	Acceptance of standard outsourcing contract arranged by provider	[27]
			×	×	×	Cust	Governance	Commitment to outsourcing by customer	[38]
				×		Cust	Governance	Complexity of integrating multiple providers	[22]
	×	×	×	×	×	Cust	Governance	Governance capability of outsourcing project	[38]
×	×					Cust	Governance	Information on outsourcing market	[21]
		×				Cust	Governance	Information security policy	[27]
×	×	×				Cust	Governance	IT considered an undifferentiated commodity to be outsourced	[6,16,29,34]
		×				Cust	Governance	Outsourcing scope (total vs. selective)	[27]
×						Cust	Governance	Patriotic perception of offshore outsourcing	[6]
×	×	×				Cust	Governance	Purpose of outsourcing	[16,29]
×	×	×				Cust	Governance	Realism of expectations for outsourcing	[16,29,34,38]
×	×					Cust	Governance	Requirement for different subcontractors	[22]
×						Cust	Governance	Soundness of outsourcing cost-benefit relationship	[25]
×		×	×	×		Cust	Governance	Top management commitment	[27,35]
×			×	×	×	Cust	Personnel	Level of internal resistance to outsourcing	[19,24,38]
			×	×	×	Cust	Personnel	User involvement	[35]

×					×	Cust	Strategy	Alignment between business strategy and IT	[38]
×	×					Prov	Availability	Number of available providers	[43]
			×	×	×	Prov	Capability	Consistency of capabilities between different regional providers	[22]
		×	×			Prov	Capability	Existence of certification and quality model by provider	[21]
	×		×	×	×	Prov	Capability	Qualification of provider's staff	[24,25,38,40]
	×					Prov	Viability	Provider viability	[35]
			×	×		Tran	Accessibility	Physical access to provider's site	[22]
			×	×		Tran	Communication	Language and communications between customer and provider	[35,40]
			×	×		Tran	Communication	Quality of communications and transmission systems between customer and provider	[41]
					×	Tran	Complexity	Complexity of operations	[41]
			×	×	×	Tran	Complexity	Interdependence between tasks, business units and functions	[30,42,43]
			×	×		Tran	Complexity	Interdependence of services and contracts among providers	[22]
×	×	×			×	Tran	Complexity	Technical complexity of services to outsource	[38,42]
		×	×	×		Tran	Contract	Contract penalties for non-performance	[27]
		×				Tran	Contract	Extension of provider's rights in outsourcing contract	[22]
		×				Tran	Contract	Inclusion of service level agreements in outsourcing contract	[27]
		×		×	×	Tran	Contract	Outsourcing contract length	[22,27,40]
					×	Tran	Contract	Pricing framework of outsourcing contract	[38]
			×	×		Tran	Culture	Cultural differences between customer and provider	[6,19,35,36, 40,41,42]
		×	×	×		Tran	Governance	Agendas of customer and provider	[22]
		×	×	×		Tran	Governance	Degree of shared accountability between customer and provider	[22]
			×	×		Tran	Location	Different time zones between customer and provider	[35,40]
			×	×		Tran	Location	Geographic separation between customer and provider	[38,41]
		×			×	Tran	Regulatory	Laws and regulations in provider's country	[27]
×	×	×	×	×		Tran	Size	Size of the outsourced service	[38,40]
		×		×		Tran	Specificity	Specificity of assets used by provider to supply outsourced services	[43]

The analysis of the collected works resulted in the consolidation of 127 mitigation actions which are listed in Table 5. This is the construct with the largest pool of instances, although no single issue clearly stands out over the rest. Yet, the analysis by focus shows a strong incidence of the mitigation actions in governance related practices (Transaction Control and Project Management), followed by the Relationship and Capability categories. As it might be expected, the stage Outcomes does not contain any issue, highlighting the reasoning that mitigation actions must be timely implemented.

A note of caution regarding this list is that some of the actions advanced in literature are actually goals, instead of specific means that may diminish the severity of negative outcomes. This implies that some items classified as risk mitigation actions would benefit from a concretization, by indicating specific actions that might contribute to the achievement of the formulated goal. Indeed, for some of these items, it might be possible to interpret them as inverse negative outcomes.

Table 5. Customer-side mitigation actions

Stage						Focus	Item	Authors
D	PS	RS	RB	RM	O			
×	×	×	×	×		Capability	Develop IS outsourcing expertise	[16,22]
			×	×		Capability	Develop outsourcing project management capability	[29]
			×	×		Capability	Ensure customer user-provider liaison capability	[34]
×	×	×	×	×		Capability	Resort to external consultant advice	[22,29,32]
				×		Capability	Retain key IS business skills	[16,22,29]
				×		Capability	Retain key IS technical skills	[22,29]
			×			Change management	Establish change management	[32]
×						Commitment	Get buy-in from business unit management	[22]
×						Commitment	Get buy-in from regions	[22]
×						Commitment	Make senior management sign business case for outsourcing	[16]
				×		Commitment	Provide management focus and time	[22]
			×	×		Communication	Ensure fit between outsourcing task and communication medium	[32]
				×		Communication	Monitor communications network link with provider	[22]
			×	×		Communication	Undertake video conferencing and face-to-face work with provider	[32]
		×				Contract	Negotiate detailed and complete contract	[16,34]
		×				Contract chunkification	Distribute outsourcing services among providers (horizontal chunkification)	[7,29,41]
		×				Contract chunkification	Divide outsourcing work into sequential non-overlapping activities (vertical chunkification)	[7,16,29,41]
			×			Contract dissemination	Disseminate contract highlights to entire user community	[34]
		×				Contract interdependence	Design interdependent contracts between independent providers	[22]
		×				Contract length	Negotiate short-term contracts	[24,34]
		×				Contract length	Preview additional extension option in contract	[29]
		×				Contract termination	Establish rules and options for contract termination	[16,22,34]
				×		Contract termination	Prepare for end of contract	[22]
			×	×		Contracts portfolio	Manage the overall small-scale deals as a portfolio	[22]
				×		Control	Retain control over IS strategy	[29]
				×		Cost drivers	Understand outsourcing transaction cost drivers and corresponding market prices	[22]
				×		Cost overruns	Minimize costs overruns	[22]
				×		Cost savings	Project cost savings over contract length	[29]
		×	×			Culture	Establish and ensure shared values when provider wants profit and the customer wants to control costs	[22]
			×			Data repository	Share outsourcing project data repository	[32]
				×		Disputes resolution	Resort to mediation and arbitration to resolve disputes	[7]
		×				Documentation	Establish standards for service documentation	[32]
×						Feasibility	Balance performance requirements for services to outsource with capabilities of technology	[34]
		×				Financing options	Negotiate with provider financing options for the outsourcing contract	[23]
		×				Flexibility	Ensure sourcing alternatives in contract	[22]
		×				Flexibility	Include in contract flexibility rights	[7,22]
				×		Flexibility	Retain switching possibilities	[29]
		×				Flexibility	Use performance-based contracting where possible	[34]
		×				Incentives	Include in contract efficiency incentives	[30]
		×				Infrastructure	Ensure asset refreshment at market standards and prices	[22]
				×		Intellectual property rights	Retain intellectual property rights	[29]

×					Justification	Analyze outsourcing need before contracting	[29]
×					Justification	Assess outsourcing ‘soft’ factors, not just price/cost	[29]
×					Justification	Determine what IT gives business advantage	[16]
×					Justification	Distinguish between core/non-core business and IT assets and activities	[29,16]
×					Knowledge	Ensure full understanding of the nature of the work to be outsourced	[24]
×					Knowledge	Ensure understanding of systems and products	[16]
				×	Knowledge	Retain business understanding of services outsourced	[29]
	×				Knowledge	Understand if and how provider earns a profit	[34]
				×	Maintenance	Retain standards maintenance	[29]
			×		Measurement	Establish detailed performance metrics that aggregate to overall service metrics	[22]
		×			Measurement	Establish performance measures and service-level agreements	[16,29,30,34]
		×			Measurement	Introduce in contract provision to business contribution measurement	[29]
			×		Methodology	Avoid non-appropriate development methods	[32]
		×			Non-competition	Include non-compete clause in contract	[34]
				×	Ownership	Retain ownership of IS assets	[16,29]
		×			Parties expectations	Delineate in contract expectations from both customer and provider perspectives	[16,34]
		×			Personnel	Define personnel policies at the signing of outsourcing contract	[30]
			×	×	Power balance	Ensure power balance between parties	[22]
		×			Pricing	Avoid time and material contracts	[32]
		×			Pricing	Contract on a market-competitive price and service basis	[16]
		×			Pricing	Forecast against fixed-price limitations such as volume constraints	[22]
		×			Pricing	Negotiate adequate pricing framework with provider	[16,22,29]
		×			Pricing	Stipulate in contract update of resource usage charging after customer’s systems become running at the provider’s operating environment	[31]
		×			Pricing	Unbundle lumped prices to assess cost drivers or benchmark	[22]
			×	×	Project management	Direct provider’s efficiency	[22]
			×	×	Project management	Ensure delivery of accountabilities plus planning and executing initiatives	[22]
			×		Project management	Establish clear and comprehensive outsourcing management structure	[29,32]
			×		Project management	Establish project management	[32]
				×	Project management	Perform complete project management of outsourcing transaction	[22,23,32,34]
			×	×	Project management	Perform daily contract management	[16,29]
	×				Provider capability	Demand from providers customer references that illustrate turnaround cases	[34]
	×				Provider capability	Evaluate provider capabilities	[32]
			×	×	Provider competition	Maintain ongoing rank of providers panel members based on performance	[22]
	×				Provider competition	Promote competitive bidding mechanism between providers	[22,29]
			×	×	Provider direction	Provide clear directions to the provider	[22]
	×				Provider quality	Select supplier with sound financial position, stable customers, proven track reports, and stable strategic partners	[34]
			×	×	Relationship	Communicate with provider	[19]
		×			Relationship	Contract a good foundation for relationship between customer and provider	[29]

			×		Relationship	Develop a preferred provider relationship to deal with unanticipated work over the contract length	[29]
			×		Relationship	Expedite outsourcing relationship by using a strategic partner, establishing a joint venture or involving a subsidiary	[32]
			×		Relationship	Make provider participate in the formulation of design specifications	[23]
			×	×	Relationship	Manage relationship	[22]
			×		Relationship	Retain relationship building	[16]
			×		Relationship	Set processes in place to let relationship develop	[29]
		×			Requirements	Balance unique needs and standardization needs in contract	[22]
			×		Requirements	Perform face-to-face requirements analysis	[32]
			×	×	Risk management	Ensure risk management is performed in low value contracts	[22]
		×			Risk sharing	Make the provider share the risks	[26]
×					Scope	Consider opting for selective outsourcing or outsourcing with multiple providers	[24]
×					Scope	Consider passing complete outsourcing of projects, except design specifications, to provider	[23]
×					Scope	Consider restricting outsourcing to technology implementation	[29]
×					Scope	Define outsourcing scope	[22]
				×	Security	Consider using virtual private networks for highly sensitive data	[34]
				×	Security	Encrypt data	[34]
	×				Security	Ensure security and disaster recovery at provider	[22,29]
				×	Security	Retain access control in-house	[34]
	×				Selection quality	Establish multi-disciplinary group for provider selection	[29]
	×				Selection quality	Undertake thorough provider selection process	[29]
×					Strategy	Consider multiple objectives for outsourcing (economic, technical, strategic)	[29,34]
×					Strategy	Design outsourcing project by partitioning work in tranches	[29]
			×	×	Strategy	Opt for incremental or parallel implementation	[34]
×					Strategy	Perform IS capacity planning	[22]
×					Strategy	Provide strategy and direction for outsourcing decision	[22]
×					Strategy	Source incrementally	[34]
	×				Strategy	Source to multiple suppliers	[7,34]
×					Strategy	Stabilize IT applications before outsourcing	[16]
		×			Subcontracting	Establish in contract various rights over the subcontracting (access, selection, veto, etc.)	[22]
		×			Subcontracting	Require full disclosure and customer approval of all subcontractors	[34]
				×	Total cost of ownership	Manage total cost of ownership	[22]
			×	×	Tran	Manage the contract as well as the entity or equity investment	[22]
				×	Tran benchmarking	Benchmark transaction	[22,30]
			×	×	Tran control	Apply control mechanisms to the outsourcing transaction	[7,22,24,29]
				×	Tran control	Audit compliance	[22]
				×	Tran control	Audit costs and efficiency	[22]
				×	Tran control	Audit internal controls at provider	[22]
				×	Tran control	Audit provider timesheets	[22]
			×		Tran control	Establish monitor and coordination mechanisms	[23]
				×	Tran control	Monitor all providers are operating as an efficient and united front	[22]
				×	Tran control	Monitor transaction	[22,34,41]
				×	Tran control	Perform regular reviews of transaction	[16,29,30]
				×	Tran control	Perform updates of price/service/requirement	[29]
			×	×	Tran control	Undertake regular provider-business management reviews	[16,29]
×					Tran trade-offs	Ensure cost-service trade-offs are focused and clear	[29]
			×		Transition	Plan and test transition	[34]
			×	×	Work organization	Stage work hours with offshore provider	[32]
				×	Workload	Monitor and manage customer's outsourced workload	[22]

4.2 Provider side view

The analysis of the collected literature clearly showed an imbalance between the works that identify IS outsourcing risk elements related to the customers and those related to providers. Indeed, of the 34 papers analyzed, only four list risks from the perspective of the provider, and of those, only two are totally dedicated to the risks of IS outsourcing from the standpoint of providers. Actually, of the 727 risk elements that we found in the literature, 693 consist of issues related to the customer, and only 34 regard the provider side (a proportion of 19:1). Consequently, the richness and diversity of the catalog from the provider side is much lower when compared to the customer side. Although this might be understandable, given the greater number of potential customers in the market in comparison to the number of providers, we argue for the need to perform further research on IS outsourcing risks from the provider's standpoint.

An illustration of the above mentioned situation is that for providers we only categorized one risk element as an undesirable consequence and one risk element as a negative outcome, both of which were found on [22]. The undesirable consequence was formulated as "No economies of scale from sharing assets with other customers", it is located at the execution phase and it is a financial type of loss. The negative outcome was phrased as "Staff adopts customer's culture rather than provider's culture", it is located at the Relationship Building stage, it has a locus on Personnel and a focus on Culture.

In what concerns dangers, the analysis resulted in 10 issues, listed on Table 6. Three of those issues have a focus on Capability, two on the Environment, and two on Governance. With the exception of two issues, the other dangers have an impact on the outcomes stage. None of the dangers were placed on the Provider Selection or Relationship Structuring stages. The set of dangers are based on the works [45] and [46], the two studies that contemplated the IS outsourcing risk topic from the perspective of the provider.

Table 6. Provider-side dangers

Stage					Focus	Item	Authors
PS	RS	RB	RM	O			
				×	Capability	Ineffective knowledge transfer between customer and provider	[45,46]
				×	Capability	Insufficient speed of implementation of new technologies by provider	[46]
				×	Capability	Uncertainty about availability of staff to provide outsourcing services	[45]
		×	×		Communication	Ineffective communications between customer and provider	[46]
			×	×	Customer structure	Changes in customer's corporate structure	[45]
			×	×	Environment	Changes in customer's country government policy	[45]
				×	Environment	Exchange rate fluctuations	[45]
		×	×	×	Governance	Ineffective coordination between customer and provider	[46]
			×		Governance	Poor management of customer's expectations during the course of outsourcing project	[45]
				×	Requirements	Ambiguity in customer's requirements capture	[45]

The provider-side factors are in number of 13 and show a more balanced distribution between the five stages of the IS outsourcing process from the perspective of the provider, as can be observed in Table 7. Their locus is also well distributed between Customer, Provider and Transaction. In terms of focus we found Capability has the most represented class.

Finally, regarding mitigation actions, we found just one work that explicitly advanced mechanisms for providers to reduce the impact of IS outsourcing risks. The six issues, listed in Table 8, have all different focus, and none has an impact on the stages of Relationship Structuring and Relationship Building. Although some of the risk mitigation actions may have an impact on more than one stage, all of them were classified as enabling the reduction of risk on the Outcomes stage of IS outsourcing.

Table 7. Provider-side factors

Stage					Locus	Focus	Item	Authors
PS	RS	RB	RM	O				
	×	×	×	×	Cust	Capability	Outsourcing experience of customer	[45]
	×	×	×	×	Cust	Culture	Customer's mindset regarding IS outsourcing	[45]
				×	Cust	Provider replacement	Easiness of replacement of the provider by the customer	[46]
	×		×	×	Cust	Size	Customer size	[45]
×	×	×	×	×	Prov	Capability	Expertise with outsourcing	[43]
×	×	×	×	×	Prov	Capability	Expertise with the outsourcing services to provide	[43,46]
			×	×	Prov	Capability	Project management capability	[45]
×					Prov	Competition	Level of international competition in the area of IS outsourcing	[46]
			×		Prov	Governance	Effectiveness of procedures for solving emerging problems or conflicts with customer	[46]
			×	×	Tran	Contract	Retention of outsourcing contract rollover discretion by the customer	[22]
			×	×	Tran	Contract	Sufficiency of formal warranties in outsourcing contract for fulfilling contracted outsourcing tasks	[46]
				×	Tran	Specificity	Specificity of assets used by provider to supply outsourced services	[45]
		×	×		Tran	Trust	Level of mutual trust between customer and provider	[46]

Table 8. Provider-side mitigation actions

Stage					Focus	Item	Authors
PS	RS	RB	RM	O			
×				×	Certification	Globally certify processes	[40]
×				×	Communication facilities	Ensure quality communication facilities	[40]
			×	×	Contract	Manage contract	[40]
×				×	Local partners	Resort to reliable local partners near the customer	[40]
			×	×	Service levels	Offer standardised service levels	[40]
				×	Development tools	Use global development tooling	[40]

5. Conclusion

The search for a theory of IS outsourcing risk is a long and difficult endeavor. In this paper we attempted to begin attacking that challenge by proposing a conceptual framework comprising the main constructs of the theory and by elaborating a catalog of IS outsourcing risks based on literature. This catalog is structured in two parts – the customer-side view and the provider-side view, which in turn are composed by five sets of classified risk elements, namely dangers, negative outcomes, factors, mitigation actions, and undesirable consequences.

For practitioners this catalog offers a systematic review and classification of the IS outsourcing risks found on the literature. This artifact may prove useful for those considering outsourcing the management or operation of theirs IT assets or activities, those seeking to market their outsourcing services, and those that already embarked in such a transaction. By foreseeing important elements influencing the success of an outsourcing process, the artifact may assist practitioners performing the corresponding IS outsourcing risk analysis, self-diagnosing weaknesses, drawing attention to possible future troubles, and helping to understand how certain outcomes materialized.

For researchers, we think that the catalog can form a basis on which to build research efforts that may finally lead to the synthesis of an IS outsourcing risk theory. The catalog was developed according to a conceptual framework that we believe capture the main distinctions of the risk concept. Moreover, the catalog holds on an extensive review of the existing literature that explicitly addressed IS outsourcing risks, not only listing, but also condensing and categorizing each of the risk elements present in the literature reviewed.

Nevertheless, this work has several limitations. One cannot consider the catalog as exhaustive or complete. Probably, it will never be a complete artifact – it is possible that new risks emerge, new factors have to come into play, and new mitigation actions have to be devised. Additionally, different types of IS outsourcing may have associated specific subsets of risks, a situation that the presented catalog does not address, since it treats indistinctly outsourcing varietals. A third limitation is the subjective interpretation underlying the condensing and categorization of each of the risk elements found on the literature. Although we tried to minimize this limitation by splitting the analysis of risk elements among the authors and by allocating blocks of risk elements to more than one of the authors in order to evaluate and improve the reliability of the analysis, there may still be room for discordant interpretations.

The move towards the generation of an IS outsourcing theory admits (and requests) many future works. At the conclusion of this study we advance six avenues for research. One is to complement the part of the catalog related to the provider's viewpoint. In possession of a more rich categorization of the IS outsourcing risks from the perspective of the providers, we would be able to relate the risk perspectives of the two stakeholders in an IS outsourcing transaction. A second suggestion is to complement the constructs danger and negative outcome with a risk profile. Recognizing the operational difficulty of adopting an approach that could take into account the contingencies of a specific customer or provider, an alternative way to assist in risk profiling might be to assess the possibility of dangers and negative outcomes by indexing it to the factors. A third proposal for future research is to conduct a field study in order to assess the comprehensiveness of the catalog. This could consist of a retrospective study of a series of IS outsourcing cases in the risk sphere. The fourth proposition involves equalizing the granularity of the issues that instantiate each of the constructs that make up the catalog. An additional idea for future work derives from the complementary view of risk as opportunity that can produce gains. Adopting this view, where IS outsourcing benefits are conceived as (eventually positive) risks, one could extend the theory to encompass the interplay between IS outsourcing dangers and opportunities. The final suggestion is to pursue in full extent the structure of the conceptual framework. Besides proposing the fundamental constructs of interest in the realm of IS outsourcing risks, the conceptual framework establishes a relationship between the constructs. The test and exploration of the relationships between the items composing the catalog, namely between issues pertaining to the construct factor and to the construct danger, danger and negative outcome, mitigation action and negative outcome, and negative outcome and undesirable consequence, would effectively constitute a network of connections between the items, and substantiate a theory of IS outsourcing risk.

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Resource allocation in IT projects: using schedule optimization

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Resource allocation in IT projects: using schedule optimization

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Abstract:
Resource allocation is the process of assigning resources to tasks throughout the life of a project. Despite sophisticated software packages devoted to keeping track of tasks, resources and resource assignments, it is often the case that project managers find some resources over-allocated and therefore unable to complete the assigned work in the allotted amount of time. Most scheduling software has provisions for leveling resources, but the techniques for doing so simply add time to the schedule and may cause delays in tasks that are critical to the project in meeting deadlines. This paper presents a software application that ensures that resources are properly balanced at the beginning of the project and eliminates the situation in which resources become over-allocated. It can be used in a multi-project environment and reused throughout the project as tasks, resource assignments and availability, and the project scope change. The application utilizes the bounded enumeration technique to formulate an optimal schedule for which both the task sequence and resource availability are taken into account. It is run on a database server to reduce the running time and make it a viable application for practitioners.

Keywords:
project management; optimization; resource allocation; bounded enumeration.

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1. Introduction

This paper discusses allocation of renewable resources within Information Technology (IT) software development projects. While the overall process of IT development is similar to managing projects in any other industry, it has some distinct differences. First, IT projects rely almost exclusively on renewable human resources. As personnel are assigned tasks, they complete them in a particular sequence and pass the project on to the next person in the chain. Once freed, the worker then begins work on the next project. Second, IT projects are considered intellectual work in which information about the project must be shared with co-workers, and so adding more workers to speed things up usually does not help, but may make things worse [1]. Third, the direct costs of an IT project are almost exclusively due to labor costs [2]. Some IT applications may require hardware and software acquisitions; however, these are generally not considered direct variable costs, because they are considered part of the firm's IT infrastructure and can be reused for other projects. Additional characteristics of IT projects include project environments in which multiple projects are concurrently active and that many projects are given pre-planned deadlines (i.e., they are time boxed). Time boxing causes project managers to carefully evaluate the project scope in order to meet pre-planned deadlines, while the nature of the work and prior experience may fix the number of personnel assigned to any particular task.

These factors form the basis of this analysis of IT project scheduling and resource allocation methods in this paper. We therefore focus on fixed sets of human resources with different skill sets forming separate labor pools who are attempting to complete a project in the minimum amount of time (minimized make span). Our analysis includes multiple projects that may be competing for the same sets of human resources.

The first step in creating a work plan for a new IT project is to identify and schedule the set of tasks necessary to complete the project. The resulting schedule must observe all of the technical constraints imposed by the project (i.e., the sequence of tasks) and the applied constraints imposed by the number of available resources. In the planning stages, project schedulers often estimate task duration based on the number of resources available and therefore over allocation of resources for a single project is not expected. Once the project gets underway, however, resources can easily become over-allocated due to a number of different factors, such as changes in personnel, lack of availability of personnel due to vacations, sick leaves or changes of employment or because a number of projects may be competing for the same set of resources. The result is that resources assigned to certain tasks may not be able to complete them within the planned schedule and this situation calls for immediate action on the part of the project manager. To be competitive, an organization must attempt to schedule all tasks so that the project is completed in the minimum time.

Scheduling IT projects proceeds as just described and includes identifying tasks, estimating their duration and placing them on a timeline (Gantt chart) that visually displays their sequence, duration, and start and end date. Resources are then assigned to each task from available labor pools, which are separated by skill set. IT projects resemble assembly lines in that different pools of resources perform tasks at specific times during the project. That is, business analysts generally are assigned to the project near the beginning and they build a business case for the application. Next, the systems analysts begin to gather requirements and formulate models of how the software will work. This goes into the design specifications that are passed to programmers who implement the application. The completed application is then sent to quality engineers who provide alpha testing to clear up any bugs and ensure that the application meets the users' requirements. This may be followed by beta testing with a sample of users not involved in the application's development to further refine the program and identify bugs. Once any identified bugs are removed, the completed application is sent to those who are responsible for its deployment and training of users. The duration of the tasks contained in each of these stages is dependent upon what must be done, the complexity of the tasks and the number of resources available at the time. While this may seem like a straightforward process, problems with the planned schedule can occur when multiple projects are being executed at the same time. Problems can also occur when changes are made to the project itself or to the labor pool to which a set of tasks is assigned. Any of these situations can cause delays, which can in turn affect the cost of one or several projects.

Delays can also be caused by the over-allocation of resources. Delays in one project may affect other projects that are being executed concurrently, causing a slowdown in production and fewer projects meeting their deadlines. When resources become over-allocated, the project managers must devote time to reallocating tasks to additional personnel or to different time periods. Although this can sometimes be done automatically in sophisticated project management software, the process is not particularly straightforward, it consumes a lot of time and the result is usually less than satisfactory. A solution to this problem is to schedule the tasks in all active projects while taking into account the maximum number of resources available. Doing so would prevent over-allocating any resource. We take this approach in this study by introducing a software application that takes the production schedule as input and produces an optimal schedule as output. The software is programmed to recognize the restrictions imposed by the sequence of tasks and by the number of resources from one of several resource pools. Because of this, the resulting schedule yields no over-allocated resources. The application can be used in a multi-project environment and can be run throughout the lifetime of any project, thus providing more current estimates to the project manager.

We have found that over-allocation of resources is a common problem within firms engaged in IT development. In fact, this study was prompted by representatives from a large petro-chemical company who were having difficulty with resource allocation. Project managers in the company often found that they had IT developers who were often over scheduled even though a sophisticated commercial project management program was used to plan, assign and track activities in a large number of concurrent projects. The company asked us to assist them with solving the problem, and so we turned our attention to creating the program that we introduce in this paper.

This paper is organized as follows. The first section is devoted to a detailed explanation of the over-allocation problem and a survey of the literature relevant to it. The next section discusses the software artifact that we produced, including the logic upon which it is based and the results of testing it against a number of artificially generated project networks. The last section outlines the remaining work to be done and provides a description of the experimental design, the variables to be measured, the metrics to be used and the definitions of what would be considered successful findings.

2. Overview and literature review

Scheduling tasks in a project is a complex and time consuming endeavor and has been studied and improved since the Critical Path Method (CPM) and Program Evaluation and Review Technique (PERT) methods were introduced in the 1950s. CPM is known to suffer from its inability to deal with the problem of limited resources [3]. PERT was designed to take into account some of the uncertainty in estimating the duration of tasks that comprise a project [4], by including a set durations for each task based on an optimistic, expected or pessimistic estimate and computing a weighted average to act as the best estimate. CPM and PERT are applied to one project at a time and neither specifically address the restrictions imposed by limited resources [5]. It is doubtful that they were ever intended to be used in a multi-project environment in which different but concurrent projects would compete for the same set of resources.

While the original project management techniques were designed to help better manage large and complex projects, it quickly became apparent that improvements were needed in order to help reduce costs and shorten the time to completion. In addition, because resources are limited in any project endeavor, this constraint needed to be added to the technique. A significant amount of research was accomplished in the ensuing decades, devoted to minimizing the duration of the project and accounting for the limitations imposed by limited resources. Wiest [6] pointed out that although the critical path may represent the longest sequence of tasks in a project, the idea of it being critical becomes meaningless when resources are limited, because any task may be delayed due to the lack of resources. He identified a critical sequence to account for both the required sequencing of tasks and the constraint of limited resources, but warned that the linear programming techniques (at the time) were infeasible for practically sized projects due to their computational requirements. Computational efficiency was analyzed and reported by Davis [7], who discussed the problems encountered when attempting a mathematical formulation of the resource constrained scheduling problem. Herreoelen, De Reyck and Demeulemeester [8], followed in this vein by discussing the computational efficiency of several optimization techniques developed since Davis' [7] analysis.

Gutjahr and Nemhauser [9] also addressed the computational difficulty of the class of scheduling problems by stating that because of the large number of possible solutions, a complete enumeration of them is impractical. They presented a more efficient technique that eliminates some solutions during the computation because they violate one or more of the constraints imposed. An exact solution can then be determined much more quickly and efficiently than other techniques. Their method was applied to the resource constrained scheduling problem by Davis and Heidorn [10], which we discuss later.

The difficulty of the scheduling problem seems to have challenged researchers into searching for solutions. For example, Moodie and Manville [11] presented an integer linear programming (ILP) technique aimed at solving the assembly line balancing problem, which is similar to finding an optimal schedule for a project. Held and Karp [12] presented a dynamic programming solution to scheduling problems and demonstrate the technique by applying it to both the traveling salesman and the line balancing problems. Dynamic programming has been applied to this problem by numerous researchers since then [cf. e.g., 13, 14]. Goldratt [15] introduced his theory of constraints and the critical chain as a way of viewing, managing and scheduling projects.

Robinson [16] published an algorithm that determines the cost-time function in order to find the project's minimum duration resulting from the optimal allocation of resources to each activity. Implicit in his study is that the number of resources can be adjusted to shorten the duration of any particular task. In software development we find this generally not to be the case because an organization assigns resources (from limited resource pools) to tasks based on the need for specific skills to accomplish the task and because adding more resources to a project tends to slow it down [1]. Adding resources to shorten a project may work well when the work does not involve creative activity or communication among workers; however, in software development, adding more workers is, in Brooks' words, "Like dousing a fire with gasoline…" [1, p. 14].

When limited resources are taken into account the problem is labeled as the Resource Constrained Project Scheduling Problem (RCPSP). This type of scheduling problem is known to be NP hard [17], because the solution space grows much faster than the problem space. It can therefore quickly become intractable for practically sized projects due to the amount of computation required, which is manifested as computing time. Much work has been devoted to this problem, which has generally been addressed either through heuristics or exact solutions [18] and aimed at scheduling around the limitations imposed by scarce resources. Heuristic solutions tend to be favored because they are fast and provide reasonable results, while exact solutions, such as linear and dynamic programming techniques require too much time for practically sized problems. Davis and Patterson [19] compared the results of eight widely used heuristics to an optimum solution produced through the bounded enumeration technique found in [10]. Their results showed a wide variance in the ability of each of the 8 heuristic techniques to produce schedules that were close to optimal, with the average percentage increase above optimal ranging from 5.6% to 16%. Of the 83 test projects used in the analysis, the ability of heuristics to find an optimal schedule also varied widely and ranged from 1 to 24 test cases [19].

Recent work focusing on heuristics has employed such techniques as genetic algorithms and artificial intelligence [cf. e.g., 20] and hybrid techniques [21]. Studies have also analyzed multi-mode problems [22] and have applied meta-heuristics to the multi-mode problem [23]. Additional work has been done recently on exact approaches as well, including mixed integer programming [24] and dynamic programming [25].

Bandelloni and colleagues [26] provided a definitional distinction between resource allocation and resource leveling. They said that resource allocation applies to the case when resources are limited and the scheduling objective is to "keep the project completion time as close as possible to the critical path length such that the resource constraints are met" [26, p. 162]. They further classified resource leveling as a process in which there are no resource limits and the consumption of resources can be controlled to follow a desirable shape. The focus of this study will be on the allocation of resources in a software development project with the goal of scheduling resources to perform specific tasks and ensuring that they are not over-allocated, that is, they are not scheduled to perform so many tasks that they cannot perform them in the time required.

Despite the distinction provided by [26], we should note that the terms resource leveling and resource allocation are often used interchangeably. For example, most project management software programs have options for "resource leveling." This function attempts to solve the allocation problem and can be invoked when the project manager discovers that a resource is over-allocated. In addition, [27] compared the resource allocation capabilities of seven commercial project management programs, but his analysis seems to address a resource leveling function, because he asked the programs to optimally allocate resources while at the same time find the minimal makespan for a project, suggesting a causal link between the two. In any case, the problem we study here is intended to provide an optimal schedule in the planning phase that incorporates the resource limitations and by doing so, will encounter no over-allocation problems throughout the life of the (unchanging) project. We will also discuss the effects of various types of changes on the project schedule.

When a project manager is faced with an over-allocated resource, he can invoke the resource leveling option in his software. Doing so generally causes one or both of two things to occur: some tasks are reassigned to others who are under-allocated and/or some tasks are delayed until enough resources become available to complete the task(s) affected by the over-allocation. How this is done by the software is not particularly straightforward and each package may use its own proprietary method to do so [27]. The results can be difficult to understand and even more difficult to manage, as it may require a larger time investment by the project manager into activities that are not a part of the project. It may also require that some tasks be split by interrupting work on one task to make resources available for others. It is sometimes recommended that leveling of over-allocated resources be done individually and manually [28].

Our stated goal in this paper is to introduce a software program that produces an optimal schedule that accounts for both the technical and the resource constraints of a project in order to prevent over-allocation of resources. A schedule produced at the beginning of a project that conforms to this definition will have no over-allocated resources; however, the conditions under which software development projects are conducted may change and this may result in resource allocation problems. There are three factors that may affect the allocation of resources during the life of a project. The first is an increase in scope of the project that will necessitate more effort to complete it. This is not an uncommon occurrence in software development, and has been listed as the 14th most often reason for IT project failure [29]. It has also been found to occur in 23% of all IT projects [29]. Secondly, resources may become unavailable during periods in which they were originally thought to be available. This may occur for a variety of reasons (e.g., vacation, sickness, or the loss of people to other jobs). Finally, several projects that compete for the same resources may be executed concurrently. Managing multiple simultaneous or overlapping projects can increase the level of difficulty enormously over the single project case, because management must attempt to balance the resources [30]. This can adversely affect competitiveness since a bidding process must take into account those resources already committed when preparing a bid on a new project, which may be executed concurrently with others.

There have been numerous heuristics developed and used because of the low computational expense, and several exact solutions exist but are not often used in practice for the opposite reason. One exact method that shows promise and is used here, is the bounded enumeration method of [10]. This method takes a set of fixed-duration tasks, which must be completed in a specific sequence and which require a fixed number of resources from one or more resource pools. The first step in the algorithm is to divide them into unit duration tasks. Thus, if the unit duration was one day, a five day task would be divided into 5 one-day tasks. The schedule can then be displayed in a network diagram or as a Gantt chart, either of which makes the technical sequence easy to see. The diagram or chart can be annotated with the number of resources needed for each task from each resource pool. Each resource pool is assumed to contain a maximum number of resources that cannot be exceeded.

The method used in [10] begins evaluating the sequence of activities by entering the first task into the algorithm and determining those sets of tasks that could follow based upon the restriction imposed by the technical sequence. These are termed feasible subsets, but they do not include resource constraints. This process continues so that a set of feasible subsets is created for each stage in the project. The number of stages initially equals the length of the critical path, but may be extended as the program processes the inputs. The next step is to eliminate from consideration any feasible subset that cannot meet the resource constraints. This leaves a set of paths through the project network that will meet all technical and resource constraints. The final step is to determine which path is the shortest, i.e., has the least number of time periods (steps) and therefore conforms to the definition of minimum make span.

3. The software artifact

We created a software application that employs the bounded enumeration technique just described. Its performance is exceptionally fast because it makes use of the speed and power of a database server to reduce the computing time required. To be useful to practitioners, it must be able to find a solution in a reasonable and practical amount of time. We now provide the details of its implementation and in the next section provide a tabulation of the results of its performance.

A predetermined schedule is used as input. This schedule can be taken from a network diagram and it must include the required sequence of activities (the technical constraint), the duration of each task and the number of resources required for each task from each resource pool. A production schedule produced in a commercially available project management software program (e.g., Microsoft Project, Primavera, or SAP's PS module) or a custom scheduling program can provide this input. This data must be treated by an interface, which converts it into a format that can be stored within a relational database. The database consists of 6 separate but related tables. As part of the processing, the actual ask descriptions in the production schedule are replaced with a 5 character code before being entered into the main task table. The entity relationship diagram for the database is shown in Fig. 1.

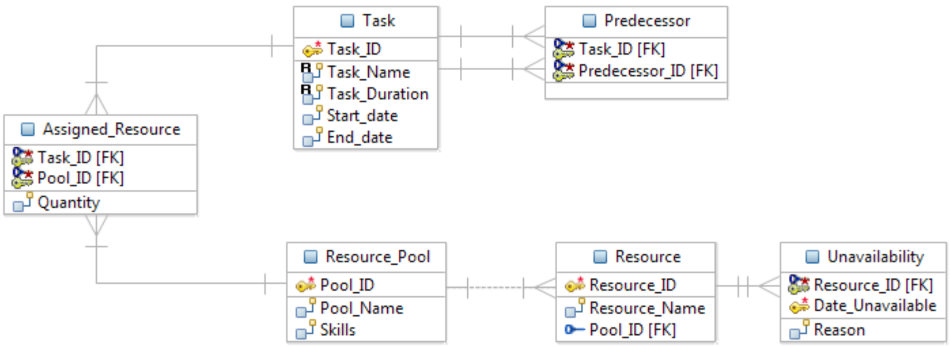

Fig. 1. Relational Schema

The Task table holds data relating to each task in the project and is related to the Predecessor table, which identifies the predecessor of each task. A simple SQL query of these two tables will yield the technical sequence of the project. Resources are recorded in the Resource table by name and are assigned to a specific labor pool. Because the details of each pool are recorded in a separate table (the Resource Pool table), there is no limit to the number of pools that can be included. This can be particularly advantageous because it can be used to separate beginning workers from those with much greater experience and therefore provide a better assessment of the duration of a task. Although both start and end dates are recorded in the Task table, these entries are generally not used in the program because these dates will be determined after the program runs. There are two exceptions. First, the initial start date for the first task is used as a reference from which all other dates can be calculated using the task durations. Second, any tasks that have been completed can be eliminated from the algorithm and a new reference start date can be used. This allows the program to be run in the middle of a project and ignore those tasks that have been completed and will no longer affect its outcome.

There are several temporary tables used to store the data as it is processed by the program that are not shown in Fig. 1. They are described below and are depicted in Fig. 2. The purpose of these tables is to hold data that is obtained by joining the related tables to produce a single storage area for each process used in the program. As each process in the algorithm is executed, the resulting data is reformatted and moved into a new table. While the structure of these tables is permanent, the data contained within them is transient, meaning that it is kept only for the life of the project. As projects are executed and completed, tasks which have been completed are removed; as new projects are added, their tasks are then stored in the tables. The data from old projects can then be archived for future analysis or simply deleted.

Production data is pre-processed by an interface, which accepts the production schedule as input, encodes the task names as 5 character codes, separates each task into single time-unit tasks and formats it for entry into the six tables in the database. This process is shown in figure 2 as part of the interface. Once formatted, the database server then queries the data within these six tables and processes it as described below. The result is an optimal schedule that can be returned to the production system via an interface that will re-format the output as needed for the production system. Obtaining the optimal schedule is performed as follows:

1) Create a matrix of tasks, their predecessors, duration and the number of resources required for each task from any number of resource pools. This matrix is stored in the first temporary table. This process is very quick. For a 25 task project, it usually takes about 30 to 60 seconds (see table 1).

2) Query the first temporary table and create a list of the project tasks in the order they must be performed (the technical sequence) and store the result in the second temporary table. This list will show a set of tasks that can be performed in one period and all of the tasks that could possibly follow these tasks (called feasible subsets) in the next period in each row of the table. In addition to recording these sets of tasks, the program also records the sum of the resources required to perform them from each resource pool. This table can grow to be quite large even for small projects. As an example, for a project with 25 independent tasks, we found that the program had created over 22,000 entries in this table.

3) Query the second table and create an adjacency matrix (“A” network) and store the results in a third temporary table. This table stores sets of tasks that are compatible, that is, one set can follow another based upon the technical sequence and the resource limitations imposed by each pool. Thus, many of the subsets from the second table are eliminated and this table is generally much smaller. We have found that this process consumes the most amount of time. For the 25 task sample project mentioned previously, the program ran in about 13 to 15 minutes (see table 1).

4) Analyze the third temporary table to determine the optimal path. The optimal path is defined as the one with the fewest number of steps to completion; however, the program also analyzes the cost of each step by summing the number of resources multiplied by number of activities required for each activity within the step. The optimal path is stored in the fourth temporary table, but is not easily interpreted because it accumulates activities as the project progresses. This process ran much quicker than predicted, which was usually less than 10 seconds (see table 1).

The result obtained in step 4) above is sent back to the interface for further processing before it can either be viewed by the project manager and/or returned to the production system to update the production schedule. Ideally, the PM will view this output and determine its suitability before updating the production schedule. Within the interface, the duplicated tasks are removed, all single time-unit tasks are re-combined, the task codes are replaced with their original descriptions and named resources are assigned, and finally, in a multi-project environment, different projects are separated into independent schedules and these optimal schedules are sent back to the production system to replace/update the original schedule(s). We should note that the interface is currently not a part of the program as it is now written, but would be added later once the details of the formatting for the production system are known.

Fig. 2 shows the flow of processing and encapsulates each stage within a rectangle. The production system, which holds the original schedule is shown on the left, the interface is depicted in the middle and the optimizing program is shown on the right of the diagram and is labelled as the Processor. Steps 1 through 4 as described above are labeled in the figure as Process 1 through 4. The data store labeled, “Project Data,” is the data contained in the six related tables shown in Fig. 1. The temporary tables are those data stores in the figure shown below each process.

As was mentioned, the Interface portion has not been implemented, so the performance testing of the program was performed by inputting data manually into the database. The program was run in four stages, which correspond to the four steps described previously, and run times were recorded. The output was then checked for accuracy and in some cases, was re-entered back into simple Gantt charts for comparison against the original schedule. We next present the results of our testing.

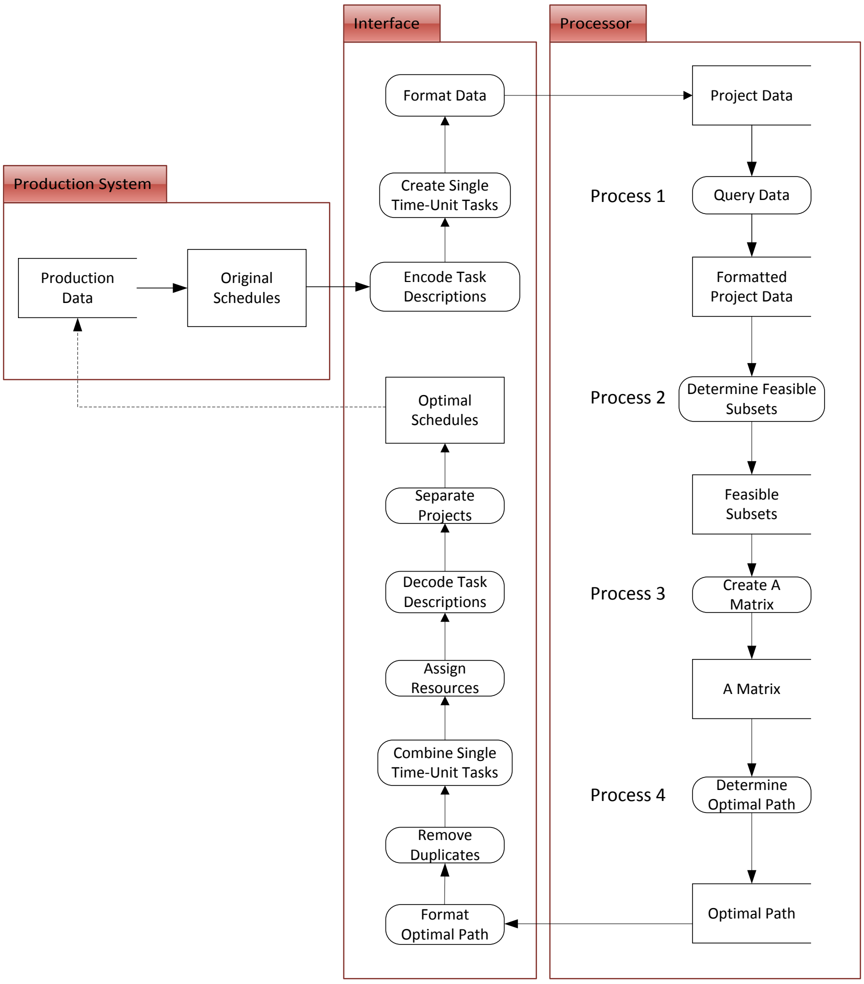

Fig. 2. Data flow to produce an optimal schedule

4. Results

As is well known, the number of possible paths through a network increases rapidly with the size of the network. This fact renders the problem NP hard and it has a major effect on the amount of time required to solve it for an optimal path. Therefore, the next step to help evaluate the utility of this program is to measure its performance as the problem grows in size and complexity. Our initial testing included only small programs, consisting of ten or fewer activities, three resource pools and a maximum availability of 5 resources per pool. This testing was performed to verify the accuracy of the algorithm. The program responded correctly and quickly for each of these tests. For performance under load, however, we needed to increase the size of the projects and the quantities of resources required. To create larger projects, we implemented a small program to randomly generate a set of tasks with durations from 1 to 6 time periods and assign a random number of required resources from each of three resource pools. We initially limited the project size to 25 tasks and gradually increased it to 50 tasks. We also varied the maximum number of resources from 6 to 10, but held the number of resource pools constant to 3. We ran the program on both a workstation and on the database server directly to compare performance. The server had 2 CPUs each with 6 cores running at 3.3 Ghz, 128 GBytes of

RAM and the workstation was equipped with a quad-core CPU running at 2.8 Ghz, with 32 GBytes of RAM. Storage of the data was controlled by DB2 v 9.7, which placed the data into tables on a separate storage area network.

Table 1 shows the run times associated with each process in the program. These processes correspond to the processes numbered 1 through 4 and described above.

Table 1: Program Run Times for 25 Task Example Project

	Workstation		Server	
Resources in each pool	**6**	**10**	**6**	**10**
Process 1	51 sec.	51 sec.	34 sec.	32 sec.
Process 2	15 mins.	13.5 mins.	15.0 mins.	12.7 mins.
Process 3	5.3 sec.	6.5 sec.	5.4 sec.	4.9 sec.
Process 4	1.02 sec.	1.4 sec.	.9 sec.	.85 sec.
Total Run Time:	15.9 mins.	14.5 mins.	15.7 mins.	13.3 mins.

The average run time for the four runs in table 1 was 14 minutes and 51 seconds, which seems to be an acceptable result for practitioners. Interestingly, the hardware differences between the workstation and the server were substantial, yet it seems that the program runs in about the same amount of time. This may be due to the fact that the optimization process is a serial and recursive operation; however, one would think that a server with more memory and faster CPUs would still be able to complete a set of serial processes much faster than a workstation not so equipped. There seems to be a larger difference in performance when the maximum number of resources per pool was increased; however, as stated previously, adding more resources to an IT project will probably not shorten its duration. The exception to this occurs when the resources are working on different projects, and so we varied the maximum number of resources available to simulate this occurrence.

The computation for multiple projects is identical to the computation for single projects. Tasks from different projects need not be analyzed separately since they are held in separate technical paths; that is, each project follows a different technical sequence and so the need for coding them differently during the program execution is absent. Tasks from different projects can be coded by project and added to the database as though it was a single project. The output as produced will then produce an optimal path for all projects that were added to the mix and can be easily discerned when displayed on a Gantt chart. It is only after the computation is complete and the need to view different projects separately becomes apparent that the task codes are grouped by project and treated once again as separate projects either for viewing by the PM or sent back to the production system for updating.

5. Limitations and directions for future research

This study considered only artificially generated projects that were formulated by an application, which was programmed to create tasks of arbitrary duration in a specific sequence. Each project created had a sequence of tasks, some of which were dependent upon others and some of which could be completed concurrently. We also limited the number of labor pools to three and the maximum number of resources in each pool to 6 for one run and 10 for a second run. Although the these projects had good face validity to be representative of production projects, our focus was solely on determining whether the software was able to successfully complete its task of schedule optimization and record the time it takes to do so. There are other factors that practitioners encounter in a production environment that are not dealt with here, and so this represents a limitation for which more research is needed.

We also did not induce changes in the schedules at specific points during the life of a project to check the effects that this might have on the schedule. Our purpose here was to create a software package that determined an optimum schedule and suggest that the technique could be used at any point in a project as things change (e.g., project scope, number of resources, etc.). We feel confident that the software will perform adequately in such an environment as the concept could easily be applied in a changing environment, but more research is needed to check this.

We did not evaluate the software by assuming a multiple project environment. While this may seem like a major limitation, it should not affect the output of our program, because more than one project can be added simply by identifying the projects in the task code, adding them to the input, running the program and then separating them when the run is complete. Projects that compete for the same resources must be scheduled with regard to those restrictions, and so we feel that the program itself will be unaffected by adding additional projects to the mix. The place that this will have an effect is in the interface where projects have to be correctly coded for input to the program and correctly separated in the output from the program.

Additional research is needed to determine the difference in costs from the output produced by heuristics that are easy to apply and quick to run in an automated environment and the exact solution that we present here. The question of whether creating a program to determine an exact solution can reduce costs enough to justify its investment remains unanswered. Only continued research will tell. However, we should note that an impetus for this study itself was the noticeable lack of control that some supervisors and PMs have over the schedule when it includes limited resources. This continues to be a problem for large companies who may understand the limitations imposed by the number of resources available, but have a difficult time working these limitations into their scheduling process.

6. Conclusion

The length of time that it takes to complete a project can affect the ability of a firm to compete. By completing a project faster than its competitors, a firm will have a competitive edge because the overall project cost is reduced. Optimal scheduling of an IT project is constrained by both the technical sequence of activities and the limitations imposed by having a limited number of resources. Most IT shops in large companies attempt to execute several projects within fixed time periods and these projects can compete for the same resources. Given these conditions, we created a software program based upon previous research that should assist the PM in creating an optimal schedule. Our program has the following advantages:

- The output provides an exact solution. The PM knows that the project cannot be completed any sooner than the schedule produced.
- The program can be run at any time during the project to update the schedule as changes are incorporated or encountered.
- The program completes in a reasonable period of time so that it becomes viable for use in a production environment.
- It can be used in a multi-project environment where projects may compete for the same sets of resources.
- Resources can be placed into separate pools that are grouped together by skill set. Less experienced workers can be placed into pools that are different from experts to help better estimate task durations.
- Resource leveling is no longer required. Some software packages have options that allow the PM to level the resources when it is discovered that they are over-allocated. Because this program takes the resource limitations into account, there can be no over-allocation and the problem can only develop if changes in the number of resources occur during the life of the project. If this does occur, the changes can be incorporated to the program and it can be run again to find a new optimal schedule.

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