Lappeenranta-Lahti University of Technology LUT
School of Engineering Science
Industrial Engineering and Management

Master's Thesis

Teemu Komulainen

THE PAY-OFF METHOD AND TOPSIS AS A TOOL FOR INFORMATION SYSTEM INVESTMENT EVALUATION AND SELECTION

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D.Sc. Mariia Kozlova

ABSTRACT

Lappeenranta-Lahti University of Technology LUT
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The pay-off method and TOPSIS as a tool for information system investment evaluation and selection

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Keywords: the pay-off method, TOPSIS, information system investment

The objective of the thesis is to construct a tool for information system investment evaluation and selection using the pay-off method and TOPSIS. The challenge identified in the literature to evaluate the different qualitative and quantitative aspects of information system investments acted as the motivation for the study. The applicability of the tool is assessed by means of a case study. The study shows that the pay-off method and TOPSIS are both suitable for the evaluation and selection of information system investments. By combining the two methods, one can evaluate the profitability of the competing information system investments and identify the alternative that best fulfills the different quantitative and qualitative criteria set by the organization.

TIIVISTELMÄ

Lappeenrannan-Lahden teknillinen yliopisto LUT
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Tuotantotalouden koulutusohjelma

Teemu Komulainen

Tuottojakaumamenetelmä ja TOPSIS tietojärjestelmäinvestointien arvioinnissa ja valinnassa

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Tämän diplomityön tavoitteena on laatia työkalu tietojärjestelmäinvestointien ennalta-arviointiin ja valintaan tuottojakaumamenetelmää ja TOPSIS-menetelmää soveltaen. Työtä motivoi kirjallisuudessa tunnistettu haaste arvioida tietojärjestelmäinvestointien monia laadullisia ja määrällisiä tekijöitä. Kehitetyn työkalun soveltuvuutta arvioidaan tapaustutkimuksen keinoin. Tutkimuksen perusteella voidaan todeta, että tuottojakaumamenetelmä ja TOPSIS soveltuvat hyvin tietojärjestelmäinvestointien arviointiin ja sopivimman investoinnin tunnistamiseen. Menetelmiä yhdistämällä pystytään sekä ennalta-arvioimaan investointien kannattavuutta että tunnistamaan se vaihtoehto, joka täyttää yrityksen sille asettamat laadulliset ja määrälliset kriteerit parhaiten.

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Helsinki 16.6.2021

Teemu Komulainen

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LIST OF ABBREVIATIONS

IT	Information technology
IS	Information system
MCDM	Multiple-criteria decision-making
TOPSIS	Technique for order preferences by similarity to an ideal solution
OR/MS	Operations research and management sciences
AHP	Analytical hierarchy process
NPV	Net present value
ROI	Return on investment
IRR	Internal rate of return

1 INTRODUCTION

This research aims to facilitate the information system (IS) procurement process by proposing a new method for evaluating and selecting information system investments. The evaluation and selection of information system investments is an integral part of the system procurement process where the decision-maker aims to identify the optimal information system investment from a set of competing alternatives. A poorly conducted evaluation of the investments may lead to erroneous decisions, financial losses, unattainable benefits, and abandoned or failed projects. Therefore, in a competitive environment, selecting the right information system can be a key factor in determining the success of many organizations.

Selecting the optimal information system investment from a set of competing alternatives, however, is a complex process where the decision-maker needs to consider a wide range of different strategic, technical, operational, and financial aspects of the investments. The indirect role of information systems to the company’s bottom line poses a number of challenges that traditional assets do not impose. The focus shifts from measuring hard and quantitative benefits to measuring soft and qualitative benefits. Traditional capital budgeting methods are not designed for evaluating non-financial information which makes them sub-optimal for evaluating IS investments.

In this research, we propose a method for information system investment evaluation and selection that can help to identify the optimal investment while considering both financial and non-financial information. The method combines a financial investment evaluation technique, known as the pay-off method, and a multiple-criteria decision-making method, known as TOPSIS (the technique for order preferences by similarity to an ideal solution).

The rest of the introductory chapter is organized as follows. Next, we discuss about information systems as an investment. Then we discuss about the background and the motivation of the study, after which we review the relationship of the study to other disciplines and define the objective and the scope of the study.

1.1 Information systems as an investment

Information systems are considered as enablers for business change and pivotal for efficient and effective running of modern businesses. The importance of investing in new information systems has become a topical issue within organizations. Largely motivated by the strive for competitive advantage and the need to deliver better products and services through robust supply chains. In today's competitive and global marketplace, information systems are also often needed just to stay in business. (Irani and Love, 2008)

While there does not seem to be a uniform definition of what constitutes as an information system and technology investment, many academics seem to follow the definition by Willcocks (1994):

> "A capital investment in information systems and/or technology (IST) is any acquisition of hardware or software, or any 'in-house' development project, that is expected to add or enhance an organization's information systems capabilities and produce benefits beyond the short term" (Willcocks 1994, p. 32).

What distinguishes IS investments from other capital investments is their substantial human and organizational interface (Irani and Love, 2008). According to Stratopoulos and Dehning (2000), it is more important how businesses manage and utilize their information systems than how much they invest in them. In their research, Irani and Love (2000) demonstrated that it is often the soft, human, and organizational factors that determine the efficient utilization of information systems. Information system investments are also characterized by long payback periods, uncertainty, unpredictability, high risk, several portfolio benefits, and significant intangible and indirect costs (Bardhan et al., 2004; Love and Irani, 2004; Milis and Mercken, 2004). The indirect costs of IS are argued to be more significant than direct costs (Irani and Love, 2008). In fact, according to Hochstrasser and Griffiths (1991), indirect costs can be four times greater than those of a direct nature.

When acquiring new information systems, many companies are using competitive tendering as a purchasing tactic. In competitive tendering, formal bids are gathered from a number of suppliers. This process takes time and effort but helps to identify the optimal information system and system provider. The purchasing process typically follows a four-step process, as illustrated in figure 3 below. The process begins by first specifying the requirements for the new system, followed by sending out the requests for proposal. Once received, the purchasing company evaluates the proposals and selects the optimal information system and system provider with whom to sign the contract. (Bannister, 2004)

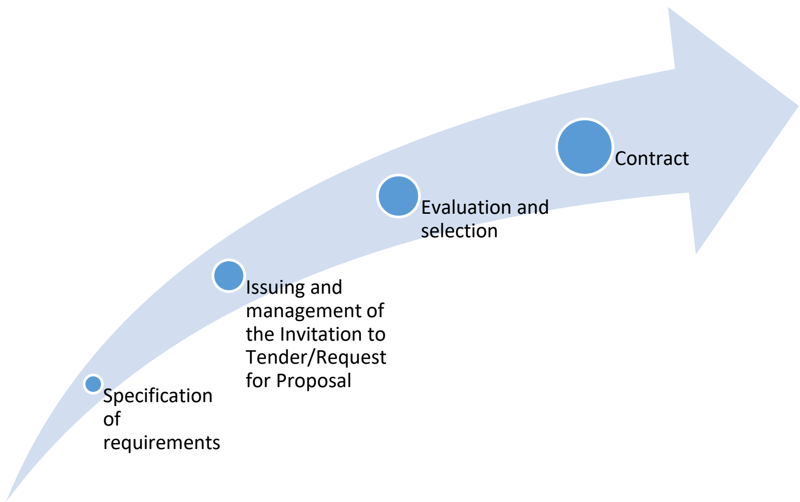

Figure 1. Competitive tendering process (Adapted from Bannister, 2004, p. 51)

The evaluation and selection of optimal information system investments is a complex task, in which the practitioners aim to decide whether to proceed with a purchase or project at all, which of a number of potential investments should receive priority and/or funding if resources are limited, and which of the proposed solutions to buy (Bannister, 2004). The indirect role of information systems to the company's bottom line poses a number of challenges when evaluating investments into new information systems that traditional assets do not impose. The focus shifts from measuring hard and quantitative benefits to measuring soft and qualitative benefits, such as competitive advantage, reduced costs, increased productivity, new products or services, improved product delivery, and better customer service (Bannister, 2004).

1.2 Background and motivation of the study

The research was conducted in cooperation with a Nordic IT consultancy firm (hereafter the "service provider") and a public organization that is part of the Finnish social security system (hereafter the "case company"). The service provider acts as the client of the research while the case company provided the settings for the case study.

The research began after the case company had purchased a license for a new data virtualization software from the service provider. Even though the case company had thoroughly evaluated the investment, they agreed that there is a need for a more reliable and rigorous method for evaluating and selecting optimal IS investments.

On this basis, a preliminary literature review was conducted to gain a general understanding of how investment decisions are made for new information systems and how the investments are evaluated.

The literature on evaluating and selecting information system investments is vast. While many academics have proposed different methods for evaluating information system investments, much research indicates that many organizations have no formal evaluation techniques in place or that they are relying on traditional capital budgeting methods or even gut instinct when evaluating their IS investments (Ballantine et al., 1996; Bardhan et al., 2004; Gunasekaran et al., 2001; Paul and

Tate, 2002). Hochstrasser (1994) concluded from his research that only 16% of the companies sampled were using rigorous methods to evaluate and prioritize their IT investments. According to Marthandan and Tang (2010), most organizations are using traditional capital budgeting methods, such as return on investment (ROI), pay-back period, and discounted cash flow (DCF) analysis to evaluate their information system investments. A survey conducted by Paul and Tate (2002), showed that over 86% of the CFOs that responded claim to use traditional capital budgeting methods for information system investment evaluation. A study by the Kellogg School of Management showed that 80 percent of the CIOs responded expressed significant difficulty when evaluating IT investments and that most of the respondents did not have a formal process to prioritize project funding (Chabrow, 2003).

Traditional capital budgeting methods are useful when evaluating investments in capital assets with hard and quantifiable costs and benefits. However, many academics argue that these methods alone are not optimal for evaluating information system investments (Irani and Love, 2008; Milis and Mercken, 2004). Traditional capital budgeting methods require expressing the costs and benefits of the investment in monetary terms, which poses a challenge when evaluating IS investments that are known for their supportive nature. Identifying and quantifying intangible and hidden costs and benefits, such as improved decision-making or user training costs, is difficult. In fact, the challenge of identifying the costs and benefits attributable to an information system and quantifying the intangible and non-financial benefits is a recurring problem in the academic literature (Bannister, 2004; Counihan et al., 2002; Gunasekaran et al., 2001; Willcocks, 1994). Due to the difficulty of quantifying the “softer”, intangible benefits, many academics argue that traditional capital budgeting methods are inappropriate or even misleading when evaluating information system investments (Bannister, 2004; Farbey et al., 1994; Irani and Love, 2002; Marthandan and Tang 2010; Willcocks, 1994).

To overcome the challenges in IS investment evaluation, many scholars have presented different investment evaluation methods, originating from disciplines such as finance, accounting, and operations research and management science (OR/RM). These methods include analytical hierarchy process (AHP), balanced scorecard, information economics, and many different multiple-criteria decision-making methods (Chou et al., 2006; Hanine et al., 2016; Milis and Mercken, 2004). A thorough review of different investment evaluation methods used in IS investments was conducted by Schniederjans et al. (2004), who listed over fifty methods and techniques that can be used for information system investment evaluation. The list by Schniederjans et al. (2004), is presented in appendix 1.

One of the first methods designed specifically for evaluating information system investments is known as COCOMO (constructive cost model). The model was designed by Barry Boehm in 1970 and it was presented in his book "Software Engineering Economics" in 1981. COCOMO is based on the study of 63 historical software projects, making it arguably one of the best-documented models for software investment evaluation. However, based on the preliminary literature review, the model does not seem to be in widespread use for the evaluation and selection of IS investments. This may be partly explained by the complexity of the model. COCOMO utilizes a regression formula for estimating the cost of a software project while considering different parameters such as size, cost, effort, duration, and the quality of the project. The model was also originally developed for estimating the costs of software development projects, rather than a decision support tool for the acquisition and selection of alternative information systems, which may in part explain the absence of the model in IS evaluation and selection literature. (Boehm, 1981)

Based on the preliminary literature review, a few observations could be made. First, there seems to be an abundance of different techniques proposed for IS investment evaluation, which suggests that there is no one right method. Secondly, majority of organizations seem to rely on traditional capital budgeting methods when evaluating information system investments even though they are argued for being sub-optimal. Thirdly, there seems to be a lack of empirical research about combining both financial and non-financial investment evaluation techniques for thorough IS investment evaluation.

Motivated by these findings, we continue the study by investigating how a method that combines both financial and non-financial investment evaluation techniques could be used for the evaluation and selection of information system investments. The proposed method is a combination of the pay-off method and TOPSIS (the technique for order preferences by similarity to an ideal solution). Both methods have shown promising results in IS investment evaluation and selection and are considered suitable in uncertain decisions involving multiple criteria and points of view (Collan et al., 2014; Hanine et al., 2016; Wang and Lee, 2009; You et al., 2012). These methods and how they have been utilized for IS investment evaluation and selection is discussed in more detail in the literature review of the study.

1.3 Relationship to other disciplines

The study is at the intersection of three major disciplines: corporate finance, decision-making, specifically multiple-criteria decision-making, and information technology, as illustrated in figure 2 below.

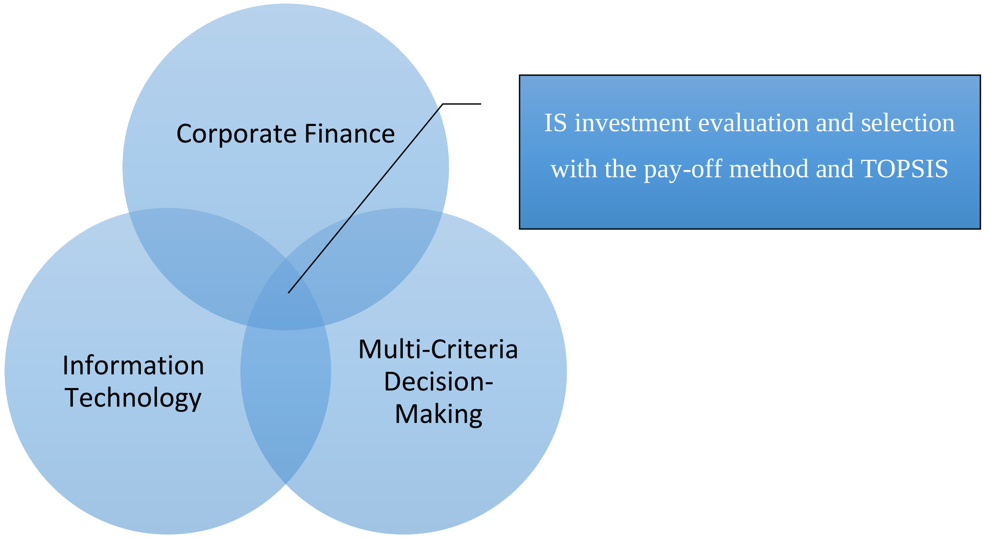

Figure 2. Relationship to other disciplines.

Corporate finance is a discipline that focuses on how corporations deal with funding sources, capital structuring, and investment decisions. Corporate finance aims to maximize the value of the company through financing and investment decisions. Corporate finance provides different capital budgeting methods, such as net present value (NPV), return on investment (ROI), and internal rate of return (IRR) that have been used for decades to evaluate the profitability of different capital investments. The pay-off method, first introduced by Collan et al., (2009), is a relatively new capital budgeting method that introduces fuzzy logic to discounted cash flow analysis. (Vishwanath, 2007)

Multiple-criteria decision-making (MCDM), on the other hand, is a discipline withing operations research and management science (OR/MS) that focuses on decision support tools and methodologies for facilitating the decision-making process in ill-structured problems involving multiple criteria, objectives, and points of view (Doumpos and Zopounidis, 2014). MCDM methods, such as analytical hierarchy process (AHP) and TOPSIS are typically used in decision-making problems that involve different financial, regulatory, social, and environmental aspects, such as bank performance evaluation, credit scoring, asset screening and selection, and investment appraisal (Doumpos and Zopounidis, 2014).

This research is at the intersection of the three disciplines while focusing on the pay-off method and TOPSIS, and how the methods could be used together to facilitate the information system investment evaluation and selection process. The study aims to provide new perspective to information system investment evaluation and selection by combining both financial and non-financial evaluation techniques originating from corporate finance and multiple-criteria decision-making. The study is also among the first to combine the pay-off method and TOPSIS for evaluating and selecting information system investments.

1.4 Objective and scope

The objective of the research is to develop a new approach for evaluating and selecting information system investments utilizing the pay-off method and TOPSIS. The research objective is divided to three research questions that guide the study towards its objective.

Research objective

1) Develop a technique for the evaluation and selection of information system investments using the pay-off method and TOPSIS.

Research questions

1) What prior academic research exists about the evaluation and selection of information system investments?
2) How the pay-off method and TOPSIS have been utilized to facilitate the evaluation and selection of information system investments?
3) What added value is received by combining the pay-off method and TOPSIS for information system investment evaluation and selection?

The first two research questions are answered in the literature review. First, a more holistic understanding of the topic is formed by reviewing the current trends, challenges and techniques used in information system investment evaluation and selection. Then, the focus of the literature review is narrowed to the evaluation and selection of IS investments using the pay-off method or TOPSIS. Once the literature review is conducted, a method for evaluating and selecting IS investments using the pay-off method and TOPSIS is proposed. The objective of the third research question is to assess the benefits of using the proposed method for IS investment evaluation and selection. To provide an answer to the third research questions, the functionality of the proposed method is tested by means of a case study.

1.5 Structure of the study

The study is organized in six main chapters. The chapters are illustrated in figure 3 below. The first chapter gives an introduction to the topic and discusses about the background and the motivation of the study. The chapter also reviews the relationship to other disciplines and presents the objective and scope of the study.

Chapter 2 presents the literature review. First, the literature review continues the discussion started in the background of the study by discussing the key characteristics of IS investment evaluation and selection. Then, the focus is narrowed on the evaluation and selection of information system investments using the pay-off method and TOPSIS. The aim of the literature review is to inspect prior literature of the topic and review how these two methods have been used for evaluating and selecting optimal IS investments.

In chapter 3, we discuss about the research method. The study was conducted following a constructive research approach. We review the steps in constructive research and discuss how the approach guided the study.

Chapter 4 presents the proposed method for evaluating and selecting optimal information system investments. First, we review the logic behind the pay-off method and TOPSIS, and then we propose how these two methods could be applied together for identifying optimal IS investments.

In chapter 5, the functionality of the proposed method is tested by means of a case study. The aim of the case study is to demonstrate and evaluate the functionality of the proposed method. The applicability of the proposed method is also discussed at the end of the chapter.

The final chapter summarizes the study and discusses about the theoretical contribution of the study and potential subjects for further research.

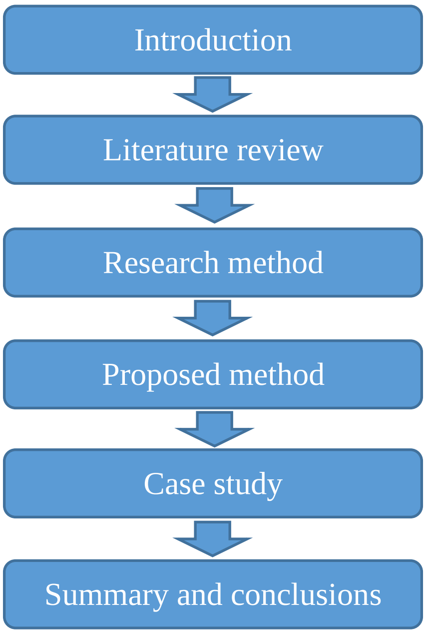

Figure 3. Structure of the study.

2 LITERATURE REVIEW

The objective of a literature review is to create a foundation for advancing knowledge and to facilitate the development of research in a particular field or discipline (Webster and Watson 2002). The literature review of the study follows a state-of-the-art review method where the objective is to form a state of the art of a particular subject from the most recent relevant literature. The literature review of the thesis focuses on articles that discusses about the evaluation and selection of information system investments and how the pay-off method and TOPSIS have been applied to facilitate the evaluation process. By reviewing the existing research on the topic, we create the theoretical background for the study and identify the areas where more research is desirable.

The source material of the literature review was selected using a three-step literature selection process, illustrated in figure 3 below. The databases searched include Ebsco (Business Source Complete and Academic Search Elite), Elsevier Science Direct, Emerald eJournals, and Springer link eJournals. The search was limited to articles written either in English or Finnish and created from 2000 onwards.

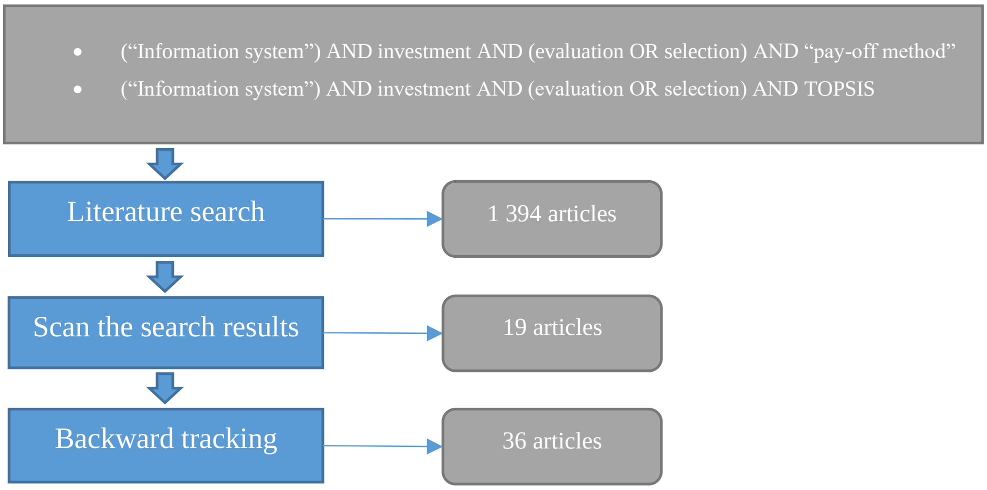

Figure 4. Literature selection process.

The first step of the literature selection process is to determine the relevant search-strings and conduct the literature search. The focus of the literature selection is on articles that particularly discusses about the evaluation or selection of IS investments using the pay-off method or TOPSIS. The search-strings used are illustrated in figure 4 above.

The second step of the literature selection process is to scan and short-list the articles that were discovered in the first step. After scanning the titles and the abstracts of the papers, all irrelevant and duplicate articles were removed, resulting to a set of most relevant literature identified during the database search.

The third and final step of the literature selection process is called backward tracking. In backward tracking the short-listed articles are examined for relevant references that might have been missed during the first database search. At the end of the literature selection process, we are left with a set of 36 journals and articles that are considered as most current and relevant literature.

The literature review of the study is divided to three entities. First, we continue the discussion started in the beginning of the study by reviewing the current trends, methods, and challenges in IS investment evaluation and selection. Then we discuss about the pay-off method and TOPSIS in IS investment evaluation and selection. The findings from the literature review are presented at the end of the chapter.

2.1 IS investment evaluation and selection

The evaluation and selection of information system investments is an integral part of the system procurement process where the decision-maker aims to identify the optimal information system investment(s) from a set of competing alternatives. A poorly conducted evaluation of the investments may lead to erroneous decisions, financial losses, unattainable benefits, and abandoned or failed projects (Irani et al., 2014). In fact, Hochstrasser (1992) argues that the high failure rate in information system investments is partly attributable to the lack of solid but easy to use management tools for evaluating, prioritizing, monitoring, and controlling IS investments. Therefore, it is important for organizations to set up appropriate evaluation measures and techniques. (Bannister, 2004)

One of the problems in IS investment evaluation is that traditional capital budgeting methods are often difficult to apply and can even provide misleading results (Bannister, 2004). Traditional capital budgeting methods are useful when the costs and savings are clear and easy to measure. However, this is not usually the case in information system investments. To evaluate more complex investments more sophisticated methods are needed (Bannister, 2004).

Bannister (2004) has divided the evaluation and selection of IS investments to a five-step process as follows:

1. The criteria for evaluation and selection are drawn up, classified and ranked.
2. The products/proposals on offer are assessed against each criterion.
3. The overall score of each product against all of the criteria is calculated.
4. The best product is selected.
5. Follow-up checks are undertaken to confirm the decision.

Determining the correct criteria for any decision is fundamental for making the right decision. Bannister (2004) divides the criteria to two categories: qualifying criteria and selection criteria. Qualifying criteria are the criteria that the system must meet to be considered for purchase at all. They are the minimum requirements which an alternative has to fulfill. They can also be considered as threshold levels that are used to exclude irrelevant investment alternatives, thus keeping the focus only on the relevant system alternatives. Qualifying criteria can be, for example, price or some key system features, like the ability of supporting the existing technology stack. (Bannister, 2004; Huizingh and Vrolijk, 1995).

Selection criteria, on the other hand, are the criteria that are used to differentiate one system from another. They are the factors that are used to judge the alternatives. While failure to meet a selection criterion do not automatically rule out the proposal, the cumulative effect of not meeting several might rule it out. It is also common that the selection criteria are not all equally important, meaning that one criterion can have a larger influence on the decision than another. The criteria can also be both qualitative and quantitative. Quantitative criteria, also known as tangible or "hard" criteria, are typically easier to measure and evaluate, such as price, system capacity, and number of support staff. What makes the evaluation of information system investments challenging, though, are the significant qualitative, intangible criteria. These criteria are often subjective and involve judgements by IT managers and system users. Examples of qualitative criteria include competitive advantage, new products or services, improved product delivery, and better customer service. (Bannister, 2004; Irani and Love, 2008)

The criteria that are used to evaluate and select the information system investments has been investigated by many researchers. Much research indicates that most organizations are using traditional capital budgeting measures, such as payback period, NPV, ROI, and IRR as their evaluation criteria (Ballantine and Stray, 1996; Marthandan and Tang, 2010; Paul and Tate, 2002). According to Milis and Mercken

(2004) and Ballantine and Stray (1996), the widespread use of traditional capital budgeting methods in IS investment evaluation and selection is partly explained by the fundamental assumption that organizations' primary objective is to maximize profit/shareholder wealth. And according to the accounting and finance literature, in order to achieve that objective, a common investment evaluation method is needed that can be applied equally to the whole spectrum of investment decisions (Vishwanath, 2007). Another factor that might explain the widespread use of traditional capital budgeting methods is that they are well known and understood and based on generally accepted principles (Milis and Mercken, 2004). Milis and Mercken (2004) also notes that the responsibility for all investments, including IS investments, has remained firmly with the finance director which in turn might contribute to the success of the traditional capital budgeting methods.

While accounting and finance literature may state that traditional capital budgeting methods are appropriate techniques to evaluate all capital investments, many academics criticize the use of these techniques to evaluate information system investments in an efficient way (Ballantine and Stray, 1998; Irani and Love, 2000; Milis and Mercken, 2004). One major challenge is the difficulty of measuring the costs and benefits attributable to the investment. While some benefits might be more tangible and easier to measure, a significant portion of the benefits of information systems are intangible or "hidden" from the decision-maker. Even though costs are typically easier to measure than benefits, a significant portion of the costs of IS investments are also intangible or hidden (Willcocks, 1994). Typical examples of these types of costs include training costs and costs that arise from transitioning from the old system to the new one (Milis and Merken, 2004; Apostolopoulos and Pramataris, 1997).

Traditional capital budgeting methods are also conservative by nature. They tend to favor low-risk investments with short payback time and penalize investments with long-term payoffs. This can be harmful for IS investments that are characterized by high risk and long term pay-off times. When investing in new information systems, there are also several parties involved, each with their own objectives. If the evaluation and selection of information system investments is solely based on traditional capital budgeting methods, only the objectives of the management are considered. However, because the benefits generated by the investment often depend on the system users, neglecting their objectives may lead to sub-optimal choice. Therefore, focusing solely on financial criteria may diminish the benefits of an IS investment. (Milis and Mercken, 2004)

To capture the full spectrum of the costs and benefits of information system investments, Parker et al. (1988) suggests dividing the criteria to two domains: business domain and technology domain. The business domain includes four main criteria: return on investment (ROI), strategic match, competitive advantage, and organizational risk. The technology domain criteria include strategic architecture alignment, definitional uncertainty risk, technical uncertainty risk, and technology infrastructure risk. Hanine et al. (2016), on the other hand, used five main criteria for selecting the optimal ETL software. These were functionality, reliability, efficiency, and maintainability. When evaluating and selecting among logistics information technologies, Kahraman et al. (2007) divided their criteria into 4 main groups. The main groups consist of tangible benefits, intangible benefits, policy issues, and resources. The tangible benefits include cost savings, increased revenue, and ROI. The intangible benefits, on the other hand include customer satisfaction, quality of information, multiple use of information, and setting tone for future business. Policy issues includes risk and necessity level, and risks include cost and completion time. Boehm (1981), on the other hand, estimates the cost of software projects by considering different parameters, such as effort, size, quality and duration. Chou et al. (2006) conducted a thorough literature review of different IS evaluation criteria. They condensed their findings to a set of 36 criteria ranging from different quantitative criteria like software costs and improved cash flow to different qualitative criteria such as improved information quality and improved communications.

The vast amount of different evaluation criteria emphasizes the complexity of information system investments and the many factors that need to be considered for making the optimal investment decision. It is also apparent that there is no fixed set of criteria that could be used for all IS investments and by all organizations. In fact, according to Gunasekaran, et al. (2008) the evaluation criteria should be based on the organizational strategies, goals, and objectives. However, commonly employed criteria can be categorized as follows: strategic impact, tactical considerations, operational performance, financial measures, non-financial indicators, tangibles, and intangibles (Gunasekaran, et al., 2008).

Once the selection criteria and their importance have been determined, the investment alternatives are assessed against each criterion. The way the investment alternatives are assessed depends on the criteria. When it comes to traditional capital budgeting measures like ROI or NPV, the investment that provides the largest return on investment or the largest net present value is preferred. When assessing the performance of the alternatives against qualitative criteria, a common approach is to utilize expert judgements drawn from a linguistic scale (Esanbedo et al., 2021; Hanine et al., 2016; Kahraman et al., 2007; Oztaysi, 2014; Xing et al., 2009). Commonly, points from 0 to 10, or percentage scores from 0% to 100%, are given. Expert judgements, however, are subjective and therefore there might be discrepancies amongst different subject matter experts. Therefore, determining a crisp number that captures the views of multiple stakeholders is challenging. To capture the subjective expert judgements, many academics have suggested the use of fuzzy numbers (Chen and Cheng, 2009; Chou et al., 2006; Vahdani et al., 2013). Fuzzy logic states that everything is a matter of degree (Zadeh, 1965). In practice, by utilizing fuzzy numbers, the expert judgements can overlap and merge with one another (Irani et al., 2002).

Next in the literature review, we investigate how the pay-off method and TOPSIS have been utilized in the evaluation and selection of information system investments.

2.2 The pay-off method in IS investment evaluation and selection

The pay-off method, first introduced by Collan et al. (2009), is an investment evaluation method designed for the analysis of assets that suffer from difficulties in estimation precision and often face high uncertainty. The method utilizes fuzzy logic in investment analysis. Fuzzy logic, developed by Zadeh (1965), provides the means to mathematically model and interpret vague and uncertain information (hence the term fuzzy). (Collan et al., 2009)

The pay-off method is based on most likely and maximum and minimum possible cash flow scenarios. According to Collan and Heikkilä (2011), the use of cash flow scenarios is a common practice to cope with uncertain information. The use of minimum and maximum range is also suggested by Willcocks (1994) for estimating intangible benefits of information system investments.

The estimated cash flow scenarios are used to form a pay-off distribution that is a fuzzy representation of the profitability of the investment. When the pay-off distribution is presented graphically, it also facilitates the comparison of different IS investment alternatives. By considering the pay-off distribution as a fuzzy number, it is also possible to utilize fuzzy logic to calculate different descriptive metrics that portray the risk and success rate of the investment. (Collan, 2012)

When evaluating information system investments, Collan et al. (2014) emphasize the importance of decision support tools that can capture the uncertainty and estimation inaccuracy. Therefore, they propose the pay-off method for evaluating the profitability of a logistics system. Collan et al. (2014) recognizes the difficulty of estimating the costs and costs savings of the complex IS investment. However, by utilizing the pay-off method, they are able to model the uncertain information. Collan et al. (2014) found the pay-off method suitable for evaluating the profitability of the investment. They found that in an uncertain investment, a triangular fuzzy number that is formed from three cash flow scenarios is a much better representation of reality than single crisp numbers. They also praise the visual aspect of the method, saying that a graphical presentation of the results together with the descriptive metrics provides the practitioners a comprehensive and holistic picture of the investment alternatives (Collan et al. 2014).

While Collan et al. (2014) utilized the pay-off method for evaluating the profitability of a logistics information system, You et al. (2012) applied the method for evaluating an ERP system investment. In their research, You et al. (2012) treated ERP implementation as a compound real option where the decision-maker has the option to either expand, contain or abandon the project after the first phase of implementation. You et al. (2012) created three cash flow scenarios for each option. As a result, they got three pay-off distributions (one for each option) which they could compare and use to select the best option to exercise. You et al. (2012) found the pay-off method well suited for evaluating ERP system investments. They state that uncertainty is the main culprit that causes most of the failures in ERP implementation and by utilizing the pay-off method, the practitioners can in fact take advantage of the uncertainties by capturing the upside benefits and containing the downside losses (You et al. 2012, p.60).

According to the research by Collan et al. (2014) and You et al. (2012), the pay-off method seems suitable for the evaluation of the profitability of information system investments. The pay-off method does not assume that the practitioners are certain about the future cash flows of the investment. Instead, the method is able to transform uncertain and imprecise estimations into a fuzzy number, known as the pay-off distribution, which describes the profitability of the investment. As shown by Collan et al. (2014), by considering the pay-off distribution as a fuzzy number, it is also possible to calculate different descriptive statistics that describes the expected return, potential and the risk of the investment. The pay-off distribution can also be easily visualized, providing an intuitive and human friendly way of comparing multiple investment alternatives, and thus greatly facilitating the evaluation and selection of the most optimal IS investment. In addition, as demonstrated by Collan et al. (2013), the descriptive statistics received from the pay-off analysis can also be easily incorporated as decision criteria in multiple-criteria decision-making methods. All these capabilities justify the selection of the pay-off method as a tool for evaluating the profitability of information system investments.

2.3 TOPSIS in IS investment evaluation and selection

Multiple-criteria decision-making (MCDM) provides decision support tools and methodologies for facilitating the decision-making process in ill-structured problems involving multiple criteria, objectives, and points of view (Doumpos and Zopounidis, 2014). MCDM has become a major discipline in operations research and management science and is being used in a wide variety of different decision-making problems, ranging from supplier selection, engineering, and manufacturing to robot selection (Agarwal et al., 2020; Ng, 2008; Singh and Benyoucef, 2011; Vahdani et al., 2013; Özcan et al., 2017).

One of the well-known classical MCDM methods is the technique for order of preference by similarity to ideal solution (TOPSIS), developed by Hwang and Yoon (1981). TOPSIS aims to identify the best alternative from a set of competing alternatives. The best alternative in TOPSIS is regarded as the alternative that is simultaneously nearest to the optimal solution and farthest from the inferior solution (Tzeng and Huang, 2011). The logic and mathematics behind TOPSIS are discussed in more detail later in the study.

MCDM methods have been widely used in different IS investment evaluation and selection problems (Chen and Cheng, 2007; Chou et al., 2006; Esanbedo et al., 2021). TOPSIS, and its variations, have also been utilized to facilitate many IS investment decisions. Hanine et al. (2016) used an integrated AHP-TOPSIS method for selecting the optimal ETL software, Wang and Lee (2009) used a fuzzy TOPSIS and entropy method for selecting a new information system to improve work productivity for a computer center, Xing et al. (2009) utilized TOPSIS to assess the risks in IT projects, and Kahraman et al. (2007) used a hierarchical fuzzy TOPSIS model for evaluating and selecting among logistics information technologies.

The integrated AHP-TOPSIS approach, designed by Hanine et al. (2016), was able to identify the optimal ETL software while considering a wide range of both tangible and intangible criteria. The method produced consistent results and it was considered to function satisfactorily. However, capturing an accurate representation of the uncertain expert judgements was considered challenging (Hanine et al., 2016). Similar observations were made by Oztaysi (2014) who compared classical TOPSIS and fuzzy TOPSIS for selecting a content management system. Both approaches were found applicable for the task and showed consistent and similar results. However, the fuzzy approach was considered better at incorporating uncertainty to the decision-making problem (Oztaysi, 2014). Kahraman et al. (2007) came to a similar conclusion when they used fuzzy TOPSIS to identify optimal logistics information technology (LIT). They stated that the evaluation and selection of LIT is a difficult issue that involves both qualitative and quantitative aspects, as well as complexity and imprecision (Kahraman et al., 2007). However, they considered that the developed fuzzy TOPSIS approach was able to facilitate the complex decision-making problem.

Based on the state-of-the-art literature review, many researchers seem to consider TOPSIS as a suitable method for IS investment evaluation and selection. TOPSIS can produce a simple ranking of the alternatives while considering both qualitative and quantitative criteria as well as the varying importance of the criteria. TOPSIS is also one of the well-known MCDM methods and it is easy to integrate with traditional capital budgeting methods, as shown by Kahraman et al. (2007) who used ROI as one of the criteria.

2.4 Literature review findings

The literature review focused roughly on three areas. First, a more holistic understanding of the topic was formed by reviewing the current trends, challenges, and methods in IS investment evaluation and selection. Then, the focus was narrowed on the pay-off method and TOPSIS and how these methods have been applied in IS investment evaluation and selection.

By reviewing the relevant literature, the following points emerge:

- IS investment evaluation and selection is considered as a multi-criteria decision-making problem that involves many tangible and intangible criteria and uncertain and incomplete information.
- even though there are many different methods proposed for IS investment evaluation and selection, companies are mostly relying on traditional capital budgeting methods.
- The hidden and intangible costs and benefits are significant in information system investments but difficult to quantify in monetary terms.
- The difficulties in identifying and measuring the hidden and intangible costs and benefits are thought to be a major obstacle in IS investment evaluation.
- Both the pay-off method and TOPSIS have been found useful in different IS investment problems but there is little evidence of their integrated use for IS investment evaluation and selection.

Based on the literature review, we can also determine the following requirements for a successful IS investment evaluation and selection method:

- The method should be able to evaluate multiple different criteria, including both tangible and intangible costs and benefits, risks and the features and functionalities of the systems.
- The method should be able to identify the best IS investment alternative from a set of competing alternatives while considering the different criteria listed above.

- The method should be able to model and interpret uncertain information.
- The method should be easy to understand and based on proven theories.

Before the proposed method is presented, the research approach that guided the study and the construction of the proposed method is shortly discussed.

3 RESEARCH APPROACH

The study is conducted following a qualitative constructive research approach as introduced by Kasanen et al., (1993). Constructive research aims to solve a real-world problem by implementing a new construction that has both practical and theoretical contribution. The approach is widely used in technical sciences, mathematics, operations analysis, and clinical medicine (Kasanen et al. 1993). Constructive research approach provides a framework for developing a solution to a problem that is also practically relevant and has some theoretical contribution, making it a natural choice as our research method.

Kasanen et al. (1993) use five key elements to characterize constructive research approach, as illustrated in figure 5 below.

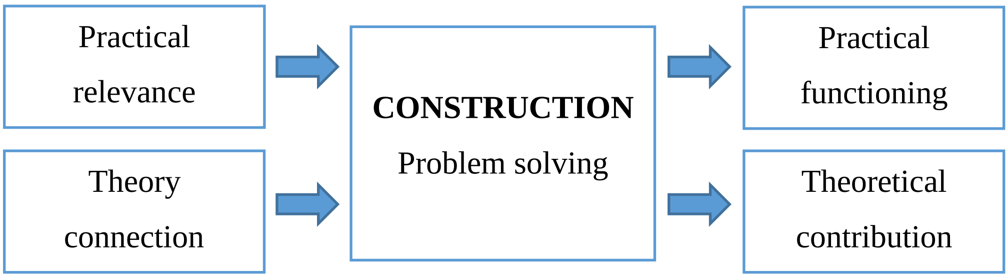

Figure 5. Constructive research (Adapted from Kasanen et al., 1993)

As seen from the figure above, the essence of constructive research is the construction, i.e., the solution to the initial problem. All human artefacts, such as models, diagrams, plans, organization structures, commercial products, and information systems are considered as constructions (Lukka, 2003). The construct of this research is the proposed method for evaluating and selecting information system investments. This construction can be interpreted as a managerial construction, which are characterized by Kasanen et al. (1993) as entities that solve problems that emerge when running business organizations. It is also essential that the problem and the construction are both theoretically and practically relevant, and that the actual working of the solution can be demonstrated (Kasanen et al., 1993).

Kasanen et al. (1993) divide constructive research approach to a process with six phases. The phases are listed in table 1 along the corresponding steps of the study.

Table 1. Constructive research process (Adapted from Kasanen et al., 1993)

Phase	Constructive research	Constructive research for designing a method for IS investment evaluation and selection
1	Find a practically relevant problem which also has research potential.	The challenge of evaluating and selecting optimal IS investments was initially identified when the case company acquired a license for a data virtualization software form the service provider. Similar challenges were also identified during a preliminary literature review. Little evidence was also found regarding the integrated use of the pay-off method and TOPSIS for a more thorough IS investment evaluation and selection.
2	Obtain a general and comprehensive understanding of the topic.	A literature review was conducted to gain a deeper understanding of IS investment evaluation and selection, and how the pay-off method and TOPSIS have been used to facilitate the decision-making process.
3	Innovate, i.e., construct a solution idea.	A method for evaluating and selecting the optimal IS investment was constructed. The method is based on the pay-off method and TOPSIS.

4	Demonstrate that the solution works.	The functionality of the proposed method is demonstrated by the means of a case study.
5	Show the theoretical connections and the research contribution of the solution concept.	The study proposes a new method for IS investment evaluation and selection based on the pay-off method and TOPSIS. Thus, it is considered to have a contribution to disciplines, such as corporate finance, multiple-criteria decision-making, and information technology. The theoretical contribution is discussed at the end of the study.
6	Examine the scope of applicability of the solution.	The applicability of the proposed method for evaluating and selecting information system investments is evaluated against the requirements identified during the literature review. The applicability of the method is discussed after the case study.

The first step is to find a practical problem that also has research potential. According to Lukka (2003), an ideal topic is the one that appears to be paradoxical or under analyzed in prior literature. The problem addressed in the study is a managerial problem of how to evaluate and select the optimal information system investment. The challenge was first identified when the case company purchased a license for a data virtualization software. After a literature review it also became apparent that the evaluation and selection of information system investments is a widely recognized challenge and that there is potential for more research – especially regarding investment evaluation methods that can combine both financial and non-financial information. The observations of the first phase are discussed in the first chapter of the study.

The objective of the second phase of constructive research is to obtain a comprehensive understanding of the topic. This was achieved by conducting a literature review. First, a general understanding was established on how information system investments are evaluated and what methods are proposed in the literature. These findings are discussed in chapter 1. Once a general understanding of the topic was established, two evaluation methods were selected for a more thorough review. The literature review focuses on the pay-off method and TOPSIS and forms an understanding of how they can be used for the evaluation and selection of optimal information system investments. The literature review is presented in chapter 2.

The third phase of constructive research focuses on constructing a solution to the initial problem. Lukka (2003) emphasizes the importance of this phase, saying that if an innovative construction cannot be designed, there is no point continuing the project. However, if the construction fails to provide the desired solution to the problem, the research might still be interesting from the academic point of view (Lukka, 2003). The construction of the study is the proposed method for evaluating and selecting optimal information system investments. The proposed method combines the pay-off method and TOPSIS. These two methods and how they can be combined for more thorough IS investment evaluation are presented in chapter 4.

According to the fourth phase of the constructive research approach, the functionality of the solution needs to be demonstrated as well. This is the first level practical test of the designed construction (Lukka, 2003). The functionality of the proposed method for IS investment evaluation and selection is demonstrated by means of a case study in chapter 5.

The fifth step in the constructive research approach is to show the theoretical connections and the research contribution of the solution concept. In this phase, the researcher reflects the findings back to prior theory (Lukka, 2003). According to Keating (1995) and Lukka (1999), the principal alternatives for theoretical linkage in any study are the development of a new theory, the refinement of an existing one, its testing or its illustration. If the designed construction is found to work in the primary case, it provides a natural contribution to prior theory (Lukka, 2003). The study proposes a new method for IS investment evaluation and selection based on the pay-off method and TOPSIS. Thus, it is considered to have a natural contribution to disciplines, such as corporate finance, multiple-criteria decision-making, and information technology. The theoretical contribution is discussed at the end of the study.

The final phase of the constructive research process is to ponder the scope of applicability of the solution. In this phase, the researcher should step back from the empirical work and analyze the learning process forgone during the research (Lukka, 2003). The researcher should analyze whether the construction passed the first market test and produced the anticipated results and to what extent the construction could be transferable to other organizations (Lukka, 2003). Kasanen et al. (1993) divides market tests to three categories: weak market test, semi-strong market test and strong market test. To pass the weak market test, a manager responsible for the financial results of a business unit should be willing to apply the construction in actual decision making (Kasanen et al., 1993). It should also be noted that even the weak market test is relatively strict, and a tentative construction will not probably pass it (Kasanen et al., 1993). On this basis, it can be stated that the case study does not qualify as a weak market test. The case study was conducted in a scenario where the actual decision to purchase the data virtualization software was already made. The objective of the case study is to test and demonstrate the functionality of the proposed method rather than provide support in an actual decision-making problem. The applicability of the solution is discussed after the case study in chapter 5.

4 THE PAY-OFF METHOD AND TOPSIS FOR IS INVESTMENT EVALUATION AND SELECTION

This chapter focuses on developing the proposed method for evaluating and selecting optimal information system investments. In constructive research approach, this is known as constructing the solution to the initial problem.

The proposed method is a combination of the pay-off method and TOPSIS. The method is strongly inspired by Collan et al. (2013) who developed a method for ranking patents using three possibilistic moments derived from the pay-off analysis in a TOPSIS–AHP framework. Similarly, in the proposed method, three descriptive statistics are calculated using the pay-off method and used as one of the criteria in TOPSIS.

The circumstances under which the proposed method is used are such that the purchasing company has already identified the potential information system alternatives and received the bids from the system providers, leading to a set of potential information system investments competing for funding. The company is now left with the task of identifying the optimal information system investment from a set on competing alternatives. The proposed method is designed to facilitate this decision-making process. The method is also well suited in the common information system investment evaluation and selection process, as described by Bannister (2004). Table 2, below, illustrates the steps in the proposed IS investment evaluation and selection method.

Table 2. The proposed method for information system investment evaluation and selection.

Step 1	Determine the selection criteria and the importance of the criteria.
Step 2	Utilize the pay-off method to calculate the descriptive statistics.
Step 3	Assess the alternatives against each criterion.
Step 4	Utilize TOPSIS to rank the alternatives.

Next, we provide a detailed introduction to the pay-off method and TOPSIS, and then we discuss about the proposed method and its steps in more detail.

4.1 The pay-off method

The pay-off method uses net present value (NPV) scenarios to create a pay-off distribution for an asset or an investment project (Collan, 2012). Therefore, in order to understand the logic behind the pay-off method, one needs to first understand the concept of net present value.

Net present value (NPV) analysis is a traditional capital budgeting method where the estimated future net cash flows are discounted back to the present value. The methodology is based on a concept known as time value of money, which states that an amount of money today is worth more than the same amount in the future. There are multiple reasons why a cash flow today is worth more than a similar cash flow in the future, including inflation, opportunity cost, preference for current consumption and riskiness of the cash flow. Due to inflation, the value of money decreases over time. The higher the inflation, the lower the value. Opportunity cost, on the other hand, is what a company sacrifices by choosing one option over another. Money available today can be invested profitably in some productive activity and thus it is more valuable than the same amount in the future. (Vishwanath S.R., 2007)

To take the time value of money into account, the future cash flows need to be transformed to present value. The process of transforming a cash flow to present value is called discounting. The rate of interest at which present and future values are traded off is called the discount rate. Discount rate may be thought of as the expected return forgone by investing in a particular asset rather than in an equally risky alternative asset in the capital market. (Vishwanath S.R., 2007)

Net present value of an investment is the sum of the present values of expected cash flows and the initial investment. NPV may be calculated as:

$$NPV = -C_0 + \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \cdots + \frac{C_n}{(1+r)^n} \tag{1}$$

where C_0 is the cost of the initial investment and $C_1 \ldots C_n$ are the expected net cash flows for n time periods, and r is the discount rate. In other words, NPV is the excess of present value of cash inflows over the initial investment. The rule is to take the investment if NPV is larger than zero and reject it if NPV is less than zero. (Vishwanath S.R., 2007)

To illustrate the methodology, let’s look at a simplified example. Suppose you are assigned with a task to evaluate the profitability of a new information system investment. Let’s say the system will cost 100 000 € and the estimated cost savings (net cash flow) due to improvements in operational efficiency will be 20 000 € per year. Management expects a lifespan of 5 years for the system and suggests an annual discount rate of 5%. Net present value for the information system may be calculated as follows:

$$NPV = -100\,000 + \frac{20\,000}{1+0{,}05} + \frac{20\,000}{(1+0{,}05)^2} + \frac{20\,000}{(1+0{,}05)^3} + \frac{20\,000}{(1+0{,}05)^4} + \frac{20\,000}{(1+0{,}05)^5}$$
$$= -13\,410\ €$$

The net present value of the information system is -13 410 €, meaning that the costs of the investment exceed its earnings, making the investment unviable within the five-year evaluation period.

One of the drawbacks of NPV, when considering information system investments, is that it assumes that the cash flows are certain. As a result, the decision-maker is left with a single number that represents the value of the investment. Relying on a single value might be justified if the future cash flows of the investment are fixed or easy to estimate. However, this is often not the case, especially in information system investments which are known for their ambiguous cash flows. Future cash flows of information system investments are often difficult to identify (Azadeh et al., 2009; Irani, 2002; Vishwanath, 2007).

To tackle the uncertainties within the future cash flows, the pay-off method adds two new cash flow scenarios to the analysis, namely minimum and maximum possible scenarios. What makes the pay-off method interesting in the field of IS investment evaluation, is that the method does not assume that the cash flows are certain. By calculating a net present value for the three scenarios, the decision-maker can form a triangular pay-off distribution that is a fuzzy representation of the value of the investment. (Collan, 2012)

To illustrate the methodology, let’s follow the example above, and utilize the pay-off method to evaluate the profitability of the new information system investment. Now, in addition to the best estimation, we have estimated the minimum and maximum possible cash flow scenarios as well. The initial investment cost and the expected net cash flows for each scenario for five years are presented in table 3 below.

Table 3. Net cash flows for each scenario

	Minimum possible scenario	Best estimate	Maximum possible scenario
Initial cost	100 000 €	100 000 €	100 000 €
Cash flow year 1	10 000 €	20 000 €	25 000 €
Cash flow year 2	10 000 €	20 000 €	30 000 €
Cash flow year 3	10 000 €	20 000 €	40 000 €
Cash flow year 4	10 000 €	20 000 €	40 000 €
Cash flow year 5	10 000 €	20 000 €	40 000 €

The best estimate scenario represents the scenario that the decision-maker believes is most likely to happen. In that scenario, the cash flows are the same as before with an initial investment cost of 100 000 € and annual net cash flows of 20 000 €. The minimum and maximum possible scenarios, on the other hand, form the lower and upper boundaries for the pay-off distribution, and the most likely scenario falls somewhere between them. To form the pay-off distribution, three cumulative net present values are calculated for each scenario over the investment horizon. (Collan, 2012) Cumulative net present values were calculated using equation 1 above with the same 5% discount rate. The cumulative net present values for each scenario are illustrated in table 4 below.

Table 4. Cumulative net present values for each scenario

Scenario	Year					
	0	1	2	3	4	5
Minimum possible	-100 000 €	-90 476 €	-81 406 €	-72 768 €	-64 540 €	-56 705 €
Best estimate	-100 000 €	-80 952 €	-62 812 €	-45 535 €	-29 081 €	-13 410 €
Maximum possible	-100 000 €	-76 190 €	-48 980 €	-14 426 €	18 482 €	49 823 €

As one can see from table 4 above, the most likely NPV for the investment after five years is the same -13 410 €, which again suggest not to undertake the investment. However, instead of only a single, most likely NPV, we now have three different net present values that as a whole form the pay-off distribution. By looking at the pay-off distribution, we can see that the investment will have a net present value somewhere between -56 705 € and 49 823 €, while landing most likely somewhere near -13 410 €. This tells us that the investment is expected to be unviable, but it still has some potential for a positive result. This information is much easier to understand when presented graphically. Figure 6 below, is a visual representation of the three cumulative net present values in table 4 as a function of time.

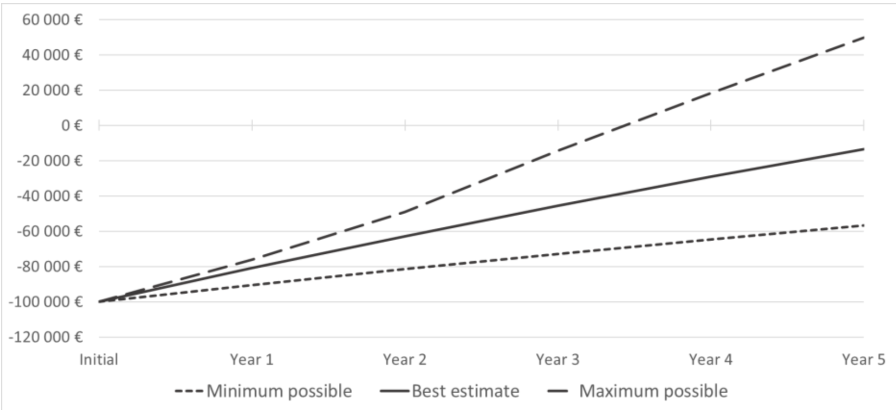

Figure 6. Cumulative net present values for each scenario.

The figure above tells how the three net present values behave over time. The upper and lower lines represent the minimum and maximum possible scenarios, while the one in the middle, is the most likely, best estimate scenario. The three net present values at the end of the investment horizon form a triangular fuzzy number that represents the pay-off distribution. The triangular fuzzy number refers to a connected set of possible values, where each value has its own weight between 0 and 1. The most likely net present value is assigned with a full weight of 1. The minimum and maximum possible net present values are assigned with a weight of 0. (Collan, 2012) The pay-off distribution is illustrated in figure 7 below.

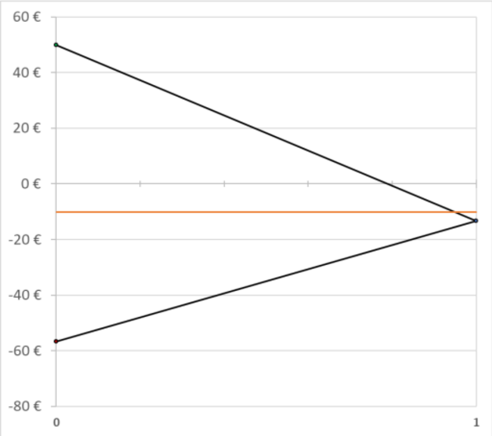

Figure 7. Pay-off distribution and the mean NPV.

The pay-off distribution tells us several things about the investment. In addition to the expected pay-off, it tells us the probability of different outcomes and the risk of the investment in a visual manner. The larger the gap between the upper and lower boundaries (minimum and maximum NPV) of the distribution, the greater the risk. The closer the weight of a possible NPV is to 1, the higher its probability. (Collan, 2012)

From the pay-off distribution, we can also calculate various descriptive statistics, such as mean NPV, success factor, and risk factor. Mean NPV is a single number that represents the center of the distribution. Mean NPV takes the shape of the pay-off distribution into consideration. The higher the mean NPV, the better. (Collan, 2012) Mean NPV is calculated from a triangular fuzzy number using the formula introduced by Carlsson and Fullér (2001):

$$E(A) = a + \frac{\beta - \alpha}{6} \tag{2}$$

where a is the best guess NPV, and α and β are the distances between the minimum NPV and the best guess NPV and the maximum NPV and the best guess NPV, respectively. If the values from the previous example are inserted to the equation above, one receives a mean NPV of -10 087€. The mean NPV is slightly higher than the best guess NPV because the large maximum possible NPV “pulls” the mean NPV higher. The mean NPV was illustrated by the orange line in figure 7 above. (Collan, 2012)

A ratio that can be described as a success factor can be calculated from the pay-off distribution. The success factor is the percentage of the pay-off distribution that is on the positive side. By splitting the distribution where the NPV is zero, one is left with two areas: a positive area (area above zero) and a negative area (area below zero). The comparison of the positive and negative areas tells us about the possibility of a profitable investment. The larger the positive area, the greater the possibility is for a positive NPV. Vice versa, the larger the negative area, the greater the possibility is for a negative NPV. The success factor is calculated simply by dividing the positive area by the area of the total distribution and multiplying it by 100% to get the percentage of the total distribution. In other words, it is the percentage of the pay-off distribution that is above zero. It is a numerical way to tell the possibility of having a positive net present value after a period of time. (Collan, 2012)

The risk factor tells the possibilistic standard deviation of the pay-off distribution. Standard deviation is a commonly used measure of financial risk. The method for calculating the possibilistic standard deviation from a triangular fuzzy number was introduced by Carlsson and Fullér (2001) and Fuller and Majlender (2003), who calculate it as an absolute number. Collan et al. (2014) on the other hand suggest calculating the risk factor as a percentage of the mean NPV. The risk factor as a percentage of the mean NPV can be calculated using the following equation:

$$Risk\ factor\ \% = \frac{\frac{\sqrt{(\alpha-\beta)^2}}{24}}{E(A)} \quad (3)$$

where $E(A)$ is the mean NPV, and α and β are the distances between the minimum NPV and the best guess NPV and the maximum NPV and the best guess NPV, respectively.

4.2 TOPSIS

The technique for order preferences by similarity to an ideal solution (TOPSIS), developed by Hwang and Yoon (1981), is a multiple criteria decision-making method designed to identify the ideal solution from a set of alternatives. According to the method, the ideal solution is the alternative that is simultaneously nearest to the positive ideal solution (best solution) and farthest from the negative ideal solution (worst solution) (Tzeng and Huang, 2011).

TOPSIS is typically conducted in seven steps: (1) formulate the decision matrix, (2) calculate the normalized decision matrix, (3) calculate the weighted normalized decision matrix, (4) calculate the positive and negative ideal solutions, (5) calculate the distances from the positive and negative ideal solutions, (6) calculate the similarity to the positive ideal solution, and finally (7) rank the alternatives. (Mateo, J. R. S. C., 2012; Tzeng and Huang, 2011)

Step 1. Formulate the decision matrix

Before formulating the decision matrix, one needs to determine the alternatives, criteria, and the weight of the criteria. When determining the alternatives, it is recommended to define some minimum requirements the alternatives must pass before including them to the decision matrix. This ensures that the matrix contains only viable alternatives and remains compact. Cost is a good example of a minimum requirement. If an alternative exceeds the budget, there is no need to include it to the decision matrix. (Huizingh and Vrolijk 1995; Mateo, J. R. S. C., 2012)

The criteria can be either benefit-type criteria or cost-type criteria. In TOPSIS, the optimal solution is the alternative that maximizes benefit-type criteria and minimizes cost-type criteria. For example, a decision-maker might wish to maximize the number of features (benefit-type criteria) in a new information system and minimize its costs (cost-type criteria). The criteria can also be either quantitative or qualitative. Quantitative criteria, also known as tangible or “hard” criteria, are typically easier to measure and evaluate. Qualitative criteria, on the other hand are much harder to assess and often require input from IT managers and system users. There are multiple ways to assess the alternatives against qualitative criteria. A simple method is to determine a scale, such as the one in table 6 below, from which scores are given for each alternative based on how well they perform with respect to each criterion. (Huizingh and Vrolijk 1995; Mateo, J. R. S. C., 2012)

Table 5. Linguistic scale for evaluating qualitative criteria (Adapted from Mateo, J. R. S. C., 2012, p. 3).

Rating	Scale
1	Very poor
3	Poor
5	Moderate
7	Good
9	Very Good
2, 4, 6, 8	Intermediate values

The weight of the criteria is essentially a number that reflects the importance of one criterion with respect to another. Determining the weights can be done very subjectively or more objectively with other quantitative methods, such as the analytic hierarchy process (AHP). The weights can be expressed as decimals (or percentages) so that they add up to 1 (or 100 percent). (Mateo, J. R. S. C., 2012; Schniederjans, 2004). The weights can also be determined using a linguistic scale as shown in table 6 below.

Table 6. Linguistic scale for determining the weights of the criteria (Adapted from Mateo, J. R. S. C., 2012, p. 3).

Weight	Scale
1	Very low
3	Low
5	Moderate
7	High
9	Very high
2, 4, 6, 8	Intermediate values

Once the alternatives, criteria, and the weights of the criteria are determined, the decision matrix can be formulated. The decision matrix can be expressed as a $m \times n$ matrix of n alternatives and m criteria:

Table 7. Decision matrix.

	C_1	C_2	...	C_j
	w_1	w_2	...	w_j
A_1	a_{11}	a_{12}	...	a_{1j}
A_2	a_{21}	a_{22}	...	a_{2j}
...	...	...	...	...
A_i	a_{i1}	a_{i2}	...	a_{ij}

where w_n is the weight of the nth criterion, and a_{ij} is the evaluation given to alternative A_i $(i = 1, \ldots, m)$ with respect to criterion C_j $(j = 1, \ldots, n)$. (Mateo, J. R. S. C., 2012)

Step 2. Calculate the normalized decision matrix

Because the criteria in the decision matrix are usually measured in various units, the a_{ij} values in the matrix must be transformed to a normalized scale. Normalizing the evaluations in the decision matrix enables the comparison across criteria of various units and scales. The normalized evaluation r_{ij} can be calculated as:

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \tag{4}$$

where a_{ij} is the original evaluation of alternative A_i $(i = 1, \dots, m)$ with respect to criterion C_j $(j = 1, \dots, n)$. (Mateo, J. R. S. C., 2012)

Step 3. Calculate the weighted normalized decision matrix

Once the decision matrix is normalized, a matrix of weighted normalized values is constructed. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = r_{ij} w_j \tag{5}$$

where w_{ij} is the normalized weight of the jth criterion. (Mateo, J. R. S. C., 2012)

Step 4. Determine the positive and negative ideal solutions

The positive and negative ideal solutions are determined from the weighted normalized decision matrix. The positive ideal solution (PIS) and the negative ideal solution (NIS) are composed of the best and worst criteria values, respectively, among the alternatives. (Mateo, J. R. S. C., 2012)

When forming the positive and negative ideal solutions, one should take the type of criteria into account. The positive ideal solution is the solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution is the solution that minimizes the benefit criteria and maximizes the cost criteria. Therefore, the positive ideal solution (PIS) and the negative ideal solution (NIS) has the form:

$$PIS = \{v_1^P, \dots, v_n^P\} = \{(\max_i v_{ij} \mid j \in C^P), (\min_i v_{ij} \mid j \in C^N)\} \tag{6}$$

$$NIS = \{v_1^N, \dots, v_n^N\} = \{(\min_i v_{ij} \mid j \in C^P), (\max_i v_{ij} \mid j \in C^N)\} \tag{7}$$

where C^P is a set of benefit criteria and C^N is a set of cost criteria. Essentially, the positive ideal solution is a theoretical alternative that is composed of the best available values across all alternatives whereas the negative ideal solution is composed of the worst available values across all alternatives. (Hwang and Yoon, 1995)

Step 5. Calculate the distances from the positive and negative ideal solutions

The next step is to calculate the distances between the alternatives and the positive and negative ideal solution. The distances can be calculated using the Euclidean distance. The distance d_i^P between alternative A_i and the positive ideal solution is calculated as:

$$d_i^P = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_j^P\right)^2} \tag{8}$$

where v_{ij} is the weighted normalized value of alternative A_i with respect to criterion C_j, and v_j^P is the jth element of the positive ideal solution (PIS). Similarly, the distance d_i^N between the alternative A_i and the negative ideal solution is calculated as:

$$d_i^N = \sqrt{\sum_{i=1}^{n} \left(v_{ij} - v_j^N\right)^2} \tag{9}$$

where v_j^N is the jth element of the negative ideal solution (NIS). (Mateo, J. R. S. C., 2012; Hwang and Yoon, 1995).

Step 6. Calculate the similarity to the positive ideal solution

The sixth step is to calculate the similarities to the positive ideal solution. For each alternative A_i $(i = 1, \dots, m)$ we now calculate its similarity s_i^P to the positive ideal solution (PIS):

$$s_i^P = \frac{d_i^N}{(d_i^P + d_i^N)} \tag{10}$$

where d_i^N is the distance to the negative ideal solution and d_i^P is the distance to the positive ideal solution. (Mateo, J. R. S. C., 2012; Tzeng and Huang, 2011)

Step 7. Rank the alternatives

Finally, the alternatives can be ranked based on their similarity to the positive ideal solution. The alternative with the highest s_i^P value is proposed as a solution. (Mateo, J. R. S. C., 2012; Tzeng and Huang, 2011)

4.3 Integrating the pay-off method and TOPSIS

A four-step process is proposed for the ex-ante evaluation and selection of information system investments. The proposed method combines the pay-off method and TOPSIS. The pay-off method is used to evaluate the profitability of the investment and calculate the descriptive statistics (mean NPV, success factor and risk factor). The descriptive statistics are then used as one of the criteria in TOPSIS. By utilizing the outputs of the pay-off method as the criteria in TOPSIS, we can identify the optimal investment alternative while considering both financial and non-financial criteria. The steps of the proposed method and their outputs are illustrated in figure 8 below.

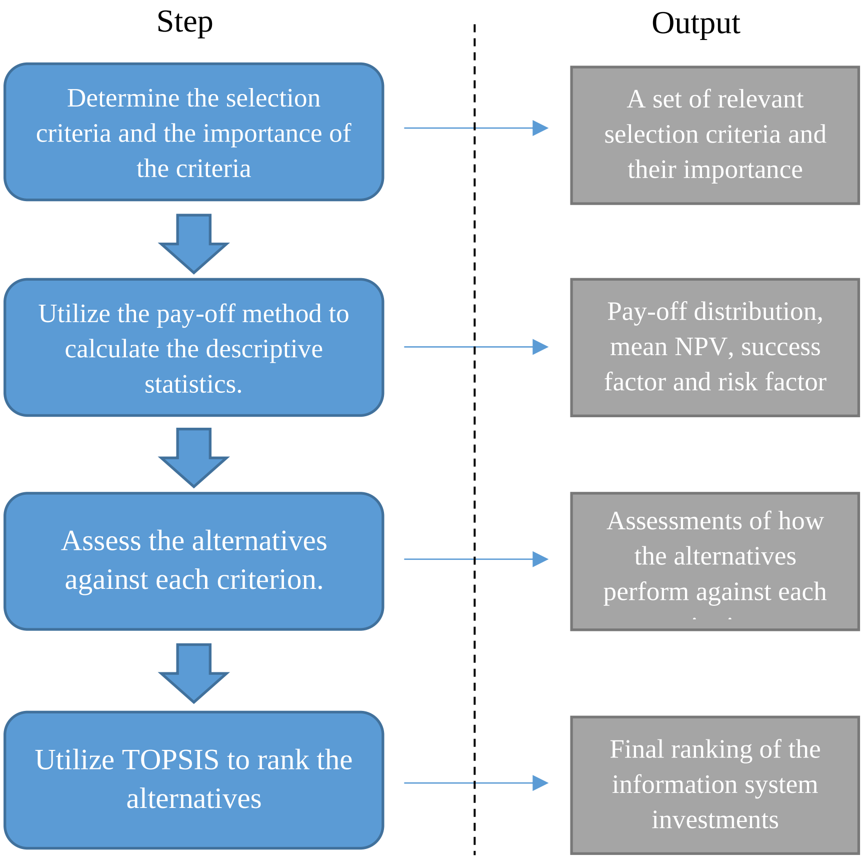

Figure 8. The proposed method for information system investment evaluation and selection.

Step 1: determine the selection criteria and the importance of the criteria

The first step is to determine the selection criteria and the weights of the criteria. At this point, the organization has already identified a set of potential investment alternatives. The selection criteria will be used to judge the alternatives while the weights represent the importance of the criteria. Determining the right selection criteria is essential for making the right decision. For determining relevant criteria and the weights of the criteria, it is recommended to gather the views multiple of subject matter experts. While there is no definitive set of correct selection criteria for evaluating all information system investments, much research suggests evaluating both business and technological domains of the investments. To capture the profitability, potential and risk of the information system investments, we recommend including the mean NPV, success factor and risk factor to the business criteria, which are calculated using the pay-off method.

Once the selection criteria have been determined, one should determine the weights of the criteria. There are different methods for determining the weights of the criteria. The simplest method, which is also the one used here, is to assign the weights to each criterion using a linguistic scale, such as the one presented in table 6.

Step 2: utilize the pay-off method to calculate the descriptive statistics

The second step is to utilize the pay-off method to calculate the descriptive statistics (the mean NPV, success factor and risk factor) for each alternative. To apply the pay-off method, one needs to first estimate three cash-flow scenarios (most likely scenario, minimum possible, and maximum possible scenario) for each investment alternative. The evaluation of future costs and income (or costs savings) of information systems is challenging. Therefore, when estimating the future cash flows, it is suggested to involve all relevant subject matter experts to the estimation process and utilize the information provided by the system providers.

Once the cash flow scenarios have been estimated, one can apply the pay-off method to form the pay-off distributions and calculate the mean NPV, success factor and risk factor. The mathematics and the steps in the pay-off method were discussed more thoroughly in chapter 4.1.

Step 3: assess the alternatives against each criterion

The third step is to assess the alternatives against each criterion. In this step, one basically needs to evaluate how each alternative performs with respect to each criterion. The values for the mean NPV, success factor, and risk factor were already calculated in the previous step. While there are different and more advanced methods for assessing the alternatives against intangible criteria, in our approach we assign scores to each alternative using a simple linguistic scale from 1 to 10, where 1 represents a very poor performance and 10 a very good performance.

Step 4: utilize TOPSIS to rank the alternatives

The last step of the process is to rank the information system investment alternatives using TOPSIS. The ranking in TOPSIS is based on the distances between the alternatives and the positive and negative ideal solution. The negative ideal solution is essentially a hypothetical alternative that is formed from all the worst possible values amongst the alternatives. The positive ideal solution, on the other hand, is formed from all the best possible values amongst the alternatives. Therefore, the optimal information system investment alternative is the one that is farthest from the negative ideal solution and closest to the positive ideal solution. The steps in TOPSIS were discussed in more detail in the previous sub-chapter.

5 CASE STUDY

According to constructive research approach, the functionality of the designed construction should be tested. The functionality of the proposed method for IS investment evaluation and selection was tested by means of a case study. The case study was conducted in a scenario where the actual decision to purchase the data virtualization software was already made. The objective of the case study is to test and demonstrate the functionality of the proposed method and examine if and how the results of the proposed method differ from the previous results of the case company.

After the case study, the applicability of the method is examined by evaluating whether the method produced the anticipated results and how it fulfills the requirements listed at the end of the literature review. To be considered applicable for the evaluation and selection of information system investments, the method should be able to identify the optimal investment while considering multiple different criteria, including both tangible and intangible costs and benefits, risks and the features and functionalities of the systems. In addition, the method should be able to model and interpret uncertain information, it should provide reliable and consistent results that are easy to interpret, and the method should be easy to understand and based on proven theories.

The case study was conducted in cooperation with the case company. The case company is part of the Finnish social security system. The company collects unemployment insurance contributions to provide unemployment and adult education benefits. To provide its services and run its businesses, the case company collects, generates, and processes a lot of data. This data is not stored in a unified manner and it is siloed across multiple business processes and information systems. The data is extracted from source systems to data consumers as needed. The organization has realized that the current ways of working will not meet the increasing demand of data analytics. As the number of information systems and volume of data increases, their current data management processes become more and more complex.

To meet the increasing demand of data, and to streamline their data management processes, the case company wanted to investigate whether they should acquire a new data virtualization system or set up a new centralized data warehouse.

Data virtualization is an approach to data management that basically makes multiple, diverse data sources appear as one. It provides a single virtual view and access to the organization’s data. A data virtualization system allows the data consumers to retrieve and manipulate data without requiring technical details about the data, such as how and where it is physically stored.

A data warehouse, on the other hand, is a more traditional alternative where the data is transferred from the source systems to a data warehouse using ETL processes (extract, transform, and load). Data warehouse is a central, integrated repository of data, gathered from various source systems. Data warehouse stores all the data that is loaded into its storage layer, whereas data virtualization only provides an access to the data while leaving the data to its original place.

Both alternatives would improve the company’s current data management processes and the availability of data. Now, the case company wants to know, which of the two alternatives is optimal for their organization. The proposed method was applied to facilitate this decision-making problem.

The case study includes only two investment alternatives. Ideally the proposed method would be utilized in a situation where there are multiple alternatives, and it would be truly unclear which one is the best. However, for demonstrating the functionality of the proposed method, the case study was considered sufficient.

Step 1: determine the selection criteria and the importance of the criteria

The process began by determining the selection criteria. The case company determined a set of ten criteria, including mean NPV, success factor and risk factor. The criteria and their importance are illustrated in the decision matrix below.

Table 8. Decision matrix.

Criteria	Type	Importance
Mean NPV	Benefit	4. Low to Moderate
Success factor	Benefit	5. Moderate
Risk factor	Cost	4. Low to Moderate
Total costs	Cost	7. High
Alignment with existing IT portfolio	Benefit	9. Extremely High
Improved data quality and availability	Benefit	8. Very High
Improved data management	Benefit	7. High
Required changes to existing systems	Cost	6. Moderate to High
Improved flexibility	Benefit	7. High
Maintenance workload	Cost	6. Moderate to High

One of the main criteria was the alignment of the solution to the case company's existing IT portfolio. The solution needs to integrate well with the case company's existing information systems, data sources and BI systems. It is also important that the selected solution will enable easy access to reliable data when needed and in the format needed. This was captured using improved data quality and availability as one of the criteria. Another criterion used was improved data management, which reflects how well the solution will eliminate the complexity of the data management infrastructure. The case company also wanted to minimize the required changes to the configurations in the existing information systems. Improved flexibility is a criterion that reflects the ability of the solution to adapt to changes in the surrounding business processes and data management architecture. The final qualitative criteria, maintenance workload, represents the estimated amount of workhours needed to maintain the solution and its data integrations.

The importance of the criteria was determined so that the model would prefer an alternative that would align well with the existing IT systems, improve data quality and availability, and streamline the overall data management processes and flexibility with minimum costs.

Step 2: utilize the pay-off method to calculate the descriptive statistics

The second step was to apply the pay-off method to calculate the mean NPV, success factor and risk factor. In addition to the descriptive statistics, the pay-off method provides a lot of additional insight about the profitability of the investments.

The pay-off analysis began by estimating the most likely, minimum, and maximum possible cash flow scenarios for the two investments. The case company determined a four-year forecast period for the two investment alternatives with a three percent discount rate.

The costs of the investments were divided to three categories: licensing costs, maintenance and development costs, and consultancy fees. The licensing costs of the data virtualization system were received directly from the service provider. In addition to an annual licensing fee, the system had a one-time set-up fee. The increase in licensing costs attributable to the data warehouse investment, on the other hand, was estimated by the case company's subject matter experts. The case company has the technologies required for a data warehouse environment, so the expected increase in licensing costs was significantly lower than in the data virtualization alternative.

The consultancy fees and maintenance and development costs were both estimated by transforming the estimated person-hours to a monetary unit using different rates. The case company expects to require some support from the service provider during the first year for implementing the new data virtualization system and supporting in its use. After the first year, the case company expects to be able to maintain the system themselves and only require minor support when creating new data sources to the system. Thus, the consultancy fees in the data virtualization alternative are expected to drop significantly after the first year. The case company expects that the data warehouse project will require more external help from a service provider and more time spent on maintaining and developing the environment, meaning higher consultancy fees and maintenance and development costs.

The benefits of the two alternative investments, on the other hand, were divided to two main categories: increase in productivity and reduction in IT operating costs. Both benefits are quite ambiguous and were difficult to express in monetary terms. The increase in productivity was considered to encapsule the enhanced productivity of the employees who depend on data. Due to siloed data, most of the data analysts' time was spent on searching, extracting, and preparing data. A centralized access to all data is expected to remove bottlenecks and lead to faster time to insight and better decisions. The monetary value of increased productivity was obtained by estimating the work hours saved by providing a centralized access to all data. The reduction in IT operating costs, on the other hand, represents the estimated cost savings originated by the reduction in work hours spent on maintaining the data management infrastructure. This means less storage costs and less time spent on data governance, maintaining data integrations, and resolving incidents. Data virtualization especially is expected to reduce the complexity of the data management infrastructure and the required storage of data copies.

Estimating the costs and benefits attributable to the investments was challenging. The only relatively certain cash flows were the licensing costs of the data virtualization system which were received directly from the service provider. The rest were based on the estimations of the case company's subject matter experts. Due to the difficulty of estimating the future cash flows of the investments, the case company decided to use a 15% margin of error. This means that besides the licensing costs of the data virtualization investment, the costs in the minimum possible cash flow scenario were 15% larger and the benefits 15% lower than in the most likely scenario, and vice versa in the maximum possible cash flow scenario. The cash flows of the minimum and maximum cash flow scenarios are illustrated in appendix 2. The most likely cash flow scenarios for both the data virtualization software and the data warehouse, together with the cumulative net present values are illustrated in tables 9 and 10 below.

Table 9. Most likely cash flow scenario for the data virtualization investment

Data Virtualization	Initial	Year 1	Year 2	Year 3	Year 4
Initial Licensing Costs	(94 000)				
Annual Licensing Costs		(22 560)	(22 560)	(22 560)	(22 560)
Maintenance & Dev. Costs		(30 000)	(20 000)	(10 000)	(10 000)
Consultancy Fees		(30 000)	(4 000)	(4 000)	(4 000)
Increase in Productivity		20 000	50 000	50 000	50 000
Reduction in IT Operating Costs		20 000	50 000	50 000	50 000
Annual Net Cash Flow	(94 000)	(42 560)	53 440	63 440	63 440
Discounted Cash Flow	(94 000)	(41 320)	50 372	58 057	56 366
Cumulative NPV	(94 000)	(135 320)	(84 948)	(26 891)	29 474

Table 10. Most likely cash flow scenario for the data warehouse investment.

Data warehouse	Year 1	Year 2	Year 3	Year 4
Licensing Costs	(5 000)	(5 000)	(5 000)	(5 000)
Maintenance & Dev. Costs	(20 000)	(20 000)	(20 000)	(20 000)
Consultancy Fees	(80 000)	(40 000)	(30 000)	(20 000)
Increase in Productivity	20 000	50 000	50 000	50 000
Reduction in IT Operating Costs	10 000	25 000	25 000	25 000
Annual Net Cash Flow	(75 000)	10 000	20 000	30 000
Discounted Cash Flow	(72 816)	9 426	18 303	26 655
Cumulative NPV	(72 816)	(63 390)	(45 087)	(18 432)

The cumulative net present values were also presented graphically for a more intuitive interpretation. Figures 9 and 10 below illustrate the cumulative net present values of the two investments as a function of time.

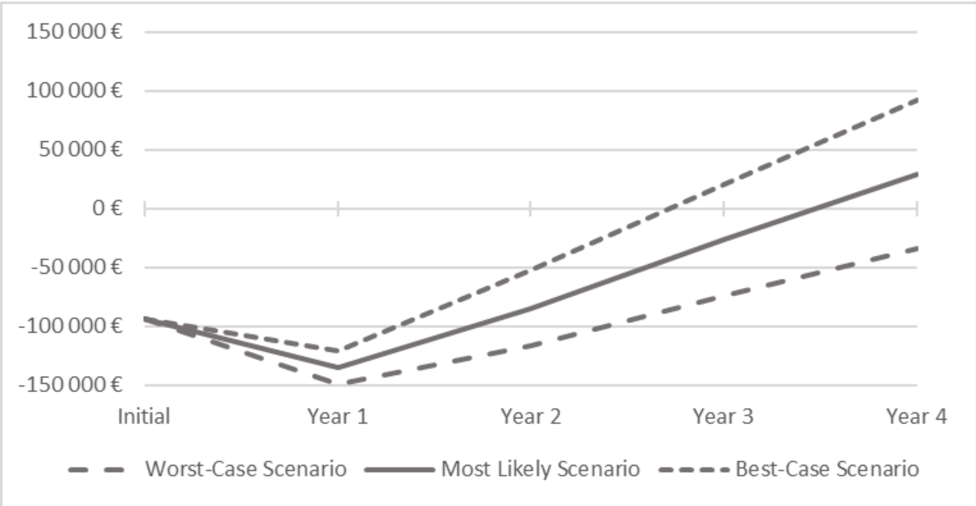

Figure 9. Cumulative net present values for the data virtualization investment.

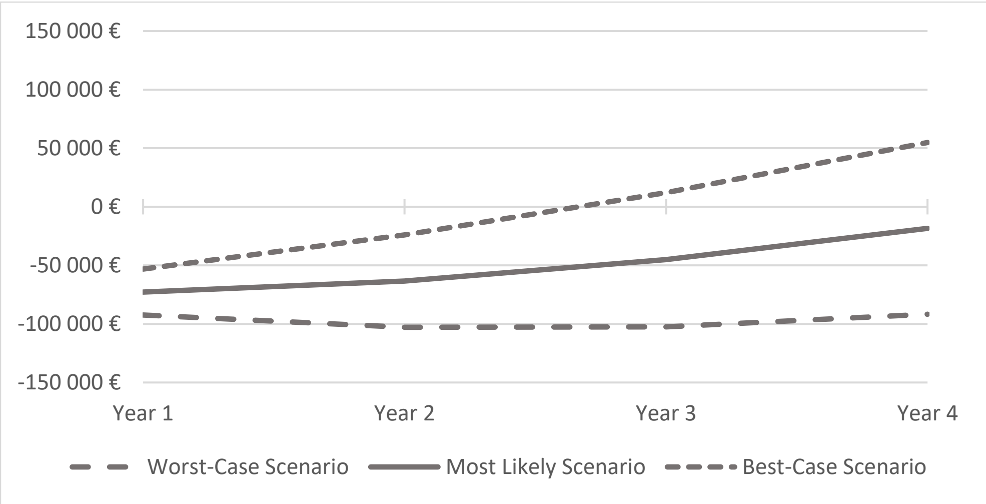

Figure 10. Cumulative net present values for the data warehouse investment.

When we look at the figures above, we can see that even though the investment to data virtualization has a higher upfront cost, it is expected to pay itself back faster than the data warehouse investment. The resulting pay-off distributions are illustrated in figures 11 and 12 below.

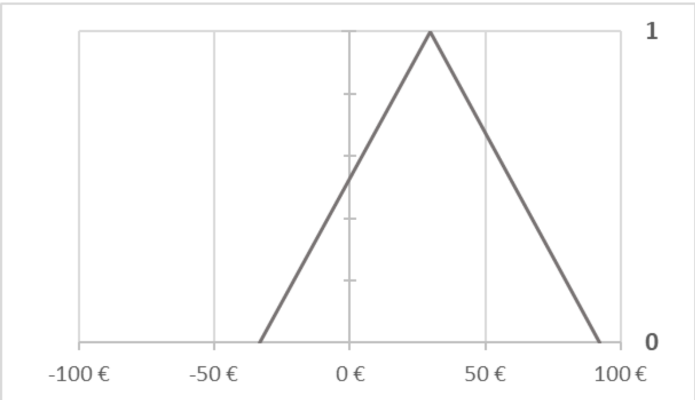

Figure 11. Pay-off distribution for the data virtualization investment.

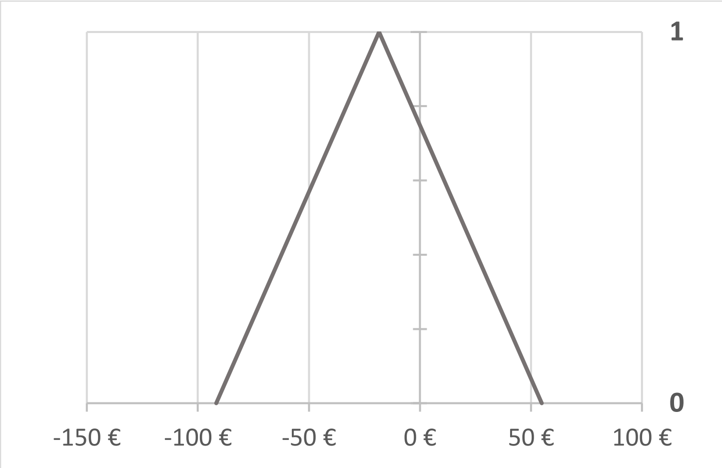

Figure 12. Pay-off distribution for the data warehouse investment.

By comparing the two distributions, it is clear that the investment to data virtualizations is financially the preferred alternative. The whole distribution of the data virtualization alternative is located more on the right, meaning that the expected return in each scenario is larger in the data virtualization investment.

The three descriptive statistics – mean NPV, success factor, and risk factor – were calculated from the pay-off distributions. Following the equations 2 and 3, we get the metrics illustrated in table 11 for the two investments.

Table 11. Descriptive statistics.

Metric	Data Virtualization	Data warehouse
Mean NPV	29 474	(18 432)
Success factor	86 %	28 %
Risk factor	87 %	162 %

The mean NPV tells the expected return of the investment. It is a good metric that also takes the shape of the distribution into account. In this case, however, because the case company decided to simply use a 15% margin of error, the pay-off distributions are not skewed to either direction, meaning that the mean NPV is equal to the most likely NPV. The success factor, on the other hand, tells the proportion of the distribution that is above zero. It basically tells the likelihood of a positive NPV. The risk factor tells the possibilistic standard deviation of the pay-off distribution as a percentage of the mean NPV.

Based on the evidence received from the pay-off analysis alone, the investment to data virtualization seems to be financially the preferred alternative. It has a higher mean NPV, larger success factor and lower risk factor. Next, we assess the alternatives against the rest of the selection criteria which we determined in the first step.

Step 3: assess the alternatives against each criterion

The third step is to assess how the information system investment alternatives perform against the rest of the criteria. The values for the quantitative criteria were acquired directly from the previous steps. The values for the qualitative criteria, on the other hand, were drawn from a scale of 1 to 9, where 1 represents a very poor performance and 9 a very good performance. The filled decision matrix is illustrated in table 12 below.

Table 12. Decision matrix

Criteria	Type	Importance	Data Warehouse	Data Virtualization
Mean NPV	Benefit	4	-18 432	29 474
Success factor	Benefit	5	28	86
Risk factor	Cost	4	162	87
Total costs	Cost	7	270 000	296 240
Alignment with existing IT portfolio	Benefit	9	9	8
Improved data quality and availability	Benefit	8	7	9
Improved data management	Benefit	7	6	8
Required changes to existing systems	Cost	6	4	7
Improved flexibility	Benefit	7	6	9
Maintenance workload	Cost	6	7	4

Step 4: utilize TOPSIS to rank the alternatives

The fourth, and last step of the process is to rank the information system investment alternatives using TOPSIS. Following the steps in TOPSIS, we get the distances between the information system investment alternatives and the positive and negative ideal solution. The steps and mathematics behind TOPSIS were discussed in more detail in chapter 4.2. The Euclidean distances between the alternatives and the positive and negative ideal solution are illustrated in table 13 below.

Table 13. Euclidean distances to the positive and negative ideal solution.

Distance	Data Warehouse	Data Virtualization
Distance to negative ideal solution ($\boldsymbol{d_i^N}$)	0,038	0,119
Distance to positive ideal solution ($\boldsymbol{d_i^P}$)	0,119	0,038

Now that we have only two alternatives, it is easy to see which one is the preferred alternative. Data virtualization has a larger distance to the negative ideal solution and a smaller distance to the positive ideal solution, which makes it the preferred alternative. The distances can also be visualized as a scatter plot, as shown in figure 13 below. The alternative that is closer to the left upper corner of the plot is the preferred alternative.

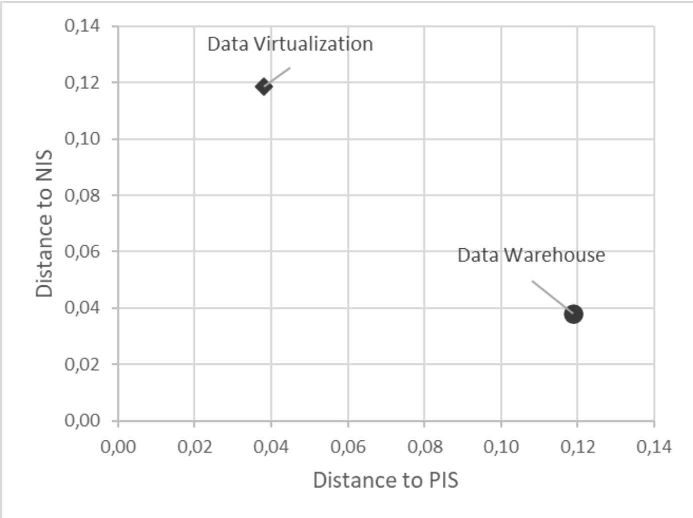

Figure 13. Distances to the positive and negative ideal solutions.

Finally, the ranking of the alternatives is determined by calculating the similarity to the positive ideal solution. The similarity can be calculated using equation 10. The similarities to the positive ideal solution and the ranking of the alternatives are illustrated below.

Table 14. Similarity to the positive ideal solution.

Ranking	**Data Warehouse**	**Data Virtualization**
Similarity to positive ideal solution ($\boldsymbol{s_i^P}$)	0,243	0,757
Ranking	**2**	**1**

According to the proposed method, data virtualization is the preferred alternative. The results of the proposed method are discussed in more detail in the next sub chapter.

5.1 Results of the case study

As a result of the proposed method, we received a ranking of the alternative IS investments. The alternative with the highest ranking is the preferred IS investment. In this case, it is the data virtualization investment. By changing the weights of the criteria or the scores of the alternatives, the decision-makers can also evaluate how sensitive the results are to changes.

In addition to the overall ranking of the IS investment alternatives received from TOPSIS, the pay-off method tells us a lot about the estimated profitability, potential and risk of the investments. The pay-off distributions, illustrated in figures x and y, represents the expected returns of the investments as a triangular fuzzy number. The expected returns of the investments are also evaluated using a crisp value: the mean NPV which is a single number that represents the center of the distribution. As seen from table 11, the mean NPV of the data virtualization investment is about 48 000€ higher than the mean NPV of the data warehouse investment.

The success factor is the percentage of the pay-off distribution that is above zero. It is a good metric that tells about the possibility of having a positive net present value after a period of time. As seen from table 11, the success factor of the data virtualization investment is 58 percentage points larger than the success factor of the data warehouse investment, suggesting that data virtualization has significantly greater chances of generating positive returns.

The risk factor tells us the possibilistic standard deviation of the pay-off distribution as a percentage of the mean NPV. As seen from table 11, the risk factor for the data virtualization investment is 75 percentage points lower than the risk factor of the data warehouse investment. This tells us that the expected return of the data warehouse investment has a higher spread with respect to its mean NPV.

By inserting the descriptive statistics to the decision matrix along with the criteria determined by the decision-makers, using TOPSIS we were able to identify the optimal investment alternative while considering a wide range of different criteria that affects the investment decision. By determining the weights of the criteria, we were also able to capture the preferences of the decision-makers. TOPSIS also produces the distances between the alternatives and the negative and positive ideal solutions. As seen from figure 13, the data virtualization investment is closer to the positive ideal solution and farther from the negative ideal solution, making it the preferred alternative.

5.2 Applicability of the method

Following the steps of constructive research approach, once the functionality of the designed construction is tested, the researcher should ponder the scope and applicability of the solution. The key question here is whether the designed construction is applicable for evaluating and selecting information system investments. The applicability of the proposed method is examined by evaluating how well it meets the requirements listed at the end of the literature review.

The first requirement was that the proposed method should be able to identify the optimal investment while considering multiple different criteria, including both tangible and intangible costs and benefits, risks and the features and functionalities of the systems. Multiple-criteria decision-making methods are designed for this kind of decision-making challenges. The case study showed that by utilizing TOPSIS, the company was able to identify the preferred IS investment from a set of competing alternatives while considering different types of criteria as well as the different importance of the criteria. Therefore, the method is considered to meet the first requirement.

The second requirement was that the method should be able to model and interpret uncertain information. For this reason, the pay-off method was considered as a suitable method for evaluating the profitability of the investments. This was also the conclusion after the case study. The case study showed that the minimum, most likely, and maximum possible cash flow scenarios was a more realistic approach for evaluating uncertain and intangible costs and benefits than a single cash flow scenario. The pay-off distribution was also considered as a more accurate representation of the possible value of the investments than a crisp profitability metric. Therefore, for evaluating the profitability of IS investments, the pay-off method was considered well suitable. Classic TOPSIS, however, utilizes crisp values to evaluate the alternatives and as such is not optimal for dealing with uncertain information. To better incorporate uncertainty to the IS investment evaluation and selection process, a fuzzy variation of the classic TOPSIS method is a possible subject for development.

The final requirement was that the method and its results should be easy to understand and based on proven theories. Even though the pay-off method and TOPSIS are not in widespread use for IS investment evaluation and selection, they are well-known in their own disciplines and based on academically proven principles and theories. The case company representatives also considered that the logic and the results of both the pay-off method and TOPSIS were simple to understand. The way the two methods were integrated was also considered to add value to the IS evaluation and selection process.

One of the challenges that emerged during the case study was the difficulty of estimating the future cash flows of the two investments. However, the use of cash flow scenarios was found to be a useful approach for quantifying the indirect and intangible costs and benefits.

Another challenge identified during the case study, was the difficulty of determining the scores of the alternatives and the weights of the criteria. The case company representatives did not fully rely on the expert judgements that were given using a simple linguistic scale from 1 to 9. The simplistic approach was selected to maintain the usability of the method. To facilitate the determination of the weights and the scores of the alternatives, it is possible to utilize AHP, for example, where the weights are determined using pairwise comparison. AHP is well suitable in the proposed method but it would increase the laboriousness of the method.

As a conclusion, the proposed method for IS investment evaluation and selection was considered applicable for the evaluation and selection of information system investments. The proposed method was considered to meet its requirements and it was well received by the case company. The method also produced anticipated results that were in line with the case company’s previous results.

5.3 Further development

The proposed method could be considered as a minimum viable product, demonstrating the integrated use of the pay-off method and TOPSIS for evaluating and selecting IS investments. Even though the proposed method was considered to function well, there are some possibilities for further development.

As discussed in the literature review, some researchers suggest real options theory when evaluating IS investments (You et al., 2012; Ullrich, 2013). Real options were not considered in the proposed method. However, the pay-off distribution can be directly used as a basis for real option valuation. The real option value can be considered as a measure of the value of the potential within the IS investment (Collan et al., 2014). The real option value calculated from the pay-off distribution could then be utilized as one of the criteria in TOPSIS.

The way TOPSIS was implemented in the study could also be developed. As previously discussed, pairwise comparison or AHP could be utilized for determining the weights of the criteria and the scores for the alternatives. As suggested by Kahraman et al. (2007) and Oztaysi (2014), fuzzy logic could also be incorporated to TOPSIS. The use of fuzzy TOPSIS would also facilitate the determination of the scores of the alternatives and the weights of the criteria by allowing the decision-makers to enter their judgments as fuzzy numbers. Utilizing fuzzy numbers in the proposed method would increase the complexity of the approach but could make it more accurate. If fuzzy logic were incorporated to TOPSIS, it would also allow the use of the fuzzy pay-off distribution directly as one of the criteria.

6 SUMMARY AND CONCLUSIONS

Next, we will summarize the study and present our conclusions. The aim of the chapter is to provide a brief summary of the research and discuss about its theoretical contribution and areas for further development.

6.1 Summary

The objective of the study was to design a method that integrates the pay-off method and TOPSIS for evaluating and selecting information system investments. To reach the objective, three research questions were formed: (1) what prior academic literature exists about the evaluation and selection of information system investments, (2) how the pay-off method and TOPSIS have been utilized to facilitate the evaluation and selection of information system investments, and (3) what added value is received by combining the pay-off method and TOPSIS for IS investment evaluation and selection.

The aim of the first research question was to form a general understanding of the topic by examining how IS investment are being evaluated and what are the main challenges in the evaluation and selection process. The first research question was answered in the literature review. The evaluation and selection of the optimal information system investment is an integral phase in the IS purchasing process where the practitioners try to decide which of a number of potential investments should receive priority and/or funding. The literature showed that while there are many different methods proposed for the task, many companies are still mostly relying on traditional capital budgeting methods which are argued to be insufficient when evaluating information system investments. Due to the supportive and indirect role of information systems and their significant intangible and hidden costs and benefits, many academics have proposed other methods for the evaluation and selection of IS investments. When reviewing the state-of-the-art literature, it became apparent that financial evaluation of IS investment alone is not sufficient, but it cannot be neglected either.

The aim of the second research question was to find out how the pay-off method and TOPSIS have been applied in IS investment evaluation and selection. The research question was also answered in the literature review. The literature showed that both methods have been found suitable for evaluating and selecting IS investments. The pay-off method is based on fuzzy logic and it is capable of modeling uncertain information. The ability of the pay-off method to model and interpret vague and uncertain information is a key feature when evaluating IS investments that are known for their intangible nature. The pay-off method transforms estimated cash flow scenarios into a pay-off distribution that can be regarded as a fuzzy representation of the profitability of the IS investments. TOPSIS, on the other hand, is a MCDM method that is designed to identify the best alternative from a set of competing alternatives while considering different types of criteria and different importance of the criteria. The best alternative in TOPSIS is the one that is simultaneously nearest to the optimal alternative and farthest from the inferior alternative. The literature review showed that the method has been used in many different IS investment related decision-making processes. The ability of TOPSIS to consider both tangible and intangible criteria is one of its main benefits when evaluating IS investments. Even though both methods have been applied in different IS investment evaluation problems, there is little evidence of integrating the two methods for more thorough IS investment evaluation and selection.

The aim of the third research question was to find out how the evaluation and selection of IS investments could be facilitated by integrating the pay-off method and TOPSIS. To provide an answer to the research question a four-step IS investment evaluation and selection process that combines the pay-off method and TOPSIS was designed. The functionality of the proposed approach was tested by means of a case study. In the proposed approach, the pay-off method is used to evaluate the profitability of the competing IS investments and TOPSIS is used to provide the final ranking of the alternatives. The three descriptive statistics (mean NPV, success factor and risk factor) received from the pay-off analysis are also used as one of the criteria in TOPSIS. As a result, the decision-maker is able to identify the most suitable investment alternative while considering the outputs of the pay-off analysis as well as the criteria and the importance of the criteria determined by subject matter experts. The case company considered the proposed method as a useful approach that can facilitate the complex IS investment evaluation and selection process.

6.2 Conclusions

The study was conducted following the constructive research approach. Constructive research aims to solve a real-world problem by implementing a new construction that has both practical and theoretical contribution, making it a suitable research methodology for the study. By following the steps in constructive research, we were able to satisfactorily fulfill the research objective and provide sufficient answers to the research questions.

The research has succeeded in developing a new method for IS investment evaluation and selection that integrates the pay-off method and TOPSIS. The aim of the research was not to propose new theories, but rather to illustrate and test the applicability of proven and existing theories in a novel way. Based on the results of the case study and the feedback of the case company representatives, the method was considered applicable and beneficial for evaluating and selecting IS investments.

The research has also succeeded in answering the research questions. The first two research questions were answered through the literature review. The articles identified during the literature selection process were considered as a sufficient representation of the state of the art. The third research question was answered through the case study. Even though, the case study does not meet the requirements of the weak market test, as defined in constructive research, it was considered sufficient to fulfill the research objective and provide enough information to assess the functionality and the benefits of the proposed method.

By designing a practically functioning method for IS investment evaluation and selection that was based on theories originating from corporate finance and multiple-criteria decision-making we can conclude that the research has both practical and theoretical contribution. The research has a natural theoretical contribution to disciplines such as corporate science, multiple-criteria decision-making, and information systems and technology. The research has also provided a contribution to both the client organization and the case company. The case company can utilize the designed method as a decision support tool in their IS investment evaluation and selection process. The client organization, on the other hand, can utilize the designed method in their sales processes and provide information systems and technology related investment appraisal services for their customers.

The study has also identified many areas for further research and development. The case study that was used to validate the functionality of the proposed method was relatively narrow, including only two investment alternatives. For thorough validation of the accuracy and reliability of the proposed method, more tests are needed. The utilization of fuzzy logic in TOSPIS should also be tested. By capturing the expert judgements as fuzzy numbers instead of crisp numbers could improve the accuracy and reliability of the method. It would also enable the use of the fuzzy pay-off distribution as one of the criteria. Many academics have also utilized real option valuation to capture the managerial flexibility in IS investments. The research did not focus on real option valuation, but it is seen as one of the most interesting targets for further research. Another subject for further research is the identification and quantification of the hidden, indirect, and intangible costs and benefits of IS investments. The research approached the challenge by enabling the decision-makers to input their estimations using a range of possible values captured by the minimum and maximum cash flow scenarios. Even though, the approach was considered helpful and a more realistic representation of the uncertain investment than a single scenario alternative, the quantification of the intangible benefits was still considered extremely challenging. A reliable framework for quantifying the intangible benefits of IS investments is seen as one of the key areas of further research.

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APPENDICES

Appendix 1: IS investment evaluation methods

Table 15. Financial techniques for IS investment evaluation (Adapted from Schniederjans et al., 2004, p. 109)

Technique	**Description**	**Type of criteria**	**Evaluation timing**
Accounting rate of return	Compare the average after-tax profits with initial investment cost	Tangible	Ex ante or ex post
Breakeven analysis	Compare the present value of costs with the present value of benefits	Tangible and intangible	Ex ante, most often
Cost benefit analysis	Compare costs with benefits that can be directly and indirectly attributed to the system	Tangible and intangible	Ex ante or ex post
Cost benefit ratio	Calculate the ratio of costs of an IT investment to its benefits measured in monetary terms and compare to a threshold ratio	Tangible	Ex ante and ex post
Cost revenue analysis	Compare costs with benefits that can be directly attributed to the system	Tangible	Ex ante, most often
Internal rate of return	Calculate the return that equates the net present value of an investment to zero	Tangible	Ex ante or ex post
Net present value	Discount cash inflows and compare them to cash outflows	Tangible	Ex ante or ex post
Payback period	Calculate the time required to recoup the initial cost	Tangible	Ex ante, most often
Profitability index	Calculate the per dollar contribution of an investment	Tangible	Ex ante or ex post
Return on investment	Calculate the return of an investment	Tangible	Ex ante or ex post

Table 16. OR/MS techniques for IS investment evaluation (Adapted from Schniederjans et al., 2004, p. 110)

Technique	Description	Type of criteria	Evaluation timing
Analytical hierarchy process	Calculate the score of decision maker's pair wise comparisons	Tangible and intangible	Ex ante
Decision/Bayesian analysis	Calculate the expected value of investing in alternative investments	Tangible and intangible	Ex ante
Delphi evidence	Obtain consensus of experts' opinion concerning the best alternative investment	Tangible and intangible	Ex ante and ex post
Game playing	Calculate payoff of investment based on actions of the competition, mathematics, and economy theory	Tangible and intangible	Ex ante
Multi-objective, multi-criteria approaches	In general, develop a measure of utility provided by an IT investment	Tangible and intangible	Ex ante and ex post
Simulation	Model how investment will perform and impact the organization	Tangible and intangible	Ex ante and ex post

Appendix 2: Minimum and maximum possible cash flow scenarios for data virtualization and data warehouse investments

Table 17. Minimum possible cash flow scenario for the data virtualization investment

Data Virtualization	Initial	Year 1	Year 2	Year 3	Year 4
Initial Licensing Costs	(94 000)				
Annual Licensing Costs		(22 560)	(22 560)	(22 560)	(22 560)
Maintenance & Dev. Costs		(34 500)	(23 000)	(11 500)	(11 500)
Consultancy Fees		(34 500)	(4 600)	(4 600)	(4 600)
Increase in Productivity		17 000	42 500	42 500	42 500
Reduction in IT Operating Costs		17 000	42 500	42 500	42 500
Annual Net Cash Flow	(94 000)	(57 560)	34 840	46 340	46 340
Discounted Cash Flow	(94 000)	(55 883)	32 840	42 408	41 172
Cumulative NPV	(94 000)	(149 883)	(117 043)	(74 636)	(33 463)

Table 18. Maximum possible cash flow scenario for the data virtualization investment

Data Virtualization	Initial	Year 1	Year 2	Year 3	Year 4
Initial Licensing Costs	(94 000)				
Annual Licensing Costs		(22 560)	(22 560)	(22 560)	(22 560)
Maintenance & Dev. Costs		(25 500)	(17 000)	(8 500)	(8 500)
Consultancy Fees		(25 500)	(3 400)	(3 400)	(3 400)
Increase in Productivity		23 000	57 500	57 500	57 500
Reduction in IT Operating Costs		23 000	57 500	57 500	57 500
Annual Net Cash Flow	(94 000)	(27 560)	72 040	80 540	80 540
Discounted Cash Flow	(94 000)	(26 757)	67 905	73 706	71 559
Cumulative NPV	(94 000)	(120 757)	(52 853)	20 853	92 412

Table 19. Minimum possible cash flow scenario for the data warehouse investment

Data warehouse	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Licensing Costs	(5 750)	(5 750)	(5 750)	(5 750)
Maintenance & Dev. Costs	(23 000)	(23 000)	(23 000)	(23 000)
Consultancy Fees	(92 000)	(46 000)	(34 500)	(23 000)
Increase in Productivity	17 000	42 500	42 500	42 500
Reduction in IT Operating Costs	8 500	21 250	21 250	21 250
Annual Net Cash Flow	(95 250)	(11 000)	500	12 000
Discounted Cash Flow	(92 476)	(10 369)	458	10 662
Cumulative NPV	(92 476)	(102 844)	(102 387)	(91 725)

Table 20. Maximum possible cash flow scenario for the data warehouse investment

Data warehouse	**Year 1**	**Year 2**	**Year 3**	**Year 4**
Licensing Costs	(4 250)	(4 250)	(4 250)	(4 250)
Maintenance & Dev. Costs	(17 000)	(17 000)	(17 000)	(17 000)
Consultancy Fees	(68 000)	(34 000)	(25 500)	(17 000)
Increase in Productivity	23 000	57 500	57 500	57 500
Reduction in IT Operating Costs	11 500	28 750	28 750	28 750
Annual Net Cash Flow	(54 750)	31 000	39 500	48 000
Discounted Cash Flow	(53 155)	29 220	36 148	42 647
Cumulative NPV	(53 155)	(23 935)	12 213	54 861