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Managing an IT Portfolio on a Synchronized Level or: the Costs of Partly Synchronized Investment Valuation

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Abstract:

IT investments are usually risky by nature and account for a considerable part of annual investment budgets. Though value-based IT portfolio management (ITPM) aims at sustained economic growth and long-term value creation regarding IT investments, companies often fail to implement a synchronized ITPM approach that considers all relevant risk-/return components within IT investment valuation. In this paper we compare a synchronized and an only partly synchronized valuation of IT investments within a company`s ITPM by means of an optimization model. We show that an only partly synchronized IT investment management leads to sub-optimal investment decisions as especially stochastic interdependency structures are neglected. Furthermore, we analyze how different risk-/return structures of IT investment opportunities affect the valuation error resulting from an only partly synchronized IT investment valuation and conduct a comprehensive simulation study to further validate our findings.

Keywords: *IT Investment Valuation, Risk-/ Return Management, IT Portfolio Management, Stochastic Interdependencies, Capability Maturity Models*

1. Introduction

In recent years, companies of almost all industrial sectors have shown a distinct growing need for making information technology (IT) a core component of their business model and success. As a consequence, IT meanwhile plays a crucial role in nearly all business activities across different divisions and levels from top to bottom, a fact which is also reflected in the frequently significant share of IT investments (in the following we will not differentiate between the terms “IT investment” and “IT project”) in a company’s annual budget (DataCenter, 2010). To ensure that IT contributes to creating long-term competitive advantage and sustainable value, companies need to align their IT and thus all IT investment decisions with the overall company strategy and the conjoined business objectives. For that, IT governance and thus IT strategy need to assist the business in realizing its goals by supporting the company-wide strategy through a well-defined IT portfolio management approach (Weill and Ross, 2004; Gottschalk, 1999). In line with the concept of a value-based management, such an IT portfolio management (ITPM) has to balance risks and returns of a company’s IT and therefore treats the entirety of a company’s IT investments as a portfolio of assets similar to a financial portfolio (Jeffery & Leliveld, 2004; Cho & Shaw, 2009). To evaluate the maturity of a company’s actual implementation of ITPM, so-called capability maturity models were proposed in literature. Within these models an ITPM is categorized by four maturity levels: ad hoc, defined, managed and synchronized (Jeffery & Leliveld, 2004; Oh, Ng, & Teo, 2007; Reyck et al., 2005). Thereby, the empirical study of Jeffery and Leliveld (2004) indicates that usually only IT portfolios of such companies significantly contribute to long-term value creation, that have implemented an ITPM on a synchronized level. Managing an IT portfolio on a synchronized level in particular means aligning all activities to the concept of value-based management. For this, a sound management and valuation of a company`s IT portfolio is required, that is based on financial metrics and especially takes into account an IT portfolio’s risks. A careful consideration of an IT portfolio's risk is especially important as IT investments are regarded as highly risky by nature. This is e.g. supported by the results of the study of Dewan, Shi, and Gurbaxani (2007) that in particular indicates that IT investments contribute substantially stronger to a company's overall risk position than other investment types. Consequently, if risk is not considered adequately, IT investments may be valued systematically wrong and resources might be allocated in a non value-adding way (Maizlish & Handler, 2005).

However, a synchronized ITPM has to go beyond the consideration of a single IT investment's risk. Instead, also the various (stochastic) interdependencies occurring between different IT investments have to be taken into account, as those might heavily affect the IT portfolio's risk. In general, interdependencies arise if resources consumed or outputs generated by an IT investment influence the use of resources or outputs generated by one or several other IT investments (Kundisch & Meier, 2011). Literature particularly distinguishes two types of interdependencies, that is, *intratemporal* and *intertemporal* interdependencies (Kundisch & Meier, 2011). Intratemporal interdependencies exist between different IT investments at a certain point of time (e.g. Gear & Cowie, 1980; Cho & Shaw, 2009) and therefore affect planning decisions with respect to the actual IT portfolio (e.g. interdependencies that occur if scare resources are shared among different IT investments simultaneously). In contrast, intertemporal interdependencies exist between different points of time (e.g. Bardhan, Bagchi, & Sougstad, 2004; Benaroch & Kauffman, 1999) and thus occur if today's IT investment decisions influence future IT investments et vice versa (e.g. if a current IT investment leverages or reduces the value of a future project).

Since such interdependencies can have a tremendous impact on the risk-/return structure of a company's IT portfolio, their careful consideration is crucial to avoid unfavourable IT investment decisions (Santhanam & Kyparisis, 1996; Lee & Kim, 2001; Bardhan et al., 2004;

Benaroch, Jeffery, Kauffman, & Shah, 2007). In this context, Lee and Kim state that "the cost of difficulty in data gathering for modeling is not so critical than the risk in selecting the wrong project without considering the interdependencies" (Lee & Kim, 2001).

Despite their undoubted importance, interdependencies still are only rarely taken into account within IT investment decisions, as companies very often do not manage their ITPM on a synchronized level regarding the consideration of interdependencies. Therefore, in the following we speak of a *partly synchronized* ITPM, if a company has already established a quite mature ITPM that is mainly based on financial metrics and considers the risks of single IT investments in a synchronized way, but still shows an insufficient quantitative consideration of interdependencies. We use the term *synchronized* ITPM, if a company additionally considers interdependencies. Considering the obvious gap between a synchronized management of interdependencies according to theory and the actual, in this regard often not satisfying implementation of ITPM in many companies, various important questions arise: First, how big is the "valuation error" in case IT investments are valued based on an only *partly synchronized* ITPM which is neglecting (stochastic) interdependencies? Through this, how much value contribution is destroyed by possibly wrong decisions? Consequently, how much should a company invest in improving the maturity of its ITPM regarding the consideration of interdependencies?

The aim of our paper is to provide some answers to the stated questions by means of developing and applying a quantitative approach for the ex ante valuation of IT investments. In doing so, we first determine the optimal IT investment decisions by assuming that an ITPM is implemented on a synchronized level. Thereby, we focus on the consideration of interdependencies and explicitly take into account intratemporal interdependencies as well as intertemporal interdependencies. In a second step, we compare these optimal investment decisions to the results in case an only *partly synchronized* ITPM (where interdependencies are not considered) is applied. By determining the valuation error that results from the negligence of intratemporal and intertemporal interdependencies we are able to derive an approximate value for reasonable investments in improving a company's ITPM from an only partly synchronized to a synchronized level which also manages interdependencies on the highest degree of maturity. Possible examples for such investments could be the development and implementation of a decision support system (DSS) considering interdependencies or investments in the underlying data base.

The remainder of the paper is organized as follows: At first, we provide an overview of IS literature streams relevant to ITPM and IT investment valuation and substantiate the problem context. Afterwards we introduce the optimization problem and derive the optimal investment decisions first for the case of a *synchronized* ITPM and in a second step for a *partly synchronized* one. Based on that, we conduct sensitivity analyses as well as an extensive simulation study to answer our research questions. Afterwards we suggest a step-wise operationalization approach that might support companies in deciding, whether improving a company's ITPM with regard to the consideration of interdependencies is beneficial in the particular case. Finally, the paper concludes by summarizing the key findings, discussing strengths and limitations as well as by pointing out topics for further research.

2. Problem Context and Related Literature

In our approach we aim to quantify the valuation error that occurs in case an ITPM is applied on an only partly synchronized level and thus stochastic interdependencies are neglected when valuating IT investments. Consequently, our approach is strongly related to research in the fields of ITPM and IT investment valuation. Thus, in the following section we first point out the importance of ITPM, which aims on improving the value contribution of a company's

IT portfolio. We illustrate the role and objectives of ITPM, its elements and the importance of a high maturity to ensure ITPM contributes to long-term value generation of the company. As the valuation and selection of new IT investment opportunities is a crucial task within ITPM, we in a next step discuss literature concerned with IT investment valuation. Thereby, we in particular aim to carve out to what extent current literature considers risks and interdependencies within IT investment valuation and thus is in line with the objectives of a synchronized ITPM.

2.1. Importance of ITPM

Due to the increasing penetration of IT in business practices, it plays a significant role in nearly all business activities across different divisions and levels from top to bottom. Considering a value-based view, the intention and goal of ITPM consequently is the decomposition of the company's objectives into the value-based management of a company's IT as well as into the valuation processes regarding new IT investments (Maizlish & Handler, 2005). ITPM thereby treats the entirety of a company's IT investments "[…] as a portfolio of assets similar to a financial portfolio […] by balancing risk and return […]" (Jeffery & Leliveld, 2004) and consequently aims at accomplishing the Herculean task of aligning the company's IT with its strategic intent. Considering the significant share of IT investments within a company's yearly investment volume, the close link between an IT portfolio and the overall strategic objectives obviously becomes vastly important (Rai, R. Patnayakuni, & N. Patnayakuni, 1997).

Another crucial challenge within ITPM is the fact that IT investments have to be considered as vastly risky due to their enormous technological complexity, the uncertainty about their economic impact, the possibility of a rapid obsolescence, or challenges in implementation (Mata, Fuerst, & Barney, 1995; Dewan et al., 2007). Beyond that, companies ordinarily have plenty of different IT projects simultaneously running across different functions and business units, leading to numerous interdependencies that further influence the risk position of the IT portfolio (Jeffery & Leliveld, 2004). Hence, the value-based view of an ITPM also has to consider the IT portfolio's risk and return in order to improve the IT portfolio's and company's long-term value contribution in accordance with the conjoined business objectives. Research in this context emphasizes that companies, which apply an active, effective and therefore mature ITPM can generate measureable value from IT investments (Maizlish & Handler, 2005). An IT portfolio's contribution to sustainable value-creation of the company thereby primarily depends on an ITPM's maturity and the manner of its application in the company.

To assess an ITPM's maturity, several ITPM maturity models have been established and developed in literature and business practice. In this paper we follow the ITPM maturity model by Jeffery and Leliveld (2004), Oh et al. (2007) and Reyck et al. (2005) which segments an ITPM into nine elements. Each element thereby addresses an important topic of managing an IT portfolio and is characterized by its maturity stage, namely *ad hoc*, *defined*, *managed and synchronized*. The maturity of each element influences an ITPM's effectiveness, e.g. the ITPM's capability to align the IT portfolio with the business objectives, the grade of financial metrics application, the consideration of risk, the consideration of interdependencies between projects, constraints, the involvement of top management etc. However, the elaboration of the nine elements varies heavily in the four maturity stages of an ITPM. At the *ad hoc* stage, decisions about IT investments are conducted in an uncoordinated way without a defined process. Companies that have already reached the *defined* stage have identified key components of their IT portfolio and roughly estimate costs, benefits and risks to value and prioritize IT investments. Companies operating at the *managed* stage differ from those at the defined stage in having a standardized ITPM process that enables a project selection, which in general is linked to corporate objectives. Still, the activities at the managed stage can be improved due to the fact that an ITPM that is conducted at a *synchronized* stage can create significant additional value for a company (Jeffery & Leliveld 2004). Hence, after a thorough consideration of the costs and benefits involved, companies should aim at improving their ITPM to a synchronized stage or at least try to improve as much elements of their ITPM as possible to this stage. In order to reach this stage, ITPM has to ensure an optimal alignment of the company's IT portfolio with the key business objectives and a high quality of IT investment valuation. This reveals the necessity to implement metrics, which allow for the consideration of the business objectives as well as the specific characteristics of IT investments within valuation. Next to valuating the risk of single IT investments, this in particular requires a careful consideration of the manifold interdependencies existing in the IT portfolio. In doing so, IT investments can be valued, compared, conducted and managed in line with the goals of a value-based management and thus significantly contribute to the company's value. Hence, companies should aim to improve their ITPM to a synchronized stage to assess both the risk that is associated with each IT investment and the various interdependencies that exist between a single IT investment and the existing IT portfolio as well as within a certain IT investment. As outlined in the introduction, we speak of an only *partly synchronized ITPM* in case a company already takes into account the general risk of an IT investment, but still lacks the consideration of interdependencies.

Having outlined the importance of a mature ITPM, in the next subsection we analyze to what extent current literature regarding IT investment valuation takes into account crucial elements of an ITPM on a synchronized level. Thereby we will focus on the aspect of financial analysis as well as the consideration of risk and interdependencies.

2.2. IT investment Valuation Based on a Synchronized ITPM

The business value of IT investments in general (cf. e.g., Chau, Kuan, & Liang, 2007; Kohli & Grover, 2008; Schryen, 2010) and the ex ante valuation of IT investments in particular (cf. e.g., Renkema & Berghout, 1997; Sylla & Wen, 2002; Walter & Spitta, 2004) has been intensively discussed in IS literature. Thereby, it is widely agreed upon the fact that determining an IT investment's value contribution is far from trivial (Bannister & Remenyi, 2000; Chan, 2000). According to an ITPM on a synchronized level, the valuation of an IT investment should always comprise a financial analysis. To address this issue, in our paper we follow Kauffman and Weill (1989), who emphasize that the best IT investments are the ones that help maximizing the value of a company. Thus, the value contribution of an IT investment should be determined by its quantitative, financial impact on the company (Primrose, 1990), measured on the basis of future net cash flows (Probst & Buhl, 2012; Walter & Spitta, 2004). This seems appropriate for several reasons: First, this approach supports a value-based management and value creation as a concretization of the shareholder value principle, which aims at maximizing the net present value of all future cash flows (Buhl, Röglinger, Stöckl, & Braunwarth, 2011). Second, valuating IT investments based on their net cash flows ensures that valuation is not influenced by accounting policies. Third, cash flow approaches build the quantitative, monetary basis within IT investment valuation that, in a second step, can be extended by qualitative criteria to allow for the consideration of effects that can hardly be measured in monetary terms (Irani & Love, 2002).

When determining the ex ante value contribution of an IT investment based on its future net cash flows, companies need to consider that these cash flows are usually uncertain due to several risks (Dewan et al., 2007; Maizlish & Handler, 2005; Sauvé, Queiroz, Moura, Bartolini, & Hickey, 2011). One source of risk is e.g. the vulnerability of hardware and software as they can be sabotaged or stolen. Others are for instance delays, complexity, dynamic changes in a company's environment, or a wrong anticipation of the investment's benefits, implementation efforts, or operational costs. This can lead to several underestimations or overestimations and also threaten the success of an IT investment (Sylla & Wen, 2002). In view of the fact that the failure or delay of an IT investment can cause serious negative effects, companies have to integrate the uncertainty of the associated cash flows in their IT investment valuation approach. Following a value-based view, the source of risk in IT investments thereby can be expressed by both negative and positive deviations from the expected net cash flows (Dewan et al., 2007). Furthermore, this risk of IT investments has to be taken into account according to the risk attitude of the decision maker (Rose et al., 2004). Although there exist a few articles like Sylla and Wen (2002), Au and Kauffman (2003), Benaroch et al. (2007), Dewan et al. (2007) and Verhoef (2005) which explicitly consider the described type of uncertainty within IT investment decision making, "[…] the consideration of risk is virtually absent in the growing literature […] on IT investments […]" (Dewan et al., 2007). This is also confirmed by the recent (meta) literature reviews of Schryen (2010) and Schryen (2013) who states that this subfield of IS business value research requires more attention.

This applies all the more for research dealing with the consideration of (stochastic) interdependencies within the ex ante valuation of IT investments. Focused on approaches to valuate single IT investments, papers like Renkema and Berghout (1997), Sylla and Wen (2002) and Walter and Spitta (2004) mostly neglect stochastic interdependencies occurring between different IT investments and within the IT portfolio. Approaches considering intratemporal interdependencies are e.g. provided in Fogelström et al. (2010), Cho and Shaw (2013), Zimmermann, Katzmarzik, and Kundisch (2012) and Fridgen and Moser (2013). However, these papers mainly address intratemporal interdependencies within the *existing* IT portfolio and therefore do not focus on decisions about *additional* IT investments. Even though monitoring the performance of an existing IT portfolio is important, effective decision making within ITPM furthermore requires the possibility to value additional IT investments against the background of the existing IT portfolio (Jeffery & Leliveld, 2004; Oh et al., 2007). Intertemporal interdependencies are regarded in numerous approaches based on real option theory (Benaroch

& Kauffman, 1999; Fichman, Keil, & Tiwana, 2005; Taudes, Feurstein, & Mild, 2000). Although basically allowing for a value-based valuation these approaches are subject to vigorous criticism. Criticism thereby is mainly focused on the restrictive assumptions resulting from the (pragmatic) application of financial option pricing theory (Bardhan et al., 2004). Beyond that, the use of real option based approaches is not very helpful for our research questions, as we do not consider the valuation of IT projects characterized by an additional option value.

Summarizing our literature overview, we can state that risks are not considered sufficiently within IT investment valuation literature so far. Moreover, our literature review shows that in particular risks resulting from stochastic intratemporal and intertemporal interdependencies are neglected to a large extent. Even though a few papers address stochastic interdependencies, existing literature does not provide an explicit and focused analysis on the question to what extent stochastic interdependencies affect IT investment decisions. Thus, in our paper we aim to analyze the valuation error that occurs in case an ITPM is managed on an only *partly synchronized* level and thus in particular stochastic interdependencies are neglected within IT investment valuation.

3. Synchronized versus Partly Synchronized IT Investment Decisions

According to the design-science research guidelines outlined in (Hevner, March, Park, & Ram, 2004) we in the following start with developing our artifact, an optimization model that aims on determining the optimal investment decisions within a *synchronized* ITPM and an only *partly synchronized* ITPM. In doing so, we at first present the assumptions of our model followed by the examination of the optimal investment decisions within a synchronized ITPM and a partly synchronized ITPM by means of a comparative analysis. As pointed out by (Hevner et al., 2004), mathematical models are a common approach to represent an artifact in a structured and formalized way. For the evaluation of our model, we hereinafter conduct a sensitivity analysis, which shows the influence of key parameters on the results of the model, and moreover carry out a comprehensive simulation study to analyze selected investment scenarios in detail.

3.1. Assumptions

Subsequently, in a two-period model we consider the decision problem of a company that wants to allocate a given IT investment budget on two different, risky IT investments. The following assumptions are made:

A1. Decision Problem: At time $t = 0$, the existing IT portfolio of a company C generates a total stochastic cash flow $\widetilde{CF}^C := \left(\overline{cf}_0^C, \widetilde{cf}_1^C, \widetilde{cf}_2^C\right)$. For $\overline{cf}_0^C$ does not affect the results of the model, this deterministic periodical cash flow is assumed to equal 0. $\widetilde{cf}_t^C$ with $t \in \{1,2\}$ denotes for the periodical stochastic cash flow (free cash flow) of the company at time t. The company invests a constant IT budget IB at times $t = 0$ and $t = 1$ each for one period. Thereby, the decision on the allocation of the respective periodical IT budgets IB is taken at $t = 0$ for both points in time, as the decision relevant information at time $t = 0$ does not differ from that at $t = 1$. The company invests a share $x_t \in [0; 1]$ with $t \in \{0,1\}$ in a one-periodical IT investment of type A with the uncertain return $\tilde{r}_A$, and the remaining share $(1 - x_t)$ into another one-periodical IT investment of type B with the uncertain return $\tilde{r}_B$. For reasons of simplicity, the different returns $\tilde{r}_A$ and $\tilde{r}_B$ apply to all investments of each investment type and are respectively constant for both periods. From the allocation of the periodical IT budget IB results the total investment cash out flow $\overline{CF}^I := \left(\overline{cf}_0^I, \overline{cf}_1^I, 0\right)$, where $\overline{cf}_t^I = -IB$ denotes for the periodical cash outflows at times $t \in \{0,1\}$. Furthermore, allocating the IT budget IB on the risky IT investments A and B generates the total stochastic cash flow $\widetilde{CF}^i := \left(0, \widetilde{cf}_1^i, \widetilde{cf}_2^i\right)$ with $i \in \{A, B\}$, where

$\widetilde{cf}_t^A = IB \cdot x_{t-1} \cdot (1 + \tilde{r}_A)$ and $\widetilde{cf}_t^B = IB \cdot (1 - x_{t-1}) \cdot (1 + \tilde{r}_B)$ denote for the periodical stochastic cash flows at times $t \in \{1,2\}$.

A2. Corporate Cash Flow: After allocating the IT budget IB, the company's IT portfolio generates the total stochastic cash flow $\widetilde{CF}^{\hat{C}} := \left(\widetilde{cf}_0^{\hat{C}}, \widetilde{cf}_1^{\hat{C}}, \widetilde{cf}_2^{\hat{C}}\right)$ where $\widetilde{cf}_t^{\hat{C}} = \widetilde{cf}_t^C + \overline{cf}_t^I + \widetilde{cf}_t^A + \widetilde{cf}_t^B$ denotes for the periodical stochastic cash flows at times $t \in \{0,1,2\}$.

A3. Net Present Value: The stochastic net present value of the IT portfolio's total cash flow $\widetilde{CF}^{\hat{C}}$ is the sum of the periodical stochastic cash flows $\widetilde{cf}_t^{\hat{C}}$ discounted to $t = 0$ using the risk-free interest rate r_f.

$$\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right) = \sum_{t=0}^{2} \frac{\widetilde{cf}_t^{\hat{C}}}{(1 + r_f)^t}$$

A4. Risk Measure: The risk of a stochastic cash flow $\widetilde{cf}_t$ is quantified by its variance $\sigma^2\left(\widetilde{cf}_t\right)$.

A5. a) Stochastic Intratemporal Interdependencies: The periodical stochastic cash flows $\widetilde{cf}_t^C$ of the IT portfolio and $\widetilde{cf}_t^i$ of an IT investment with $i \in \{A, B\}$ are intratemporally stochastically interdependent at times $t \in \{1,2\}$. These interdependencies are quantified by the correlation coefficients $\rho_t^{C,i}$ with $\rho_t^{C,i} \in [-1; 1]$.

b) Stochastic Intertemporal Interdependencies: The periodical stochastic cash flows $\widetilde{cf}_1^i$ and $\widetilde{cf}_2^i$ within a total stochastic cash flow $\widetilde{CF}^i$ with $i = \{C, A, B\}$ are intertemporally stochastically interdependent. These interdependencies are quantified by the correlation coefficients $\rho_{1,2}^i$ with $\rho_{1,2}^i \in [-1; 1]$.

A6. Value Contribution The value contribution of the stochastic net present value $\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)$ results from the additive combination of its expected value and its quantified risk, i.e. its variance, taking into account a risk aversion parameter α with $\alpha \in R^+$.

$$V\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right) = E\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right) - \alpha \cdot \sigma^2\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right)$$

This preference-based valuation approach is well-founded by decision theory and therefore represents a suitable method for measuring the absolute, risk-adjusted value contribution of an investment (Zimmermann et al., 2012). According to this approach, the risk of an IT investment is weighted with the individual risk aversion of the decision maker and is subtracted from the project's expected net present value. Thus, the higher the variance of an IT investment's net present value or the higher the individual risk aversion, the lower the risk-adjusted value contribution of the IT investment.

3.2. Mathematical Model and Comparison of Synchronized and Partly Synchronized Investment Decisions

In the following, based on the assumptions presented above, we derive the optimal investment shares and value contributions according to a synchronized ITPM on the one hand and an only partly synchronized ITPM on the other hand. Afterwards we compare the results and quantify the financial disadvantages resulting from the negligence of stochastic interdependencies within an only partly synchronized ITPM.

3.2.1. Synchronized Investment Decisions and Value Contribution

As outlined in the assumptions, the valuation of the IT portfolio and the IT investments is based on the stochastic net present value. The company maximizes its value contribution with respect to the investment shares x_t with $t \in \{0, 1\}$ and thus determines the optimal allocation of the IT budget IB to the risky IT investments A and B.

Consequently, the return component of the value contribution is the expected value of the stochastic net present value $E\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right)$. The risk component of the value contribution is represented by the variance of the stochastic net present value $\sigma^2\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right)$.

Within a synchronized ITPM, in addition to the variances of the single cash flows, the risks resulting from intratemporal and intertemporal interdependencies between the cash flows have to be considered as well. Therefore in addition to the variances of the existing portfolio $\sigma^2\left(\widetilde{cf}_t^C\right)$ and the stochastic cash flows of the risky IT investments $\sigma^2\left(\widetilde{cf}_t^i\right) = x_{t-1}^2 \cdot IB^2 \cdot \sigma^2(\tilde{r}_i)$ with $i \in \{A, B\}$, the *intra*temporal covariances $Cov\left(\widetilde{cf}_t^C, \widetilde{cf}_t^i\right)$ with $i \in \{A, B\}$ at times $t = \{1,2\}$ and the *inter*temporal covariances $Cov\left(\widetilde{cf}_1^i, \widetilde{cf}_2^i\right)$ with $i \in \{C, A, B\}$ also have to be taken into account when determining $\sigma^2\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right)$. The variance $\sigma^2\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right)$ of the stochastic net present value including all risks resulting from the stochastic interdependencies states as follows:

$$\sigma^2\left(\widetilde{NPV}\left(\widetilde{cf}^{\hat{C}}\right)\right) = \underbrace{\sum_{t=1}^{2} \frac{\sigma^2\left(\widetilde{cf}_t^C\right) + IB^2 \cdot x_{t-1}^2 \cdot \sigma^2(\tilde{r}_A) + IB^2 \cdot (1 - x_{t-1})^2 \cdot \sigma^2(\tilde{r}_B)}{(1 + r_f)^{2t}}}_{\text{Stand-alone risks}} + \underbrace{\sum_{t=1}^{2} \frac{2 \cdot \left(\rho_t^{C,A} \cdot \sigma\left(\widetilde{cf}_t^C\right) \cdot x_{t-1} \cdot IB \cdot \sigma(\tilde{r}_A) + \rho_t^{C,B} \cdot \sigma\left(\widetilde{cf}_t^C\right) \cdot (1 - x_{t-1}) \cdot IB \cdot \sigma(\tilde{r}_B)\right)}{(1 + r_f)^{2t}}}_{\text{Risks resulting from intratemporal interdependenies}} + \underbrace{\frac{2 \cdot \left(\rho_{1,2}^C \cdot \sigma\left(\widetilde{cf}_1^C\right) \cdot \sigma\left(\widetilde{cf}_2^C\right) + \rho_{1,2}^A \cdot x_0 \cdot x_1 \cdot IB^2 \cdot \sigma^2(\tilde{r}_A) + \rho_{1,2}^B (1 - x_0) \cdot (1 - x_1) \cdot IB^2 \cdot \sigma^2(\tilde{r}_B)\right)}{(1 + r_f)^3}}_{\text{Risks resulting from intertemporal interdependenies}} \quad (1)$$

This calculation of the risk component is carried out analogously to the calculation of a variance within classical financial portfolio selection theory. However, whereas classical financial portfolio selection theory usually considers a single-period model setting, we consider a two-period model and are additionally including the risks resulting from intertemporal interdependencies. Moreover, we calculate the risk of stochastic net present values (i.e. the risk of absolute values) in contrast to calculating the risk of stock returns (i.e. the risk of relative values) as in financial portfolio theory.

Based on the risk and return components, the optimal synchronized (S) investment shares of the company are determined by optimizing the objective function V_S (=synchronized value contribution) within a synchronized ITPM (cf. assumption A6). The restrictions $x_t \geq 0$ and $x_t \leq 1$, according to assumption A1, are taken into account by solving the optimization problem via a Lagrangian optimization with the Lagrange multipliers (slack variables) λ_t and φ_t. The optimization problem of the company states as follows:

$$\max_{x_0,x_1} L(x_t,\lambda_t,\varphi_t) = V_S\left(\widetilde{NPV}\left(\widetilde{CF}^{\hat{C}}\right)\right) + \sum_{t=0}^{1}\lambda_t x_t - \sum_{t=0}^{1}\varphi_t(x_t - 1) \qquad (2)$$

Using the Karush-Kuhn-Tucker theorem (Kuhn & Tucker, 1951), the vector of the optimal synchronized investment shares $\left(x_0^{S^*}, x_1^{S^*}\right)$ can be determined, where $x_t^{S^*}$ at times $t = \{0,1\}$ represents the optimal investment share at time t. By investing the optimal amount $IB \cdot x_t^{S^*}$ in the risky IT investment A and $IB \cdot \left(1 - x_t^{S^*}\right)$ in the risky IT investment B at times $t = \{0,1\}$, the company maximizes the value contribution of these investments regarding risk and return. Each higher investment in the IT investment A than $IB \cdot x_t^{S^*}$ results in more additional risk than additional return compared to the IT investment B. At any lower level of investment in IT investment A, a marginal increase of the investment share generates a higher additional return than additional risk compared to the alternative investment.

If the Karush-Kuhn-Tucker conditions are fulfilled for the vector of the optimal investment shares $\left(x_0^{S^*}, x_1^{S^*}\right)$, this is a necessary and sufficient optimality criterion, such that $\left(x_0^{S^*}, x_1^{S^*}\right)$ represents a global maximum of the optimization problem.[2] The optimal solution $\left(x_0^{S^*}, x_1^{S^*}\right)$ of

[2] In this model, these conditions are fulfilled if $\rho_{1,2}^{i} \in]-1;1[$ with $i \in \{A, B\}$.

this restricted optimization problem determines the maximum value contribution of the company`s IT portfolio for a synchronized ITPM (V_S):

$$V_S\left(x_0^{S^*}, x_1^{S^*}\right)$$

3.2.2. Partly Synchronized Investment Decisions and Value Contribution

As mentioned above, the valuation within an only partly synchronized ITPM differs to the synchronized valuation above regarding the considered risk components. In the following, we will optimize the investment decisions within a partly synchronized ITPM taking into account only the stand-alone risks of the cash flows and neglecting the risks resulting from interdependencies. Referring to the risk component presented in equation (1), only the first summand of the risk component is included in the partly synchronized valuation.

The valuation within an only partly synchronized ITPM is carried out again via a Langrangian optimization using the differing risk component discussed above. This optimization delivers the partly synchronized (*P*) investment shares $\left(x_0^{P^*}, x_1^{P^*}\right)$, which determine the maximum value contribution for a only partly synchronized ITPM (V_P):

$$V_P\left(x_0^{P^*}, x_1^{P^*}\right)$$

3.2.3. Costs of Partly Synchronized Investment Valuation

As only in a synchronized investment valuation all relevant risk components are taken into account, only these investment shares $\left(x_0^{S^*}, x_1^{S^*}\right)$ lead to an optimal value contribution from the perspective of a long-term, value-based investment management. To determine the loss of value contribution of the company`s IT portfolio, that occurs, if the risk components resulting from interdependencies are not considered adequately, we determine the synchronized value contribution based on the only partly synchronized investment shares $\left(x_0^{P^*}, x_1^{P^*}\right)$:

$$V_S\left(x_0^{P^*}, x_1^{P^*}\right)$$

Since the optimal investment shares of an only partly synchronized optimization $\left(x_0^{P^*}, x_1^{P^*}\right)$ do not maximize the synchronized optimization problem in general, the synchronized value contribution based on these investment shares $V_S\left(x_0^{P^*}, x_1^{P^*}\right)$ can never exceed the maximum synchronized value contribution based on synchronized investment shares $V_S\left(x_0^{S^*}, x_1^{S^*}\right)$, such that:

$$V_S\left(x_0^{P^*}, x_1^{P^*}\right) \leq V_S\left(x_0^{S^*}, x_1^{S^*}\right)$$

The extent of the disadvantage of an only partly synchronized IT investment valuation, the so-called "costs of partly synchronized investment valuation" (CPI) can now be easily quantified by the difference of the synchronized value contributions $V_S\left(x_0^{S^*}, x_1^{S^*}\right)$ and $V_S\left(x_0^{P^*}, x_1^{P^*}\right)$:

$$\text{CPI} = V_S\left(x_0^{S^*}, x_1^{S^*}\right) - V_S\left(x_0^{P^*}, x_1^{P^*}\right) \geq 0$$

This clarifies that an only partly synchronized valuation of IT investments generally does not lead to optimal value contributions, in case the risky IT investments involve linear stochastic intratemporal and intertemporal interdependencies. Instead, the incomplete consideration of interdependency risks leads to either an underinvestment or an overinvestment in the respective investment alternatives and as a consequence to a suboptimal risk-/return position of the IT portfolio. Thus, if the investment decisions of the company are purely based on a valuation of returns and stand-alone risks, the potential of the synchronized value contribution of the available IT investments cannot be fully exhausted.

3.3. Analysis of Key Parameters

In this section, we analyze how intertemporal and intratemporal interdependencies influence the optimal synchronized and partly synchronized investment shares as well as the CPI. To isolate the effects of the interdependencies, we examine two investment alternatives with identical stand-alone variances $\sigma^2(\tilde{r}_A)$ and $\sigma^2(\tilde{r}_B)$ and identical expected returns $E(\tilde{r}_A)$ and $E(\tilde{r}_B)$ and perform sensitivity analyses for such a setting. For reasons of simplification and without limiting the implications of our mathematical model, we assume the risk-free interest rate to equal zero.

3.3.1. Influence of Intertemporal Interdependencies

To separate the impact of the intertemporal stochastic interdependencies, we assume the intratemporal stochastic interdependencies $\rho_t^{C,A}$ and $\rho_t^{C,B}$ of the IT investments A and B to be zero, i.e. $\rho_t^{C,A} = \rho_t^{C,B} = 0$. Within an only partly synchronized perspective, the interdependency structures of the IT investments (and the IT portfolio) are not taken into account. Therefore, the neglected risks are the greater the higher the intertemporal correlations of the risky IT investments are. As a consequence, the optimal investment shares in an partly synchronized perspective differ from the optimal synchronized investment shares in case of different intertemporal interdependency structures of the IT investments, i.e. $\rho_{1,2}^A \neq \rho_{1,2}^B$. In particular, depending on whether the intertemporal correlation $\rho_{1,2}^A$ or $\rho_{1,2}^B$ (and through this the risk resulting from the respective interdependency) is higher, e.g. $\rho_{1,2}^A > \rho_{1,2}^B$, an overinvestment in A respectively an underinvestment in B occurs in a partly synchronized valuation perspective compared to a synchronized perspective (or vice versa). Figure 1 illustrates that the difference between the optimal investment shares in a partly synchronized perspective (blue) and the optimal synchronized investment shares (green) reaches its maximum, if the intertemporal correlations are $\rho_{1,2}^A = 1$ and $\rho_{1,2}^B = 0$ at the same time (or vice versa). It should be noted that only positive intertemporal interdependencies $\rho_{1,2}^i > 0$ are taken into consideration, since the stochastic cash flows of IT investments are typically influenced similar over time by external or investment specific influences.

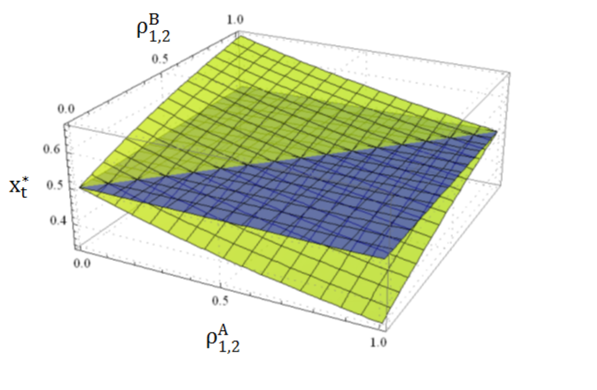

Figure 1: Optimal synchronized/ partly synchronized investment shares depending on intertemporal interdependencies

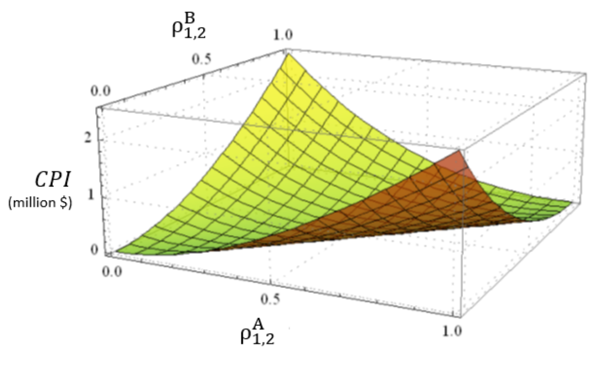

Figure 2: Costs of partly synchronized investment valuation depending on intertemporal interdependencies

In consequence of different optimal investment shares in a partly synchronized and synchronized perspective, CPI arise. The CPI reach their maximum under the given assumptions, if the intertemporal correlations are $\rho^{A}_{1,2} = 1$ and $\rho^{B}_{1,2} = 0$ at the same time (or vice versa) as the difference between the optimal investment shares in a partly synchronized and synchronized perspective reaches its maximum in this case. Figure 2 shows the resulting financial disadvantage CPI depending on the intertemporal correlations $\rho^{A}_{1,2}$ and $\rho^{B}_{1,2}$ of the IT investments. In line with this, the CPI decrease if the difference between the intertemporal interdependencies of the IT investments A and B declines. This effect leads to the fact that there exist no CPI in the presented setting, if the intertemporal stochastic interdependencies of the investment alternatives A and B are equal, i.e. $\rho^{A}_{1,2} = \rho^{B}_{1,2}$.

3.3.2. Influence of Intratemporal Interdependencies

To separate the impact of the intratemporal stochastic interdependencies, we assume the intertemporal stochastic interdependencies $\rho^{A}_{1,2}$ and $\rho^{B}_{1,2}$ of the IT investments A and B to be zero, i.e. $\rho^{A}_{1,2} = \rho^{B}_{1,2} = 0$. For sake of simplicity we assume for each IT investment that the intratemporal interdependencies $\rho^{C,i}_{1}$ and $\rho^{C,i}_{2}$ with $i \in \{A, B\}$ between the existing IT portfolio and the new IT investment are equal in both points in time. Just as the intertemporal interdependencies, also the intratemporal interdependencies are only taken into account in a synchronized perspective. The basic effect of the intratemporal interdependencies on the synchronized and partly synchronized investment shares and on the CPI is the same as of the intertemporal interdependencies. Thus, analogous to the case shown in the previous section, an overinvestment in A respectively an underinvestment in B occurs in a partly synchronized valuation perspective, if the intratemporal correlation $\rho_t^{C,A}$ of IT investment A is higher than the intratemporal correlation $\rho_t^{C,B}$ of IT investment B (or vice versa). Figure 3 shows the optimal partly synchronized investment shares (blue) and the optimal synchronized investment shares (green) depending on the intratemporal interdependencies $\rho_t^{C,A}$ and $\rho_t^{C,B}$ of the IT investments A and B. Under the given assumptions there results a difference between the optimal investment shares of the partly synchronized and synchronized perspective, reaching its maximum if the intratemporal correlations are $\rho_t^{C,A} = -1$ and $\rho_t^{C,B} = 1$ at the same time (or vice versa).

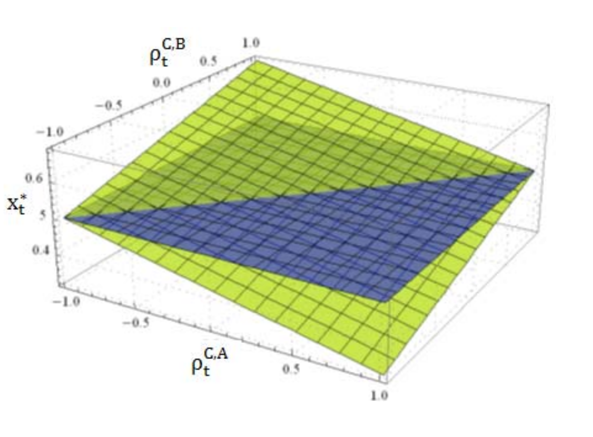

Figure 3: Optimal synchronized/ partly synchronized investment shares depending on intratemporal interdependencies

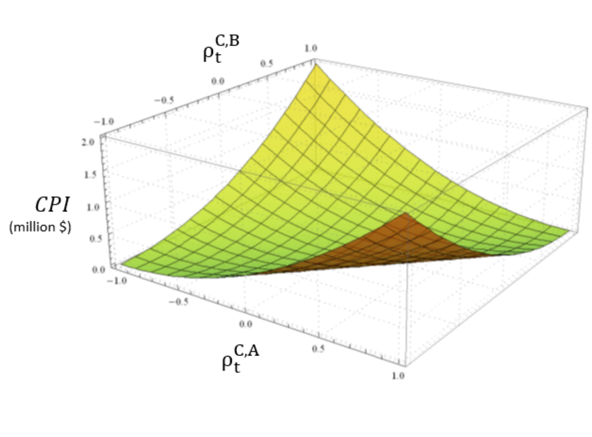

Figure 4: Cost of partly synchronized investment valuation depending on intratemporal interdependencies

Analogous to the case shown in the previous section there arise CPI, if the intratemporal interdependency structures of the IT investments differ (see Figure 4). The CPI are again maximal, if the difference between the intratemporal correlations of the IT investments is maximal, i.e. if $\rho_t^{C,A} = -1$ and simultaneously $\rho_t^{C,B} = 1$ (and vice versa).

Summarizing the findings of the analyses in section 3.3, we can state that the CPI increase with increasing *differences* between the respective interdependencies of the two IT investment alternatives A and B. Thus, the more heterogeneous the IT investment alternatives are regarding their interdependency structures, the higher are the CPI. These results suggest that managing IT investments in a synchronized way is especially important for companies that hold portfolios of IT investments that largely differ regarding their interdependency structure. Nevertheless, so far, we only varied the intertemporal and intratemporal interdependencies ceteris paribus and showed the basic influence of the interdependencies on optimal investment shares and on the CPI. To broaden our understanding regarding the influence of different risk-/return parameter settings and to be able to derive more substantiated managerial implications, we will conduct a comprehensive simulation study in the next section.

3.4. Simulation Study

We simulate all parameters in broad ranges and in different settings to receive a comprehensive understanding of the importance of a synchronized ITPM and of how stochastic interdependencies influence companies` IT investment decisions.

3.4.1. Basic Setting (with homogeneous investment alternatives)

At first we will simulate a basic setting where the input parameters will be set as follows:

Table 1. Input values for the basic setting of the simulation study

Variable	**Lower bound**	**Upper bound**	**Variable**	**Lower bound**	**Upper bound**
$E(\tilde{r}_A)$	0	0.25	$\widetilde{cf}_1^C$	200 (million $)	
$E(\tilde{r}_B)$	0	0.25	$\widetilde{cf}_2^C$	200 (million $)	
$\sigma^2(\tilde{r}_A)$	0	0.35	$\sigma^2(\widetilde{cf}_1^C)$	50 (million $)	
$\sigma^2(\tilde{r}_B)$	0	0.35	$\sigma^2(\widetilde{cf}_2^C)$	50 (million $)	
$\rho_1^{C,A} = \rho_2^{C,A}$	-1	1	$\rho_{1,2}^C$	0	1
$\rho_1^{C,B} = \rho_2^{C,B}$	-1	1	IB	100 (million $)	
$\rho_{1,2}^A$	0	1	α	0.01	
$\rho_{1,2}^B$	0	1	i	0	

Within our simulation study, we apply fictive input values for the two IT investment alternatives A and B as well as for the company's IT portfolio and the IT investment budget. The risk-free rate is set to zero for reasons of simplicity, but does not limit the implications of the simulation study. In order to receive meaningful results despite of using fictive input values, we let the interdependencies vary across their full value range. Also, the values for the returns and risks of the investment alternatives are varied across quite wide ranges up to 25% for the expected returns and 35% for the variances. The absolute values for the cash flows and the variance of the existing IT portfolio as well as for the IT investment budget were hold constant over the various simulations to allow for a meaningful comparison regarding the magnitude of the results. The values were chosen to represent an enterprise with a significant but not excessively large IT budget: in a recent research report of the Enterprise Strategy Group, 27% of the enterprises stated to have an IT budget between 50 and 250 million $ for 2014, another 21% stated to have an even higher IT budget up to more than one billion $ (Enterprise Strategy Group, 2014). An IT investment budget of 100 million $ therefore seems reasonable for our simulation study. As outlined in Bamberg and Spreman (1981), the value for the risk aversion is dependent on the absolute value of the respective investment budget (so-called absolute risk aversion). As we are applying an IT investment budget of 100 million $ in our simulation study, according to Bamberg and Spreman (1981) a value of 0.01 for the risk aversion is reasonable, representing a moderately risk averse company.

When applying our model for decision support in practice, one has to bear in mind that all input values regarding the risk-/return structures as well as the IT investment budget always have to be chosen depending on the company specifics. Hence, a company specific analysis based on a company specific parameterization of our model is still required to support investment decisions of a certain enterprise. Consequently, we will discuss the importance of tailoring a synchronized ITPM to the needs and characteristics of a specific company in section 4. Thereby, we will also propose a reasonable approach for the application and implementation of such a synchronized ITPM.

To receive soundly interpretable results we conduct a simulation with 100.000 iterations, varying the uniformly distributed input parameters in the presented ranges. The simulation parameterizes the model outlined in section 3.2 and in particular delivers values for the synchronized and for the only partly synchronized investment shares, the respective value contributions and the CPI (see esp. the formulas in sections 3.2.1, 3.2.2, and 3.2.3). Before further analyzing the results, at first the simulation runs that deliver non-value-adding investment decisions have to be sorted out. This can be achieved by comparing the value contribution of the company`s IT portfolio *with* the new IT investments to the value contribution of the company`s IT portfolio *without* the new IT investments. A company will only conduct such investments providing a positive risk-adjusted value contribution. In our basic setting about 38% of the simulation runs do not add any value to the existing IT portfolio and will therefore not be examined any further.

A further analysis of the remaining simulation runs and thereby especially the CPI leads to the following graph and the descriptive statistics included:

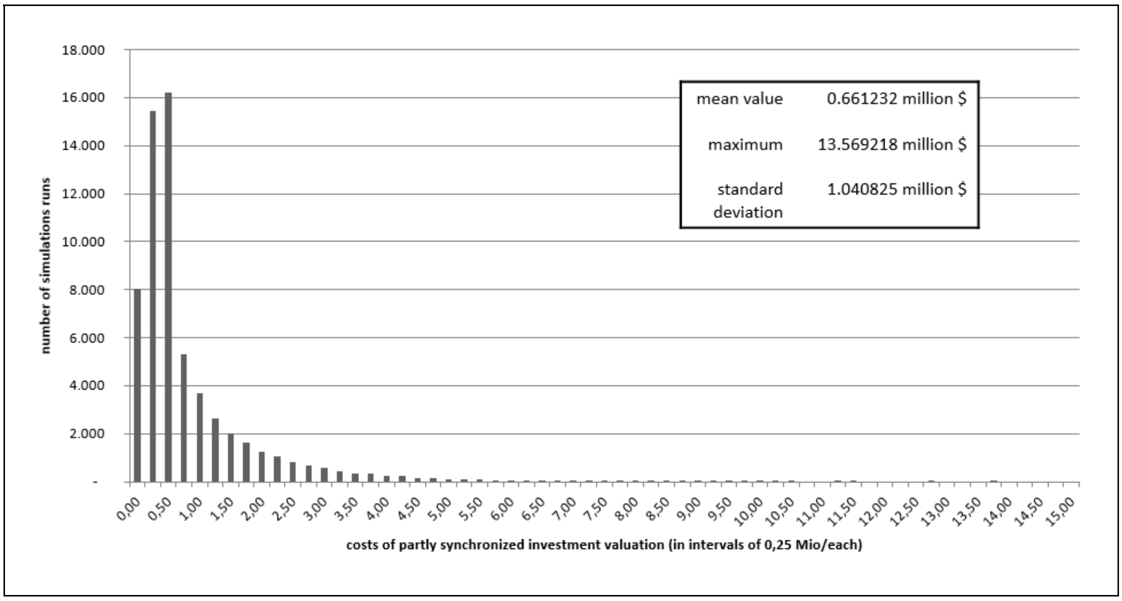

Figure 5. Results of the Simulation Study

The graph and the descriptive statistics offer us various findings. First, we see, that within about 8,000 simulation runs there occur no CPI (column on the far left-hand side). In those simulation runs the risk-/return structure of either investment alternative A or B is dominating the other investment alternative in such an extent, that, both in a synchronized as well as in a partly synchronized valuation perspective, the whole available investment budget IB is invested in one of the alternatives. Thus, those simulation runs deliver a border solution (and therefore an identical solution) for both perspectives.

Further above we already discussed, that an only partly synchronized investment valuation in general leads to suboptimal investment decisions, meaning that such decisions add less value to the company`s IT portfolio than synchronized investment decisions. Analyzing the results of the simulation we moreover find that partly synchronized investment decisions may even lower the value of a company`s already existing portfolio, i.e. those partly synchronized investment decisions might even destroy value. In the basic setting of our simulation study, this value-destroying effect occurs in about 3.26% of the simulation runs.

Furthermore the simulation results show that in a large number of simulation runs the CPI are in the intervals 0 – 0.25 million $ (15,432 simulation runs) and 0.25 – 0.5 million $ (16,209 simulation runs). This seems rather low at first sight – however, this judgment may relativize when taking into account that, first, the synchronized and partly synchronized value contributions of the investment alternatives average at about 16 million $, and, second, that these figures represent the CPI that result from only *one* investment decision considering two investment alternatives. As a consequence, even those relatively low CPI could add up to millions for companies that hold rather voluminous IT portfolios – and moreover especially when considering a longer planning horizon. Considering a company that continuously invests a constant IT investment budget, and naively projecting the CPI based on the mean value of 0.66 million $ in our two-period model, e.g. CPI of 3.3 million $ would result for a 10-period time horizon. This naively projected figure is further leveraged when taking into account that a precise calculation should additionally consider the interdependencies between the multiple two-period time frames. Furthermore, a company usually decides about investments in more than just two alternatives, so that additional risks would result from the additional interdependencies, and therefore an additional raise in CPI.

Nevertheless, besides the high number of simulation runs with rather low CPI, in 21.39% of the simulation runs the CPI do exceed 1 million $ and in 4.27% they do even exceed 3 million $. The maximum value for CPI is quite high with 13.569218 million $ and, compared to the average value contribution of the investment alternatives at about 16 million $, further underlines the importance of a synchronized ITPM. As we have seen that the results for CPI cover a quite big range, it is not surprising that the value for the standard deviation is also high with 1.040825 million $. This further underlines the fact that even one single (or few) investment decision(s) could be responsible for significant CPI that would easily justify investments in a synchronized ITPM.

Taking a closer look at the specific simulation runs reveals that the CPI tend to be rather low, if the risk-/return structures (and especially the intratemporal and intertemporal interdependencies) are rather similar, i.e. the two investment alternatives are quite homogeneous. In contrast, simulation runs that show rather heterogeneous investment alternatives tend to lead to rather high CPI. For example, in the simulation run showing the maximum value for CPI of 13.569218 million $, investment alternative A shows a much higher return and is much riskier than alternative B, with returns being 24.20% versus 0.38%, variance being 12.55% versus almost 0%, intratemporal interdependencies being 0.74 versus 0.47, and intertemporal interdependencies being 0.92 versus 0.44.

Summarizing the results of the first step of our simulation study, we can state the following: if the IT portfolio respectively the relevant IT investment alternatives are rather homogeneous regarding their risk and return structure, the CPI tend to be rather low. This confirms the results of our sensitivity analyses in section 3.3, where we claimed that a rising heterogeneity (especially regarding the interdependency structures) leads to rising CPI.

3.4.2. Alternative Settings (with heterogeneous investment alternatives)

To further examine the presented model and the aspect of heterogeneity regarding the risk-/return structure of the investment alternatives, in a next step we adjust several ranges of the simulation setup. Thereby we focus on the input values for the risk-/return structures of the investment alternatives. We adjust in a way that increases the heterogeneity, i.e. the difference between the two investment alternatives by first choosing different ranges for the return and the variance of the two investment alternatives (scenario 1) and second by additionally choosing different ranges for the intertemporal interdependencies (scenario 2). Thus, investment alternative A is holding less and less risk in the alternative scenarios compared to investment alternative B, which consequently represents the more risky investment alternative. The altered ranges for the input values for these two additional scenarios are included in the table below (scenario 1 = S1; scenario 2 = S2):

Table 2. Altered Input values for the alternative scenarios of the simulation study

Variable	**Lower bound**	**Upper bound**	**Variable**	**Lower bound**	**Upper bound**
$E(\tilde{r}_A)$	0	0.25 **S1=S2: 0.1**	$\widetilde{cf}_1^C$	200 (million $)	
$E(\tilde{r}_B)$	0 **S1=S2: 0.1**	0.25	$\widetilde{cf}_2^C$	200 (million $)	
$\sigma^2(\tilde{r}_A)$	0	0.35 **S1=S2: 0.15**	$\sigma^2(\widetilde{cf}_1^C)$	50 (million $)	
$\sigma^2(\tilde{r}_B)$	0 **S1=S2: 0.15**	0.35	$\sigma^2(\widetilde{cf}_2^C)$	50 (million $)	
$\rho_1^{C,A} = \rho_2^{C,A}$	-1	1	$\rho_{1,2}^C$	0	1

$\rho_1^{C,B} = \rho_2^{C,B}$	-1	1	IB	100 (million $)
$\rho_{1,2}^{A}$	0	1 **S2: 0.4**	α	0.01
$\rho_{1,2}^{B}$	0 **S2: 0.4**	1	i	0

Based on these additional simulations, we in the following compare the results to the basic setting above and discuss the differences that result from the different parameter constellations. The table below summarizes some key figures and statistics:

Table 3. Comparison of key results of the different scenarios

Ratio / statistic	**Basic setting**	**Scenario 1**	**Scenario 2**
% of simulation runs with value-destroying investments in partly synchronized valuation	3.26	7.94	14.78
% of simulation runs with CPI > 1 million $	21.39	33.27	59.80
% of simulation runs with CPI > 3 million $	4.27	8.06	20.67
Mean value of CPI (million $)	0.661232	0.998419	1.824201
Standard deviation of CPI (million $)	1.040825	1.291761	1.696513

The percentage of simulation runs that deliver value-destroying investment decision in an partly synchronized approach raises from 3.26% in the basic setting to 7.94% in scenario 1 (where the ranges for the returns and the variances differ) and even to 14.78% in scenario 2 (where additionally the ranges for the intertemporal interdependencies of the two investment alternatives differ). Furthermore, as expected, the rising heterogeneity leads to a rapidly increasing number of simulation runs where the CPI exceed a value of 1 million $ (33.27% in scenario 1 and even 59.80% in scenario 2 compared to 21.39% in the homogenous basic setting), or even exceed a value of 3 million $ (8.06% in scenario 1 and even 20.67% in scenario 2 compared to 4.27% in the homogenous basic setting). The mean value of the CPI, as a consequence, increases to almost 1 million $ in scenario 1 and even to over 1.8 million $ in scenario 2. The standard deviation increases with the rising heterogeneity of the investment alternatives up to almost 1.7 million $ in scenario 2.

As already discussed in the previous section, the CPI result from wrong investment decisions within an only partly synchronized ITPM. Thereby either an underinvestment in investment alternative A (when the interdependency risks of alternative A are lower than the interdependency risks of alternative B) or an overinvestment in A (when the interdependency risks of alternative A are higher than the interdependency risks of alternative B) can occur (et vice versa for alternative B). Comparing the (wrong) partly synchronized investment shares to the (correct) synchronized investment shares of the simulation results delivers the following:

Table 4. Comparison of the investment shares of the different scenarios

Ratio / statistic	**Basic setting**	**Scenario 1**	**Scenario 2**
% of simulation runs with overinvestment in investment alternative A within the partly synchronized approach	43.51	25.62	3.21
% of simulation runs with underinvestment in investment alternative A within the partly synchronized approach	43.51	74.38	96.79
% of simulation runs with correct investments decisions within the partly synchronized approach	12.98	0.00	0.00

As presented above, the ranges for the input values in the basic setting are equal for both investment alternatives. In this homogeneous setting the percentage of simulation runs that deliver an overinvestment in investment alternative A and that deliver an underinvestment in investment alternative A are pretty much the same at 43.51% (only differing on the forth decimal place). And there are still 12.98% remaining, where the only partly synchronized valuation leads to correct investment shares (due to the border solutions we already discussed above). As in the alternative scenarios investment alternative A holds increasingly less risks compared to investment alternative B, and as in an only partly synchronized approach this difference in risk is neglected, this partly synchronized optimization leads to an increasing underinvestment in investment alternative A. In scenario 2 even 96.79% of the simulation runs show an underinvestment in investment alternative A and respectively an overinvestment in investment alternative B. This leads to investment decisions (and subsequently an IT portfolio) that holds crucially higher risks than favoured.

Summarizing, the alternative settings of our simulation study confirm that an increasing heterogeneity between the considered investment alternatives regarding their risk-/return structure tends to lead to significantly higher CPI than in a homogeneous setting. Therefore, the higher the heterogeneity of a company`s IT portfolio and between the relevant IT investment alternatives, the higher the importance of a synchronized ITPM. Hence, the decision about the implementation of a synchronized ITPM (as well as its support by an adequate DSS) is a very individual one. On the one hand, it depends on the heterogeneity of a company`s IT portfolio. On the other hand, it depends on the costs necessary for establishing such a synchronized ITPM. This comprises both the initial conception and implementation costs as well as continuing operating costs. Thus, establishing a synchronized ITPM may not be profitable respectively necessary for companies that hold quite homogeneous IT portfolios.

To address this trade-off, in the following section we discuss some central requirements which a corresponding DSS within a synchronized ITPM should meet and we also present a step-wise approach that may help companies to take on a sound decision about the firm-specific importance of implementing a synchronized ITPM.

4. Implementation of a Synchronized ITPM

In the previous section, we quantified the disadvantage of an only partly synchronized IT investment valuation by the so-called "costs of partly synchronized investment valuation" CPI. Thereby, the conducted sensitivity analyses as well as the simulation study showed that this valuation error reaches a significant level in case the IT portfolio and the IT investment alternatives are rather heterogeneous regarding their risk-/return structures.

Based on these results we can derive several managerial implications that might help companies to further improve and develop their value-based ITPM as well as its support by an adequate

DSS. A value-based synchronized ITPM should be based on rigor methods that aim on optimizing the value contribution of the company's IT portfolio by taking into account both, risk and return of IT investments and in particular considering their intertemporal and intratemporal interdependency structures. Hence, the optimization approach presented in our paper can serve as a theoretically sound foundation for the functional conception and implementation of a value-based DSS within a synchronized ITPM. A central challenge considering the implementation of such a synchronized DSS and the decision processes based thereupon is the reliable estimation of central model parameters such as the intertemporal and intratemporal correlations or the IT investments' stand-alone variances. To ensure reliable parameter estimations, companies in particular have to gain comprehensive historical data about past and current IT investments. Based on historical data, the major input parameters of the model can be estimated more reliable by applying IT-supported statistical evaluation procedures and with that, the validity of the model can be increased. This is especially important, as our sensitivity analyses have shown, that the model is quite sensitive with respect to the intertemporal and intratemporal interdependencies, and even rather low estimation errors could lead to distinctly diverging results.

As already discussed in the context of the simulation study, the conception and implementation of a synchronized DSS as well as establishing the required underlying data base, of course, involves costs both for initial conception and implementation as well as continuing operating costs. Thus, when deciding on whether the implementation of such a sound information system is advantageous, a company has to balance these costs against the economic benefits coming along with a synchronized investment valuation. Thereby, the economic benefits can be interpreted as the reduction of the CPI.

But how can a company mindfully take on that decision? The CPI will not be known until a synchronized DSS and the underlying data base are implemented and, based on that, a comparison with only partly synchronized decisions becomes possible. Thus, the economic benefits of a synchronized DSS and a profound information basis will only be known ex post. As this well-known information paradox cannot be solved in general, we suggest a stepwise approach regarding the evaluation and implementation of a synchronized DSS:

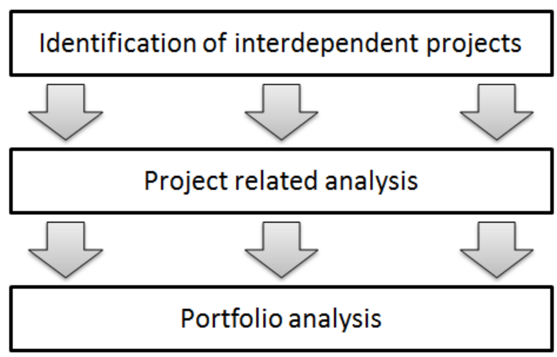

Figure 6. Stepwise approach for the evaluation and implementation of a synchronized DSS

Step 1. Identification and preselection of (one or few) interdependent projects: Our sensitivity analyses have shown that the extent of the CPI is influenced by the specific characteristics of the IT project, its complexity, its financial volume and in particular by its interdependencies to the existing IT portfolio and other IT projects. Thereby, in particular rather complex and long-term oriented IT projects that affect large parts of a company's IT landscape typically are characterized by significant intertemporal as well as intratemporal interdependency structures. This, for example, usually holds true for large IT transformation projects that affect essential architectural aspects of the company's IT or large parts of the application landscape. Consequently, in a first step, companies should focus on identifying and preselecting such planned IT projects that are supposed to involve strong and numerous interdependencies. As for such IT projects the CPI are expected to be rather high, in a second step the identified IT projects should be analyzed in more detail.

Step 2. Project related analysis: The basic aim of this second step is to get a solid assessment of both, the "synchronized value" of the identified IT projects and the CPI associated with these very IT projects. As a result, a company should be enabled to gain a fundamental understanding of the advantageousness of a sound information basis supporting synchronized investment decisions. Therefore, a more detailed analysis of the selected IT projects is necessary within this step. At first, a quite rough estimation by experts or responsible projects managers seems appropriate. The experts or project managers can identify reasonable ranges for the relevant input parameters and best-/worst-/average-cases can be estimated. Based on these initial expert assessments, first estimations regarding the IT project's synchronized value and the CPI can be conducted. In case that these first estimations indicate high CPI, in a next step a more thoroughly analysis of the model's major input parameters seems appropriate. As mentioned above, for a sound estimation of these parameters in particular comprehensive historical data has to be gained and analyzed by means of IT-supported statistical evaluation procedures. Based on a detailed estimation of the relevant input parameters, a subsequent synchronized optimization of the respective IT investment decisions can be performed based on the presented model. However, as gathering, preparing and evaluating a comprehensive data base usually comes along with significant costs (e.g. for required working time of employees), companies are well-advised to put emphasis on a careful preselection of IT projects as well as solid expert assessments in a first step.

Step 3. Portfolio analysis: The project related analyses on the one hand lead to optimal synchronized decisions regarding the IT projects considered and on the other hand provide sound information on the extent of the CPI that would result from further taking on decisions based on an only partly synchronized ITPM. Considering the analyses of the selected IT projects, the company in a next step has to decide on whether it is advantageous to invest in implementing a companywide synchronized DSS to support future IT investment decisions, building up the underlying broad information basis as well as establishing the associated decision processes. Thereby, the implementation of a companywide DSS is supposed to be beneficial especially in case the project related analyses conducted in step 2 revealed high CPI and the company's IT portfolio contains numerous additional IT projects that show similar characteristics regarding volume, complexity and interdependency structures compared to the IT projects considered in step 2. In this case, the implementation of a companywide DSS may enable a large reduction of CPI. Reversely, if the CPI were evaluated as relatively low in step 2 and/or the company's IT portfolio holds only very few IT projects that involve a similar complexity and resulting strong interdependency structures as the IT projects analyzed in step 2, a full implementation of a synchronized DSS might not be profitable. In this case, the costs for implementation may exceed the potential reduction of the CPI that can be achieved by means of the synchronized DSS.

Summing up, the advantageousness of building up a sound information basis and implementing a sound DSS within a synchronized ITPM based on the optimization approach presented in this paper depends on the detailed structure of a company's IT portfolio as well as the specific characteristics of its IT projects.

5. Practical Implications, Limitations and Conclusion

Based on a theoretical optimization model we have shown that IT investment decisions can differ significantly depending on whether they are based on an only partly synchronized or a synchronized ITPM respectively its underlying optimization approach. As interdependencies are neglected in an only partly synchronized ITPM, investment decisions consequently are based on an incomplete and therefore incorrect valuation of an IT investment's risks. We quantified the resulting financial disadvantage of an only partly synchronized IT investment valuation by the so-called "costs of partly synchronized investment valuation" (CPI). Furthermore, in sensitivity analyses we examined the impact of intertemporal as well as intratemporal interdependency structures on the CPI. Moreover, the results of our simulation underline the importance and relevance of a synchronized ITPM, especially when the IT portfolio and the IT investment alternatives of a company are rather heterogeneous regarding their risks and returns and particularly regarding their interdependency structures.

Although the results of our model allow for deducing several managerial implications, the presented model nevertheless shows some limitations with respect to the assumptions made that offer opportunities for future research:

- In the model at hand the company takes all investment decisions at time $t = 0$. By extending the underlying research questions to a dynamic optimization model with multiple decision points in time, it is also possible to include time-varying information in the analysis.
- So far, our model only considers two investment alternatives. As mentioned in the discussion of our simulation study, the investment setting of most companies usually shows up considerably more complex, offering distinctly more investment alternatives. Extending our model to allow for the consideration of an arbitrary number of investment alternatives in a portfolio context would be a promising next step and further strengthen the applicability of our model for real word investment decisions.
- In the current model only portfolio effects regarding the risk of IT investments were taken into account by stochastic intertemporal and intratemporal interdependencies. Portfolio effects regarding returns that, for instance, result from economies of scale or scope were not taken into account.
- As the model developed in this paper constitutes only a first theoretical approach to quantify and analyze the CPI, further empirical research is necessary to examine the model's applicability in different real world decision settings. Thereby, from an empirical point of view two main starting points are given: First, with detailed case studies relying on field

data, the applicability of the model for different application scenarios, e.g. within different industries or for different types of IT investments, can be validated. Furthermore, by means of detailed field experiments the results found by analyzing our analytical model could be substantiated and the model's robustness could be validated. This seems to be valuable especially with regard to the most important input parameters like the stand-alone variances or the intertemporal and intratemporal correlations. Second, another link for subsequent empirical research concerns the profound estimation of the model's input parameters which is a particular challenge regarding the operationalization of our theoretical approach. At this, particularly the estimation of the stochastic interdependency structures, i.e. the intertemporal and intratemporal correlations, is of major importance. Thus, the exploration of concrete interdependencies by means of statistical sampling methods based on historical data may help companies to better forecast and estimate the stochastic interdependency structures of planned IT investments.

Despite these potential starting points for further research, as a first step we have shown the strong impact of intertemporal and intratemporal interdependency structures on IT investment decisions. Taking into account the results of our theoretical analysis, especially companies, that hold quite heterogeneous IT portfolios, are well-advised to abstain from making investment decisions based on DSSs within an only partly synchronized ITPM. Instead, such companies should rather incorporate a synchronized DSS to consequently contribute to sustainable value creation within a synchronized ITPM.

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