University of Augsburg
Prof. Dr. Hans Ulrich Buhl
Research Center
Finance & Information Management
Department of Information Systems
Engineering & Financial Management

Discussion Paper

Interdependencies between Automation and Sourcing of Business Processes

by

Katzmarzik Arne [1], Henneberger Matthias[1], Buhl Hans Ulrich

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[1] At the time of writing this paper, Katzmarzik Arne and Henneberger Matthias were research assistants at the Research Center Finance & Information Management and the Department of Information Systems Engineering & Financial Management at the University of Augsburg.

WI-338

Universität Augsburg, D-86135 Augsburg
Visitors: Universitätsstr. 12, 86159 Augsburg
Phone: +49 821 598-4801 (Fax: -4899)
www.fim-online.eu

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ABSTRACT

Automating business processes or relocating the processes to low-wage countries are two frequently used measures to decrease cost. With the main focus on cost reduction, however, productivity differences between locations as well as interdependencies between automation and sourcing are often inadequately considered. In fact, automation and sourcing opportunities are usually evaluated independently of each other. This common practice can systematically lead to decisions that consume expected savings. In this paper, a decision model is proposed that is designed to simultaneously derive optimal degrees of automation and relocation for business processes. Our approach considers various process execution costs and productivity levels as well as the effects of business process automation on sourcing decisions in order to maxime the return of a firm. We find that a false decision on the extent of automation may have significant influence on return. Furthermore, in the case of higher complexity, retaining work at the high-wage site becomes more attractive. Finally, we find that staff fluctuation at low-wage sites may not necessarily reduce attractiveness of such sites in general. This research helps executives to better understand the influence certain parameters may have on joint automation and sourcing decisions.

Keywords: business process, automation, relocation, offshoring, productivity, staff fluctuation, decision model

1 INTRODUCTION

Increased competition and economic pressure forces global companies to reduce business process execution costs. Two frequently used measures to achieve this goal are automation and sourcing. On the one hand, advances in information technology facilitate business process automation to increase efficiency (Miller & Parkhe, 1999; Parkhe & Miller, 2002). On the other hand, enabled by globalization, processes can be sourced entirely or partially to foreign countries to exploit wage differences. This is accomplished either by outsourcing the business processes to external service providers that are located abroad or by shifting the processes internally from one site to another. Relocating business processes, whether in-house or through outsourcing, has become very attractive in recent years and had been facilitated by improved communication technologies (Agrawal, Farrell, & Remes, 2003).

In general, business processes dealing with information instead of physical goods are largely independent of the location and at the same time provide potential for automating at least part of the process. In these cases, automation and sourcing decisions are closely interrelated. For example, simple tasks in the financial services domain, such as entering paper orders into an order processing system, could be cost effective if they are performed by staff members in low-wage countries or if they are completely or partially automated. For example, optical character recognition (OCR) technologies can be used for the automatic scanning and processing of paper orders. Therefore, an integrated decision support model considering automation and sourcing is crucial.

The objective of this paper is to analyze automation and sourcing decisions, as they pertain to relocation in particular. We consider automation and sourcing as two opposed but interrelated alternatives. Thereby, this research approach is design science oriented. We introduce a normative decision model proposing an optimal allocation of (parts of) business processes to these alternatives. Thus, we contribute to the existing literature by providing an integrated approach at the interface between automation and sourcing. This approach reveals insights concerning the considered problem and can form the foundation for further research. Additionally, we take into account the effects of high staff fluctuation at low-wage sites. The applicability of our model is demonstrated by a case that is based on data from a large financial services provider.

The remainder of this paper is organized as follows: in section 2, we provide an overview of related work and describe the conceptual fundamentals for the rest of the paper, including the definitions of important terms; in section 3, the decision model is presented, analyzed and illustrated using an example case; in section 4, the limitations and managerial implications are discussed; and in section 5, we conclude with an outlook on further research.

2 LITERATURE REVIEW

Automation and sourcing are instruments that are used to reduce the overall cost of performing business processes. *Automation* refers to the use of computers or machines to perform work original done by humans (Bainbridge, 1983). *Sourcing* can be separated into the organizational and the regional dimensions, which are independent of each other to a certain extent. With respect to the organizational dimension, outsourcing is defined as the procurement of services from sources that are external to the organization (Lankford & Parsa, 1999). With respect to the regional dimension, regional sourcing (e.g offshoring) refers to relocating jobs to foreign countries without distinguishing whether the provider is external or affiliated with the firm (Levy, 2005). In this text, we focus on the regional dimension because the cost reduction potential of relocation to low-wage countries can be realized both with in-house and outsourcing engagements and generally refer to *relocation*, which shall represent all aspects of regional sourcing. Because this paper aims to examine specific economic effects that are enabled by both automation and sourcing, in particular relocation, in a high-level integrated approach, we discuss the literature relevant to automation, sourcing and their relationship. From the literature, we deduce *requirements for the development of an integrated decision model (RM)* for automation and sourcing in subsection 2.1. We then provide an overview of the decision models proposed by other authors for automation or sourcing decisions in subsection 2.2.

2.1 Requirements for a Decision Model that Considers Automation and Relocation

In this subsection, we elaborate requirements for modeling from literature, which form the conceptual foundation for our modeling. Though these requirements for modeling may seem quite obvious, the model reveals in-depth insights into the problem. Automation and sourcing decisions are mostly examined independent of each other in the literature. For example, a particular strand of business process management papers, or papers that discuss the standardization of business processes typically address the partial or full automation of business processes. Sourcing decisions are addressed in the literature that deals with business process outsourcing or relocation. Consequently, decisions on sourcing and automation are generally separated from each other. Business processes are often standardized and automated in a first step, followed by a subsequent sourcing decision in a second step (cf. Balasubramanian & Gupta, 2005). However, the recent literature describes the relevance of considering the relationship between automation and sourcing (Braunwarth, Kaiser, & Müller, 2010) because automation in a first step influences the characteristics and manageability of the business processes. For instance, automating part or all of a process may change the interfaces between process steps. Furthermore, automation may reduce the manual work to be performed, so that relocating the remaining tasks to a low-wage country may be no longer attractive in terms of cost savings. Additionally, foregoing automation of the process steps will affect the average complexity of the manual tasks in the remaining process steps. Simple tasks in a process are usually automated first, whereas more sophisticated and complex process steps, which require intelligence or human creativity, are still performed manually (Lewis & Jones, 1995). Therefore, with increasing levels of automation, the average complexity of the manual process steps increases, which again influences the optimal degree of relocation. Thus, the decisions on automation and sourcing of a process should be integrated (Braunwarth, Kaiser, & Müller, 2010).

RM 1: Interdependencies between automation and sourcing should be considered in an integrated model for decisions on business processes.

Automation requires technical effort and ultimately, an investment. Automation costs include for instance acquisition costs for process-specific software and hardware, license fees and introduction costs for the automation solution (e.g. staff trainings) (Alpar, 1992). While some process steps are very inexpensive to automate, such as entering input data into a software program, others are not. In fact,, automation may result in uneconomically high expenses for the latest technologies to replicate the most complex process steps (Nikolaidou, Anagnostopoulus, & Tsalgatidou, 2001). These characteristics lead to the following requirement for the modeling with respect to the behavior of automation costs.

RM 2: By increasing the degree of automation, the costs increase exponentially.

Manual process execution is primarily characterized by variable costs, and selecting the country or the general site where the process should be performed is a crucial success factor (Yang, Kim, Nam, & Wim, 2007; Dibbern, Winkler, & Heinzl, 2008). In the literature, numerous articles on the criteria and the factors that drive relocation decisions have been published (Farrell, 2005; Quélin & Duhamel, 2003). Although a number of motives for relocating the execution of business processes, such as access to a larger pool of human capital, improved position in global markets, concentration on core business activities or more flexibility in reacting to market changes, have been discussed, the main motive is wage arbitrage due to lower human resource (HR) costs (Quélin & Duhamel, 2003) and thus reduced labor costs. However, relying only on labor costs may lead to wrong decisions, as productivity of human is of great importance when using information systems in such information based processes (Byrd & Turner, 2001). Thus, *productivity levels* which may differ from site to site (Criscoulo & Leaver, 2005) (and are in general lower in low-wage locations) due to cultural or environmental differences or communication issues (Winkler, Dibbern, & Heinzl, 2006; Kankanhalli, Tan, Wei, & Holmes, 2004) should be considered in the decision.

RM 3: Variable *effective labor costs* that are calculated by considering not only wage levels but also productivity levels should be included in a decision model.

With respect to relocation, additional factors are relevant. Relocating business processes completely or partially to a remote location usually causes *transaction costs*, such as management or communication costs (Aubert, Rivard, & Patry, 2004). Furthermore, a factor that has become increasingly important is high staff fluctuation at low-wage sites (Krick & Voß, 2007). This is especially true for sites with a specialization on IT/BPO, such as India (Joseph, Ng, Koh, & Ang, 2007). In turn, this may result in a reduced productivity or expensive training for new employees. Therefore we postulate:

RM 4: Transaction costs and effects of staff fluctuation should be considered.

The literature on automation and sourcing (also in the related area of IT sourcing) is manifold. Examinations have been conducted in more specific areas as well, such as the following: risk (Aron, Clemons, & Reddi, 2005), decisions in a portfolio context (Santhanam & Kyparisis, 1996), intertemporal dependencies valuated or modeled with options (Benaroch, Jeffery, Kauffman, & Shah, 2007), effects of quality (Davamanirajan, Kauffman, Kriebel, & Mukhopadhyay, 2006), and enhancing flexibility of process execution (van der Aalst & Basten, 2002; Gebauer & Schoder, 2006). All of these publications cover specific aspects of automation and sourcing. Nevertheless these aspects are not essential for the basic relationship between automation and sourcing and will therefore not be covered in detail in this paper.

For our examination we have to provide a detailed examination of the differences in *productivity levels* at sites distributed all over the world. These starting points were considered to be of high importance by several authors (Braunwarth, Kaiser, & Müller, 2010; Dibbern, Winkler, & Heinzl, 2008; Carmel & Tija, 2005; Cusumano, MacCormack, Kemerer, & Crandall, 2003), and as we will see in the following chapter, they have not yet been subjected to this type of quantitative research.

2.2 Related Work on Automation and Sourcing

In the literature, most articles that address decision support on automation or sourcing are qualitative approaches (see e.g., Stohr and Zhao (1997) as well as Gebauer and Scharl, 1999 for automation, and Rouse and Corbitt (2004) as well as Levina and Su (2008) for sourcing). There are only few approaches suggesting quantitative decision models in related research areas.

In the area of business process automation, Wei, Macwan, and Wieringa (1998) propose a quantification of the optimal automation degree considering the task load and process complexity. Additionally, Sheridan and Parasuraman (2000) propose a method to quantify the expected value of the gain of either human execution or automation. Balasubramanian and Gupta (2005) propose an ex ante estimation of the degree of automation using metrics (e.g. the ‘activity automation factor’). Although these approaches provide well-founded decision support for automation, they do not consider the effects on and the interdependencies with sourcing.

Yang, Kim, Nam, and Min (2007) identify influence factors for sourcing and propose a decision model using the analytic hierarchy process method. Beimborn (2007) analyzes cooperative sourcing with different independent actors. His analytical models and simulation approaches are based on game and agent theory. Braunwarth and Ullrich (2010) present a basic model for decisions on how to execute process steps. In their model, one sourcing decision at a time can be made for each step in isolation from the other steps to maximize the cash flows. Consequently, these studies differ from our approach both in methodologies and in the research questions covered, and they do not consider automation.

Vom Brocke and Lindner (2004) and vom Brocke (2007) apply investment accounting methods to support sourcing decisions on business processes. They distinguish three levels of evaluation as follows: the operational level, the budgeting level and the corporate level. At the operational level, in-payments and out-payments are directly related to process design and sourcing decisions. In contrast to our model, their approach requires detailed modeling of the processes and allows decisions for individual process steps in a multi-period model. However, we are interested in the general relationship between sourcing and automation and therefore apply a one-period model.

In the area of IT sourcing, quantitative decision models exist to locate an allocation at sites that apply decision criteria similar to ours. For instance, Zimmermann, Katzmarzik, and Kundisch (2011) present a method to allocate software development projects efficiently to sites using Markowitz’s portfolio theory or theories proposed by Dutta and Roy (2005), who present a system dynamics approach for finding an optimal offshoring degree. In these cases, the research questions are different from our contribution because automation is not considered and the focus is on IT sourcing instead of processes.

In summary, to the best of our knowledge, there is no publication that uses an integrative quantitative approach that combines automation and sourcing. Thus, we plan to start filling this research gap.

3 A MODEL SUPPORTING INTEGRATED AUTOMATION AND SOURCING DECISIONS

We now present a model to support sourcing and automation decisions. Subsection 3.1 introduces the overall model setting as a generic form of the model. In subsection 3.2, a basic model allowing an analytical solution is presented, which illustrates the fundamental relationships of the decision problem. In subsection 3.3, the model is extended by integrating a functional dependency between sourcing and automation, which is necessary to apply it to more realistic settings. Additionally, the model is operationalized with a real world case. Finally, in subsection 3.4, we analyze the effects of selected influence factors using a sensitivity analysis.

3.1 General Form of the Model

In this subsection, we will introduce the notation and the general form of the model to provide a basic understanding of the decision problem under consideration. The generic modeling, and in particular the introduced influence factors, are concretized in the following subsections.

We consider, in a one-period model, a company that is reengineering and reevaluating the sourcing strategy for its business processes, whereby the decision for each process can be made independent of each other. Hence, we consider only a single process in our model that is executed with a known frequency, $\boldsymbol{V}$. There are different alternatives to perform the process. The business process (or a part of it) can be automated, relocated to a low-wage site or retained at the original site. We make a basic assumption that allows modeling of the relationship between automation, retention (i.e. work kept onshore at the high-wage site) and relocation.

Assumption 1: The total work required to execute the process can be performed by using any possible combination of retention, relocation and automation, whereas each part of a process can only be executed by one alternative exclusively.

We introduce the decision variables, ω, κ, and λ, where ω represents the degree of retention, λ represents the degree of relocation and κ represents the degree of automation, under the following constraints:

1) $\omega, \lambda, \kappa \geqq 0 \quad and \quad \omega + \lambda + \kappa = 1$

Depending on the number of transactions and an income, **E,** per process execution, the total income **I** can be written as a function of the number of transactions and the income for one instance: **I(V,E)**.

Manual work is characterized by site-specific productivity, $\mathbf{PR_n}$ ($PR_n > 0$), and site-specific labor costs, $\mathbf{LC_n}$ ($LC_n > 0$). The index, **n**, denotes the site, with **n=H** for the original high-wage site and **n=L** for the new low-wage site. The productivity represents the time required for executing one instance of the process. Furthermore, for the new site, transaction costs, **T**, arise due to international coordination. Thus, costs at the high-wage site for executing one instance of the process can be represented by the function, $\mathbf{HWC(LC_H,PR_H)}$, and the costs for the low-wage site can be represented by $\mathbf{LWC(LC_L,PR_L,T)}$.

Automation causes a fixed upfront investment depending on the specific degree of automation chosen. Automation costs are expressed as a function of the maximal amount of money, **A**, for full automation and the automation degree as follows: **AC(A,κ)**.

Because the cost functions for manual work are scaled to one instance of a process, these costs have to be multiplied with the frequency of process executions and the corresponding decision variables of each of the alternatives:

$$R(\omega,\kappa,\lambda) = I(V,E) - (\omega \cdot V \cdot \mathrm{HWC}(\mathrm{LC_H},\mathrm{PR_H}) + \lambda \cdot \mathrm{V} \cdot \mathrm{LWC}(\mathrm{LC_L},\mathrm{PR_L},T) + \mathrm{AC}(\mathrm{A},\kappa))$$

Having structured the general decision problem, the next step is to concretize it.

3.2 Basic Model and Analysis

3.2.1 Model development

Based on the general form, we define a simplified setting that enables an analytical examination of the fundamental effects between the alternatives. In this stage, we still neglect the interdependencies between the automation and manual work postulated in RM 1.

The costs for manual work at the original site or the high-wage site depend on the site-specific conditions, such as wage levels and productivity, and the number of transactions (cf. RM 3). In addition, according to RM 4, the productivity at the low-wage site includes the effects of potential staff fluctuation because the risk of a high fluctuation rate may increase as sourcing to such a location in increased.

Assumption 2: High-wage and low-wage sites are characterized by both labor costs $\mathbf{LC_n}$ and productivity $\mathbf{PR_n}$. Based on this the resulting effective labor costs, which can be calculated as the ratio of labor costs and productivity, are assumed to be higher at the high-wage site. Thus, in case of lower effective labor costs at the high-wage site, for instance due to high productivity at the high-wage site or very low at the low-wage site, it would be not recommendable to relocate any part of the process. The costs for manual work are assumed to increase proportionally with the amount of work conducted. Additionally, the transaction costs, **T**, increase at the low-wage site due to international coordination. Furthermore, the productivity of the low-wage site decreases by the negative scale factor, **S**, with increasing degrees of relocation.

In this paper, we model productivities dependent on effects such as staff fluctuation,which we want to examine. In this first stage, the productivity at the high wage site is still kept fixed and expressed by the basic productivity $\mathbf{P_H}$ (underlying any effects such as influence of automation on manual work). The productivity of the low-wage site is characterized by its estimated basic productivity $\mathbf{P_L}$ and the effects of staff fluctuation as mentioned above. Both productivities can be calculated as follows:

$$2)\ PR_H = P_H \qquad and \qquad PR_L(\mathrm{S}, \lambda) = \frac{P_L}{1 + S \cdot \lambda}$$

Thus, the costs at each site for executing one instance of the process are now written as a ratio of labor costs and productivity as follows:

3) $\text{HWC}(\text{LC}_{\text{H}},\text{PR}_{\text{H}}) = \frac{LC_H}{P_H}$ *and* $\text{LWC}(\text{LC}_{\text{L}},\text{PR}_{\text{L}}(\text{S}, \lambda)) = \frac{LC_L}{\frac{P_L}{1+S\cdot\lambda}} + T = (1+S\cdot\lambda)\cdot\frac{LC_L}{P_L} + T$

As discussed, the process steps are characterized by various complexities, which results in varied automation costs per process step (cf. RM 2). Because the process steps that are easy and inexpensive to automate are usually automated first, we assume the following:

Assumption 3: Automation costs rise exponentially up to the maximum extent.

Thereby, the modification factor **γ**>1 represents the exponential increase in automation costs. The automation costs can be written as follows:

4) $AC(\text{A},\kappa) = A\cdot\kappa^{\gamma}$

Assumption 4: The income generated by one instance of a process is fixed.
Thus, the total income can be calculated as the product of the income per transaction and the number of transactions:

5) $I(V,E) = V\cdot E$

The decision should be made based on the characteristics of the given alternatives and the attitude of the decision maker.

Assumption 5: The decision maker is risk neutral and aims to maximize the return.

Based on these assumptions, the return can be expressed as a function of the costs of each alternative and their shares in the process execution represented by the decision variables. We substitute ω with $1-\kappa-\lambda$ (cf. equation 1) to express the return, **R**, only depends on to variables, κ and λ. Thus, ω is now implicitly considered and the maximization problem based on the return function is represented by:

6)
$$R(\kappa,\lambda) = V\cdot E - \left((1-\kappa-\lambda)\cdot V\cdot\frac{LC_H}{P_H} + \lambda\cdot V\cdot((1+S\cdot\lambda)\cdot\frac{LC_L}{P_L} + T) + A\cdot\kappa^{\gamma}\right) \rightarrow \max!$$
$$s.t.:\ \lambda,\kappa\in[0;1] \quad and \quad \lambda+\kappa\leqq 1$$

In maximizing the problem described in equation 6, the optimal degrees of the considered alternatives can be calculated. Table 1 lists the notation and all parameters of the return function incl. the parameters introduced in the next subsection to provide a better overview.

*** Insert Table 1 about here ***

3.2.2 Model analysis

We now examine the model analytically and deduce general statements on the model parameters. For reasons of simplicity, we assume only in this subsection that automation costs increase quadratically, i.e. $\gamma=2$, to enable a simple but meaningful analytical solution.

The Hessian that is formed by the second partial derivatives is negative definite, thus the objective function is concave and given the convex set formed by the constraints (see Figure 1) every local maximum is also a global maximum (Simon & Blume, 1994). In order to find the optima of inequality-constrained problems, we apply the Lagrange multiplier method and calculate a system of inequalities called the 'Karush–Kuhn–Tucker conditions' (Simon & Blume, 1994). The resulting candidate solutions are shown in Table 2. Thereafter, the analysis of the set of complementary slackness conditions proceeds by considering all possible cases differing by which constraints are binding. In case no constraint is active, we derived the solution shown in case A in Table 2.

*** Insert Table 2 about here ***

*** Insert Figure 1 about here ***

To test the feasibility of this solution, it has to fulfill the constraints leading to the following conditions:

7) $\kappa^* \geqq 0$; $\lambda^* \geqq 0$ *and* $\lambda^* + \kappa^* = \dfrac{\dfrac{LC_H}{P_H} - \dfrac{LC_L}{P_L} - T}{2 \cdot \dfrac{LC_L}{P_L} \cdot S} + \dfrac{V \cdot \dfrac{LC_H}{P_H}}{2 \cdot A} \leqq 1$

Due to positivity of all parameters according to the assumptions and because - according to assumption 2 - effective labor costs at the high-wage site are higher than those at the low-wage site, the first two conditions from inequality 7) are fulfilled. Concerning the latter condition of inequality 7), it is important to examine if the decision variables are within their upper bounds. The latter condition is not necessarily fulfilled as this strongly depends on the model parameterization. Futhermore, this case (degrees are larger than allowed, and following other degrees become negative) is not feasible due to the model assumptions. The effects which would occur in such cases are addressed in the discussion section.

If results of case A are infeasible according to inequality 7), i.e. no inner solution, the optimum lies on the boundary of the constraint set and one of the other cases with one or two active constraints (cf. cases B to G) becomes relevant. In case of one active constraint, the optimal allocations have to be determined according to cases B to D whereby the two other constraints have to be fulfilled. In case the other constraints are not fulfilled, two constraints are active and cases E to G are relevant. Lastly, the return for each of the possible cases has to be calculated. The case with the highest return is the optimal solution.

Based on these solutions, one can derive general statements concerning the problem. At first we discuss results for the inner solution, i.e. no active constraints, which implies that all alternatives are relevant (case A). Then we examine the constrained solutions and exemplify under which conditions they occur.

Results concerning relocation are not surprising: The larger the difference between effective labor costs per process execution at the low-wage site and the high-wage site are, the more should be relocated. Furthermore, negative scale effects representing effects such as high staff fluctuation have decreasing influence on the degree of relocation. More interesting are statements on automation: The degree of automation rises with increasing effective labor costs of the high-wage site. Thus, automation is a viable substitute for costly human work which cannot be performed profitably. Furthermore, the degree of automation increases in case of lower total automation costs which may be achieved by technological progress. Despite of that, lower transaction volume leads to a lower degree of automation. The reason is that automation requires an upfront investment that is independent of the transaction volume while costs of manual work are variable. To compensate a lower transaction volume it is thus reasonable to perform a process manually rather than automating it.

If results of case A are infeasible, the other cases become relevant. The interpretations for these possible cases are given in the following. In case of no retention (case B), relocation and automation are direct substitutes. One can state that relocation becomes less attractive with a higher amount of transactions as the marginal costs for performing an instance of the process are higher for relocation than for automation. In case of no relocation (case C), retention and automation are direct substitutes. For this case, the same relations between these alternatives as for the unconstrained case (case A) are on hand. Interestingly, in the case of no automation (case D) is not a candidate solution. This means that an allocation only on relocation and retention is less advantageous than an allocation including automation. The reason is that automating a (at least marginal) part of the process is always economically reasonable from a theoretical point of view as automation is attractive as long the marginal costs for automation, which are especially low in the range of little automation degrees, are lower than the marginal costs for the human workforce. Cases E and F are special cases of case D, and thus always less attractive than an allocation including automation. Case G is trival as only automation is considered.

3.3 Model Extension

In this subsection, we examine the effects on the productivity of manual work due to the foregoing of automation. By automating the tasks in a first step, the number of process steps that require manual performance decreases. Because simple tasks are automated first, this affects the average process complexity of the remaining manual process. If simple task are automated, humans have to perform only the more complex and thus more laborious process steps. Following, a higher average complexity causes additional effort for the human workforce when processing process steps and thus the average productivity in executing the remaining more complex process steps decreases.

Assumption 6: With increasing degrees of automation, process complexity increases and thus the average productivities of manual work execution decrease.

Therefore, the complexity factor, $\boldsymbol{C_n}$, represents the change in the average complexity and is calculated as the ratio of *average productivity with no automation* over *average productivity with full automation*. To model this, we assume that this complexity factor is the base and the degree of automation is an exponent implying decreasing productivities of manual work with higher degrees of automation.

$$8)\ PR_H(C_H,\kappa) = \frac{P_H}{C_H^{\ \kappa}} \quad \wedge \quad PR_L(\mathrm{C_L,S},\ \kappa,\lambda) = \frac{P_L}{(1+S\cdot\ \lambda)\cdot\ C_L^{\ \kappa}}$$

Obviously, the productivity may be different at the two sites, and the complexity factor may also differ from site to site. For a comparative analysis of the complexity changes (cf. subsection 3.4), we include a weight factor, $\boldsymbol{M_C}$, that represents the relationship between the complexity changes of both sites as expressed in the following equation:

$$9)\ M_C = \frac{C_L}{C_H} \Rightarrow C_L = C_H \cdot M_C$$

The costs of manual work for execution of one instance of the process are now calculated as follows:

$$10)\ \mathrm{HWC(LC_H,PR_H(C_H,}\ \kappa)) = \frac{LC_H}{\frac{P_H}{C_H^{\ \kappa}}} = C_H^{\ \kappa} \cdot \frac{LC_H}{P_H}$$

$$11)\ \mathrm{LWC(LC_L,PR_L(C_L,S,}\ \kappa,\lambda)) = \frac{LC_L}{\frac{P_L}{(1+S\cdot\ \lambda)\cdot\ (C_H\cdot\ M_C)^{\kappa}}} + T = (1+S\cdot\ \lambda)\cdot\ (C_H\cdot\ M_C)^{\kappa} \cdot \frac{LC_L}{P_L} + T$$

With these additional assumptions, the objective function is now expressed as follows:

$$12)\ R(\kappa,\lambda) = V\cdot E - \left((1-\kappa-\lambda)\cdot V \cdot C^{\kappa} \cdot \frac{LC_H}{P_H} + \lambda \cdot V \cdot ((1+S\cdot\lambda)\cdot(C_H \cdot M_C)^{\kappa} \cdot \frac{LC_L}{P_L}) + T) + A\cdot\kappa^{\gamma} \right)$$

This enhancement complicates the return function. As a consequence, a unique analytical solution of the maximization problem cannot be determined non-ambiguously. The problem has to be solved numerically. Thus, in the following operationalization, we implement and solve equation 12) with the 'NMaximize' function of the 'Mathematica' program using the figures from the real world case.

3.3.1 Operationalization: Introduction of a real world case

The following case will serve as a running example to further illustrate the application of the model. It refers to a typical decision situation and is based on real business cases. Names and all possible identifying details are omitted, and the data have been anonymized for confidentiality reasons.

The A-BANK, a large European financial services provider, operates all over the globe and plans to reengineer and reorganize several of its business processes. In the following paragraphs, we consider the process for handling high-value payments and checks for business clients, which consists of 23 process steps, and generates a fixed income of € 4.8 per instance. The estimated frequency is 2,200,000 times in the next period.

The following alternatives have been identified by A-BANK for the process under consideration:

Germany (high-wage site): Up to this point, A-BANK processed their checks at one of its German sites characterized by high wages, but also high productivity.

India (low-wage site): A-BANK runs a large shared service center in India. This offshore site has become very popular due to the large and mature talent pool. A disadvantage lies in the cultural differences to Western countries and high staff fluctuation. The labor costs are significantly lower than in Germany. In addition to labor costs, transaction costs due to international distribution arise. Thus, the total costs for each transaction consist of labor and transaction costs.

Process Automation: A-BANK is able to implement several process steps with a new software system and can install OCR systems for check handling. There are different levels that differ in the scope of the automation and in the recognition quality. The latter influences the manual effort required in subsequent process steps. For instance, low recognition quality means that (manual) controlling steps are still required in the process.

In order to apply the model, parameters had to be determined. For each process step, automation costs were estimated and similar process steps were clustered by complexity and costs together with experts of the A-Bank. They found that some process steps were easy and inexpensive to automate whereas others were extremely complex, resulting in very high automation costs. We classified five different types with estimated costs for the automation as shown in Table 3 and Fig. 2.

*** Insert Table 3 about here ***

*** Insert Figure 2 about here ***

Based on this analysis, we estimated the automation costs to increase exponentially with an exponent γ of about 2.0. The maximal automation costs (parameter A) were determined by the sum of the costs for automating all steps, which are €21 mn.

With the data of the A-Bank, we were able to determine the average labor costs and productivities per employee and month for both sites under consideration. Labor costs were calculated as the sum of average HR payments per team member and additional expenses for benefits, space and overheads. In case of the A-Bank, the German labor costs were € 5,000 per employee and month, while the Indian labor costs were € 1,900 and thus significantly lower.

We considered the rate of completed transactions per employee as a measure for the productivity. To obtain the productivity of the German site, we calculated the average number of completed transactions per month from historical data. By dividing this figure by the size of the responsible team, we determined the productivity of each process step and ultimately the average productivity for the entire process. Because there was no such data for the Indian site, we compared the productivities of already relocated processes with the productivities of the German site. Table 4 provides information about the average productivities. These data could be used to calculate the average productivities and the complexity factors (cf. Table 4) for each site. These factors in turn are used to calculate the relation factor, $\mathbf{M_c}$, according to equation 9).

*** Insert Table 4 about here ***

The transaction costs were estimated based on internal reports. These costs consist of two main components. First, a new management team for coordination and problem solving between both sites had to be installed. Second, to ensure proper communication, the infrastructure had to be developed and it was assumed that the help of translators from an internal service center is required for a certain extent of transactions. Because the effort for management and communication depends largely on the amount of work relocated and is easily scalable by team size or working hours, the transaction costs were broken down to costs per single transaction.

Finally, Table 5 provides an overview of the parameters used in the case.

*** Insert Table 5 about here ***

3.3.2 Optimization

Figure 3 depicts the return depending on the degrees of automation and relocation. Therefore, the restriction $\kappa+\lambda\leq 1$ is considered, and only relevant combinations of positive returns are depicted because the negative returns are subject to very high automation degrees (cf. Profile I in the following). To illustrate the behavior of the return that is subject to automation and relocation, profile cuts I and II were made to the return, which maximizes κ and λ.

*** Insert Figure 3 about here ***

Profiles I and II in Figure 3 represent the return depending on automation or relocation, respectively, whereas the other decision variable, λ or κ, is kept fixed at the return maximizing position.

*** Insert Figure 4 about here ***

Concerning automation (Profile I), the return reaches its maximum at the value of 0.17. Beyond this optimal degree, the return decreases significantly, in particular for higher degrees of automation. This finding is due to the exponentially increasing automation costs. Hence, we can state that the return reacts very sensitively to variations in the automation degree in this context, which underscores the results found in the model analysis above. Selecting an adequate number of suitable process steps can positively affect the return, but the wrong decision can cause enormous losses due to high fixed costs. More generally, these effects can be referred to as a "risk of too high automation".

Regarding relocation (Profile II), the return reaches its maximum at 0.75. The influence of the degree of relocation on the return is significantly smaller than the influence of the automation degree. For higher degrees of relocation, the attractiveness decreases as the scale effect makes relocation more expensive and the attractiveness of the original more expensive high-wage site increases. In summary, relocation can be a viable alternative due to the cost advantages, but the negative effects, such as staff fluctuation, lead to the retention of some aspects of the work at the high-wage site.

3.4 Sensitivity Analysis of Selected Influence Factors

In this subsection, we examine how variations in the scale factor representing negative effects, such as staff fluctuation at the low-wage site and the complexity due to productivity changes may affect the optimal allocation. We consider only these factors because the impact of the basic input factors, such as labor costs or productivity, is quite obvious.

We performed a typical sensitivity analysis by varying only one of the examined parameters at a time. Figure 5 depicts the change in the optimal degrees for automation, relocation and retention when the scale factor is varied within a feasible interval.

*** Insert Figure 5 about here ***

In case of a low value for the scale factor, work is only relocated and automated. Retaining work at the original site is not attractive in terms of cost. With increasing values, the relocation degree declines and is partially substituted by a higher automation degree. The reason is additional costs with high relocation degrees. At a certain point, the expensive high-wage site becomes a viable alternative, whereas the degree of relocation breaks down; relocation is substituted by retention, whereby the automation degree stagnates. However, the decrease in the degree of relocation slows down because relocation is still associated with a certain cost reduction potential. Because the staff fluctuation at low-wage sites is significantly higher compared to the high-wage site, which is represented by the scale factor, firms should pay attention to all characteristics of a site instead of focussing too heavily on obvious factors, such as wage levels, or they should be careful when choosing a high degree of relocation. This is especially true for processes that require deep knowledge and costly training. In summary, although staff fluctuation has negative effects, in the above example, relocation is still reasonable from an economic standpoint.

Effects on the productivity of manual work caused by automation are now examined by varying the complexity factor, $\mathbf{C_H}$, for the high-wage site. Due to the $C_L = C_H \cdot M_C$ relationship, the effects of changing the complexity are considered for both sites simultaneously in this approach. The resulting allocations are shown in Figure 6.

*** Insert Figure 6 about here ***

From the start, the automation degree declines and is directly substituted by both relocation and retention, whereas retention has increase rates compared to relocation. Upon initial examination, this is surprising because an increasing complexity factor leads to increasing costs for manual work, and we expected a shift of additional manual work to automation. However, these results provide evidence that less automation should be preferred to incurring higher costs for manual work. In the context of the example, one can conclude that total manual work can be more attractive compared to (partial) automation because an employee can do the work in 'one piece' instead of starting in the middle of a process. For instance, if an employee has collected the input data himself, he can directly start with processing and does not require any orientation for the specific case to be executed in the instance of the process. Finally, with higher rates of complexity differences, results suggest that automation should be avoided. Instead, one should concentrate on retention and relocation. Less complex tasks could be executed at the inexpensive low-wage site to profit from wage differences.

4 DISCUSSION

Limitations

The introduced model is based on a set of assumptions. However, these limitations define the extension potential. First, we assumed infinitely divisible processes. In reality, processes may not always be divided as proposed by the model. However, most processes consist of several steps and can almost be allocated as optimized, which was true in the context of our example with 23 process steps. Thus, feasible discrete allocations may lie near the theoretical optimum, which also delivers a favorable economic solution. Our model is especially applicable when process steps can be more or less independently sourced or automated because interdependencies are not explicitly included in the calculations.

Second, we only considered the regional dimension of sourcing. By extending the model to the organizational dimension, problems such as in-house relocation versus (external) offshoring could be examined. Therefore, the proposed generic cost structures can be concretized to consider specific characteristics of the various sourcing alternatives.

Third, the decision variables are defined in an interval. This assumption can be relaxated by allowing negative values or values larger than 1 (representing 100%). As potential result, for instance an allocation of *250% relocation* and *-150% retention* could be proposed. At first sight, that may seem not feasible, but such a model extension may allow integrating outsourcing in terms of offering capacity of own offshore centers to third parties. By building up offshore capacities exceeding the own demand and selling services to third parties – at best for "high-wage site" prices - such an allocation might make sense. This idea could be pursued in further research.

Fourth, the interface costs between process steps that are executed at different sites are not directly considered in our model but will likely increase with business process fragmentation. They will reach their maximum if a process is allocated to several distributed sites. If our model proposes an allocation in which an alternative is insignificantly small, i.e. only a single step should be executed with this alternative, considering such costs may lead to disregard this alternative due to reduction of interface costs. Such an allocation would also be a starting point for extending the model with further research.

Fifth, in the recent version of the model, we neglected risk. However, such decisions are usually associated with underlying uncertainty. For instance, the number of transactions can deviate from initial estimations. Such false estimations can have negative effects on the return because the chosen allocation may no longer be optimal. Therefore, our model could be the basis for an extension by uncertainty.

Sixth, in our model only a single process is considered. However, during such reengineering projects, many typically interrelated processes are usually affected. By treating the processes as a portfolio, decisions can be more sophisticated. For instance, interdependencies between processes and thus a potential increase in risk can be better identified and thus avoided. If the processes or certain process steps would be highly correlated, it might be sensible to execute them through different alternatives. A starting point could be portfolio theory, which has already been applied to IT sourcing decisions as discussed above.

Finally, income has been modeled independently of the alternative that was chosen for performing the process, although the quality of the process may depend on how the activities are executed. For instance, a customer help desk in the original high-wage country may generate more value for clients and may justify the higher prices compared to a customer help desk that is situated in a low-wage country, for instance due to potential communication problems. Based on this example, it seems that a high-wage site could be more attractive. Therefore, further research could examine different income levels depending on the type of execution.

Managerial Implications

In practice, sourcing and automation decisions for business processes gain increasing importance. With the presented model, we can support such decisions and provide evidence for several facts.

Relocation decisions are primarily motivated by wage differences (Quélin & Duhamel, 2003). This is correctly reflected by the model. Additionally, we included productivity differences and high staff fluctuation at the low-wage site in our model. As the real world case demonstrates, these factors can have a very high impact on the optimal degree of relocation. Therefore, the analysis shows that concentrating on wage differences as a decision criterion can be shortsighted. Although the estimation of wages is quite simple, the wages in some popular low-wage countries show enormous growth rates that should be considered; estimating the influence of factors, such as productivity and staff fluctuation, is more complex and becomes even more difficult with increasing global and cultural distances (Winkler, Dibbern, & Heinzl, 2006). Nevertheless, the effort for estimating these parameters properly seems to be justified. Managers should be aware that inexact estimations can jeopardize cost reductions.

Although high staff turnover in low-wage countries has obvious negative effects on relocation, the optimal allocation in the example still includes a certain degree of relocation. Because relocation may still be attractive in spite of high staff fluctuation, managers should carefully consider two factors in the relocating processes; the characteristics of a site (such as staff fluctuation or productivity as mentioned above) should be examined in detail and the characteristics of a process are important. Therefore, shifting complex tasks, which require intensive training, to a location with high staff turnover may be risky although low or medium degrees of relocation might be preferable.

For information processing tasks, increasing the degree of automation is often an alternative to relocating the tasks to low-wage countries. In general, automation substitutes the more expensive alternative of manual work. This suggests that automation can be applied to replace unprofitable human work particularly for processes that are executed with high frequency or over a long period of time.

In addition to cost reduction, sourcing and automation decisions are driven by new requirements or changing conditions, such as additional process parts or extended workload. Estimating the future transaction volume is important. High up-front investments that are necessary when parts of a process are automated may not pay off if the transaction volume and thus the overall income decrease. Incomplete information about the transaction volume may lead to insufficient capacity utilization of the information system or automating solution. Given such a negative case, manual work becomes more attractive compared to automation because the initial investments are lower and the costs for manual work are more variable.

Processes consist of several tasks, which may have heterogeneous requirements. Therefore, the less complex tasks should be performed using an inexpensive alternative, such as relocation or automation of simple tasks, which can be implemented at low cost. Complex tasks, for instance those based on client interactions, could be then executed at the high-wage site. Such two-alternative solutions could also be more economically favorable if the interface costs could be lowered as discussed above.

5 CONCLUSION

Although automating and sourcing decisions about business processes are of extremely high importance, only a few quantitative decision support models have been proposed. In particular, there is a lack of research considering both alternatives in an integrated approach. In this paper, an approach for determining optimal degrees of automation and relocation – which captures the regional dimension of sourcing – is proposed. For this purpose, we identify and model the interdependencies between a manual and an automated execution of (parts of) business processes. Applying the model delivers recommendations for automation or site selection of business process steps. The model is illustrated by applying data from a business process of a major financial services provider.

The model is based on a fairly general setting. Thus, our analysis provides interesting insights into the economic trade-off and the general structure of the decision problem. By analyzing and modeling interdependencies between automation and manual work, this paper shall provide a basic understanding for such relations. In particular, the model provided evidence for the following facts. First, deviations from the optimal degree of automation, for instance those due to fewer transactions than expected, may have significant influence on return. Second, automation should be a substitute for unprofitable manual work, whereas the marginal rate of substitution increased with higher effective labor costs. Third, higher complexity is associated with increased importance of the need for selective sourcing. Based on such a selection and the concentration on specific alternatives, the effects of the alternatives are better utilized, for instance by limiting the execution of complex tasks to high-skilled staff at the high-wage site and by performing simple tasks by one low cost alternative. Finally, staff fluctuation may not necessarily indicate reduced attractiveness of a site in general. Although, for a particular process requiring intensive training, a currently high fluctuation at a low-wage site may lead to a reduced shifting of work to this site (and thus a lower degree of relocation), sourcing to such a low-wage site is still economically reasonable. In summary, the analysis of the proposed model for supporting sourcing and automation decisions not only revealed interesting insights but also formed the foundation for further research.

REFERENCES

Agrawal, V., Farrell, D., & Remes, J. K. (2003). Offshoring and beyond. *McKinsey Quarterly*, Special Edition, 24-35.

Alpar, P. (1992). Automation of Banking Functions and Its Managerial Implications. *IEEE Transactions on Engineering Management*, 4(39), 378-385.

Aron, R., Clemons, E. K., & Reddi, S. (2005). Just Right Outsourcing: Understanding and Managing Risk. *Journal of Management Information Systems*, 2(22), 37-55.

Aubert, B. A., Rivard, S., & Patry, M. (2004). A Transaction Cost Model of IT Outsourcing. *Information & Management*, 7(41), 921-932.

Bainbridge, L. (1983). Ironies of Automation. *Automatica*, 6(19), 775-780.

Balasubramanian, S., & Gupta, M. (2005). Structural Metrics for Goal based Business Process Design and Evaluation. *Business Process Management Journal*, 6(11), 680-694.

Beimborn, D. (2007). *Cooperative Sourcing – Simulation Studies and Empirical Data on Outsourcing Coalitions in the Banking Industry*. Wiesbaden, Germany: Gabler.

Benaroch, M., Jeffery, M, Kauffman, R. J., & Shah, S. (2007). Option-Based Risk Management: A Field Study of Sequential Information Technology Investment Decisions. *Journal of Management Information Systems*, 2(24), 103-140.

Benaroch, M., & Kauffman, R. J. (1999). A Case for Using Real Options Pricing Analysis to Evaluate Information Technology Project Investments. *Information Systems Research*, 1(10), 70-86.

Braunwarth, K., Kaiser, M., & Müller, A. (2010). Economic Evaluation and Optimization of the Degree of Automation in Insurance Processes. *Business & Information Systems Engineering*, 1(2), 29-39.

Braunwarth, K., & Ullrich, C. (2010). Valuating Business Process Flexibility Achieved through an Alternative Execution Path. *Proceedings of the 18th European Conference on Information Systems (ECIS)*, Pretoria, South Africa.

Byrd, T.A., Turner, D.E. (2001). An Exploratory Analysis of the Value of the Skills of IT Personnel: Their Relationship to IS Infrastructure and Competitive Advantage. *Decision Sciences*, 32(1), 21-54.

Carmel, E, & Tjia, P. (2005). *Offshoring Information Technology: Sourcing and Outsourcing to a Global Workforce*. Cambridge, UK: Cambridge University Press.

Criscuolo, C., & Leaver, M. (2005). Offshore Outsourcing and Productivity. *Presented at OECD Conference on Globalisation of Production*.

Cusumano, M., MacCormack, M. A., Kemerer, C. F., & Crandall, B. (2003). Software Development Worldwide: The State of the Practice. *IEEE Software*, 20(6), 28-34.

Davamanirajan, P., Kauffman, R. J., Kriebel, C. H., & Mukhopadhyay, T. (2006). Systems Design, Process Performance, and Economic Outcomes in International Banking. *Journal of Management Information Systems*, 2(23), 65-90.

Dibbern, J., Winkler, J., & Heinzl, A. (2008). Explaining Variations in Client Extra Costs between Software Projects Offshored to India. *MIS Quarterly*, 2(32), 333-366.

Dutta, A., & Roy, R. (2005). Offshore Outsourcing: A Dynamic Causal Model of Counteracting Forces. *Journal of Management Information Systems*, 2(22), 15-35.

Farrell, D. (2005). Offshoring: Value Creation through Economic Change. *Journal of Management Studies*, 3(42), 675-683.

Gebauer, J., & Scharl, A. (1999). Between Flexibility and Automation: An Evaluation of Web Technology from a Business Process Perspective. *Journal of Computer-Mediated Communication*, 5(2).

Gebauer, J., & Schober, F. (2006). Information System Flexibility and the Cost Efficiency of Business Processes. *Journal of the Association for Information Systems*, 3(7), 122-147.

Joseph, D., Ng, K.-Y., Koh, C., & Ang, S. (2007). Turnover of Information Technology Professionals: A Narrative Review, Meta-analytic Structural Equation Modeling, and Model Development. *MIS Quarterly*, 3(31), 547-577.

Kankanhalli, A., Tan, B. C. Y., Wei, K. K., & Holmes, M. C. (2004). Cross-cultural Differences and Information Systems Developer Values. *Decision Support Systems*, 2(38), 183-195.

Krick, R., & Voß, S. (2007). Further Steps in Analyzing the Dimensions of Hofstede's Model of National Culture for Potential Relevance to Risk Analysis in Global Software Development. In Mäkiö, J., & Betz, S. (Eds.), *Offshoring Software Development*, Karlsruhe, Germany: Universitätsverlag Karlsruhe.

Lankford, W. M, & Parsa, F. (1999). Outsourcing: A Primer. *Management Decision*, 4(37), 310-316.

Levina, N., & Su, N. (2008). Global Multisourcing Strategy: The Emergence of a Supplier Portfolio in Services Offshoring. *Decision Sciences*, 3(39), 541-570.

Levy, D. L. (2005). Offshoring in the New Global Political Economy. *Journal of Management Studies*, 3(42), 685-693.

Lewis, S., & Jones, J. (1990). *The Use of Output and Performance Measures in Government Departments, Output and Performance Measurement in Government: The State of the Art*.

Miller, S. R., & Parkhe, A. (1999). *Home-Country Environment as a Source of International Competitiveness: An Analysis of the Global Banking Industry*. Working Paper, Michigan State University.

Nikolaidou, M., Anagnostopoulos, D., & Tsalgatidou, A. (2001). Business Process Modelling and Automation in the Banking Sector: A Case Study. *International Journal of Simulation Systems, Science & Technology*, 2(2), 65-76.

Parkhe, A., & Miller, S. R. (2002). Is There a Liability of Foreignness in Global Banking? An Empirical Test of US Banks' X-Efficiency. *Strategic Management Journal*, 1(23), 55-75.

Quélin, B., & Duhamel, F. (2003). Bringing Together Strategic Outsourcing and Corporate Strategy: Outsourcing Motives and Risks. *European Management Journal*, 5(21), 647-661.

Rouse, A. C., & Corbitt, B. (2004). IT-Supported Business Process Outsourcing (BPO): The Good, the Bad and the Ugly. *Proceedings of the 8th Pacific-Asia Conference on Information Systems (PACIS)*, Shanghai, China (2004).

Santhanam, R., & Kyparisis, G. J. (1996). A Decision Model for Interdependent Information System Project Selection. *European Journal of Operational Research*, 2(89), 380-399.

Sheridan, T. B., & Parasuraman, R. (2000). Human Versus Automation in Responding to Failures: An Expected-Value Analysis. *Human Factors*, 3(42), 403-407.

Simon, C. P., & Blume, L. (1994). *Mathematics for Economists*. New York, NY: Norton.

Stohr, E. A., & Zhao, J. L. (1997). A Technology Adaptation Model for Business Process Automation. *Proceedings of the 30th Hawaii International Conference on System Sciences*, 4.

van der Aalst, W. M. P., & Basten, T. (2002). Inheritance of Workflows: an Approach to Tackling Problems Related to Change. *Theoretical Computer Science*, 1-2(270), 125-203.

vom Brocke, J. (2007). Service Portfolio Measurement: Evaluating Financial Performance of Service-Oriented Business Processes. *International Journal of Web Services Research*, 2(4), 1-32.

vom Brocke, J., & Lindner, M. A. (2004). Service Portfolio Measurement: A Framework for Evaluating the Financial Consequences of Out-Tasking Decisions, *ACM SIG Proceedings of the ICSOC04*, New York, NY.

Wei, Z. G., Macwan, A. P., & Wieringa, P. A. (1998). A Quantitative Measure for Degree of Automation and Its Relation to System Performance and Mental Load. *Human Factors* 2(40), 277-295.

Winkler, J., Dibbern, J., & Heinzl, A. (2006). Success in Offshoring of Application Development-Does Culture Matter?. *Proceedings of the 14th European Conference on Information Systems (ECIS)*, Goteborg, Sweden.

Yang, D. H., Kim, S., Nam, C.,& Min, J. W. (2007). Developing a Decision Model for Business Process Outsourcing. *Computers and Operations Research*, 12(34), 3769-3778.

Zimmermann, S., Katzmarzik, A., & Kundisch, D. (2011). IT Sourcing Portfolio Management for IT Services Providers - An Approach for Using Modern Portfolio Theory to Allocate Software Development Projects to Available Sites. *The DATA BASE for Advances in Information Systems*, in press).

Tables

Notation	Description
κ	Degree of automation (decision variable)
λ	Degree of relocation (decision variable)
ω	Degree of retention (decision variable)
R	Return (function)
I	Total income (function)
HWC/LWC	Costs for work conduction at the high-/low-wage site (function)
PR_n	Productivity (function) for site n
AC	Automation cost (function)
V	Transaction volume: frequency of process executions
E	Income generated per instance of the process
LC_n	Labor costs at site n: cost of HR per period of time
P_n	(Basic) productivity at site n: time required for executing one instance of the process (not including any examined effects)
T	Transaction costs per instance of the process in case of relocation
S	Scale factor: Negative economies of scale representing effects of potential staff fluctuation at the low-wage site
A	Total possible automation costs: upfront investment for full automation of the process
γ	Exponential growth of automation costs
C_n	Complexity factor for site n: relation between average productivity with no automation over average productivity with full automation
M_c	Relation between complexity factors of both sites (used as mathematical construct for illustrative reasons in 3.4)

Table 1: Parameters and variables of the model

Case	Active Constraints (AC) for Optima (number of AC, interpretation)	$\kappa^* \in [0;1]$	$\lambda^* \in [0;1]$	ω^* (=1- κ^* - λ^*)[a] $\in [0;1]$
A[b]	No constraint active (0, inner solution)	$\frac{V \cdot \frac{LC_H}{P_H}}{2 \cdot A}$	$\frac{\frac{LC_H}{P_H} - (\frac{LC_L}{P_L} + T)}{2 \cdot S \cdot \frac{LC_L}{P_L}}$	$1 - \lambda^* - \kappa^*$
B	$\kappa + \lambda = 1$ (1, no retention)	$1 - \lambda^*$	$\frac{2 \cdot A - V \cdot T - V \cdot \frac{LC_L}{P_L}}{2 \cdot A + 2 \cdot V \cdot S \cdot \frac{LC_L}{P_L}}$	0
C	$\lambda = 0$ (1, no relocation)	$\frac{V \cdot \frac{LC_H}{P_H}}{2 \cdot A}$	0	$1 - \kappa^*$
D	$\kappa = 0$ (1, no automation)	This case is not a possible optimality candidate due to the assumed positivity of the parameters.		
E	$\lambda = 0$; $\kappa = 0$ (2, only retention)	This case is not a possible optimality candidate due to the assumed positivity of the parameters.		
F	$\kappa = 0$; $\kappa + \lambda = 1$ (2, only relocation)	This case is not a possible optimality candidate due to the assumed positivity of the parameters.		
G	$\lambda = 0$; $\kappa + \lambda = 1$ (2, only automation)	1	0	0

Table 2: Analytical optima

[a] The dependent variable ω is listed here for reasons of completeness though it is only implicitly considered in the optimization problem.
[b] Case A is feasible if the condition written in inequality 7) is true.

Type	Quan-tity	Estimated workload share concerning the process [%]		Estimated automation costs [€ mn]	
		per step	per type	per step	per type
I	9	4	36	0.14	1.26
II	7	4	28	0.62	4.34
III	5	4.8	24	1.40	7.00
IV	1	5.5	5.5	4.00	4.00
V	1	6.5	6.5	4.40	4.40
∑	23		100		21.0

Table 3: Breakdown of the automation costs

Extent of automation (automated types)	Average productivity		Complexity factor	
	Germany	India	Germany	India
No automation -	1,100	700	-	-
I	1,075	675	-	-
I, II	1,025	625	-	-
I, II, III	950	575	-	-
I, II, III, IV	850	500	-	-
Full automation I, II, III, IV, V	700	400	$\frac{1{,}100}{700} = 1.57$	$\frac{700}{400} = 1.75$

Table 4: Productivities

Symbol	V	E [€]	LC_n [€]	P_n	T [€]	S	C_n	M_C	A [€]	γ
Site 1	2.2 mn	€4.8	5,000	1,100	-	-	1.57	1.1	21 mn	2
Site 2			1,900	700	0.8	0.25	1.75			

Table 5: Model parameters

Figures

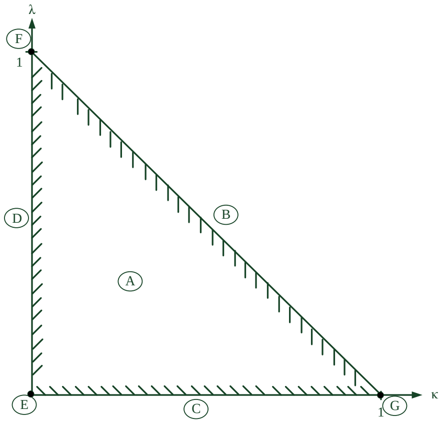

Figure 1: Boundaries and candidate solutions

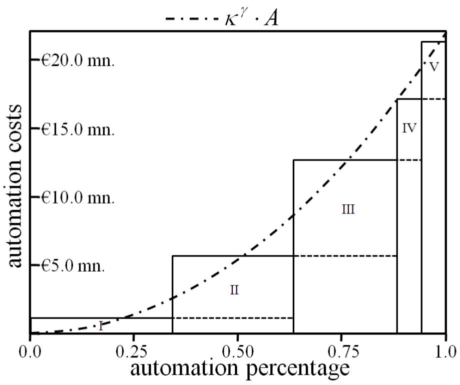

Figure 2: Determination of A and γ

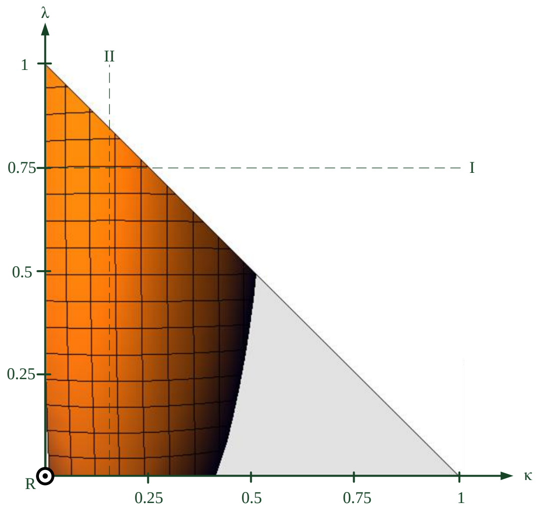

Figure 3: Return depending on degrees of automation and relocation

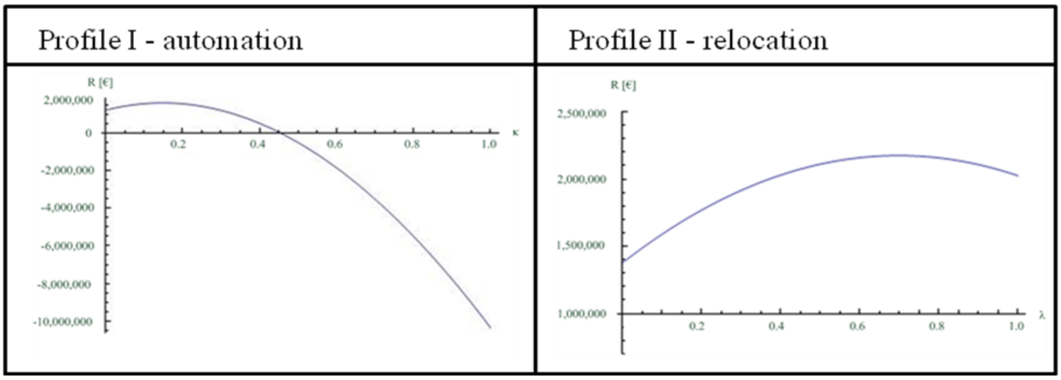

Figure 4: Profile cuts of Fig. 3 (Profile I, II)

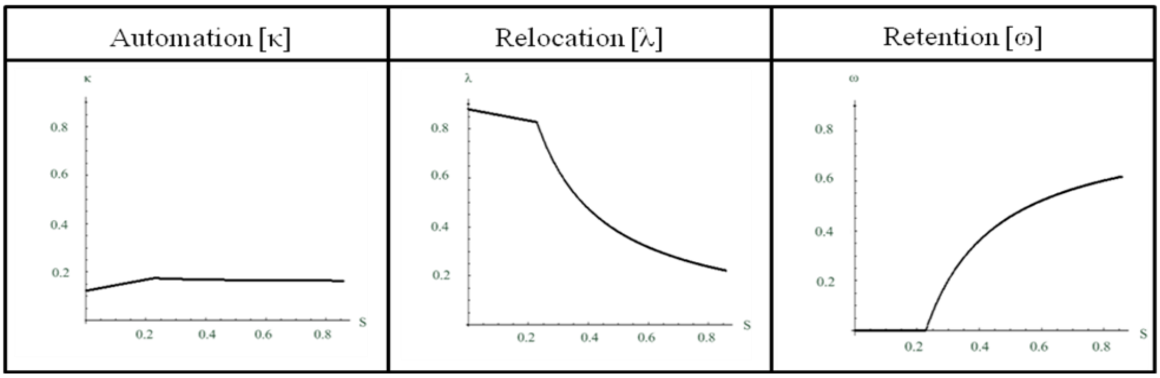

Figure 5: Allocation due to variation of the scale factor

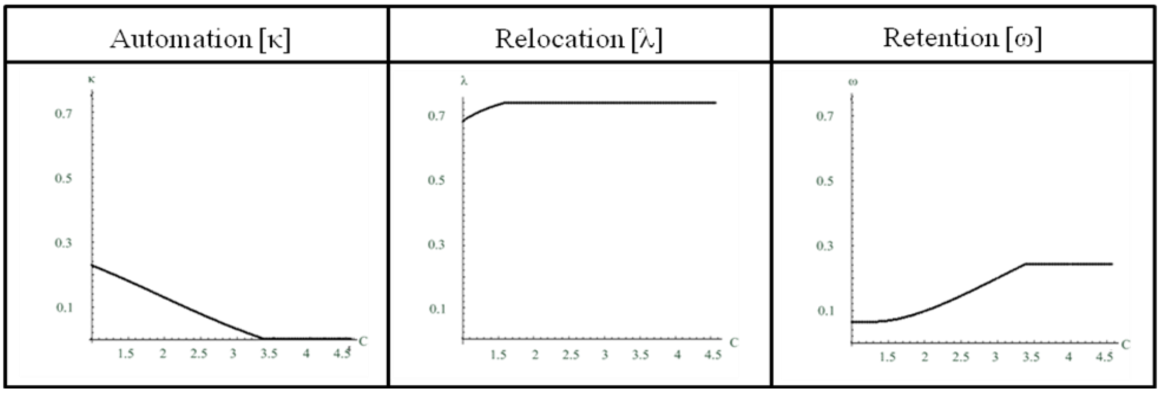

Figure 6: Allocation due to variation of the complexity factor