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A portfolio theory approach to identify risk-efficient enablers of change in global production networks

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Abstract

In recent years, due to the shift of markets and the global competitive environment companies have attempted to increase efficiency by operating in globally distributed production networks. But these networks have often grown historically neglecting a future-oriented strategy. Nowadays, the consideration of investments into these complex, hierarchical and heterogeneous network structures is in companies' focus. This so-called migration planning has become a complex decision-making problem. Here, changeability is increasingly referred to as a factor of success. Adequate methods are needed to operationalize and quantify the costs but also the benefits and consequently the profitability of change enabling measures. But the determination of the optimal degree of changeability is crucial to enable flexible and fast migrations of the network configuration. However, currently there is no approach in the literature which values the reduction potential with regard to migration costs by investments in enablers of change or even accelerators of change under uncertain future developments of key drivers of change. By developing a method to monetarize occurring time expenses of planning, implementation and ramp-up activities for the migration of the network configuration the presented approach describes how these migration costs can be estimated and major cost drivers be influenced through investments in enablers or accelerators of change. Furthermore, the resulting cost savings are contrasted with the investment expenditures to determine the return on investment of the respective enablers and accelerators. Based on the principals of modern portfolio theory in a last step bundles of enablers and accelerators are built to minimize the risk of misinvestments and to establish an efficient and tailor-made implementation plan based on the decision maker's risk preferences.

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1. Introduction

1.1. Motivation and Problem Formulation

Nowadays manufacturing companies act in global production networks [1]. Along with the global expansion of manufacturing sector and advances in ICT technology, competitive intensity increased and cost pressures intensified [6, 9, 13, 17]. Furthermore, the business environment is changing drastically [13]. In the context of globalization, companies are facing several drivers of change including, for example, rising labor costs, changing customs and fluctuating customer demands. Thus, production networks must be adapted to these changes market continuously and planned actively [9, 15, 17]. However, efforts to increase the adaptability of production concentrate on individual production sites or systems [3]. The adaptability and in particular changeability of production networks are rarely considered. Nevertheless, changeability enables companies to react flexibly and rapidly to unforeseen changes [13]. Since the future development of so-called drivers of change are hard to predict multiple scenarios must be considered simultaneously [1].

Summarizing it can be stated that changeability becomes increasingly important on production network level. The active planning of global production networks must include the

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determination of an optimal degree of changeability. Hence, companies need models to evaluate the cost-effectiveness of changeability promoting measures, so-called enabler of change [13, 18].

1.2. Objective and Research Questions

The objective of this paper is to detail the holistic approach of [11]. Its objective is to identify risk-efficient migration strategies in global production networks. The approach was divided into three sub-modules: (1) *Optimization*, (2) *Enabler of Change* and (3) *Migration process*. The paper focused both, the description of the overall approach and the formalization of an optimization model to determine an optimal migration strategy (Module (1)). The model is formulated as Markovian Decision Process (MDP). It enables to identify state-dependent actions for adapting the network configuration on resource and capacity level. As mentioned in [11] an action represents a concrete realization of the network configuration. The state-dependent actions are called migration paths. They are robust with regard to the definition and evaluation of robustness of [16]. In total Module (1) presents a flexible and reactive planning approach.

The second module *Enabler of Change* focuses on the active preparation of these adaptions through the proactive implementation of so-called enabler of change. Enabler of change describe a property of an object of a production systems that enables the object to change [5]. Enabler of change can be hierarchically differentiated into primary and secondary enabler of change [13]. Primary enabler of change are universality, modularity, mobility, compatibility and scalability [13]. Secondary enabler of change describe the primary in more detail [13]. Examples are mobile machines, standardized connectors, scalable plant. They increase the adaptability of change objects. The changeability is measured by cost and time expenses of a change process. Implementing adequate enabler necessary, change processes can be performed more efficiently and effectively [4]. However, changes in the environment are hardly predictable (see 1.1) and the implementation of enabler of change always causes costs. Hence, determining an optimal degree of changeability is a complex decision-making problem. Possible opportunities and risks must be considered deciding about a proactive implementation in enabler of change.

The decision problem of determining and optimal degree of changeability is thematic focus of this paper and will detail the approach of [11]. With regard to the described aspects following research questions can derived for this paper:

- What potential savings of the migration costs of global production networks can be realized by enabler of change?
- How can enabler of change be bundled optimally to enable savings while minimizing the risk of misinvestment?

1.3. Structure of the Paper

The structure of this paper is as follows: In section 2 research approaches with regard to the above mentioned research questions are examined and the deficit is derived. In chapter 3 a four step approach to detail module (2) *Enabler of Change* of [11] is presented. Chapter 4 focuses on a valuation model to approximate potential savings of the migration costs in production networks through a proactive implementation of enabler of change (c.f. 4.1). Furthermore, a mathematical decision-making model to determine risk-efficient bundles of enabler of change (so-called portfolios) is formalized (c.f. 4.2). Finally, the application of the presented approach is demonstrated exemplarily (c.f. 5).

2. Literature review

Research approaches in the field of evaluation and planning of the changeability of production systems will be discussed chronological in the following:

Hernandez ([5]) evaluates the changeability of plant objects based on qualitative and quantitative measures. Furthermore, he plans a requirement profile for changeability to derive primary enabler of change. *Heger* ([4]) evaluates the changeability of plant objects combining a changeability potential analysis, benefit analysis and the net present value (npv). This enables the selection of objects within factory planning phase. *Sudhoff* ([15]) evaluates the monetary benefit of mobile production systems. Therefore he applies real options, which model the possible transfer the system to another site of a production network. *Möller* ([12]) applies an option based evaluation, too. He compares different enabler of change in a comparative analysis. Evaluation criteria is an extended npv, including the npv and the option value of the enabler of change. *Klemke* ([6]) plans changeability of a factory. He compares the demand for change and the changeability of a factory. In case of a deficit an analysis of potential enabler of change follows including an evaluation of enabler of change in a relevance-cost-portfolio.

Summing up, enabler of change are rarely examined as a valuation object. Frequently, the focus is on the evaluation of the changeability of change objects (e.g. operating capital) (c.f. [4],[5],[6]). A systematic assessment of the monetary benefits of enabler of change is not state of the art. Although the reduction of the time of change is mentioned by enabler of change (c.f. [6]), an evaluation of its monetary benefits is not addressed. Approaches to the economic evaluation of the ability to transform exist [12, 15]. They also take into account the risk of investing in changeability. But diversification effects by bundling different enablers of change are, however, not addressed by any of the approaches. Furthermore, except for [15] the network level is neglected. However, [15] limits his evaluation on the mobility of production systems between two different production sites and does not consider other enabler of change.

3. Approach

The developed approach aims on the identification of risk-efficient bundles of enabler of change and thus the determination of an optimal degree of changeability in production networks. The approach is divided into four consecutive steps:

1. Reconfiguration analysis
2. Preselection of enabler of change
3. Cost Potential of enabler of change
4. Identification or risk enabler of change

The optimal migration strategy identified with the formalized MDP in [11] serves as basis.

In the first step, a monte-carlo simulation is executed. Its objective is to analyze the migration strategy statistically and to identify critical state transitions of the network configuration. The so-called *reconfiguration analysis* is similar to the one described in [8]. For each decision point of the multi periodic planning horizon the probability of occurrence of a configuration (respectively migration path c.f. 1.2) is quantified. Critical state-transitions are defined by consecutive decision points with different probabilities of occurrence of a configuration respectively migration path. Different probabilities mean that for different mutually exclusive future developments of key drivers of change different configurations respectively migration paths are optimal.

The critical state transitions are then analyzed individually. For critical change objects technical, organizational and spatial enabler of change are pre-selected. Change objects are in context of this approach production stages, production technologies and resources as well as material and component suppliers and outsourcing partners. The pre-selection is based on a comprehensive catalog of enabler of change. The catalog was developed based on a literature review and expert workshops. Analogous to the state transitions, change objects will be considered as critical, if they are not part of the intersection of the change objects of different migration paths. The pre-selection includes object-specific (e.g. scalable assembly line) and non-specific enablers (e.g., clustering of competence units for the ramp-up). A well-balanced pre-selection of specific and non-specific enablers promotes risk diversification effects. Nevertheless, for all pre-selected enabler of change the reduction potential for cost and time expenses of the change process must be estimated specifically for each object.

In step three savings in the migration costs caused by a proactive implementation of the pre-selected enabler of change are quantified. For this reason a time-driven activity-based-costing model is developed to approximate migration costs with and without the proactive implementation enabler of change in production networks. The model will be detailed in 4.1.

Finally in step four, risk-efficient bundles of enabler of change are determined applying a mathematical decision model (c.f. 4.2). The Return on Investment (ROI) is considered as decision-making criterion. It is determined by dividing the quantified savings (step 2) by the investments in the enabler of change. In case of a misinvestment a negative ROI results. Due to the uncertainty about the future development of the key drivers of change an investment in an enabler of change is associated with risk. In general, discrete probabilities of occurrence are assigned to the different mutually exclusive future developments of key drivers of change (c.f. [11]). As a result, the expected value and standard deviation of the ROI of an enabler of change can be calculated. The standard deviation is considered as the indicator of risk. The model offers the possibility to invest proactively in a single enabler of change or a bundle. In order to ensure the comparability of different portfolios an investment budget is defined. It is assumed that the non-invested budget is invested riskless on the capital market. Bundling enablers realizes the diversification effects according to the modern portfolio theory of Markowitz [10]. A dominance analysis can finally eliminate dominated portfolios and determine the set of risk-efficient bundles.

4. Monetary evaluation of reduction potential and identification of risk-efficient enablers of change

In this section a time-driven activity-based-costing model to approximate the cost-reduction potential of enablers of change is described. Furthermore the mathematical decision model to identify risk-efficient enablers of change is formulated.

4.1. Cost model to approximate the monetary potential of enabler of change

According to the holistic approach of [11] migration costs incur for changes of the network configuration regarding activities of production stages, technologies, material and component supplier and outsourcing partners. The migration costs can be differentiated in:

- Allocation costs for production stages
- Allocation costs for technologies and products
- Transaction costs for acquisition and qualification of external supplier and outsourcing partners

These migration costs depend on specific cost parameters. One can differentiate between investment costs and process costs. The investment costs of resources are known and can be parameterized directly, whereas process costs need to be approximated. In this paper a time-driven activity-based costing model is presented to approximate process costs. Consequently, the change processes to allocate production stages, technologies and products to sites as well as the acquisition of suppliers and outsourcing partners and their qualification are decomposed into individual process activities (c.f. Table 1.). Again these process activities can be divided. For the subdivided activities cost drivers (e.g. time, man-days) and their cost rates are derived (c.f. Table 1.). By estimating the resource demand (e.g. time, man-days) of the activities the cost parameter on subordinate level can be determined. This can be done in a bottom-up approach with formalized cost functions for each (sub-)activity.

Table 1. Process activities and cost drivers

	Process activities	Sub-activities	Cost driver*
Allocation costs – production stage	Resource development (physical resources)	Investment	I
	Resource development (human resources)	Recruiting	MD
	Competence development	Expatriats	T
		Training	T
Allocation costs – products and technologies	Planning process	Planning	T
	Infrastructure development	Building, Connections, …	MD
		Build-up	T
	Resource development (human resources)	Recruiting	MD
	Competence development	Training	T
	Process qualification	Capability studies	T
	Ramp-up	Opportunity Costs	T
	Resource development (production resources)	Investment	I
Transaction costs	Search	Partner search	T
	Control	Interface Definition Contract Agreement	T
	Control	Process Development	T
		Material/Components certification	MD

*I: Investment costs; MD: Man-Days; T: Time

To approximate savings in the migration costs by a proactive implementation of enablers of change (c.f. 3 – Step 3) the reduction potential of the resource demand of the process activities must be predicted. Finally, by using the formalized functions the migration costs with and without enabler of change can be compared. Using a potential enabler of change ‚*Concentration of competences – Global Ramp-up Team*' the effects will be explained. By introducing a *Global Ramp-up Team'*, build-up, training and process qualification time can be reduced drastically. This is due to the fact, that the accumulation of experience and application of standardized and robust methods and tools for ramp-up causes time savings. Again, this leads indirectly to reduced opportunity costs since product and technology ramp-up can be accelerated and the desired performance of the production system can be reached faster. As a result, additional capacities are available and less inventories as backup are necessary. In total, by implementing the enabler of change '*Global Ramp-up Team'* considerable savings are feasible.

4.2. Identification of risk-efficient enablers of change

The decision model for the determination of risk efficient enabler of change is formulated as a One-Period-Model [7]. The following explanations are used for the mathematical derivation of the essential components.

Planning horizon $\boldsymbol{T}$: There are two points in time, the decision point $\tau = 0$ and the subsequent point $\tau = 1$. Therefore, it is $T = 0, 1$. These two points are subsequent decision points with critical state transition of the MEP formalized by [13].

State Space $\hat{\boldsymbol{Z}}$: For each point in time $\tau \in T$ a finite, non-empty set of states $\hat{Z}^\tau \in \hat{Z}$ is defined**.** For the initial point $\tau = 0$ there is exactly one state $\hat{z}^0$, which is assumed to be known. For the point in time $\tau = 1$ a finite, non-empty set of states exists. A state $\hat{z}^\tau = (conf^\tau, \hat{s}^\tau, a^\tau) \in \hat{Z}$ includes the initial network configuration at the beginning of τ, $conf^\tau$, the characteristics of the key drivers of change $\hat{s}^\tau$ and a recommendation for a reactive change of the network configuration, that is the optimal migration path a^τ. The migration paths are the result of the application of the formalized MDP [11] (c.f. [11] Chapter 5.3).

Transition law $\hat{\boldsymbol{p}}$: The transition law $\hat{p}$ defines the probability of the transition from $\hat{z}^\tau$to $\hat{z}^{\tau+1}$. Only the transition of the clustered key drivers of change $\hat{s}^\tau$ is stochastic while the action a^τ is deterministic. Thus, it follows:

$$\begin{aligned} \hat{p}(\hat{z}^0 \to \hat{z}^\tau) = \hat{p}\big((conf^0, \hat{s}^0, a^0) \\ \to (conf^\tau, \hat{s}^\tau, a^\tau) \big) = \hat{p}(\hat{s}^0 \to \hat{s}^\tau) \end{aligned} \tag{1}$$

The transition law corresponds to the transformed transition law presented by [13] (c.f. [13] Chapter 5.2).

Action space $\hat{\boldsymbol{A}}$: For the stage $\hat{z}^0$ a finite, non-empty set of actions $\hat{A}(\hat{z}^0)$ exists. An action $\hat{a}^0 \in \hat{A}(\hat{z}^0)$ includes a portfolio of enablers of change. A portfolio consists of $j = 1, \dots, J$ enablers of change. In which J denotes the number of preselected enablers of change.

The admissible action space $\hat{A}(\hat{z}^0)$ is defined implicitly by the available investment budget:

$$\hat{A}(\hat{z}^0) = \{\hat{a}^0 \in \hat{A} : g(\hat{a}^0) \leq IB\} \tag{2}$$

Let $g(\hat{a}^0)$ be the total investment costs of the portfolio of enablers of change included in action $\hat{a}^0$ and IB the available investment budget.

Profitability equation $\boldsymbol{R}$: For each action $\hat{a}^0 \in \hat{A}(\hat{z}^0)$ there is a return for a possible successor state $\hat{z}^\tau \in \hat{Z}^\tau$, which can be calculated with the following equation:

$$R(\hat{a}^0, \hat{z}^\tau) = \sum_{j \in J} \alpha_j * Ind_j(\hat{a}^0) * r_{j,\hat{z}^\tau} + R_{rl}(\hat{a}^0) \tag{3}$$

Let α_j denote the share of the total investment costs portfolio $\hat{a}^0$ associated with the enabler of change j. Moreover, let $Ind_j(\hat{a}^0)$ be an indicator function to mark whether the enabler of change j will be part of portfolio $\hat{a}^0$, $r_{j,\hat{z}^\tau}$ the ROI of enabler of change j if state $\hat{z}^\tau$ occurs and $R_{rl}(\hat{a}^0)$ the remaining capital of the investment budget IB if portfolio $\hat{a}^0$ is chosen which is assumed to be invested in a risk-free asset.

The return of the enabler of change j in state $\hat{z}^\tau$ $(r_{j,\hat{z}^\tau})$ can be calculated by:

$$r_{j,\hat{z}^\tau} = \frac{e_{j,\hat{z}^\tau} - \beta_j * I_j - \gamma_j * I_j * Ind_{j,\hat{z}^\tau}(e_{j,\hat{z}^\tau})}{I_j} \tag{4}$$

The term $e_{j,\hat{z}^\tau}$ quantifies savings of migration costs due to enabler of change j in state $\hat{z}^\tau$. These are approximated using the TD-ABC model described in chapter 4.1. Let I_j denote the investment costs, β_j the share of the utility associated with the change process and γ_j the share of sunk costs of enabler of change j. The indicator function $Ind_{j,\hat{z}^\tau}(e_{j,\hat{z}^\tau})$ is 1, if $e_{j,\hat{z}^\tau} \leq 0$, and otherwise 0. In case of a misinvestment the sunk-costs are considered in the calculation of overall ROI as negative savings, this means they are considered as costs.

In order to solve the decision model the expected value and standard deviation of the ROI of an action $\hat{a}^0 \in \hat{A}(\hat{z}^0)$ is calculated for all possible subsequent states $\hat{z}^\tau \in \hat{Z}^\tau$.

For the expected value the following applies:

$$\mu_{\hat{a}^0} = \sum\nolimits_{\hat{z}^\tau \in Z^\tau} \hat{p}(z^0, \hat{z}^\tau) * R(\hat{a}^0, \hat{z}^\tau) \quad (5)$$

The standard deviation is calculated by:

$$\sigma_{\hat{a}^0} = \left[\sum_{\hat{z}^\tau \in Z^\tau} \hat{p}(z^0, \hat{z}^\tau) * (R(\hat{a}^0, \hat{z}^\tau) - \mu_{\hat{a}^0})^2 \right]^{\frac{1}{2}} \quad (6)$$

According to Markowitz portfolio theory [10] diversification effects result from bundling of enablers of change. For further information see [7, 10].

The risk efficient portfolios can be determined by a dominance analysis.

5. Application Example

The approach introduced in chapter 3 was used exemplarily by a supplier of automation technologies. The results are presented in the following section.

5.1. Scope and Initial Situation

The historically grown production network consists of four globally distributed sites. Site 1 is the lead plant, producing the products for the global market. Site 2, 3 and 4 are regional distribution center. They supply the products to the regional markets in China, ASEAN (excl. China) and NAFTA. In status quo no production capacities are localized at site 2,3 and 4. Due to the massive growth of the Chinese, ASEAN and Northamerican markets and required 5 day delivery time for customized products the network configuration must be adapted. Potentially large orders in the Chinese and ASEAN market, increasing demand volatility due to a lack of customer loyalty as well as the uncertainty about the development of labor costs at site 2 and 3 as well as potential changes of trade barriers lead to a complex unpredictable future.

Using the MEP presented by [11], an optimal migration strategy for the network was identified. 1839 alternative configurations for a seven year planning horizon were evaluated. Stochastic developments were modeled for demand, labor costs and tariffs.

5.2. Results

By means of a reconfiguration analysis, one critical state transitions could be identified:

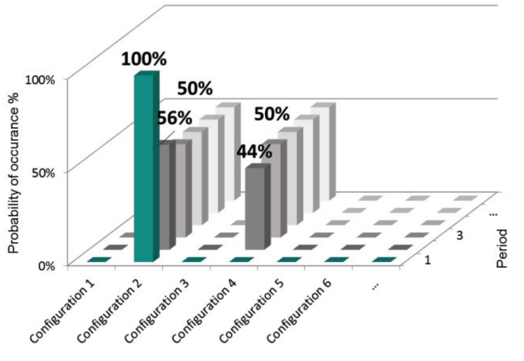

Fig. 1. Reconfiguration analysis (extract)

The transition in period 2 is critical with regard to the explanation in chapter, as the probability of occurrence of the configuration 2 and 4 in period one and two differ (c.f. Fig. 1.). For further analysis the migration strategy was analyzed in detail and led to the following explanation: In the second period the migration paths depend on the stochastic development of demand and labor costs. If the demand in the Asian market is booming, complete manufacturing and assembly stages for high & low-runner products will have to be relocated to location 2 (configuration 4). Having a moderate demand development combined with high wage increases, on the other hand, only simple manufacturing stages for high-runner products and full-scale assembly stages for all products have to be relocated (configuration 2). Independently of this, all assembly stages for all products are to be allocated at location 3.

In workshops with experts of the company, 20 concrete implementations of technical, spatial and organizational enabler of change were determined.

Subsequently, the reduction potentials were estimated. The TD-ABC model (c.f. 4.1) was formalized and implemented in Microsoft Excel® and potential savings in migration costs due to a proactive implementation of the pre-selected enabler of change were quantified.

Based on the quantified savings the decision model presented in chapter 4.2 was applied. Hence, portfolios of the pre-selected enablers were built combinatorial and evaluated:

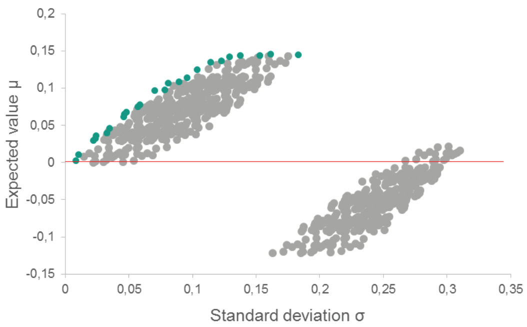

Fig. 2. Risk-efficient portfolios of enabler of change

The evaluation led to two clusters (c.f. Fig. 2.). The majority of the portfolios of the right cluster have a negative expected ROI with high standard deviations. Furthermore the portfolios are dominated by the portfolios of the left cluster. The main reason is that the portfolios of the right cluster contain at least one enabler of change which is specific for change objects of complex manufacturing stages. The expected ROI is negative as the change objects are only part of configuration 4 and only relocated with a probability of 44% (c.f. Fig. 1). The left cluster includes the risk-efficient portfolios (highlighted in green). Risk-efficient portfolios consist of unspecific enabler of change. Therefore they reduce migration costs for all future states and have consequently a low standard deviation respectively risk. The more of the investment budget is invested in enabler of change and not in a risk-free asset the higher is the expected ROI but also the standard deviation (risk).

6. Conclusion and Outlook

In this paper, an approach for determining the optimal degree of changeability in global production networks was presented. With the help of this approach, technical, spatial and organizational enabler of change can be identified, evaluated and selected. The approach was applied in an application example successfully. However, the application requires detailed data and information of companies' experts. Scenarios must be forecasted and possible enabler of change have to be preselected. Gathering these data arises considerable efforts. Moreover the estimation of potential savings by enabler of change is a critical value with significant effects on the selection. Nevertheless, the approach enables companies to actively prepare for unpredictable developments of critical drivers of change and to withstand increasing competition and cost pressures. Further research is being pursued in the area of the decision-making model for the determination of risk-efficient enabler of change. For example, the risk-affinity of the decision-maker should be taken into account during the selection process.

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