IDENTIFICATION OF CONSTITUTIVE CHARACTERISTICS FOR ADAPTABLE LOGISTICS CHAINS AS BASIS FOR AN ASSESSMENT BY SIMULATION

Gommel, H.[(a,b)]; Florian, M.[(a,b)]; März, L.[(c)]; Palm, D.[(a)]

[(a)] Fraunhofer Austria Research GmbH, Theresianumgasse 7, Vienna, 1040 Austria
[(b)] Vienna University of Technology, Theresianumgasse 27, Vienna, 1040 Austria
[(c)] LOM Innovation GmbH & Co KG, Kemptener Straße 99, Lindau, 88131 Germany

henrik.gommel@tuwien.ac.at

ABSTRACT
Logistics chains are mostly influenced by changes in their business environment. A systems adaptability is seen as one potential to effectively counteract these environmental changes. To consider the effects of adaptability on the whole supply chain, a framework for configuring adaptable logistics chain will be developed within the research project "KoWaLo". Therefore, the main constitutive characteristics of adaptable logistics chains and their specifications will be identified by a scenario based approach. In the following, these characteristics will be assessed in a case study based on a simulation model to evaluate the impact of specification changes within certain characteristics on the logistics chains KPIs. This paper deduces the approach to identify constitutive characteristics for establishing adaptable logistics chains and gives an outlook on how adaptable configurations will be assessed in a case study based on a discrete event simulation model.

Keywords: Logistics, Supply Chain, Adaptability

1. INTRODUCTION

Nowadays manufacturing companies are increasingly exposed to changes in their business environment. Current examples like sudden bottleneck situations in supply due to ecological disasters or political instabilities, or more general, the trend towards stronger customer orientation along with shorter delivery times, introduction of new products or product variants, new market trends or allocation in new markets, show the necessity for companies to handle these turbulences. Reasons for these impacts can be changes in technologies, internationalization or ongoing changes in supply and demand (Balve, Wiendahl, and Westkämper 2001; Westkämper, 2007). Such events can have significant effects on the logistics performance of a company. Therefore the topic "adaptability", which can be described as the ability of a system to perform both reactive and proactive adaptations by specifically varying processes, is an important approach to deal with turbulence and retain competitiveness (Balve, Wiendahl, and Westkämper 2001; Nyhuis, Reinhard, and Abele, 2008). In comparison to flexible systems, which only can deal with changes within a certain range, adaptable systems allow to shift the range of flexibility to a higher or lower level by specific arrangements as shown in figure 1, e.g. through investments and/or organizational arrangements (Nyhuis, Reinhard, and Abele, 2008).

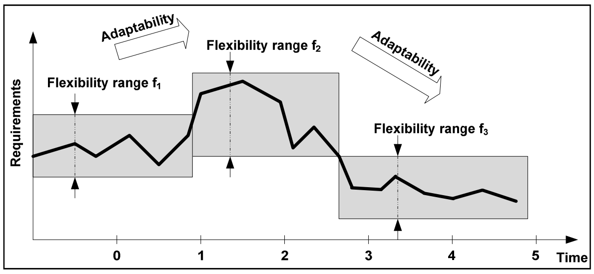

Figure 1: Adaptability as the Capability to Shift Flexibility Ranges (Wiendahl, ElMaraghy, Nyhuis, Zäh, Wiendahl, Duffie, and Brieke, 2007)

Previous research activities on adaptability have mainly focused on the factory level, the supply chain as a whole has been taken into account to a lesser extent (Nyhuis, Fronia, and Pachow Frauenhofer, 2009). First research activities in this matter were carried out by Christopher on a conceptual level without discussing defined constitutive characteristics precisely (Christopher, 2000) and Dürrschmidt by developing a concept for planning adaptable logistics systems for serial production without disclosing approaches for configuring logistics chains (Dürrschmidt, 2001). More recent research activities focusing on adaptability in logistics chains were carried out by Nyhius et al. by evaluating intra-enterprise logistics chains based on the requirement and the economic value added of an adaptable configuration (Nyhuis, Nickel, Horváth, Seiter, and Urban, 2008).
Within the research project "KoWaLo" a framework for configuring adaptable logistics chains based on concretely defined constitutive characteristics will be

developed in order to consider the effects of adaptability on the efficiency of the whole supply chain. The Austrian Research Promotion Agency funded this project with the partners Knorr-Bremse GmbH Division IFE Austria, Seisenbacher GmbH and the Vienna University of Technology. The focus of this paper is to describe the procedural method to identify the main constitutive characteristics in order to set up the configuration framework.

2. ADAPTABILITY IN LOGISTICS CHAINS

As described in the introduction adaptability offers great potential to cope with turbulences. In this respect adaptability considers structural changes in three basic principles: rapidness, flexibility and costs. Until now adaptability was primarily discussed with a focus on production systems, factory structures, organizational matters or order processing systems, thus primarily focusing on intra-enterprise issues. Within these areas of research the fundamentals of adaptability are seen in self-organizational and self-optimizing complex systems that can be (re-)configured permanently and rapidly (Westkämper, 2007). Adaptability may then in this context be empowered by modularity, compatibility, mobility, universality and scalability of equipment, space and building systems as well as on the organizational level (Klußmann, Nofen, and Löllmann, 2005).

However, in many industries 50-70% value added is contributed within a supplier network. Hence environmental dynamics do not only affect intra-enterprise matters, but also the supply-chain as a whole. Therefore the adaptable positioning of an individual company is not sufficient; in fact it is necessary to synchronize the adaptability of the whole logistics chain. To the Austrian industry, characterized by a high customer orientation, adaptability is of great importance. The research project KoWaLo addresses the problem on how adaptability can be applied to logistics chains by analyzing the logistics chain between the two Austrian companies mentioned above. To show the potential of adaptable logistics chains, company-wide case studies will be carried out.

Basically there are several reasons for the necessity of adaptable logistics chains: from the supply chain management point of view, the stability of the supply chain needs to be preserved at its best. While meeting delivery times or coping with an increased demand, companies face the problem of increased logistics costs. This leads to extra or emergency transports with for example low capacity utilization and/or the usage of expensive carriers like planes instead of trucks or trains. Along with these financial issues there are issues like increased emissions and their ecological effects. Longer-term supply shortfalls due to production breakdowns or quality problems may be considered when choosing sourcing strategies whereas changes in demand may be considered when planning distribution networks. These examples show the importance of developing a framework helping companies to empower adaptability in their logistics chains.

As major basis for configuring adaptable logistics chains, it is necessary to identify and assess the main constitutive characteristics and their respective specifications with regard to their ability to enable the logistics system to be (re-)configured continually, rapidly and in a cost effective manner. For the purpose of identifying those characteristics, an analysis of different environmental dynamics scenarios and their effects on the logistics system has to be done (Spath, 2009). By analyzing these effects together with the ability of the general constitutive characteristics of logistics systems to handle environmental dynamic, the main characteristics can be identified. The modifiable specifications of these characteristics finally allow the development of scenarios on how the logistics system can be configured aligned with the principles of adaptability.

As to secure cost effectiveness the configuration of adaptable systems has to be carried out in consideration of the systems cost effectiveness during its life cycle or a given time horizon (Zäh, Müller, and Vogl, 2005). The total costs of adaptability can be divided in system-costs (initial investments) and process-costs. Process-costs can further be divided in direct costs comprising costs for operating the system and costs for flexibility shifts, whereas the indirect costs comprise inefficiencies of the system caused by over- or under-designed systems.

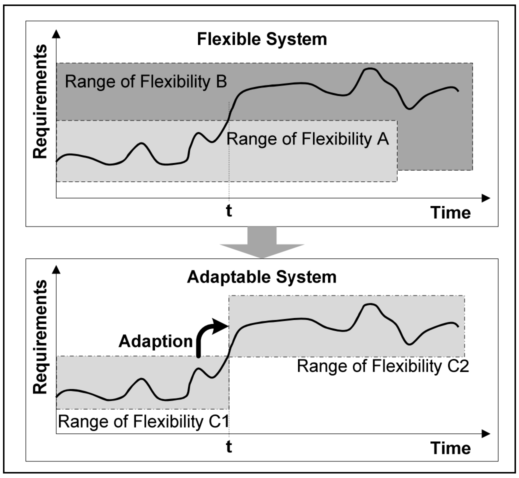

Figure 2: Demarcation between Flexibility and Adaptability.

Comparing the different systems in Figure 2 by costs generally leads to the conclusion that, due to the lower flexibility of range A, flexibility range A would induce lower system costs than range B. However, flexibility range A would induce indirect process-costs due to the inability of the system to meet the requirements over the subject time horizon. Whereas range B can meet those requirements it has inefficiencies because of the over-dimensioned flexibility considering the time spans before and after t separately. In the adaptable system the flexibility ranges C1 and C2 would induce certain system-costs that together are most likely higher than those of range A and range B, respectively. Although the shift from range C1 to C2 induces direct process costs, the indirect process cost will be minimized as each flexibility range will be synchronized with the dynamic requirements along the time span.

As there might be several scenario possibilities on how to set up an adaptable system, companies need to consider these with subject to the degree of adaptability and related total cost in order to be able to choose the most favorable configuration, i.e. the one with the lowest total cost expected. Therefore the different scenarios need to be evaluated by appraising the different types of costs for each scenario. As shown in Figure 3 the favorable scenario might not be the one with the highest degree of adaptability.

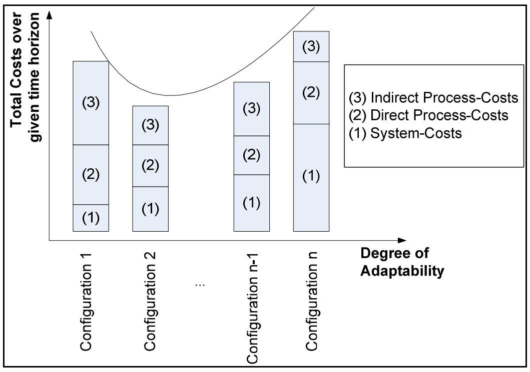

Figure 3: Total Costs Consideration of Different Scenarios (Zäh, Müller, and Vogl, 2005).

Therefore, the configuration model to be developed not only needs to consider the identification of characteristics contributing to adaptability and possible configurations of the very same, but also the assessment of the configurations degree of adaptability and the total costs over the contemplated time horizon.

Chapter 3 presents the scenario based method for the identification of major constitutive characteristics for establishing adaptable logistics chains and the assessment related to their contribution to adaptability, whereas Chapter 4 presents the simulation model for the assessment of respective configurations related to performance and cost issues.

3. APPROACH FOR IDENTIFICATION OF CONSTITUTIVE CHARACTERISTICS FOR ESTABLISHING ADAPTABLE LOGISTICS CHAINS

In order to provide adaptability in logistics chains it is essential to consider when adaptability is needed and how a configuration can be done. Therefore triggers or scenarios which induce changes in the logistics chains have to be identified. For example, such events can be customer requests to change the duration of the frozen zone or major changes in order sizes.

After defining the scenarios or rather scenario categories it is essential to identify the relevant regulating variables in logistics dealing with the impacts of the scenarios. To fulfill the requirement constitutive characteristics directly influenced by the scenario categories have to be identified.

Subsequent to the identification of possible scenario categories with impact on the logistics system and the identification of directly influenced constitutive characteristics of logistics, an assessment according to their contribution to adaptability has to be made. Therefore the intersection between these factors (scenario categories, constitutive characteristics and principles of adaptability) has to be found (Figure 4). To provide consistency a link between these factors has to be defined:

- *Scenario categories – adaptability:* Scenarios requiring adaptable structures are categorized. At this, scenarios with effects within middle termed horizons are considered. (see chapter 3.1)
- *Constitutive characteristic – adaptability:* Constitutive characteristics are rated by their flexibility and rapidness in change of specifications (e.g. changes from Just-in-Time to Just-in-Sequence within the constitutive characteristic supply concept) and the costs in associated with such changes (operation costs, investment costs, transformation costs). (see chapter 3.2)
- *Scenario categories - constitutive characteristic:* The linkage is established by key performance indicators (KPI) in logistics. At first, the direct impacts of the scenario categories on the KPIs are rated (yes/no). In the following, the KPIs directly influenced by the scenario category are used as a characterization of the scenario category. In a second step the effects of changes of constitutive characteristics specifications on the KPIs are rated (yes/no). These two assessments provide a combined analysis identifying the relevant constitutive characteristics in regards to evaluated scenario categories. (see chapter 3.3)

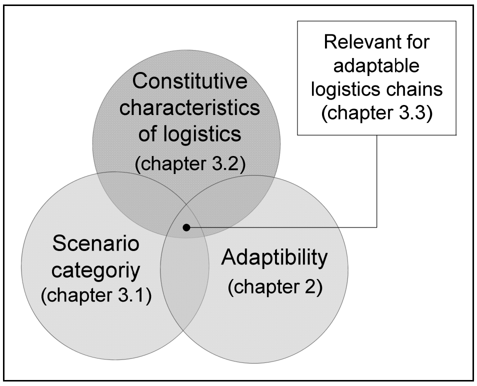

Figure 4: Identification of Relevant Regulating Variables for Adaptable Logistics Chains.

3.1. Identification of generic scenario categories

Due to the numerous different influencing factors a logistics chain can be affected by, it is important to classify them and focus on factors which require adaptable structures. The classification is based on a differentiation between short, middle and long term horizons (Figure 5).

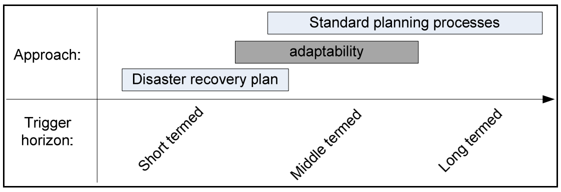

Figure 5: Classification of Triggers.

In case of short termed influencing factors, disaster recovery plans are used to provide continuous logistics processes respectively material supply (Arnold, Isermann, Kuhn, Tempelmeier, and Furmans 2008; Tang, 2006). For middle term and long term triggers standard planning processes are used. These planning processes focus on logistics changes which are not subject to shifts of the market, e.g. location planning (Tang, 2006). Whereas in case of middle term triggers which are caused by changing requirements of the market, e.g. change of frozen zones, the concept of adaptability is a promising concept to handle these recurrent changes.

To provide a generality of the concept a clustering of all middle term triggers which can be handled by adaptable systems is necessary. Within KoWaLo the generic groups “demand/customer risks”, “supply/supplier risks” and “environmental risks” were defined. More precising sub-groups were defined which focus on the changed parameters in the logistics (time, place, quantity, quality).

Changes in...	Time	Place	Quantity	Quality
Demand/ Customer	...delivery time	...point of delivery	...quantity demanded	...customer requirements
Supply/Supplier	...replenish-ment time	...point of procurement	...available capacities	...quality of supply
Environmental	...processing time			

Figure 7: Extract of Identified Scenario Categories.

3.2. Identification of constitutive characteristics in logistics

A multitude of overviews concerning constitutive characteristics of logistics can be found in literature (Arnold et al., 2008; Pfohl, 2004; Gudehus, and Kotzab, 2009; Gleißner, and Femerling, 2006). Because every overview has a different focus and provides no completeness, a unique appropriate overview has to be developed. To provide a preferably holistic overview a structured model has to be considered. In literature, different approaches exist to structure logistics system. Pfohl (2004) describes a function oriented and a performance oriented model. The functional boundary of the logistics system by phases describes the material flow beginning from the procurement market to the sales market and back. Another approach depicts the performing oriented view with focus on value added benefits for the logistics system (Figure 8). This performance oriented view allows a structured and non-redundant classification of constitutive characteristics within the logistics system. Therefore, this structure is used as the basis for the identification and classification of constitutive characteristics.

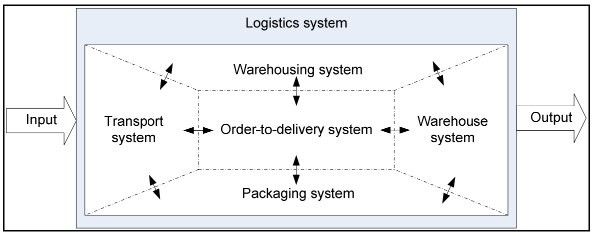

Figure 8: Performance Based Structure of Logistics Systems (Pfohl, 2004).

The literature research resulted in the identification of 90 different constitutive characteristics which can be classified within Pfohls performance oriented categories. Upon closer inspection different influences on the constitutive characteristics can be identified. Some constitutive characteristics are mainly influenced by product or strategy (e.g. design and function of products and adherent sourcing strategies: unit sourcing, modular sourcing etc.) or laws (general framework and regulations like hours-of-service regulations). Others focus on processes which have no influence on the logistics chain, e.g. processes within the warehouse system. Because these constitutive characteristics do not represent specific configuration levers for adaptable logistics chains they will be disregarded. After all 16 relevant constitutive characteristics have been identified.

	Relevant constitutive characteristics for the concept	example
Transport system	1	Transport concept
Packaging system	0	
Warehouse system	0	
Warehousing system	4	Order size, stock
Order-to-delivery system	11	Sourcing and supplier strategy
total	**16**	

Figure 9: Relevance of Constitutive Characteristics for Adaptability

3.3. Identification of adaptable constitutive characteristics

To identify adaptable constitutive characteristics, the analysis described in chapter 3.1 und 3.2 have to be merged. Herein KPIs are used as linkage between scenario categories (analysis 1) and constitutive characteristics (analysis 2). To provide a holistic collection of KPIs, the logistics KPI system of Schulte (1999), describing 146 KPIs sorted into different phases and groups, was applied. The system considers the logistics phases procurement, material flow and transport, warehouse and consignment, production planning and controlling as well as distribution. Each phase has their KPIs further grouped in the categories structure, productivity, economy and quality (Figure 10).

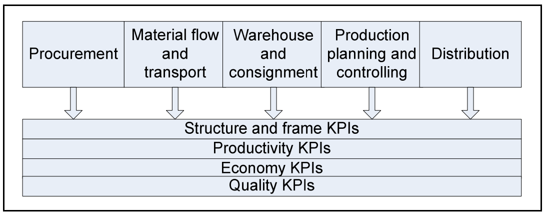

Figure 10: Logistics KPI System of Schulte (1999).

In order to merge the scenario categories and constitutive characteristics the first step is the identification of KPIs directly affected by the impact of respective scenarios. Secondly characteristics with direct influence on the respective KPIs have to be identified. Hence, the linkage between constitutive characteristics and scenarios can be established: characteristics with direct influence on a specific KPI are most likely to be taken into account to counteract a respective scenario influencing this specific KPI. Therefore, a set of characteristics can be identified for each of the scenario categories, as pictured in figure 11.

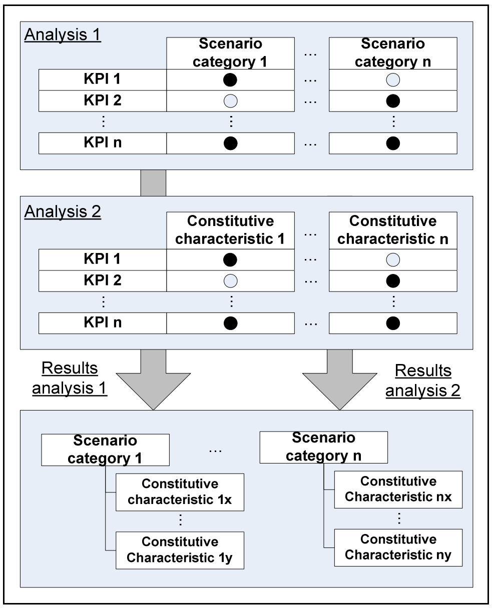

Figure 11: Combined Analysis for Identification of Adaptable Constitutive Characteristics.

3.4. Example for the identification of constitutive characteristics for establishing adaptable logistics chains

To demonstrate the concept one scenario will be treated exemplary. The selected scenario is based on a claim of customers to reduce the frozen zones in the order fulfillment process of a manufacturing company. This allows the customers to place orders within a shorter time frame. Companies with adaptable logistics are able to prepare for these triggers by considering low costs and a high logistics performance. The concept identifies constitutive characteristics which should be configured in terms of adaptability to establish economical and logistical advantages.

The first step is to assign the identified scenario to a scenario group. Using the example of frozen zone reduction, the category "Demand/Customer Risks" and "Time" was chosen (figure 7). Within analysis 1 (figure 11) the scenario has to be rated by KPIs. Therefore 13 relevant KPIs describing the scenario were defined. Among these the KPIs adherence to delivery dates, intensity of inventory or degree of information transparency are some of the relevant KPIs. The next step focuses on the impact of changes within the constitutive characteristics on the relevant KPIs (analysis 2, figure 11). When consolidating these analyses the crucial constitutive characteristics for the scenario can be identified. The characteristics below were identified for the exemplary scenario:

- *Order size:* By finding the optimal order size, frozen zones can be shortened. A balanced size has to be provided to acceptable transport and inventory costs.
- *Transport concept:* By applying the optimal transport concept changes can be performed faster. Flexible concepts like less-truck-load transports can interact better with volatility than train concepts.
- *Carrier:* Because of different start-up times between carrier concepts, the right choice is important to provide a fast change in the logistics configuration.
- *Communication strategy:* An adequate setting of communication strategy is relevant for the performance of the logistics chain. Through this, rapid changes in processes can be achieved.

4. ASSESSMENT OF ADAPTABLE CONFIGURATIONS BY SIMULATION MODEL

In order to assess the effectiveness of one or a set of constitutive criteria and their respective configurations, a discrete event simulation model was created to represent the exemplary order fulfillment process described in chapter 3.4. The simulation and evaluation model developed is depicted in Figure 12 (for higher resolution see appendix A).

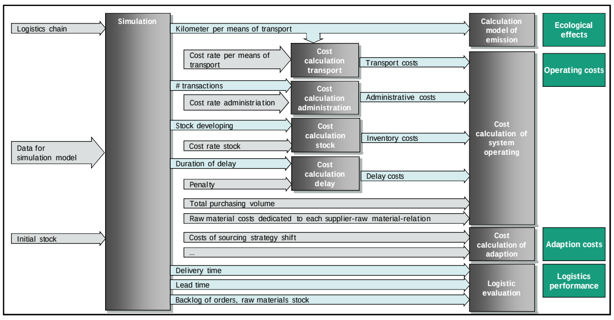

Figure 12: Structure of the Simulation and Evaluation Model.

The simulation model is based on the logistic chain of the companies named above, including inbound and outbound logistics as well as aggregated main production processes and their associated behavioural pattern concerning lead-times and deviation of lead-times. The data sets are real data sets from past production projects representing the high variant diversity in the contemplated logistic chain. By simulating dynamic effects of certain scenarios on this system, bottlenecks can be identified. By changing the specification of adaptable constitutive criteria and their theoretical effect on the systems behaviour, a statement can be made concerning the probability of an adaptable logistics chains aptitude to counteract these dynamic effects. Underlying cost rates for transport, stock, delay penalties, raw materials and adaption costs allow the evaluation of the systems total cost alongside with time effects like delivery capacity and reliability.

Hence, the simulation allows a comparison of the effects of different configurations by costs and logistics performance (as depicted in figure 3). Furthermore ecological effects in respect of transport system changes and effects, respectively, can be displayed.

The simulation application will be realized in the simulation software SLX. SLX excels in fast calculation and flexible model requirements illustration.

5. SUMMARY

Adaptable systems constitute high relevance for systems facing volatilities or continuously changing markets. According to the factors flexibility and reactivity as well as economical factors, structures can be (re-)configured to reach a high performance and low total cost. Adaptable concepts within production systems approve this statement. Nevertheless production systems only constitute one part of the value added chain and therefore adaptable concepts regarding the whole logistics chain have to be developed.

The presented approach shows a concept for the identification of relevant constitutive characteristics for adaptable logistics chains. Key elements of the concept are the scenario groups describing the impact of a change in the logistics chain. The approach to identify the relevant constitutive characteristics with KPIs out of the logistics KPI system provides a holistic view on all logistics levers. The simulation model will allow the evaluation of multiple configurations in respect of adaptability, logistics performance an underlying costs as well ecological issues like emission impacts of changes in the transport system.

Currently, the identification of characteristics and the simulation model development is completed. Further steps will be the definition of scenarios in order to deflect the impact on the system, and the evaluation of dynamic effects with the help of the simulation model.

Ongoing research will aim at the deflection of a universally valid and holistic configuration model for adaptable logistics chains that can be used as a decision support tool for companies of all sizes in order to evaluate their options to adjust their logistic system under consideration of adaptability.

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APPENDIX A: STRUCTURE OF THE SIMULATION AND EVALUATION MODEL