Flexible Container Filling Quantities
A Measure for Logistics Flexibility in the Automotive Industry

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ABSTRACT

Purpose

Supply chain flexibility has recently increased in relevance as a competitive advantage in the multi-variant line production of the automotive industry. The high number of optional extras combined with short-term changes in customer wishes cause considerable demand fluctuations. Because of the build-to-order process the customer demand is reflected in the demand for parts at the assembly line. Consequently, the challenge is to create a continuous flow of material towards the assembly line. Based on a definition of logistics flexibility a concrete measure for the implementation of this flexibility is analysed.

Design/methodology/approach

The research approach consists of two parts. First, an overview of flexibility definitions in the operations and supply chain management context is given, as well as a precise definition of logistics flexibility. Second, a concrete measure for enabling logistics flexibility is proposed and evaluated using simulation models. The measure chosen is the implementation of flexible container filling quantities to smooth the flow of material.

Findings

The results of the simulations indicate that flexible container filling quantities are associated with a continuous and production-synchronous flow of material resulting in a decrease in the total number and a smoothed workload of in-plant milk runs.

Original/value

Although there has been a great deal of discussion about the importance of flexibility, little research exists on concrete measures for its implementation. This research presents a measure for an efficient response to fluctuating demand at the assembly line in the automotive industry.

Keywords: Fluctuating Demand, Flexibility, In-plant Milk Run, Logistics Process Simulation, Supply Chain Management

1. INTRODUCTION

1.1. Motivation and Research Question

Meeting specific customer demands has become a competitive advantage in the automotive world market for European original equipment manufacturers (OEMs). Most OEMs have implemented a build-to-order process to avoid high stocks of vehicles and long lead times (Fredriksson and Gadde, 2005). The basic idea of producing cars build-to-order derives from the Toyota Pull Philosophy and the Lean Thinking of producing only what the customer demands (Miemczyk and Holweg, 2004). Lean Thinking causes companies to eliminate every kind of waste regarding time and material in the entire production process in order to address "the need for fast, flexible processes that give customers what they want, when they want it, at the highest quality and affordable cost." (Liker, 2004, p. 8). The build-to-order approach combined with highly individualized products, especially in the premium segments, means that fluctuating customer demand is reflected in the demand for parts at the assembly line. These fluctuations are also transmitted as amplified line-back to the upstream logistics processes, an effect known as the bullwhip effect (Tegel and Fleischmann, 2012). The bullwhip effect was described by Forrester as long ago as in 1961: "It is well known that factory production rate often fluctuates more widely than does the actual customer purchase rate" (Forrester, 1961, pp. 21 f.). The fluctuations of the demand for parts resulting from the build-to-order process cause disruptions in the material flows throughout the supply chain (Meissner, 2010). These disruptions need to be handled smoothly within the logistics processes.

This paper focuses on the automotive industry because of the challenging fluctuations in demand caused by the varying customer requirements combined with the high number of variants. The product diversity causes complex structures in the supply chain network and the logistics system, especially in the premium segments. The supply processes have to be flexible to fulfil the changing requirements efficiently. In order to balance out fluctuating demand, measures for the implementation of flexibility in the logistics processes need to be identified. Although there has been a great deal of discussion about the importance of logistics flexibility, little research exists on concrete measures for the implementation of flexible logistics processes. This lack of flexibility measures leads to the following research question: How can an OEM in the automotive industry achieve flexibility within its logistics processes to balance out fluctuating demand from the assembly line? In order to answer this research question some sub questions are defined:

- What does flexibility mean in the context of supply chain management and logistics?
- What type of flexibility should be focused on according to the described characteristics of the automotive industry?
- Which measure can be used to increase flexibility in logistics processes of the automotive industry?

Hence, this research paper focuses on a literature review of existing definitions and types of flexibility in different contexts and on the development and evaluation of one concrete measure for the implementation of logistics flexibility in the automotive industry.

1.2. Methodology

The methodology of this research for answering the research question consists of two parts. First, the problem of uncertainty in the business context is discussed and flexibility as an answer to a turbulent environment is suggested. A literature review gives an overview of the research area of flexibility in operations management and supply chain management. This includes a summary of existing flexibility definitions and types as well as a distinction to similar terms such as agility, adaptivity or transformability. Subsequently a certain flexibility type, logistics flexibility, is defined and the operating levers to enable this type of flexibility in the in-plant line supply of the automotive industry are discussed. Second, a concrete measure for the implementation of logistics flexibility in the supply chain of the automotive industry is presented. After the approach of this measure for dealing with fluctuating demand from the assembly line has been described, it is evaluated by simulating a case study. Therefore the supply processes considered are modelled using the System Dynamics Approach and then simulated using the software Powersim. Based on this simulation, the benefits of the flexibility measure presented are evaluated for this case study of the in-plant line supply in the automotive industry.

The paper is organized in four main chapters, including this chapter. Chapter 2 provides the literature review on flexibility in the context of logistics. The approach of flexible container filling quantities as a measure to implement flexibility in the in-plant line supply, the System Dynamics Model and the simulation, including the results, are presented in chapter 3. Chapter Conclusion gives a summary of the research.

2. THE IMPORTANCE OF FLEXIBILITY IN THE SUPPLY CHAIN

2.1. The Impact of Uncertainty in Supply Chain Management

Uncertainty and a turbulent, unpredictable business environment can be induced for instance by augmented product varieties or increased volatility of the global market (Yi *et al.*, 2011). High variability and uncertainty in customer demand can have an extreme impact on the upstream supply chain entities. If the information transmitted is distorted going up the supply chain, the stocks will be amplified for every upstream supply chain entity, thus leading to high costs. This phenomenon, called the bullwhip effect, is well-known not only in a specific industry but in several industries (Lee *et al.*, 1997).

The automotive industry in particular can be characterized by a high product variety combined with a complex supply chain network and short-term changes in customer orders. The higher the number of participants involved in a supply chain network, which is the case in the automotive industry, the more complicated the relationships among them get. Hence, there are a lot of potential sources of uncertainty, namely supplier lead time, market demand, information flow and product quality (Yi *et al.*, 2011).

In the literature, one course of action for dealing with uncertainty is to increase flexibility in the supply chain (Prater *et al.*, 2001), because flexibility in general represents the capacity to adapt to unanticipated environmental changes (Golden and Powell, 2000). Thus flexibility has become a source of competitive advantage (Dreyer and Grønhaug, 2004). Therefore the following subsection discusses the origin of the term flexibility in detail and provides an overview of the different definitions found in the literature.

2.2. Definitions of Flexibility

Nowadays discussions about flexibility are not new. In fact flexibility has appeared both in an economic and organizational context since the 1920s (Sethi and Sethi, 1990). The first finding, when researching in the field of flexibility, is the problem of defining the term. Due to the fact that flexibility can be characterized as multi-dimensional, it is not possible to define it simply and precisely (Golden and Powell, 2000). There have been several attempts in research to create a conceptual framework for the classification of flexibility (see e.g. Corrêa and Slack, 1996; Groote, 1994; Gupta and Goyal, 1989; Leeuw and Volberda, 1996; Oke, 2005; Toni and Tonchia, 1998), but it seems as though each research paper has started all over again (Barad and Sapir, 2003). Therefore the aim of this paper is to give a brief overview of flexibility in the literature and not to create a whole new conceptual framework. The term flexibility is generally defined in different research activities for example as "the ability to change or react with little penalty in time, effort, cost or performance" (Upton, 1994, p. 73), simply as "the capacity to adapt" (Golden and Powell, 2000, p. 373) or as "the capability of a firm to respond to unanticipated environmental changes in its production process and in marketplace" (Yi *et al.*, 2011, p. 272).

In the context of operations management, flexibility is mainly examined regarding manufacturing systems (Stevenson and Spring, 2007). Early definitions of manufacturing flexibility were provided for example by Gerwin (1993), Groote (1994), Gupta and Goyal (1989), Slack (1983; 1987) or Upton (1994). The definitions are quite similar but not identical. Slack (1983), for example, defines flexibility in the production context as "the ability to take up different positions or alternatively the ability to adopt a range of states" (Slack, 1983, p. 7). In other words, a production system is more flexible than another if it is capable of, for example, producing a greater product variety, achieving a range of alternative delivery lead times etc. Furthermore it is important to consider how easily a production system can change between two states in terms of costs and operational disruptions (Slack, 1983). Gupta and Goyal (1989) emphasize the importance of flexibility in dealing with changes in the operating environment. This means that flexibility can be defined as "a property of the system that indicates the system's potential behaviour, rather than its performance" (Gupta and Goyal, 1989, p. 134). Groote (1994) also takes changes of the environment into consideration by defining flexibility "as a hedge against the diversity of the environment. […] A particular technology is said to be more flexible than another if an increase in the diversity of the environment yields a more desirable change in performance (i.e. higher increase or lower decrease) than the change that would obtain with the other technology under the same conditions." (Groote, 1994, pp. 933 f.). Furthermore it has been suggested that manufacturing flexibility should be divided into different kinds of flexibility (Suarez *et al.*, 1995). Suarez *et al.* (1995) propose four basic types of flexibility, namely mix, new product, volume and delivery time flexibility. In contrast, Gerwin (1993) defines seven types of flexibility regarding the manufacturing flexibility: Mix, changeover, modification, volume, rerouting, material flexibility and flexibility responsiveness. Upton (1994) even mentions 15 different flexibility types, which are classified as "categories", but also stresses the fact that it is difficult in practice to use a prescribed list of flexibility types. This overview of manufacturing flexibility indicates how many different terms exist to describe the various types of flexibility. Sethi and Sethi (1990) found that there exist at least 50 different terms. Beach *et al.* (2000) give a very detailed review on manufacturing flexibility, as do Toni and Tonchia (1998).

In the last decades a growing number of researchers have recognized the increasing importance of flexibility in the context of supply chain management (Stevenson and Spring, 2007), because inter-company competition has shifted to supply chain competition caused by the increasingly globalized market (Yi *et al.*, 2011). In contrast to the literature on manufacturing flexibility, research on supply chain flexibility has only been in focus since the beginning of the 21st century. Several researchers in this area can be named (see e.g. Duclos *et al.*, 2003; Gong, 2008; Graves and Tomlin, 2003; Kumar *et al.*, 2006; Lummus *et al.*, 2003; Sánchez and Pérez, 2005; Wadhwa and Rao, 2004). A general definition of supply chain flexibility is: “The ability of a supply chain to mitigate, or neutralize, the risks of demand forecast variability, supply continuity variability, cycle time plus lead-time uncertainty and transit time plus customs-clearance time uncertainty during periods of increasing or diminishing volume.” (Blackstone, 2008, p. 52). According to Stevenson and Spring (2007), supply chain flexibility embraces flexibility components of the intra-company side combined with those of the inter-company side. Duclos *et al.* (2003) also state that supply chain flexibility requires flexibility within and between all supply chain entities. Therefore six components of supply chain flexibility were identified by Duclos *et al.* (2003) from an intensive literature review on manufacturing, strategic and supply chain flexibility. These components are operations system, market, logistics, supply, organizational and information systems flexibility (Duclos *et al.*, 2003). Another definition proposes that supply chain flexibility contains all the types of flexibility that have a direct influence on a company’s customer. This implies a more customer-oriented and integrated perspective (Vickery *et al.*, 1999).

Furthermore the term flexibility should not be confused with terms like agility, adaptability, transformability etc. It is clear that these terms are somehow related, but defining these terms seems as unambiguous as defining flexibility, i.e. a precise differentiation is not constructive at this point. Nevertheless some definitions are given to furnish an idea of the meaning of these terms: Agility for instance is “a business-wide capability that embraces organizational structures, information systems, logistics processes, and, in particular, mindsets.” (Christopher, 2000, p. 37). In other words “an agile firm handles change as a matter of routine.” (Vokurka and Fliedner, 1998, p. 166). Therefore flexibility can be seen as a key characteristic of an agile organization (Christopher, 2000). To determine the agility of a company’s supply chain, the cooperation of the three supply chain components inbound logistics, manufacturing and outbound logistics regarding speed and flexibility has to be considered (Prater *et al.*, 2001). The term adaptability is “the ability to change from one state to another state in a timely and cost effective manner” (Swafford *et al.*, 2006, p. 174). And Evans (1991) states that flexibility is polymorphous and thus briefly analyses the different senses of flexibility such as adaptability, versatility, elasticity and so on.

Summarizing this subsection, it has been shown that there is not only a lot of different definitions of flexibility but also a lot of different types of flexibility and related terms. In order to derive a concrete measure for implementing flexibility in logistics processes, a specific flexibility type has to be focused on. This is discussed in the next subsection.

2.3. Practical Application of Logistics Flexibility

As shown in the literature review flexibility has been studied for many years now, but as far as the application of flexibility in practice is concerned, the literature analysed is very limited. Although there are general frameworks on e.g. implementing and managing supply chain flexibility (see e.g. Kumar *et al.*, 2006), no concrete measures for applying flexibility in logistics processes can be found. Already Gerwin (1993) figures out, in the context of manufacturing flexibility, that not only theoretical but also practical analysis is important, in order to give managers concrete propositions on how to increase the flexibility of their operations. Managers need empirical research on which they can base their decisions to raise the flexibility of their factories (Suarez *et al.*, 1995).

For developing a concrete measure to raise flexibility in logistics processes of the in-plant line supply in the automotive industry, a first step is to define the flexibility type considered, which is called “logistics flexibility” in the following. As described above, there are plenty of different definitions and types of flexibility, which leads to the challenge of identifying an appropriate definition. The challenge becomes even more difficult when different names are used in the literature to refer to the same flexibility type or definition (Oke, 2005). There are even several definitions already in use for the term logistics flexibility (see e.g. Duclos *et al.*, 2003; Zhang *et al.*, 2005). But why define logistics flexibility when there are already definitions available? The reason for deriving a new definition is that this one is more precise than existing definitions and that it encompasses several dimensions.

The research of Golden and Powell (2000) is used as a framework for defining logistics flexibility. Golden and Powell (2000) have analysed several definitions of flexibility in the literature and structured them with the help of four dimensions in which a company can increase flexibility, based on and extending the work of Evans (1991). These dimensions are temporal, range, intention and focus. The temporal dimension is referring to the time period it takes to adapt to environmental changes, i.e. short-, medium- or long-term. The second dimension, range, stands for the degree to react to predictable or unpredictable changes. The intention dimension is based on the fact that changes in the environment are inevitable, so that it is up to the organization to act proactively or reactively. Whereby proactively means the attempt to control environmental changes and reactively means minimization of the impact of changes by defensive actions. The last dimension, focus, refers to the area where flexibility is gained. That can be either internally within an organization or externally in terms of managing relationships with supply chain partners. In most papers the four dimensions described are considered separately (Golden and Powell, 2000). In this paper, however, logistics flexibility is defined keeping all four dimensions in mind. Therefore the following definition of logistics flexibility is used for the remainder of this paper: Logistics flexibility in the logistics processes of an organization is the ability to respond to unpredictable and unforeseen circumstances reactively and quickly using parameters adapted beforehand without additional costs for the logistics processes considered and without changing the service level for any of the process partners. In order to make this definition more concrete it will now be explained using the example of the in-plant line supply of the automotive industry. As described above, fluctuating customer demand is reflected in the demand for parts at the assembly line. Therefore the dimension range of the logistics flexibility corresponds to unforeseeable changes in the demand for parts. The temporal dimension at the assembly line is short-term so that the flexibility has to be able to react quickly. Since the assembly line is part of the production of an organization the regarded flexibility has an internal focus. The intention dimension in this scenario is defined as reactive, because actions will take place after changes have occurred in order to minimise the impact of those changes. Furthermore, the aspects of costs and service level have to be taken into consideration when talking about logistics flexibility. The in-plant line supply in the automotive industry is only said to be flexible when no additional costs occur from the supply process compared to a non-flexible process. In addition, the service level has to be the same, i.e. the material supply has to be ensured. In order to achieve a more flexible in-plant line supply process, parameters such as, for example, personnel resources, operating resources etc. have to be adapted.

The next step for deriving a concrete measure enabling logistics flexibility is to identify the operating lever required to enable this flexibility and thus smooth the processes related to the fluctuating demand. General operating levers which compensate fluctuations in demand in the production line are time and/or inventory and/or capacity (Tegel and Fleischmann, 2012). Now these levers are transferred to the in-house logistics processes and it is discussed whether they support logistics flexibility or not. One option for reacting to sudden fluctuations in demand for parts at the assembly line is to take the time required to provide the parts. However, this is not flexible according to the definition of the proposed logistics flexibility, but only flexible in terms of the ability to deal with fluctuations. The second operating lever is stock, i.e. keeping higher safety stocks at the assembly line to balance out the fluctuations in demand for parts. This option is not relevant for logistics flexibility either, since space is generally scarce near the assembly lines of an OEM, so that a high quantity of safety stocks at the assembly line is not a feasible option. The third operating lever, capacity, can refer to different types of capacity such as personnel resources, operation resources etc. In order to gain logistics flexibility via capacity, the parameters of a certain capacity type have to be adjusted e.g. by reorganizing the personnel resources, so that the fluctuating demand for parts at the assembly line can be met quickly without additional costs which is in accordance with the logistics flexibility definition.

Based on the definition suggested in this subsection, the next chapter proposes a concrete measure using capacity as an operating lever to raise the logistics flexibility of the in-plant line supply process in the automotive industry.

3. A MEASURE TO ACHIEVE LOGISTICS FLEXIBILITY

3.1. Approach

As described in chapter 1, the build-to-order process in the automotive industry combined with the high number of variants causes fluctuating customer demand which is reflected in the demand for parts at the assembly line. This paper aims to propose a measure for the implementation of logistics flexibility considering the lean thinking, not throughout the supply chain, but in the in-plant line supply of the automotive industry. Therefore the supply of the containers with the materials for the assembly line with clocked milk runs is considered. “A milk run […] is a manually operated, cyclic transport system delivering materials and disposing of empties based on consumption using a fixed route and time schedule.” (Droste and Deuse, 2011, p. 606). The clocked supply in this context describes the time schedule based supply with the same number of time steps between the departures of one milk run vehicle. Thus the milk run cycle is the time between the departure of one milk run vehicle and the next.

The main idea behind this approach is to adjust the container ranges to an integer multiple of the milk run cycle to create a continuous workload of milk run vehicles with a reduction in the overall transportation capacity required. To achieve stable container ranges despite the fluctuating demand at the assembly line the container filling quantity has to be adjusted flexibly to the demand for parts within the next milk run cycle or a multiple of this. With this approach, according to the above definition of logistics flexibility, it is possible to respond reactively and quickly to the often unpredictable and unforeseen fluctuations in demand from the assembly line. By adapting the parameter “container range” to an integer multiple of the milk run cycle, additional costs caused by additionally needed transportation capacity for supplying demand peaks can be prevented. The overall saving potential is evaluated by a case study in chapter 3.2.

For the following research a distinction has to be made between three different part types. First, there are part types which have no different variants and are assembled in every vehicle on the assembly line. Thus demand does not fluctuate within a short time horizon like a milk run cycle. Screws are examples of such parts. Second, there are part types which have different variants but are still assembled in every vehicle on the assembly line. These parts can be supplied just-in-sequence so that one part is needed from the container within each time step (one time step corresponds to the time of one assembly cycle). Seats are examples of such parts. Thus there is no fluctuation in demand for these parts either, like the parts described first. If they are not supplied just-in-sequence they are equivalent to the following third type of parts. The third type is parts which have more than one variant and are not assembled in every vehicle on the assembly line. An example of such parts is a roof aerial, which is not assembled in a convertible. Thus the number of parts which are needed within the next milk run cycle differs every time. For the first type of parts and for the second type supplied just-in-sequence, the container filling quantity does not have to be adjusted flexibly, because there is no fluctuation in demand. This paper focuses on the second type of parts, not supplied just-in-sequence and the third type of parts. The challenge is to create a continuous flow of milk runs to the production line with smoothed and improved workload of the milk runs despite the fluctuations in demand at the assembly line.

An example is shown to explain the idea of flexible container filling quantities. First, the initial situation of full containers is described and second, the improved situation with flexible container filling quantities. Figure 3.1 shows the consumption of parts per time step for a part with take rate 0.55, i.e. this part is assembled in 55% of the vehicles on the assembly line.

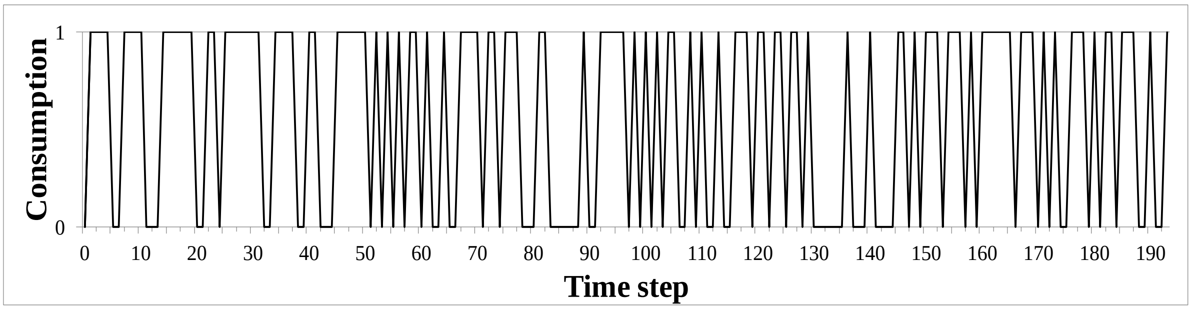

Figure 3.1 Consumption of parts per time step (take rate 0.55)

Figure 3.2 shows the actual stock range of each container filled with 22 parts based on the consumption from figure 3.1. It is apparent that the container range differs because a part is not needed in each time step.

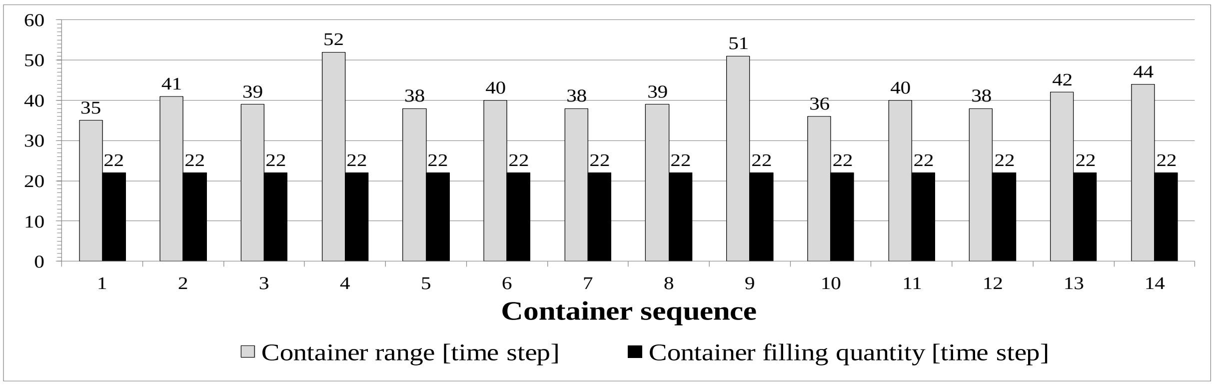

Figure 3.2 Actual container ranges per container (filling quantity 22)

The black bars in figure 3.2 show that every container is filled with 22 parts (container filling quantity). The grey bars in figure 3.2 show that the 22 parts of the containers have a range longer than 22 time steps. The 22 parts of the first container for example will last for 35 time steps based on the consumption from figure 3.1. As a result, the necessary transportation frequency of this part is not regular. Assuming a milk run every 16 time steps, starting at time step 0, according to the container ranges from figure 3.2, containers have to be delivered with the milk run at time step 0, 32, 64, 112 and so on. Consequently there is no container within the second, fourth, sixth, seventh and ninth milk run cycle. This reflects the irregular frequency of transportation demand with idle transportation capacities. To avoid this effect and to be able to use the idle capacities efficiently, it is proposed to adjust the container ranges to an integer multiple of the milk run cycle by adapting the container filling quantity flexibly to the demand for parts within this time. The number of parts which have to be filled into each container in this case is shown in figure 3.3.

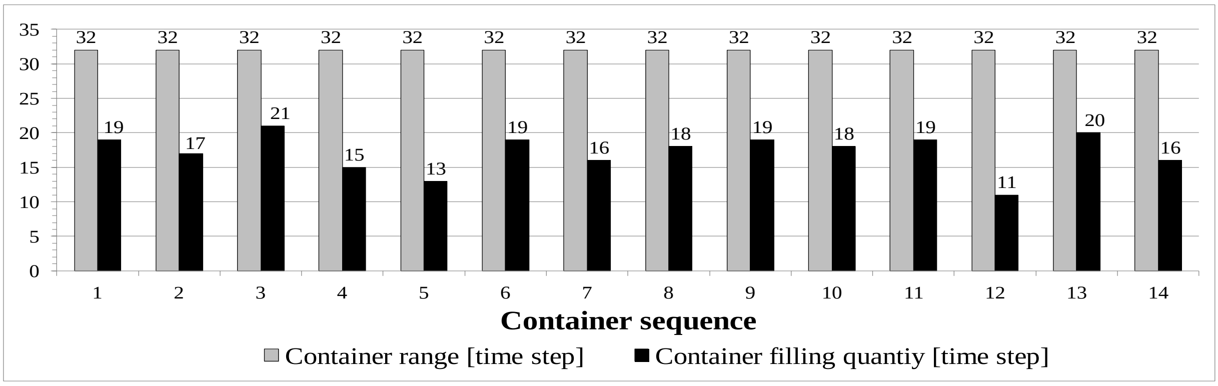

Figure 3.3 Improved container filling quantities (milk run cycle 16 time steps)

The black bars in figure 3.3 again show the container filling quantity which now differs for every container, but as a result each container in figure 3.3 has a container range of 32 time steps, shown by the grey bars, even though the demand for this part fluctuates at the assembly line. Thus the container has to be transported with every second milk run which corresponds to a regular transportation frequency. As a result, the idle capacity on every second milk run can be used efficiently for another container. The aspect of regular transportation frequency is demonstrated in figure 3.4.

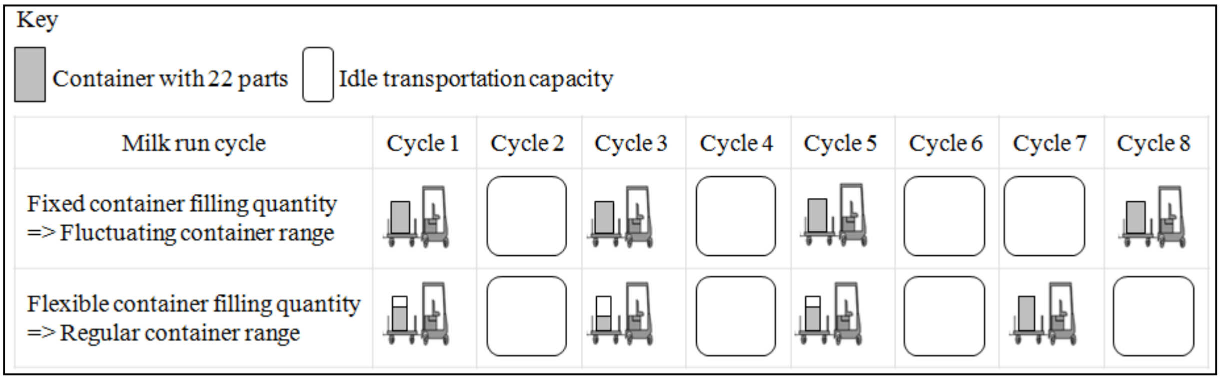

Figure 3.4 Transportation frequencies for fixed and flexible container filling quantities

In the initial situation, the fixed container filling quantities lead to fluctuating container ranges which result in irregular idle capacities on the milk runs in cycle 2, 4, 6, 7 and so on. In this case, as described above, the idle capacities cannot be used efficiently. Using the idle capacities would involve high steering efforts resulting in additional costs. The improved situation shows the process with flexible container filling quantities adjusted to the demand within every second milk run cycle. Thus the container ranges do not fluctuate so that the container has to be transported regularly with every second milk run. As a result, the regular idle capacity on every second milk run can be used for another container with the same container range. If the container range can only be adjusted to the milk run cycle, but not to an integer multiple of the milk run cycle, there will be no overall savings in the transportation capacities, because in this case every container still has to be transported within each milk run cycle. Nevertheless a continuous demand for transportation capacity with clocked and production-synchronous supply will be generated.

3.2. Simulation of the In-Plant Line Supply

3.2.1. Description of the Model

To evaluate the effects of flexible container filling quantities, this study focuses on the line supply process from an in-plant supermarket with clocked milk runs where each milk run vehicle has four trailers. At a supermarket, the parts are always handled, which means that the container filling quantity can be adjusted flexibly. The implementation of this approach for sources other than supermarkets is discussed in chapter 4.3. In this case study, each trailer can carry one container. There is more than one milk run vehicle in the field and just enough to supply all the parts. In this research a simulation model is presented to compare the initial situation of full containers with the improved situation of flexible container filling quantities. Each milk run vehicle supplies defined parts on defined routes to the assembly line. Thus the route for one milk run vehicle is always the same, but different for the different milk run vehicles. The milk runs start at the in-plant supermarket every 16 time steps and transport the containers to the assembly line. The call-offs for the parts are demand-orientated, so that the quantity of parts needed within the next milk run cycle is already known in advance. To model these processes the System Dynamics Approach is used. Discrete-Event Simulation and System Dynamics are two common used modelling tools in the field of logistics and supply chain management. In the context of the bullwhip-effect the focus of the modelling activity is on the System Dynamics Approach which is why it is used in this research (Tako and Robinson, 2012). System Dynamics is an approach for understanding and modelling complex and dynamic systems over time. The main elements are stocks, flows and auxiliaries. The interdependencies between these elements are implemented by feedback loops. This method enables in-depth understanding of complex processes (Forrester, 1961). The System Dynamics Models of the supply process of the initial and improved situation are presented in figure 3.5.

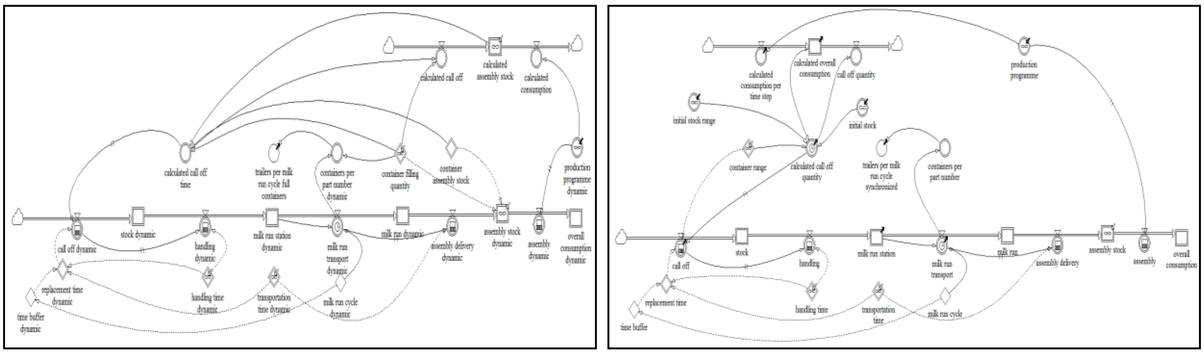

Figure 3.5 System Dynamics Model of the initial (left) and improved (right) supply process

Although the material flow is the same in both models there are differences in the information flow. In the first model, the time step when the container is empty is calculated based on the container filling quantity, which results in a calculated call-off time. This time minus the replacement time is the call-off time with a call-off quantity equal to the fixed container filling quantity. In contrast to that, in the model of the improved situation the quantity of parts which will be needed within the next milk run cycle is calculated. This results in a calculated call-off quantity rather than a calculated call-off time. In both models based on the variable "milk run transport" the trailers needed for each milk run cycle can be calculated. If the peak of this demand over time is divided by four (trailers per milk run vehicle) it results in the number of overall needed vehicles for the line supply.

3.2.2. Input Data for the Simulation

The two models are simulated for a case study using the software Powersim for 6,000 time steps for the simultaneous line supply of 42 parts with the input data from table 3.1.

Table 3.1 Input data for the simulation

Input data	Description	Values
Production programme	Number of parts consumed per time step	(0;1)
Take rate	Percentage of vehicles the part is assembled in	[0;1]
Container filling quantity	Maximum number of parts per part and container	[16;79]
Number of containers at the assembly line	Assembly stock per part in containers	2
Milk run cycle	Number of time steps between the departure of two milk runs	16
Transportation time	Time steps needed for the transport from the supermarket to the assembly line per part	(2;3)
Handling time	Time steps needed for commissioning, loading, ... per part	[3;53]
Container range in the improved situation	Multiple integer of the milk run cycle feasible with the container size	(16;32;48;64)
Initial stock at the assembly line	Number of parts per part at the assembly stock at the beginning of the simulation	[4;64]
Initial stock range	Range of the initial stock based on the production programme	(16;32;48;64)

The production programme is generated randomly based on the take rate of each part over the time steps. All the other data from the table has to be provided for the simulation, except the initial stock and the initial stock range. Thus it has to be decided in advance which container range each part should have in the improved situation. The initial stock of each part has to cover the demand until the first container with this part is delivered. The initial stock is calculated based on the production programme and the time step when the first container is delivered.

3.2.3. Results of the Simulation

At first the initial process with full containers is simulated. Figure 3.7 presents the number of trailers per milk run cycle needed for the 6,000 time steps which are required to supply the 42 parts. As can be seen in figure 3.7 there are high fluctuations of the number of milk run trailers required. The number varies between 6 and 23 trailers per milk run cycle which corresponds to between 2 and 6 milk run vehicles with four trailers each. A total of 5,349 containers are transported on 1,475 milk runs. On average 14.3 trailers are needed with a variance in the number of trailers of 8.5.

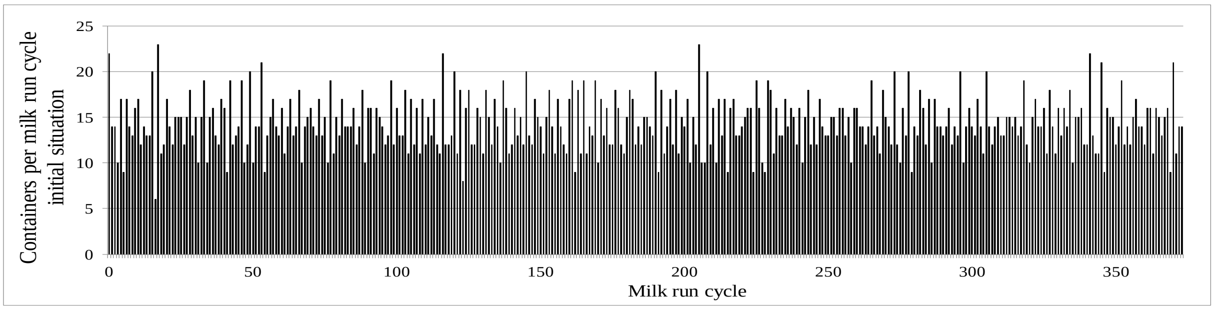

Figure 3.7 Milk run trailers needed per cycle with full containers

In contrast to that, figure 3.8 provides the results obtained from the analysis of the improved process with flexible container filling quantities depending on the demand for parts within the supply frequency. There are no fluctuations in the number of trailers needed per milk run cycle. 20 trailers are needed within each milk run cycle, which corresponds to 5 milk run vehicles with four trailers each. At this stage of the analysis it can be seen that one milk run vehicle less is needed in this case study if the container filling quantity is adjusted flexibly to the demand within the supply frequency. A total of 7,480 containers are transported on 1,870 milk runs. On average these are 20 trailers with a variance in the number of trailers of 0 of course.

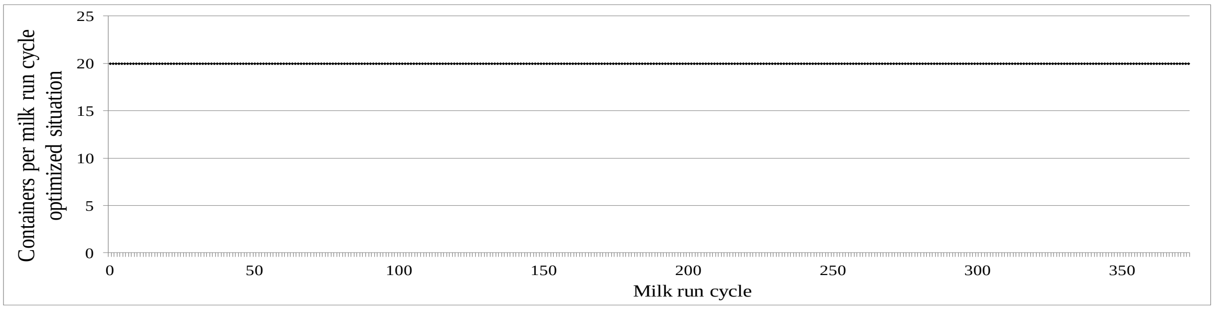

Figure 3.8 Milk run trailers needed per cycle with flexible container filling quantities

As can be seen from the data above more containers have to be transported in the improved situation. This is obvious, because the containers with flexible container filling quantity are not completely filled which means that more containers have to be transported to supply the same quantity of parts. But there are overall savings in the needed milk run capacity, because idle transportation capacity can be used efficiently based on regular demand. Despite the actual demand for transportation capacity within each milk run cycle in the initial situation the transportation capacity for the demand peaks within the 6,000 time steps has to be available at all times. Even if only 14.3 trailers are needed on average in the initial situation, the 23 trailers corresponding to 6 milk run vehicles for the demand peaks must be available. Thus 3 more trailers over 1,475 milk runs are needed in the initial situation which corresponds to capacity for 4,425 containers which can be used for other parts in the improved situation.

To sum up, it can be said that flexibility in the container filling quantity results in clocked and production-synchronous line supply with a decrease in the overall milk run capacity needed compared to the initial situation described. According to the definition of logistics flexibility from chapter 2.3 this case study shows that the adjustment of the parameter “container range” to an integer multiple of the milk run cycle is a response to the circumstances of fluctuating demand at the assembly line without additional costs caused by the milk run capacity required. Furthermore it was indicated that steering the containers using offset control by defining the initial stock range decreases the overall milk run capacity required because it makes optimum use of the capacity. Steering containers from demand peaks to earlier milk runs is also a possibility of creating a continuous workload of the milk run vehicles, but results in high steering efforts which make it much more complex. Once the optimal container ranges and the initial stock range have been defined, the approach of flexible container filling quantities is self-controlling. Although flexible container filling quantities create a continuous workload for the milk run vehicles, this measure does not prevent the bullwhip effect for upstream logistics processes. The fluctuating demand for parts at the assembly line occurs again in the demand for parts at the supermarket.

4. CONCLUSION

4.1. Summary

As illustrated by the literature review, flexibility is a relevant topic and is used to deal with uncertainties in the business environment. The term flexibility has been broadly researched in operations management concerning manufacturing flexibility and also in supply chain management with respect to supply chain flexibility. Moreover there are plenty of related and similar terms such as agility or adaptability, which complement the research area of flexibility. In this paper a definition of logistics flexibility was derived. The framework of Golden and Powell (2000) was followed to ensure this definition is more precise than existing ones and that all relevant aspects are covered. Furthermore it was discussed that there are basically three operating levers to react on demand fluctuations, namely time, stock and capacity, although only capacity seems appropriate to enable flexibility of the in-plant line supply process of the automotive industry.

Based on the definition of logistics flexibility flexible container quantities as an approach to smooth the workload of in-plant milk runs were provided. The results of the case study indicate relations between flexible container filling quantity adjusted to the demand for parts within an integer multiple of the milk run cycle and continuous flow of material with a decrease in the total number of milk runs. Thus, the measure presented is an efficient response to fluctuating demand at the assembly line in the automotive industry.

4.2. Practical Implication

The approach of flexible container filling quantities is a concrete measure for implementing logistics flexibility in the in-plant line supply. It is important that the containers do not necessarily have to be changed; only the container filling quantity has to be adjusted. If this measure is to be implemented in practice it must be ensured that there is a demand-orientated IT system which is able to show the demand for the defined time steps according to the milk run cycle rather than the number of parts which could be filled into the container as a maximum. Furthermore the initial stock at the assembly line based on the initial stock range chosen as well as the optimal container ranges based on the milk run cycle and the take rate must be defined. It is important to consider the fluctuations of the take rate. This percentage might be stable within horizons of a year or a month, but often not within a milk run cycle. Thus for the calculation of the optimal container range the highest value of the take rate within the integer multiple of the milk run cycle should be taken into account. Also it has to be considered that the level of savings in the overall needed milk run capacities depends on the possible offset-control based on the available container sizes. If there is only one container which has to be transported with every second milk run, but there is no other container for which the idle capacity on every second milk run can be used, this idle capacity will remain and the savings potential will decrease. Even if there are no savings in the overall milk run capacity needed, flexible container filling quantities result in a continuous workload and flow of milk runs with clocked and production-synchronous supply.

4.3. Limitations and Future Research

In this work the approach of flexible container filling quantities was examined for the in-plant supply of the assembly line from a supermarket in the automotive industry. In a supermarket the parts are always handled so that the number of parts can be adjusted to the demand shortly before they are assembled and the empty spaces in the containers only have to be transported over short distances. Focusing on other sources means that the right number of parts already has to be filled in by the supplier which is much more difficult for two reasons. First, the empty spaces in the containers are idle capacities that have to be transported from the suppliers to the in-plant sources. Thus it is much more difficult to achieve overall savings. Second, there is a lot of time for disruptions of planned-actual demand. If more or fewer parts are needed at the assembly line than was originally planned, the clocked supply is interrupted and must be restored by a special process.

To sum up it can be said that the measure of flexible container filling quantities has great potential to smooth the transportation workload for in-plant milk runs with a decrease in the overall number of milk run vehicles needed. Thus future research should examine the savings potentials of the flexibility measure presented for sources other than in-plant supermarkets.

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