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Procedia CIRP 79 (2019) 415–420

www.elsevier.com/locate/procedia

12th CIRP Conference on Intelligent Computation in Manufacturing Engineering, 18-20 July 2018, Gulf of Naples, Italy

Flexibility planning in global inbound logistics

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Abstract

Building on the variety of different methods to operationalize flexibility in supply chains, this paper presents a process-oriented approach for the measurement and planning of inbound logistics flexibility in global production networks. Using the automotive industry as an example, process sequences of the overseas supply like transportation, storing or handling are parameterized regarding their respective flexibility range as well as the time- and cost-related implications of their adjustment. On this basis, a model to evaluate benefits and costs associated with the investment in logistics flexibility can be derived in order to support the decision-making process for a rolling planning on a tactical level.

Keywords: Global inbound logistics; Supply chain flexibility; Logistics flexibility; Flexibility operationalization; Flexibility planning; Automotive industry

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1. Introduction

Parts logistics in the automotive industry encompasses all processes from components being provided by suppliers to their final presentation at the production line of an Original Equipment Manufacturer (OEM). It can be divided into external inbound logistics, concentrating on the delivery of parts from a supplier's facility to an OEM's plant, in-house logistics, responsible for all processes from goods receipt to assembly and reverse logistics, comprising the return of unused materials [1].

The design of these processes takes place before Start of Production (SOP) of a vehicle project and pre-defines the scope of action for the series. Focusing on external inbound logistics, this includes long-term strategic decisions for the network structure like location selection or layout design of logistics facilities. On a medium-term tactical level of several months, choices regarding the planning of area, inventory or human resources or the selection of part-based concepts for packaging, delivery and transportation are made. On an operational level, logistical processes and the use of related structures and resources are finalized during the ramp-up phase, shortly before the first car is produced [2, 3].

From an integrative perspective, inbound logistics systems include several vehicle projects at various nodes and edges of a globally expanded network. Especially international logistical chains are subject to unforeseen fluctuations with challenging consequences. In order to ensure stable supply under varying conditions, external inbound logistics must be capable of acting beyond initially determined boundaries. In this paper, logistics flexibility, as one dimension of supply chain flexibility, is discussed with a process-based view, including multiple network stages from a multi-project perspective. Building on existing research, an approach for the measurement and continuous planning of logistics flexibility on a tactical level is deducted.

2. Logistics Flexibility in Supply Chain Flexibility

2.1. Challenges in global supply chains

International logistics is defined as the sum of all activities for planning and realizing cross-border logistics processes [4]. In the context of long supply chains, logistical networks are highly interconnected, complex and dynamic. The coordination of simultaneous processes, serving to ensure the effective

10.1016/j.procir.2019.02.114

delivery of products to the right place, at the right time, in the right quantity, quality and order in a cost-efficient manner, is a demanding task [5]. In contrast to domestic supply chains, international and cross-border flow of goods has to face particular procedural as well as country-specific conditions. While the former refers to long transportation distances or higher order lead times, the latter includes macro- and microeconomic aspects in the target market [3, 4, 5, 6].

The resulting challenges are reflected in the complexity of the network in terms of the number of and distance between suppliers and customers, which affects strategic decisions in particular. Furthermore, demand uncertainties like fluctuations in volume, represented in the varying amount of ordered goods, changes in product mix in form of the composition of an offer, the frequent introduction of new products, the related increase of product customization as well as the need to meet subsequent changes in demand affect medium-term decisions on a planning level. Process-related uncertainty like the necessity to handle wrong, missing or damaged parts as well as process disruption can occur within a short time [7, 8, 9, 10, 11]. In this environment, flexibility can be seen as an important ability of a supply chain in order to cope with changing internal and external conditions to ensure reliable performance [12, 13, 14, 15, 16].

2.2. Management of flexibility in supply chains

Flexibility is a multi-dimensional, complex, polymorph and hard-to-capture construct [17, 18]. Building on research on the flexibility of manufacturing systems, the scientific discourse extended its consideration from one single unit to the flexibility of various components and sub-components of a whole supply chain [15, 17], where intra- and inter-organizational capabilities of all elements from the shop floor to the network are included [9, 12, 13, 15].

Since supply chain flexibility can be seen as a characteristic that generates both benefit and effort, its appropriate application is necessary for a system's effective and efficient operation. The management of supply chain flexibility deals with the alignment of actual and required flexibility. Generally, it encapsulates five phases. The identification phase clarifies required flexibility as the amount of change needed to respond properly, and actual flexibility as the existing capability of all chain elements to change. In the following operationalization phase the required and actual flexibility are displayed numerically, both of which can be scaled according to their potential. During the planning phase, the comparison of the given and necessary scope of action is deducted. If a gap between required and actual flexibility potential occurs, a flexibility measure needs to be identified in order to counterbalance the difference. Thereby, the benefit and cost of a flexibility measure need to be evaluated. By doing so, the assumption of its application leads to a theoretically assumed adjusted flexibility potential in form of an increase or reduction. During the adjustment phase, the flexibility potential is modified in the real system by the implementation of a flexibility measure. Within the utilization phase, the adjusted flexibility potential is actually claimed [10, 14, 16, 19, 20].

2.3. Measuring supply chain flexibility

Regarding the operationalization of supply chain flexibility, one group of approaches aims to provide a key performance indicator for flexibility [21, 22, 23], while others deduct statistical models, where flexibility is demonstrated as a latent construct, represented by various manifest indicators [8, 24]. Further methods are inspired by real options, where the value of an investment in flexibility takes the probability of occurrence of its need into account [20, 25].

As mentioned above, in the context of flexibility planning, a supply chain can be scaled by the flexibility potential of all relevant components [14]. Within the research on manufacturing systems, Slack (1983) describes flexibility by two dimensions, the range of state a system or resource is capable to achieve and the response, as the ease in terms of cost and time by which these changes can be made [26]. Upton (1994) added uniformity as a constituting element of flexibility, which demands to maintain a system's performance while varying between different states [27]. Although these dimensions could be modeled for various areas of application, only a few approaches have already adopted this differentiation in the context of supply chain flexibility [14, 28].

2.4. Planning of supply chain flexibility

Current research has recognized that the associated costs of flexibility have to be compared with its tangible and intangible benefits. In this context, empirical evidence for the direct or moderated effect of supply chain flexibility on financial measures like return on investment, return on sales and market share [11, 29] as well as on non-financial performance like customer satisfaction and customer loyalty has been found [24, 30, 31]. Nevertheless, only a few planning models, confronting the trade-off between the effort and benefit of supply chain flexibility can be identified. Aprile et al. (2005) have developed an optimization model aiming to minimize lost sales under product- and production-related uncertainty by considering flexibility of several supply chain elements [32]. Chan and Chan (2010) use agent-based simulation to indicate that flexibility within a supply chain can positively influence performance by improving the customer demand fill rate and by simultaneously considering several cost categories under varying demand and supply [33]. Schütz and Tomasgard (2011) present a two-stage stochastic programming model and include flexibility in volume, delivery and operational decision, facing demand uncertainty. Unsatisfied demand is modeled either as backlog, allowing to shift deliveries into a subsequent period, or as lost sales, which is penalized with a shortfall cost equal to 25 percent of a product's market price [34]. Esmaeilikia et al. (2016) describes a tactical supply chain model which incorporates options in sourcing, manufacturing and logistics for flexibility adjustment. On the one hand, each option relates to rising costs, on the other hand it contributes to customer service in the form of avoided backlog [35].

2.5. Logistics flexibility within supply chain flexibility

From a horizontal point of view, supply chain flexibility can be divided into constituting dimensions like product development flexibility, sourcing flexibility, production flexibility or logistics flexibility [9, 24]. Thereby, logistics flexibility enables a supply chain to adjust to changing conditions in inbound and outbound delivery as well as in support and services [13, 24]. It is achieved by the adjustment of the flow of material and related information, from the point of origin to the destination [24]. Focusing on the physical constituent part of logistics flexibility, this ability includes flexibility of processes like transportation, storing and handling as well as the related support processes like packing or commissioning. On a tactical level, flexibility in transportation includes the ability to change the mode, route or carrier of transportation, the transport capacity or frequency and the ability to conduct express delivery [12, 13, 14, 24, 35, 36, 37]. For storage processes, logistics flexibility refers to the adjustment of warehouse space regarding the total storage area as well as the ability to vary storage utilization with respect to individual storage places [13, 14, 24, 35]. Under the term handling flexibility, the availability of different equipment, the ability to vary the amount of logistics employees or operational areas are summarized [9, 12, 13, 24].

Supply chain flexibility can be divided into external flexibility types, which are demonstrated to the customer, and internal flexibility types, which are only visible inside an operating system and used to enable the former [27, 38]. Logistics flexibility can be classified as an internal type, supporting external types like volume, product mix, new product, product customization and delivery flexibility of a supply chain. In this way, figure 1 adapts the framework of Reichhart and Holweg (2007) [38].

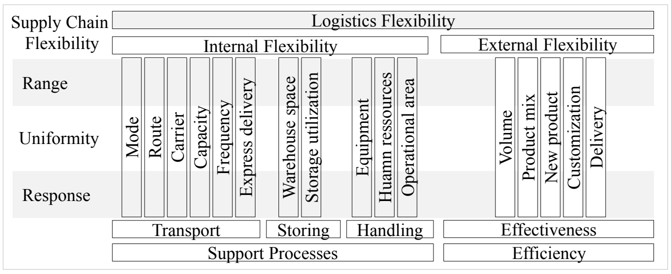

Fig. 1. Tactical logistics flexibility in supply chains.

3. Approach for measuring and planning of overseas inbound logistics flexibility

3.1. External logistics in global inbound supply

The research subject of this paper is external inbound logistics processes in international and multilevel production networks in the automotive industry. As a representative chain, the following explanations refer to globally sourced and consolidated delivered vehicle components. Directly shipped or locally sourced parts are excluded. This process generally begins after the continental overland transportation of parts from various suppliers to a consolidation center. Depending on packaging and loading, parts are either cross-docked or stored and subsequently re-packed in disposable packing. After stowing the loading units into containers, the successive pre-run of the intercontinental supply includes transportation by train to a harbor, where vessel loading is conducted. The main-run of the overseas transport from port of departure to port of destination takes several weeks and may pass feeder ports, depending on the transportation route. After customs clearance, incoming containers are stored at a container yard. Subsequently, the after-run includes truck transportation of the containers to the plant. In case of emergency, the only alternative for the oversea supply is air freight [39, 40].

3.2. Measuring of logistics flexibility and its adjustment

The approach for tactical flexibility planning in global inbound logistics is accomplished in two steps. First, a method which supports the operationalization of logistics flexibility is derived. In this context, Barad and Sapir (2003) as well as Zhang et al. (2005) confirm that logistics flexibility is scaled based on range and response [24, 41]. The following explanations refer to Pfeiffer (2016), who builds on existing approaches in production systems and supply chains to quantify the flexibility of a distribution network. The author differentiates between metrically scaled and nominally scaled flexibility types as the internal subjects of change. The range $q \in Q$ of a flexibility potential, limited by upper and lower bounds, refers to the capacity of a metrically scaled flexibility type or to the number of alternative processes for nominally scaled flexibility types. Since a flexibility measure $m \in M$ serves to adjust flexibility potential, the variation from $q1$ to $q2$ can be described as Δq [14]. Figure 2 displays the model reported by Pfeiffer (2016) in a slightly modified version.

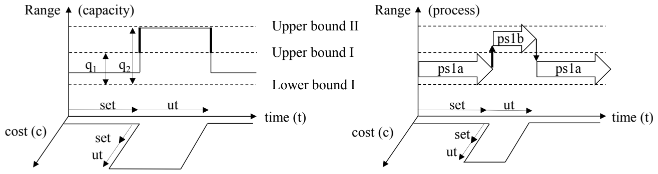

Fig. 2. Metrically and nominally scaled flexibility types.

Thereby, a pre-defined basic corridor, resulting from strategic decision, can be described with $q_{ps,t}^{min}$ as the lower bound and $q_{ps,t}^{max}$ as the upper bound of a process sequence $ps \in PS$ within a given tactical time period $t \in T$ [14, 28, 42].

$$q_{ps,t}^{min} \leq q_{ps,t} \leq q_{ps,t}^{max} \qquad (1)$$
$$\forall ps \in PS; t \in T$$

Due to the fact that implementing a flexibility measure entails corresponding expenses, setup costs $c_{ps,m,t}^{set}$ for its realization as well as utilization costs $c_{ps,m,t}^{ut}$ for its actual application need to be specified. Furthermore, the setup time $t_{ps,m}^{set}$ as well as the minimum utilization time $t_{ps,m}^{ut,min}$ and the maximum utilization time $t_{ps,m}^{ut,max}$ of a measure m need to be described [14, 28, 42].

The following explanations refer to the overseas inbound supply described in chapter 3.1. In order to consider all relevant components, factors creating a shortage per process sequence on a planning level are taken into account. Therefore, these bottlenecks are either metrically scaled by their capacity, measured in form of their throughput unit, or nominally scaled by the number of alternative processes per time period. On the basis of pre-selected measures, table 1 shows that a consolidation center needs to vary storage space as well as operational space for cross-docking or packaging by renting or canceling areas. Furthermore, the availability of human resources for all tasks from goods receipt to goods issue, related to cross-docking or packing processes, need to be varied by personnel measures. Moreover, booked transportation capacities of international logistics service providers (LSP), scaled in form of the number of delivery containers (cont), need to be adjusted for the pre-, main- and after-run. Equally, the ability to vary container storage area needs to be considered at the container yard in the target market. Since these measures can be declared as capacity-related, the ability to change a service provider for the main run, as well as the ability to switch to express delivery via air freight for a defined scope of supply, can be seen as process-related [14].

Table 1. Shortage Factors per Process Sequence.

m	Sequence	Bottleneck	Scale	Unit
1	Warehousing	Storage area	Metrically	m²
2	Cross-docking	Operational area	Metrically	m²
3	Cross-docking	Personnel capacity	Metrically	hours
4	Packaging	Operational area	Metrically	m²
5	Packaging	Personnel capacity	Metrically	hours
6	Pre-run	Transport capacity	Metrically	Container
7	Main-run	Transport capacity	Metrically	Container
8	Container yard	Container storage area	Metrically	Container
9	After-run	Transport capacity	Metrically	Container
10	Main-run	Alternative carrier	Nominally	LSP
11	Main-run	Express delivery	Nominally	LSP

Here, it needs to be considered that the cost of a measure not only depends on the flexibility range. It also varies based on the setup and utilization time, since a short-term implementation might increase the related price. Referring to the above, in case of a flexibility increase, a measure m contributes to a positive Δq. This is related to setup costs like contract negotiations and utilization costs like surcharge for additional cargo hold. For a flexibility decrease, a negative Δq is aspired. In this case, setup costs occur in form of additional costs like cancellation premiums or expenses for contract adjustments. Utilization costs can be understood as saved remaining costs like remnant costs for labor, unused areas or services provided by contractual partners. In both cases, it needs to be considered that the utilization time of a measure can exceed the targeted planning period and needs to be allocated to multiple planning periods t [14, 28, 42].

3.3. Comparison of cost and benefits of logistics flexibility

The second step of this approach is to provide a multi-period decision model, which considers the adjustment of the flexibility corridors as an investment decision for a planning period t. To determine the related expense for the adjustment of a flexibility corridor, activity-based costing is used. As described above, this includes setup cost and utilization cost for flexibility increase or decrease.

In line with current literature, the use of flexibility is divided into financial and non-financial benefit. In case of an increase of flexibility *(Δq>0)*, growth in sales figures can be expected for the financial benefit. Therefore, a pro rata revenue r^b of the contribution margin CM from non-missing sales of a number of vehicles n_t^{veh} is assigned to logistics. Furthermore, a hypothetically assumed saving on penalties, which are usually charged in the event of an order backlog, serves to reflect avoided customer dissatisfaction due to unfulfilled orders. This is quantified based on Schütz and Tomasgard (2011) in the form of a percentage share r^p of CM amounting to 25 percent [34, 42].

In case of a flexibility decrease *(Δq<0)*, the financial benefit of a measure is not the increase in sales figures, but the saving of costs for unused capacities. This means that the capacities of the process sequences are oversized and possible reduction measures must be evaluated. Therefore, an amount of $c^{ut}_{ps,m,t} < 0$ indicates cost savings.

These costs and benefits for up- and downward adjustments are added up over the time period to be analyzed, as represented in the following formula. The implementation of measures is generally supported if the flexibility value FV is positive.

$$FV = \sum_{t\in T} \frac{(r^b+r^p)\cdot CM\cdot n_t^{veh} - \sum_{ps\in PS}\sum_{m\in M}(c^{set}_{ps,m,t}+c^{ut}_{ps,m,t})}{(1+i)^t} \tag{2}$$

Table 2. Notation.

Indicators	
t	Time period $t \in T$
ps	Process sequence $ps \in PS$
m	Flexibility measure $m \in M$
Variables and parameters	
r^b	Pro rata revenue from non-missing sales
r^p	Percentage of hypothetically saved penalty fee
n_t^{veh}	Number of additional vehicle sales
$c^{set}_{ps,m,t}$	Setup cost
$c^{ut}_{ps,m,t}$	Utilization cost
i	Interest rate
CM	Contribution margin
FV	Flexibility value

4. Use case

In order to apply the developed approach, a representative inbound network is selected for an OEM's assembly plant in India, which is supplied via a consolidation center located in Europe. For this purpose, only the share allocated to India of a consolidation center that serves several countries, is considered. The case refers to the process sequences in table 1. To determine pre-installed flexibility corridors, a basic scenario with constant demand per month for five derivatives D1 to D5 is developed for a planning horizon of six months. Building on the resulting capacity utilization of the basic scenario, the actual flexibility potential for each process sequence is defined. As a premise, available human resources at the consolidation center can vary between 80 to 100 percent without consequences for tactical flexibility planning. Variations within this corridor can be handled through the use of flexible working time models on an operational level. Area utilization can vary between 70 to 100 percent without any need for action on a tactical level. In case space enlargement or reduction is nevertheless required, a minimum utilization time of two months needs to be taken into account. Furthermore, framework agreements with LSPs allow for an increase of 50 percent of the originally agreed transportation volume. If this is exceeded, the operator needs to be changed for the remaining transportation volume.

Focusing on tactical, product-related uncertainties, manifested in changing delivery programs, volume, product mix and new product flexibility is considered in an additional research scenario. In this data set, a sixth derivative (D6) is launched in March.

Table 2. Basic and research scenario [number of vehicles per month].

	Basic scenario						Research scenario					
	D1	D2	D3	D4	D5	D6	D1	D2	D3	D4	D5	D6
1	246	192	198	264	234	0	156	348	120	468	96	0
2	246	192	198	264	234	0	294	264	228	150	216	0
3	246	192	198	264	234	0	384	78	132	246	384	66
4	246	192	198	264	234	0	504	108	414	252	162	330
5	246	192	198	264	234	0	126	270	258	180	270	270
6	246	192	198	264	234	0	360	120	156	60	324	180

Figure 3 shows the monthly utilization of the individual process sequences through the research scenario. It is evident that the process sequences have different sensitivities to changes in demand. Over- or underruns of the flexibility corridors can differ along the supply chain. If the tolerance ranges of the corridors are exceeded, the use of various flexibility measures needs to be evaluated.

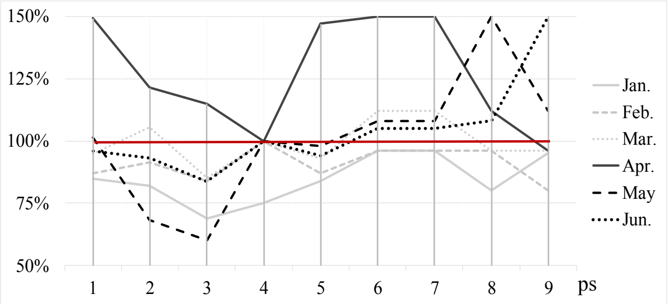

Fig. 3. Capacity utilization per process sequence.

Focusing on April as a peak month after the launch of D6, all process sequences besides ps4 are exceeded. As seen in table 3, setup and utilization costs to compensate the capacity increase are incurred. For ps1 25,042 euros arise due to space enlargement by leasing additional warehouse area. Due to the restriction that area always needs to be leased for a minimum period of two months, additional costs for unused area in May need to be taken into account in April according to the cost-by-cause principle. Since the share of increased parts for cross-docking is not high, only 349 euros for area enlargement in ps2 and 534 euros for overtime hours in ps3 need to be taken into account. As the amount of parts, which need to be packed exceeds the available flexibility potential significantly, 59,835 euros for human resources occur in ps5. Due to that measure, no additional operational area is necessary in ps4. For the pre- and main-run, 10,008 euros in ps6 and 40,034 euros in ps7 need to be considered for additional transport capacity. Comparing figure 3 and table 3, it becomes transparent that the capacity utilization at the container yard and during after-run in the target market is delayed due to the long lead time of the overseas transport. Consequently, the increased amount of shipped volume from Europe in April leads to an increase of capacity utilization at the container yard in India in May and for the after-run in June. Similar to ps1, these subsequently occurring costs need to be considered for the investment decision in April. As a result, costs of 2,404 euros in ps8 and 1,870 euros in ps9 are included in flexibility planning in April. Finally, no process-related flexibility measures are necessary in this scenario.

Due to the strong increase in demand in the month of April, the costs for the adjustment measures can be offset by the financial and non-financial benefits, which leads to 225,659 euros. Using the underlying assumptions, this leads to a flexibility value FV of 85,583 euros and an endorsement of the investment in flexibility. Due to the intra-year planning, interest rate i is not assumed in this use case.

Table 3. Research scenario.

	Planning month April								
ps	1	2	3	4	5	6	7	8	9
Process	Warehousing	Cross-docking	Cross-docking	Packaging	Packaging	Pre-run	Main-run	Yard	After-run
Unit	m²	m²	h	m²	h	cont	cont	cont	cont
%	149	121	115	100	147	150	150	150	150
€	25,042	349	534	-	59,835	10,008	40,034	2,404	1,870
Setup and utilization costs									140,076 €
Financial and non-financial benefits									225,659 €
Flexibility value *FV*									85,583 €

5. Summary

This paper presented a process-based approach for the operationalization and planning of logistics flexibility in an overseas supply network in the automotive industry. Therefore, logistics process sequences are parameterized regarding their respective flexibility range. For their adjustment, nominally and metrically scaled flexibility measures are derived and time- and cost-related implications are assigned. Subsequently, related effort as well as assumed benefit, which come with the investment in logistics flexibility, are integrated into a decision model. With this approach, flexibility in different logistical tasks is numerically expressed and transferred into a comprehensive planning model. The approach supports decision-making processes in international supply chain planning. In contrast to existing research, this concept includes numerous and dependent components of a global supply network.

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