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APPLICATION OF HYSTERESIS FOR STABLE SEGMENTATION WITHIN DIGITALIZED SUPPLY CHAIN MANAGEMENT

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ABSTRACT

Segmentation plays an important role within digitalized supply chain management in the pursuit of competitive advantages, especially in industries where complexity and volatility are present to high degrees. While research in this area is mainly focused on the development of segmentation concepts and the identification of influencing parameters, this paper focuses on the segmentation process and applies a hysteresis to provide stability and autonomous adaptability. Several novel concepts relating to the merger of hysteresis and supply chain segmentation are created, along with a discussion on the process and its requirements. In the end, the theoretical concept is validated by an industrial use case. The results substantiate the concept measured by bound capital and service level.

1 INTRODUCTION

Currently many industries face high degrees of complexity and volatility accompanied with specific challenges like shortening product life cycles, the increase in the speed of product development and changeovers. Furthermore, manufacturing processes are complex and time-consuming forcing companies to perceive supply chain uncertainties differently by exposing them to higher order variabilities (Lee et al. 1997).

To overcome these obstacles and mitigate uncertainties associated with demand and production volatility, manufacturers need to put emphasis on product and process innovation. To this end, digitalized supply chain management is a key element in an operating business and can be regarded as a major success factor (Thonemann et al. 2012; Anandhi et al. 2016). According to Schuh and Meyer (2009), supply chain management delivers concepts and methods that enable savings and enhance higher service levels. These include, amongst others, supply chain segmentation, agility and resilience, supplier and customer collaboration or end-to-end cost optimization (Anderson et al. 2014). Focusing on the topic of segmentation, the research within this field so far mainly concentrates on the development of segmentation concepts and on the identification of influencing parameters. With respect to segmentation concepts, Olhager (2003) and Christopher and Towill (2002) work out concepts considering demand volatility and lead time as main segmentation factors, which aim to select an appropriate supply chain strategy. Looking at the influencing factors of these concepts, some authors extend the aforementioned approach by taking the product life cycle into account (Aitken et al. 2003) or considering an ABC-Analysis as a relevant factor (Schlote 2005). By considering different factors, products tend to switch segments over time, as the described segmentation takes place in regular time intervals at several supply chain elements, nowadays connected by digitalization. This destabilizes the segmentation process and creates mistrust for the segmentation, resulting in nervousness of planners. Andersen et al. (2014) depict further negative aspects of nervousness in segmentation, such as increasing inventory buffers or planning costs. Based on that knowledge, a research gap can be identified by looking at the time period between two segmentation intervals and the stability of the segmentation process itself. Additionally, digitalization enables an autonomous adaptability of the process considering changing environments.

For these reasons, the idea of a hysteresis concept applied to product segmentation came about to ensure the responsiveness of environmental changes and to stabilize the process in context of digitalization. The approach takes the past state of segmentation into account for determining the new state and allowing to set the stable behavior with different boundary values. To our knowledge, the application of a hysteresis in the area of supply chain has not taken place yet. Until now hysteresis concepts have been applied to fields such as physics, economics, electrical and mechanical engineering (Tan and Iyer 2009), and can form a cross-validated basis to close the identified gap in research as it already does in the aforementioned scientific disciplines.

This paper focus on the investigation of the supply chain segmentation process itself. It documents a conceptual study of hysteresis application in supply chain segmentation and the simulation of experiments for the proof of concept in context of an industrial case study. Section 2 presents the literature review focusing on supply chain segmentation and the concept of hysteresis. In Section 3, we merge supply chain segmentation with hysteresis forming a solution in the trade-off for adequate segmentation intervals. In Section 4, the generated concepts for merging product segmentation with hysteresis is outlined and we provide the simulation setup in order to show emerging effects on the supply chain. Concluding with a summary of the results and recommendations for further research.

2 LITERATURE REVIEW AND RESEARCH BACKGROUND

2.1 Supply Chain Segmentation

Supply chain segmentation is the strategy of subdividing supply chain elements into entities with the same properties and apply tailored methods in order to increase performance (Thomas 2012). Dealing with supply chain segmentation, the most concepts and approaches involve the adaption of production or delivery strategies as a result or recommendation. Olhager (2003) distinguishes between four different product delivery strategies: Make to Stock (MTS), Assemble to Order (ATO), Make to Order (MTO), and Engineer to Order (ETO). Each strategy differs through the specific supply chain stage at which point products get assigned to distinct customer orders, also named the Customer Order Decoupling Point (CODP) (Olhager 2012). Several researchers investigated the effects of its positioning and developed concepts to identify appropriate production strategies. The approaches developed by Olhager (2003), Christopher and Towill (2002) and Aitken et al. (2003) form a base for a wide range of further research and are highly referred. Basic concepts differ from advanced ones by the number of input parameters and the abstraction from reality. As other relevant segmentation approaches we refer to the ones of Christopher and Towill (2002, Olhager (2003), Aitken et al. (2003) and Godsell et al. (2011).

According to Plenert (2014), the segmentation process for supply chains consists of three stages: analyze, build and execute. Alicke and Haller (2017) propose continuous calculations, which requires regular segmentations. The interval between segmentation runs depends on characteristics of products and industry. Schlote (2005) states that companies execute segmentation processes on a quarterly basis, to avoid both, keeping a product in the wrong segment and to switch unnecessarily between strategies. This represents the trade-off between long and short intervals of segmentation runs (Plenert 2014). The topic of planning flexibility and the ability to continuously respond to a changing environment is known as nervousness (Schönberger and Kopfer 2008; Andersen et al. 2014). Planning nervousness leads to disruptions in production plans, higher inventory buffers, and increasing costs (Pujawan 2004; Kaipia et al. 2006). Additionally, due to disruptions the planners loose confidence in the planning system or even start mistrust it (Blackburn et al. 1986). Consequently, planners attempt to stabilize the process with manual adjustments, although such activities can increase rather than descrease nervousness (Andersen et al. 2014).

2.2 Hysteresis in Science

The term hysteresis comes from the Greek term "hysteros" meaning "to be late" or "come behind". In general, hysteresis represents a defined interconnection of input and output in order to regulate the output behavior. It is mostly displayed as a loop via graphical schemes. Hysteresis are widely spread in science, including engineering, physics, or social sciences and validated in respective cases like in hydrology by Beliaev (2003), glaciology by Díaz and Schiavi (2000), materials by Smith (2005), and economics.

Depending on the specific purpose, the complexity varies from distinct states with two boundaries to exponential functions. Hence, diverse hysteresis applications appear in various scientific disciplines.

Starting with engineering science, within control theory engineering, basic forms of hysteresis are used in two point controllers. In addition, the so called Preisach Model represents one of the most widespread applications of hysteresis. The Preisach Model superposes many hysterons with given weights by summing up all elements (Mayergoyz 1991). In practice, this model is often applied in mechanical problems concerning the connection of a heavy body to a spring.

Aside from the application in natural sciences, hysteresis concepts are discussed in economics as well, mainly in micro- and macroeconomics. For example, hystereses phenomena occur in the labor market in association with unemployment (Schmid 2011). According to Winkler (2002), recruitment and cancellation show a sunk cost characteristic similar to hysteresis graphs. Dixit (1989) elaborates and validates another field of application, where he identifies that discontinuous hysteresis describes the relationship between sunk market-entry and market-exit costs in microeconomics. The principles of hysteresis allow its application in further economic areas to describe different situations. Yet, hysteresis concepts have not been connected to supply chain segmentation yet.

3 HYSTERESIS AT SUPPLY CHAIN SEGMENTATION

3.1 Structure of Hysteresis Approach

The goal of applying hysteresis to segmentation is to leverage the trade-off between short and long intervals and to provide a stable, autonomous process. First, the band of inaction at hysteresis leads to stabilizing effects: Before input changes affect the output, this predefined interval needs to be overcome. Consequently, stable behavior requires the maximum possible distance between boundaries. Secondly, hysteresis provides adaptability in order to take major changes in products' environment into account. If a boundary is exceeded or undercut, the hysteresis triggers new segmentation runs which consider the varied circumstances. Adaptable behavior requires the minimum possible distance between the boundaries. Thus, stability and adaptability have contrary requirements: a short band of inaction is needed for adaptability, while a wide band of inaction is necessary for stability.

In order to illustrate the purpose and benefits of the hysteresis approach, Figure 1 compares its application on an input parameter's course of time to thresholds. The input value is randomly generated for a distinct period of time and marked on the vertical axis. Dark gray, striped gray, and light gray areas represent the output according to the actual input value and the controlling by thresholds or hysteresis, respectively. In the case of threshold application, the output changes if either β or ε are passed through. With hysteresis, each threshold is replaced by two boundaries: α and γ replace β, δ and ϕ replace ε. If the input value exceeds the upper boundary or if it falls below the lower boundary, the output changes. The intervals $[\delta , \phi]$ and $[\alpha ,\gamma]$ represent the hysteresis's band of inaction. Comparing the two diagrams, it is clear that hysteresis reduces the number of changes from 9 to 4 in comparison to thresholds. Although the approach of thresholds in product segmentation represents a demand-driven approach as well, stability requires the concept of hysteresis.

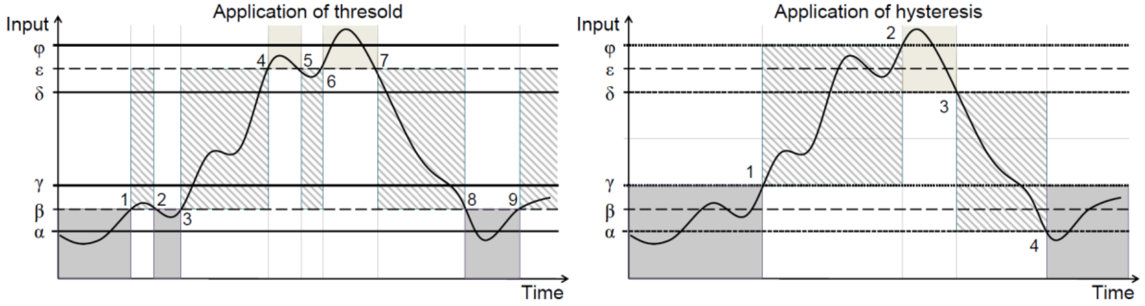


Figure 1: Comparison of Threshold to Hysteresis.

Focusing on the process requirements of both concepts, a hysteresis transforms a single, continuous input value to a single, discrete output value, while as shown by the literature supply chain segmentation takes several input parameters into account. In order to merge segmentation with numerous parameters and hysteresis with single input and output, the handling of parameters has to be outlined. There are two methods of resolution, as can be seen in Figure 2. On the one hand, there exists the multiple hystereses approach, where a specific hysteresis is derived for each input parameter. Applying multiple hystereses requires great effort in finding suitable hysteresis forms and boundaries and generating a scheme which merges the hysteresis's outputs. In contrast, multiple hystereses allows precise adjustments of the setting according to particular requirements of each input parameter. On the other hand, there is the single hysteresis approach. Instead of applying hysteresis for each parameter and merging the outcome afterwards, this approach merges all necessary input parameters for segmentation to one value which is then transferred to a distinct output by a single hysteresis. Fusing the various segmentation parameters into one requires several assumptions and may lead to inaccuracies. In addition, a fine tuning of a specific parameters' effects is missing. Positively, the application of a single hysteresis entails less effort at implementation and provides a clear outcome.

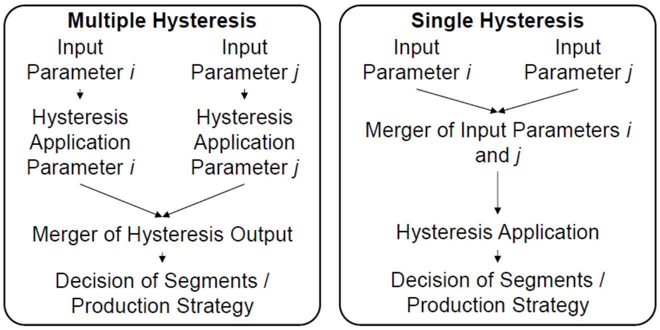


Figure 2: Structure of Hysteresis Application on Segmentation.

3.2 Concepts for Hysteresis Application

Starting with a discrete hysteresis and two output states, Figure 3 illustrates the fundamental merger of hysteresis and supply chain segmentation. The horizontal axis displays the hysteresis's input parameter, either a single segmentation parameter or the merged parameter depending on the structure of application. The vertical axis depicts both output states MTS and MTO. The colored areas represent these production strategies to pursue according to the input value. In the case of an initial MTS strategy and an increasing input value, the boundary δ triggers the change to a MTO strategy. If the input value falls below α, the strategy switches back to MTS.

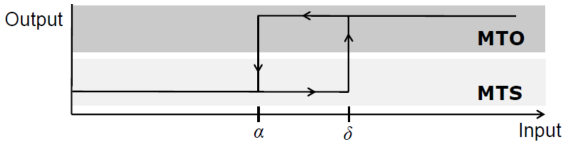


Figure 3: Discrete Hysteresis with two output states.

In the next step, we extend the model to a discrete hysteresis with three output states which are interconnected in a supply chain. The approach includes ATO as an additional output alternative. The extension requires in total two discrete hystereses for the transition from MTS to ATO and vice versa. So two additional boundaries β and γ are incorporated. Again, starting with an initial MTS strategy and increasing input value, the boundary β triggers the change to an ATO and δ to an MTO strategy. In case of a decreasing input value, the boundary γ initiates switching back to an ATO and α back to a MTS strategy. Figure 4 summarizes the different strategies, shifting the customer order decoupling point backwards in the supply chain. In comparison to a discrete hysteresis with two outputs, this approach is accompanied by less effects on the supply chain, due to a higher output granularity. Most importantly, shifting the CODP forward, results in side effects such as new bottlenecks and adaption of plans can be reduced. Furthermore, additional output stages reflect the current state in more detail.

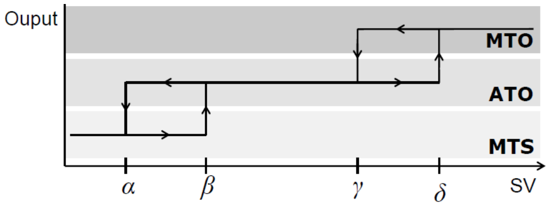


Figure 4: Discrete Hysteresis with three output states.

Continuous hysteresis with two output states replaces discrete transitions of the initial concept with a linear function. Figure 5 displays the adjusted approach. The horizontal axis still shows the input value, whereas the vertical axis switches from previously discrete output areas to the share of stock allocation at the appropriate stocking point. It represents the percentage of stock which is stored at the end of the supply chain according to the MTS or MTO strategy, on the left and right respectively. Regarding the hysteresis description, two values for initiating and completing the transition phase replace discrete triggers. Hence, the increasing branch is subdivided into δ_1 and δ_2 and the decreasing branch into α_1 and α_2.

This approach enables the additional setting of options. First of all, an allocation of stock to multiple stocking points is possible. The continuous and smooth transition phase approximates more precisely a suitable implementation in practice. Furthermore, this approach might include additional stocking points and production strategies like ATO as well. In supply chain planning, stock levels are subdivided according to their purpose and treated by specific handling rules. In continuous hysteresis, such rules become applicable. For example, minimum stock targets ensures customer satisfaction and thus is only shipped in the most urgent cases. If the horizontal part of the hysteresis scheme in Figure 5 is placed in between of the vertical extreme values (that is, 0% and 100%), the stock is separated between both stocking points for high or low input values, which represents safety stock rules. Due to the fact that the horizontal hysteresis part intersects the vertical axis, the minimum stock is independent from the input value. However, options exist for continuous rules beyond hysteresis. In order to utilize the potential for continuous stock rules, a linear function replaces the horizontal hysteresis graphs. Hence, the stocking allocation depends on the input value of the entire scheme. In case of an increasing graph beyond the hysteresis loop (for example the MTO ratio increases on the lower branch between α_1 and δ_1), minimum stock rises together with the input value. This behavior might be advantageous for some input factors, for instance if stocks and volatility correlate.

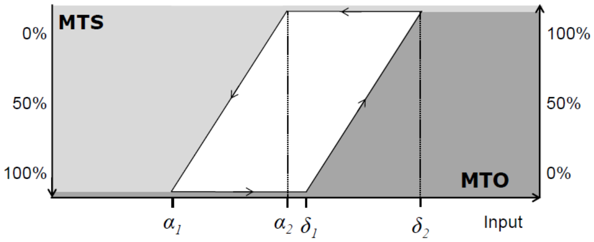


Figure 5: Continuous Hysteresis with two output states.

4 SIMULATION

4.1 Input Parameter

To investigate the outlined characteristics of a hysteresis approach for a stable and autonomous supply chain segmentation process, a simulation experiment was defined and conducted. The simulation was based on the single hysteresis model, as it was more suitable for initial research due to its easy implementation and considerable effects comparing to non-hysteretic approach. Therefore, the various input parameters needed to be merged to one segmentation input value (SV). The SV serves as input for the hysteresis approach which determines the position of the CODP within the supply chain. As this value is generated from scratch, specific purposes are considered, in particular the hysteresis requirements and a volatile, complex industry with short product life cycles. Thus, the SV is limited to an interval between 0 and 1 in order to apply a hysteresis with boundaries that are constant over time. The connection between SV, the production strategy and stocking point is defined as follows: SV = 0 recommends an MTS strategy and SV = 1 an MTO strategy. SVs which are located at the mean of both extremal values tend to ATO strategy.

Next, suitable parameters are identified which are necessary to describe the segmentation method appropriately. Olhager (2003), Aitken et al. (2003), Christopher and Towill (2002), and Plenert (2014) propose different segmentation parameters which represent widespread and commonly referenced consideration. Already taking the following case study from the semiconductor industry into account, the most recurring industry specific parameters proposed by Forstner and Mönch (2013) and Schlote (2005) are used: product diversification, value added, demand volatility, production cycle time, order lead time and the product life cycle. Each of these parameters influences the SV individually. According to the parameter and its value, the maximum or minimum values recommend either an MTS or an MTO strategy and thus require high or low SV level.

For the simulation, input data from Infineon's Automotive division is used. Product diversification is reflected through a 1:1 relation per basic product type with SV=1 and a 1:10 relation for SV=0. The value added is updated once per year and based on the cost distribution on the main manufacturing steps. Demand volatility influences the SV on a weekly basis. This parameter is represented by the Coefficient of Variation (CoV),where a CoV of 0.75 is considered as high (Forstner and Mönch 2013) and values equal to or above that level lead to SV = 1, whereas a CoV of 0 results in SV = 0. The product life cycle's contribution to the SV is calculated yearly. The maximum of the life cycle curve is assigned to SV = 0, whereas the minimum relates to SV = 1. The ratio of production cycle time and order lead time, updates the SV weekly. In case of a ratio above 1, the SV equals 1. As the production process at Infineon takes up to several months and hence, changing the production strategy from MTS to MTO or vice versa persists several weeks up to months, a time horizon of 20 years is chosen for the simulation.

The calculation of the SV proposes a process describing the merger of the input parameters mathematically. This step considers the characteristics of each parameter and its relevance for the SV. The process consists of normalization and addition. First, each of the n input parameters are normalized. This initial normalization is needed due to the diversity of the input parameters in scale and unit. Hence, the following equation determines the normalized input parameter for each i = 1,...,n input parameters at the time *t*:

$$\mathit{normalized\,input\,parameteri}\,(t) = \frac{\mathit{input\,parameteri}\,(t)}{\mathit{max}(\mathit{input\,parameteri})} \tag{1}$$

Second, the normalized input parameters are multiplied with a weighting and summed up to an *Input sum*:

$$\mathit{input\,sum}\,(t) = \sum_{\mathrm{i}=1}^{\mathrm{n}} (\mathit{normalized\,input\,parameter} \cdot \mathit{weighting}) \tag{2}$$

The third steps contains the normalization of the *Input sum* in order to provide a constant interval for the hysteresis application at a specific time:

$$SV\,(t) = \frac{\mathit{input\,sum}\,(t)}{\mathit{max}(\mathit{input\,sum})} \tag{3}$$

In order to calculate the course of the SV, several assumptions are necessary for the regularly updated parameters, as historic data is often scarcely available. Regarding demand volatility, the course of this parameter is based on a merger of the product life cycle and on existing data of a one year horizon. We assume that volatility is highest at the beginning and end of the life cycle. Concerning the ratio of production cycle time and order lead time, the production cycle time stays constant, while the order lead time refers to real data of one year and is extended to the simulation period. As a result, the light gray line of Figure 6 shows the SV on a weekly basis for a time frame of 20 years. The black line presents the moving average of SV considering twelve past events and is used for the simulation input. The aggregated SV course bases mainly on demand volatility and the ratio of production cycle time versus order lead time due to the high importance on segmentation.

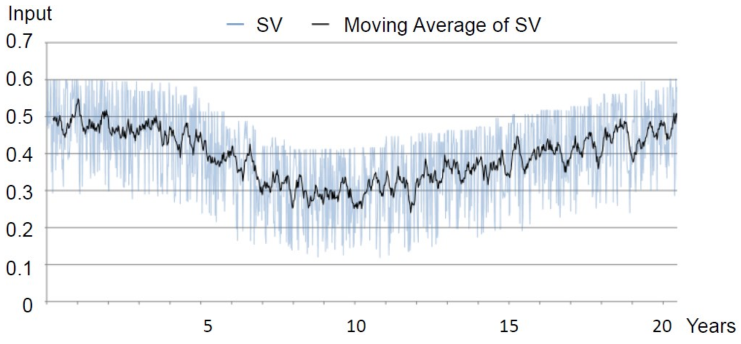


Figure 6 : Course of time of SV.

4.2 Experiment Settings

The basic experiment's target is to investigate the general characteristics of the hysteresis approach. Therefore, two experiments are conducted with both hysteresis and threshold applications, in order to compare differences. The applied hysteresis is a discrete hysteresis with three output states. Table 1 displays both experiments, the trigger method for changing segments, and the respective boundaries. The threshold values are arranged in the middle of the hysteresis interval. An extract of the SV course serves as the input for the hysteresis and the threshold experiments. The resulting effects are demonstrated on the different courses of strategy which represents the outcome of hysteresis and the threshold applications.

Extended experiments for supply chain effects aim to point out the hysteresis impact on the supply chain performance and to identify potentials. For this purpose, three experiments are conducted, using constant strategies and the hysteresis control with several boundaries, shown in Table 2. The extended model, which combines hysteresis with the supply chain, simulates the behavior of the strategies. The experiments apply a discrete hysteresis with two output states. The constant strategies MTO and MTS are applied in Experiments 1 and 2 and are assigned to one week target. Experiment 3 considers the hysteresis application which acts as an MTO or an MTS strategy depending on the boundary setting and the input values. The boundaries vary according to the Preisach plane and cover all connection opportunities for α and δ.

Table 1: Experiment set up for basic hysteresis characteristics.

Experiment	Trigger	Boundaries			
		α	β	γ	δ
1	Threshold	0.4		0.6	
2	Hysteresis	0.3	0.5	0.5	0.7

Table 2: Experiment set up for supply chain potentials.

Experiment	Strategy	Target Reach		
		MS	DB	DC
1	MTO	1	0	0
2	MTS	0	0	1
3	Hysteresis	1	0	0
		0	0	1

Figure 7 illustrates the continuously updated input parameter SV (gray line) and demand (black line) over the simulation period. During the introduction of a product and the end of life phase, the demand is determined low with a high volatility, the maturity phase contains high demand and low volatility. In order to consider demand uncertainty, the course is multiplied by random numbers.

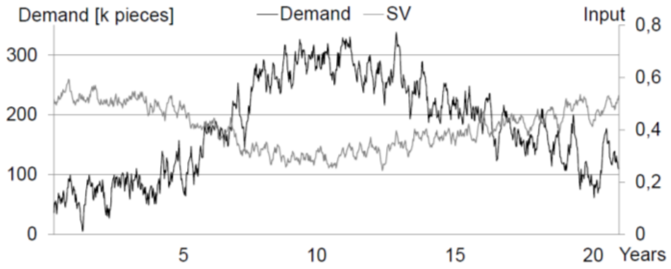


Figure 7: Continuous input for supply chain simulation.

4.3 Results

In order to show the general effects of hysteresis, stability and autonomous adaptability, the simulation applies a threshold and hysteretic approach using the basic part of the model. Figure 8 depicts the results of both experiments, reflected in Table 1. The dashed lines mark the boundaries, the black line shows an extract of the SV, and the gray line represents the strategy which either is recommended by thresholds or hystereses.

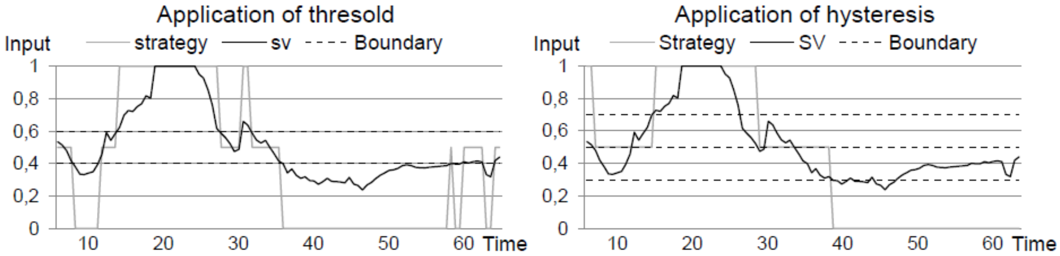


Figure 8: Comparison of basic effects between threshold and hysteresis.

The number of changes between strategies is reduced from 12 to 4 via the hysteretic application. From time unit 50 onwards, the hysteresis avoids various switches. This behavior proves the theoretical concept presented before. Changes of the input SV affect the strategy on a timely delay within the comparison of threshold and hysteresis. For example, the change between time unit 30 and 40 retards about 5 units. In case of slow decreases, the lag increases. Regarding total costs, the course resembles the product life cycle curve, as Figure 9 shows. In the maturity phase, when higher demand is observed as around year ten in figure 9, more products are located within the supply chain than during the introduction or the end of life phase. Thus, due to their correlation, the WIP and the total costs increase. Comparing both strategies, MTO bounds less capital than MTS during the entire simulation run, as shown through the bold lines. This effect is caused by increasing costs for products stored at the end of the supply chain. Focusing on the service level, MTS serves higher customer satisfaction than MTO in general, as depicted through the thin lines in the diagram. The service level of MTS resembles the product life cycle curve, due to higher demand volatility at the beginning and end of the cycle, and lower demand volatility at the maturity phase. At MTO, the service level of the first years takes high values due to low demands and the filled supply chain resulting from the warm up phase. For increasing or decreasing demand and high volatility at year 3 to 6 and 12 to 20, the parameter falls on a lower level. Nonetheless, both strategies reach the same service level for stable demand during the maturity phase.

Comparing the different courses of MTO and MTS service level and costs, it becomes obvious that one strategy does not constitute the optimal trade-off along the whole product life cycle. During the introduction and the end of life phase, the MTS strategy shows advantages in explicitly higher service levels at moderate raise of costs. During the maturity phase, both strategies reach the same service level at lower costs for MTO. To sum it up, the experiment shows advantages if the strategy is adapted during a product's life.

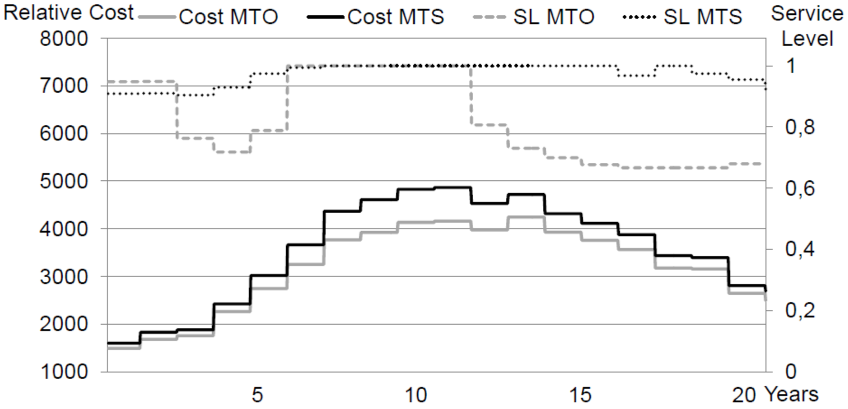
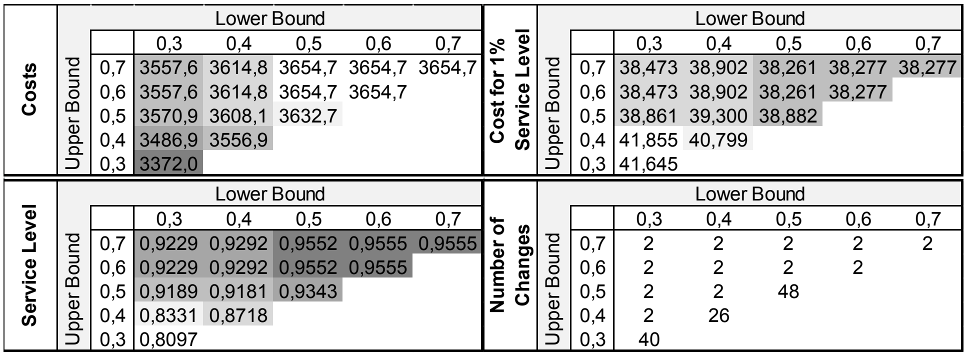


Figure 9: Cost and service level of MTO and MTS strategy.

Figure 10 displays the results of experiments, reflected in Table 2 and includes Costs, Service Level, Costs for a 1% increase of Service Level, and the Number of Changes. The structure of the tables refers to the Preisach plane which notes the hysteresis boundaries on a matrix (columns exhibit the lower bound, rows the upper bound). The intensity of the colored fields rank the results according to the applied boundaries, with dark gray areas being preferable to the light gray equivalents. The boundaries cover the interval between 0.3-0.7, depending on the range of the SC. The cost optimum is achieved at the application of low hysteresis boundaries or thresholds as both are equal. In this case, the hysteresis tends to apply a MTO strategy for a longer period of time. Conversely, hysteresis boundaries with high values of 0.7, which are located on the upper right side of the Preisach plane, tend to implement a MTS strategy. Thus, the simulation exhibits a high Service Level in this area (second part of Figure 10). In order to merge both performance indicators, the costs for 1% Service Level are determined. The optimum is located at upper bounds of 0.6 and 0.7 and a lower bound of 0.5. Although the connection implies a linear relationship, the results indicate beneficial regions. The fourth table of Figure 10 shows the number of strategy changes. For the hysteresis boundaries with the optimum costs for service level, the hysteresis triggers solely two changes thus enabling a stable segmentation process. The diagonal elements which represent thresholds, the results from presented before are supported as thresholds show a higher number of changes comparing to hysteresis.



Costs		Lower Bound				
		0,3	0,4	0,5	0,6	0,7
Upper Bound	0,7	3557,6	3614,8	3654,7	3654,7	3654,7
	0,6	3557,6	3614,8	3654,7	3654,7	
	0,5	3570,9	3608,1	3632,7		
	0,4	3486,9	3556,9			
	0,3	3372,0				

Cost for 1% Service Level		Lower Bound				
		0,3	0,4	0,5	0,6	0,7
Upper Bound	0,7	38,473	38,902	38,261	38,277	38,277
	0,6	38,473	38,902	38,261	38,277	
	0,5	38,861	39,300	38,882		
	0,4	41,855	40,799			
	0,3	41,645				

Service Level		Lower Bound				
		0,3	0,4	0,5	0,6	0,7
Upper Bound	0,7	0,9229	0,9292	0,9552	0,9555	0,9555
	0,6	0,9229	0,9292	0,9552	0,9555	
	0,5	0,9189	0,9181	0,9343		
	0,4	0,8331	0,8718			
	0,3	0,8097				

Number of Changes		Lower Bound				
		0,3	0,4	0,5	0,6	0,7
Upper Bound	0,7	2	2	2	2	2
	0,6	2	2	2	2	
	0,5	2	2	48		
	0,4	2	26			
	0,3	40				

Figure 10: Simulation result of hysteresis application.

5 CONCLUSION

Supply chain segmentation can enable competitive advantages and tackle volatile and complex industry conditions like long production cycle times or high short-term order variabilities. In practice, segmentation imposes challenges relating to process stability and autonomous decision making. As hysteresis represents a mathematical tool for stabilization and is able to adapt to a changing system, it has been shown that, this concept can be applied in order to stabilize the product segmentation process in supply chain management.

Concepts for merging the fields of hysteresis and segmentation are generated in order to provide stability and autonomous adaptability. As advanced segmentation requires several input parameters, the hysteresis can either be applied on every single parameter and the outcomes are merged afterwards (multiple hystereses concept), or the input parameters are merged prior to the hysteresis application (single hysteresis concept). Regarding the hysteresis, four concepts were presented: discrete and continuous hysteresis, with two or three output states, that can be consecutively extended to more states. Discrete concepts are used for a basic approach, while continuous concepts enable additional setting options like the allocation of stock on multiple stocking points.

In order to evaluate the hysteresis approach, several experiments are conducted within a simulation model. The hysteresis input is defined as SV and the production strategy represents the output. Regarding the simulation setup, the design bases on the internal supply chain of the Infineon Technologies AG providing all considered data for the segmentation and evaluation. On the one hand, the experiments' settings address investigation of hysteresis behavior in comparison to thresholds, on the other hand they emphasize the effects on the supply chain measured in costs and service level.

The results of the experiments support the theoretical concepts and prove the main advantages of hysteretic approaches - stability and autonomous adaptability. However, hysteresis causes time lags in strategy adaption which has to be considered at implementation. With respect to the effects on the supply chain, it is recommended to adapt the strategy during the product life cycle. The hysteretic approach shows positive effects on the applied supply chain performance indicators: the cost of bound capital decreases, while the service level increases.

The autonomous adaptability is provided by the freely adjustable hysteresis set-up. While we have chosen five different input variables, it is possible to add additional ones or to use fewer, aligned to the complexity of the respective supply chain environment Furthermore, depending on the mathematical formulation of a hysteresis function, which could be dynamic as well, the approach can adapt environment changes itself.

The underlying hysteretic approach was also validated by comparisons to well-known applications in science. Since supply chain parameters like order lead times tend to be stable over time, a cross-over validation to approaches in physics, where inputs are mostly stable as well, was considered suitable.

As this paper serves only as basic research on the merger of supply chain segmentation and hysteresis; opportunities for future investigations exist: Looking at the concept of the segmentation value further research on parameter selection and influence of each on the supply chain performance is necessary. Furthermore, the simulation can be extended by more details and more complex form. Further, additional stocking points can be included in future investigations. Finally, since the concept is tested on one single use case, the application of the developed hysteresis approach on more industries and supply chain fields might provide valuable insights and prove the validity of the model further.

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