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Fixed cost management as an Enabler for Agile Manufacturing Networks

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Abstract

Markets worldwide are tending towards higher volatility and complexity. This results in increasing uncertainty and rapidly changing requirements for producing companies. While the planning of global manufacturing networks has so far been seen primarily as a long-term optimizing task based on predictions of the future, today agility is a major competitive factor for being able to react quickly to market changes. As a result, the focus in the network design shifts from optimizing based on made assumptions to explicitly designing the adaptability of a network to unpredictable changes. One of the main obstacles thereby are high fixed costs, which are none or less changeable and hence often result in remaining costs after a change, so-called sticky costs. Thus, the purpose of this paper is to present methods to manage fixed costs and reduce possible sticky costs in manufacturing networks. Subsequently, the paper discusses to what extent an often-connected increase in costs, here called "agility costs", is acceptable to achieve a higher level of agility in the manufacturing network.

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1. Introduction

Today, producing companies have to face a rapidly changing internal and external environment and an increasing uncertainty in their requirements and restrictions. In the so-called VUCA world (volatile, uncertain, complex and ambiguous) new challenges arise both internally, in the company itself, and externally, caused by a change of the surrounding. [1]

Political instabilities, a rapid technical progress, a massive increase in customization and a barely comprehensible economic dynamic worldwide raise the complexity, volatility and uncertainty of the overall system tremendously. [2] As a result the detailed, long-term prognoses of situations, conditions and markets overall is getting significantly harder and the importance of fast responsiveness increases continuously. [3] Furthermore, the associated, changing product development process requires an additional internal shift of production. Due to short, iterative development cycles with a strong customer focus, the rising agile product development process requires higher adaptability of manufacturing networks both in the development phase itself and in the production phase afterwards. A large amount of, sometimes severe, quick change-requests require a constant reorientation of the manufacturing networks. [4]

Under these circumstances, the presumption of "consistent" design factors for manufacturing networks will only play an increasingly subordinate role in the future. Disruption and change are progressively replacing stability. Moreover, "uncertainty" is the normal condition and "certainty" the exception in the manufacturing network design.

Most of the current approaches for network design are not prepared for these conditions. Their primary targets are a detailed optimization of a network onto one operating point based on a pre-defined set of quantitative factors. [5] However, the numbers behind those factors are in most cases just historical data, human assumptions or simple projections. Thus, the network design is based on many uncertainties. In order to control this uncertainties, there have been numerous approaches for years that have endeavored to produce ever more accurate predictions using mathematical models, scenario techniques, sensitivity analysis, best and worst case calculations, etc. [6], [7], [8] The emergence of computer-aided simulations and neuronal networks has spurred this even further. [9] The basic assumption here is that a network should no longer be aligned to just one operating point but to a corridor of probable numbers. Nevertheless, the entire design is based on one singular assessment and planning of all risks in advance. "Global footprints" are then often designed for years on the basis of the estimated assumptions made.

This contradicts the idea of the unpredictability of today's VUCA world. Moreover, practice also shows that in the estimations still many false assumptions are made. Factors are wrongly assessed or not recognized, developments are not foreseen. [10] This means that manufacturing networks are not optimally designed and must be adapted afterwards. [11] Studies show that an optimization of an average manufacturing network has a cost saving potential of 45%, however most companies save only 10% [12]. The problem is that today's manufacturing networks are too slow to adapt to changing environmental conditions outside their planned corridor. The networks, respectively the corresponding locations, productions and machines, are flexible in a defined area but not easily adaptable/changeable beyond this area. [13] One reason for this slow adaption are high, non-changeable fix costs such as completely automated production lines or large administrative overhead. They often have their origin in the assumption of an ideal operation state to be achieved with a precisely described need for flexibility and a resulting optimum cost efficiency e.g. due to the exploitation of economies of scale. However, in times of a necessary adaption this results either in a refusal of change or in the occurrence of sticky costs, which remain unwillingly after e.g. a relocation of a product due to a non-divisibility or non-movability of fixed assets or certain contracts. [14]

Starting from the basic assumption to have a certain percentage of acting factors on the network, which are completely unknown in direction and height, and to which therefore a network cannot be specifically designed and optimized, it is however necessary to actively shape this adaptability. Therefore, agile manufacturing networks have to be designed, which can quickly, cost-efficiently and ideal proactively be redesigned to changed environmental conditions. [15], [16]

The paper aims to approach one aspect of this problem: The reduction of the sticky cost effects after a change through a reasonable fixed cost management. The focus is on creating a more adaptable structure where necessary and even accepting increased costs in the form of so-called “agility costs”, in order to ensure the long-term viability of the network. The authors present approaches for raising the adaptability of fixed costs. Three directions are pursued: the general reduction of fixed costs, the variabilization of fixed costs and the increase of the changeability of fixed costs. In addition, the possibly arising agility costs are described and in a first discussion set in relation to the agility benefit, which is often difficult to estimate.

2. Prior Research

In the following, prior research to the topics of manufacturing network design, uncertainty & risk, changeability & agility and cost management & sticky costs is evaluated to understand the framework conditions for the research of the paper.

Since the beginning of globalization, the design of manufacturing networks is becoming increasingly more important and represents a tremendous need for discussion in science. [17] In general, there are many approaches including a procedure for the design of manufacturing networks. Most of them focus on a holistic consideration of the manufacturing network and present an often theoretical model or method to deploy in practice. [12] Many approaches are either purely qualitative or based on, and therefore are only as good as, made estimates of quantitative factors. [18]

For this reason, an increasing number of approaches include the issue of factor uncertainty and risk in their considerations. Mathematical models, multi-criteria optimization, sensitivity analyses or scenario techniques approximate the possible fluctuations of the basic assumptions and thus potentially improve the estimation. For example, the approaches of LANZA and KREBS provide methodologies for strategic planning of global networks. Here the determination of changing requirements and time, due to an uncertain environment and a long-term planning horizon necessity, are focused. In addition to the consideration of multidimensional uncertainty in the environment, conversion drivers have to be integrated into the evaluation. The optimal design of the manufacturing network is to be determined by a multi-criteria optimization at a certain point in time. [19] [20] Besides these optimizations, GOVINDAN & FATTAHI e.g. investigate the risk and robustness measures for a network under uncertainty stochastically. [21] On the other hand, risk management approaches, like MANUJ & MENTZER, address practical procedures, processes and qualitative aspects, but deal too vaguely with the concrete design of manufacturing networks and mostly do not provide any quantitative measure. [22]

The problem with most of the mentioned approaches is that they can only be applied theoretically without practical relevance due to their mathematical limitations or are limited to a very narrow area or sector. In addition, they include only a static optimization without subsequent adaptation possibilities.

As the answer to deal with unpredictable uncertainty in global manufacturing networks, the terms changeability and agility were introduced as the logical extensions of flexibility, which is a discussion topic since decades. [23] While flexibility ensures the adaption to a predefined set of values, changeability enables the overall adaption of a network to unknown factors. Agility even more ensures a proactive, quick and cost-efficient reaction best without any longer latency. [24], [25] KREIMEIER proposes changeability by using modular production systems. [26] RAMSAUER ET AL. aim at the expansion of the understanding of agility in order to support companies with the introduction of agile measures. The approach covers all parts of an agile company but does not focus on the production itself. [27] MONAUNI presents a possibility to shift production and capacities in between the manufacturing network by creating additional capabilities. [28] While the mentioned approaches introduce first ideas of agile manufacturing and changeable networks, they are lacking specific and quantitative agile design measures and are less focused on manufacturing networks. Moreover, the cost of agility and thus the necessary trade-off between adaptability and cost-efficiency is barely addressed by them.

In general, the description and management of cost in a manufacturing network or supply chain is widely discussed in the research. Common references such as SEURING introduce many topics to accurately locate and calculate cost in the network. [29] In addition, strategic cost management, as a sub-section of the cost management, connects the accounting and the strategic management view to align cost models with business strategy and thus improve decision-making. [30] Nevertheless, fixed cost management in terms of sticky cost management or the overall flexibility and adaptability of costs is rarely in the focus of cost management.

The existing research on sticky costs focused in the last decades mainly on theoretical questions or examination studies. [31] BELTZ discusses the occurrence of sticky cost by formulating theoretical calculations for fixed and step-fixed costs as well as the influencing parameters. [32] Additionally, in recent years the authors presented the first practical formulas to calculate and assess sticky cost. [33]

The literature review shows that many approaches for the design of production networks under uncertainties exist. Some consider a first integration of agility and the sticky cost phenomenon through fixed cost. Nonetheless, all of them lack in practicability or address just one delimited topic. In summary, it can be stated that there is a deficit in concrete measures to implement agility in manufacturing networks and deal with the sticky cost effect adequately by handling the fixed costs. Furthermore, the topic of identifying agility costs and determine the right level between cost and agility benefits is barely addressed yet. The paper presents an approach to cover both of these topics and discusses fixed cost measures to enhance agility. Moreover, it is aligned with a developed framework for a dedicated agility to design agile manufacturing networks. [16]

3. Fixed cost management as an enabler for agile manufacturing networks

The concept is structured into three parts. First, a short introduction to fixed cost in manufacturing networks is given. It provides a differentiation between variable, fixed and step-fixed cost. Afterwards measures of lowering the sticky cost effect of fixed cost by reducing, converting or modifying fixed cost are proposed. In the end a definition and discussion of agility costs and their appropriate proportion concludes the paper.

3.1. Fixed costs in manufacturing networks

The total costs of a company and thus also of a production network consist of variable and fixed costs. The variable costs describe the part of the costs that is directly connected to the output quantity, while the fixed costs are independent of the produced quantity at first glance. [29] This simplified consideration of the costs refers to a limited observation period and neglects correlations and changes of fixed costs. Especially in the context of global manufacturing networks, in which long periods of time and profound changes in the fixed costs are of great importance, the fixed costs have to be further subdivided and differentiated. Certain “fixed” costs, such as particular buildings or machines, do not increase within certain boundaries, but must be increased or reduced above or below these boundaries. This fact is considered in the so-called step-fixed costs, which are just fixed in a certain quantity interval. [34] An exact differentiation to fixed costs does not exist here, however.

For this reason, the following definitions for the different cost types are used for further consideration and are displayed in Figure 1. Fixed costs are defined as costs that are (almost) independent of the quantity produced, even if the planned output quantity long-term is zero, for example, in the case of a pure development company without its own production site. This includes, among other things, the assets and personnel of a corporate headquarter including various areas such as sales and marketing. As a permissible simplification, indirect correlations, such as the demand variation of indirect departments dependent on the increase or decrease of production quantities, are not considered.

In comparison, the step-fixed costs only arise from a, at least previously planned, in-house produced quantity of one piece in the form of production buildings, personnel or machines. Furthermore, these costs increase abruptly as soon as certain interval limits are exceeded.

The distinction between fixed and step-fixed costs is especially significant when considering the sticky cost effect. This effect could occur in the fixed costs in case of a necessary change in the indirect areas and thus possibly remaining costs e.g. after a reallocation of the headquarters. However, the production area, and thus the step-fixed costs, are affected more profoundly and more frequently by condition changes in the VUCA world. Thus, the entire production network must adapt regularly and generate only minimal additional costs after a change in order to remain competitive in the long-term. As an example, the reallocation of a produced product from one location to another could be mentioned. At the new location new investments could be needed, which cannot be easily reduced in the same amount at the old location and thus remain in the network for at least some time as additional sticky costs.

Variable costs are not further subdivided and are described simply as proportional to the output quantity. Any economies of scale that may occur are therefore not integrated into consideration, since these can also lead to minor sticky costs after a product reallocation, but are not focused in the paper.

The sticky cost effect of fixed and step-fixed costs hinders the ability of the network to change. To counteract this fact, fixed and especially step-fixed cost structures should be kept as low or changeable as possible in order to be agile in times of fluctuating requirements.

3.2. Lowering the sticky cost effect of fixed costs

The approach focuses mainly on three directions to lower the sticky cost effect of fixed and step-fixed costs. The overall reduction of step-fixed cost, the variabilization of step-fixed cost and an increasing of the changeability within the (step-)fixed costs, which are all outlined in the lower part of Figure 1.

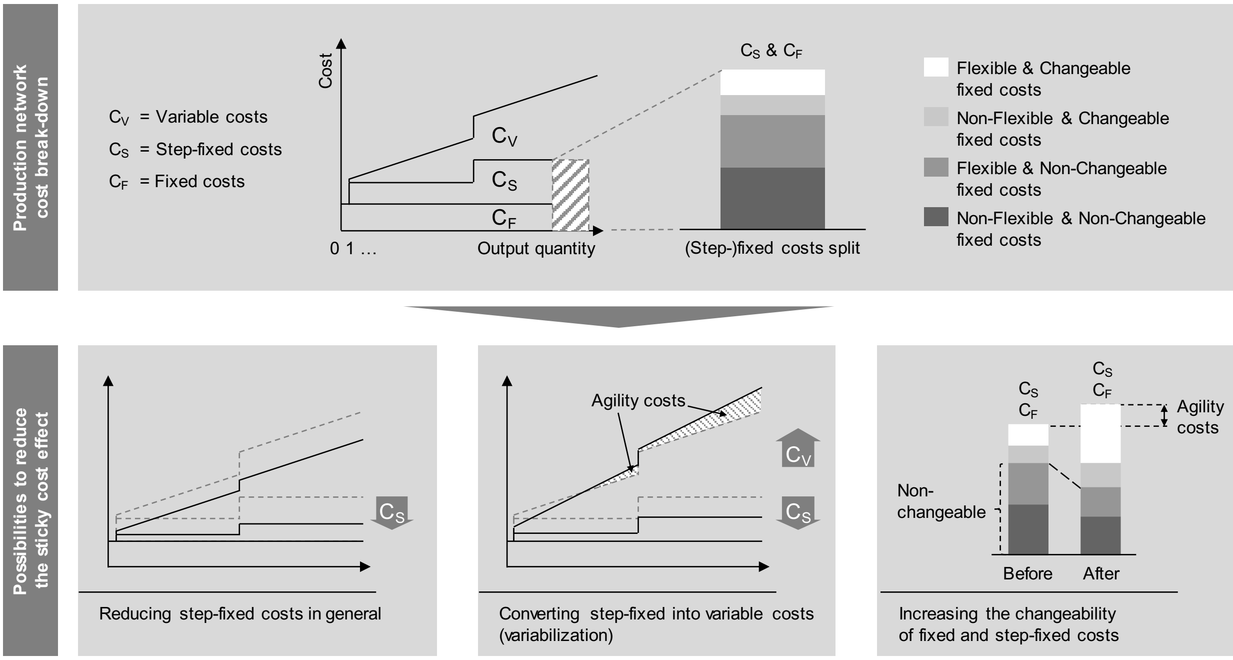

Figure 1: Lowering the sticky cost effect to enable an agile production network

<u>*Reducing step-fixed costs in general*</u>

The simple reduction of step-fixed costs is, although in theory the easiest way, in practice one of the most challenging and disruptive. At least since the rising of “lean thinking” most of the manufacturing networks today are already trying to optimize their network structures, supply chains, building usages, personnel staffing etc. up to certain level without major reduction potentials left. Obviously, in nearly every company there might still be left potential but this topic should not be focus of this paper. Nevertheless, apart from that optimizing potential there are other ways to approach a possible reduction of especially step-fixed costs by rethinking the main step-fixed cost drivers. The main step-fixed cost drivers of production locations are buildings with and without a direct correlation to production, personnel in functions such as administration that are not directly correlating to the production output, and equipment such as machines, production lines and utilities. [33] The idea is to omit or reduce these cost drivers by fundamentally rethinking and changing them to low-capital-expenditures-intense ones.

In directly production related buildings, apart from a layout optimization, the question arises if designated expansion areas, which are planned for future enhanced output flexibility and extended production lines, are necessary. Under the assumption of unpredictability, a decrease in flexibility to increase agility could be more beneficial in long term. That would mean smaller buildings without high expandability in terms of possible production output of the location and by that flexibility, but less capital expenditures and depreciations and hence a higher agility by reducing the sticky costs if the location itself is adjusted in size or relocated. In the same context, it is also possible to reduce the step-fixed costs of direct buildings even further by implementing a highly flexible equipment structure inside smaller buildings, which can easily be adapted to future needs but causes less fixed costs than an area increase. This could be achieved e.g. by reducing the level of automation, establishing an easily adaptable utility supply or providing modular intermediate stories instead of fixed story buildings. To ensure cost-efficient expandability a high degree of standardization could be used combined with a "copy-exactly" principle when implementing new locations. Thus, an agile production network of "easily" transferable, standardized micro-factories emerges, with a lead factory in a (quite) certain location.

To reduce building areas of indirect functions, the administration, controlling, purchasing, distribution or even maintenance and logistics areas of a uncertain production location could be removed to a another (certain) side e.g. the headquarter and remotely support and control the production location. This can be achieved by using the arising digitization possibilities like a completely automated information logistics, VR/AR applications and an overall implemented Internet-of-Things-structure.

The personnel of these indirect functions could be reduced in the same way. In addition, a flat hierarchy and a direct communication between production personnel and a headquarter support without an overlaying communication structure can reveal further reduction potential in the indirect personnel overhead.

Apart from the same trade-off between expensive flexibility and agility, step-fixed costs of production equipment could also be decreased by rethinking the used technologies. To achieve that, a close collaboration between the production and product development is necessary to develop products in between a fixed-cost-low production and an optimal satisfaction of customer needs. On the one hand, the core needs of the customer need to be fulfilled properly even with high fixed cost where necessary. However, all expensive technologies have to be checked for necessity and alternatives. For example, an existing product feature must not be mistaken for a customer need. On the other hand, all high-capital-expenditures-intense technology without a direct customer need should be omitted. The agile development process can help to set the right focus and indirectly reduce step-fixed cost in the manufacturing network. [4] Additionally, the choice of the right level of automation for each production task and by that a deliberate renunciation of high-capital-expenditure automation in some cases could also be beneficial.

<u>Converting step-fixed into variable costs</u> *(variabilization)*

As a second, but close connected possibility the conversion of step-fixed into variable costs, here called "variabilization", can be stated. The idea is, where step-fixed costs cannot be reduced entirely, they could be directly connected to the output quantity as variable costs. Whereas a reduction of costs also is conceivable in the fixed costs, a conversion into variable costs is only relevant for step-fixed costs, since otherwise if converting fixed costs that would leave a theoretical possibility of existing variable costs without an output quantity.

In most cases, a variabilization would mean an outsourcing of functions and by that connecting the costs directly to a product or output quantity. This is possible in most business areas such as an external production of parts, an external HR or IT support, external services partners or even an external product development. Hereby, it is important to distinguish between quantity-based and time-based contracts. If a contract is signed on a time-related basis, there is no real variabilization, but rather an increase in the changeability of the costs since the costs still occur on a fixed basis per time period and can only be reduced more quickly if necessary (see next step). For a variabilization, a quantity or product-related contract must be used.

One classical example for variabilization is a "make-or-buy" decision for different products and components. If a company chooses to "make" a component, high fixed cost usually arise. On the other hand, if procured, the arising costs are only directly connected to the produced quantity. Hence, apart from core competencies all production steps should be thoroughly evaluated for outsourcing potentials from the fixed cost management point of view. Another example could be an external development of components or component-modifications, which are not core-competencies of the company. Thus, the fixed costs of a product development can partly be changed to "product-variable" costs. With new business models of machinery and equipment manufactures even more variabilization possibilities arise by using "pay-per-use" or subscription models, where not the asset itself but the usage or even a productivity increase is charged.

Increasing the changeability of fixed and step-fixed costs

Thirdly, if fixed or step-fixed costs cannot be reduced or converted accordingly, a modification of the costs could be beneficial to reduce not the fixed or step-fixed cost themselves but the sticky cost effect of the costs. Both, the fixed and the step-fixed, costs can be indirectly described and segmented with the terms "flexibility" and "changeability". Flexibility in this context means the range of an asset for usage e.g. to produce a defined set of different products. The term refers less to the accruing costs and more to the underlying assets. However, an impossibility to react due to less flexibility triggers a direct cost impact (at least in terms of opportunity costs). In comparison, changeability refers directly to the ability of the costs to be changed and reused if necessary. The underlying assets would normally be released in this case.

A production machine for example normally got a certain range of production possibilities. In this range the usage of the machine and by that the cost of the machine are flexible. Nevertheless, if a production step outside of the possible production range of the machine is necessary, the machine must be replaced. If this is relatively simple possible then the cost of the machine could be described as changeable. The term changeability thereby consists of different parts such as a high reselling value and possibility of the machine, a functionality of other assets without the machine or the necessary start-up time of the replacement. In the conclusion, fixed and step-fixed costs consist of four different segments that are displayed in Figure 1: non-flexible and non-changeable costs, flexible and non-changeable costs, non-flexible and changeable costs, flexible and changeable costs.

To achieve an agile manufacturing network, which is able to react quickly and cost-efficiently to both minor and major change requests, both characteristics are needed. Nonetheless, with the above mentioned basic assumption of a high unpredictable uncertainty in today's VUCA world, changeability seems to be the key-factor to achieve agility in the fixed cost management. Even more, keeping in mind that the flexibility of an asset is usually connected directly to the cost of the same. Thus, an increase in flexibility to reduce sticky cost might probably cause even more fixed cost and by that an increase of sticky costs if the flexibility is exceeded. A high-automated machine which is able to produce a lot more different products than a simpler machine but costs double of it, got a higher flexibility but causes probably a higher amount of sticky costs, if its production range is exceeded at one point and inhibits by that major changes. Hence, an increase in flexibility does not necessarily mean an increase in agility.

Therefore, to achieve a reduction of the sticky cost effect, especially the non-changeable part of fixed and step-fixed costs need to be adjusted and shifted to the changeable cost parts.

One possibility to increase the changeability of the arising costs is the mentioned replacement of self-owned assets and own property with contracts, which are in most cases more easily adjustable. Buildings and machinery can be leased or rented, service contractors can replace personnel, inventories can be placed and managed by vendors, other functions such as service or maintenance can be completely outsourced.

Another direction is to increase the agility of self-owned assets and personnel directly. By using modular and mobile equipment to increase flexibility but also agility if the equipment needs to be moved to another location, the sticky cost effect can be reduced drastically. Moreover, automation could specifically be replaced by manual labor to avoid high non-changeable step-fixed costs. In addition, qualifications could be conducted and incentives could be set to ensure the movability of the most qualified personnel.

An appropriate determination of redundancies and free capacity buffers in the production network and its supply chain to ensure a possible transition and enable changeability completes the consideration.

3.3. Additionally occurring agility costs

The rearrangement by conversion or modification of the fixed and step-fixed costs ideally should happen without an increase in the total and by that unit costs. However, in many of the mentioned cases an increase may be inevitable. Thus, the total cost after the variabilization or modification could exceed the costs beforehand and thereby costs for the agility increase would occur. Both possible occurring costs for agility are outlined in Figure 1.

For example, in the variabilization process the variable procurement costs of a product could exceed the in-house manufacturing cost of the same, including the overhead costs due to existing step-fixed costs. Nevertheless, the company chooses to buy the product. This decision could, of course, also be made to safe or protect knowledge, but in this example the company's decision is mainly based on the idea of increasing agility in its network. Therefore, the increase in cost is directly connected to the increase in agility.

Another example of appearing costs for agility could also be found in the modification of fixed and step-fixed costs. If a new production machine is needed in a certain case, a decision could be made in favor of a more expensive machine without any additional features apart from its higher changeability, e.g. due to a higher resell price relation. In this case, the additional costs in comparison to a less expensive, less changeable machine are also directly correlated to an increase in changeability and by that agility. In terms of the defined segmentation parts that would mean in comparison an e.g. higher increase in "non-flexible and changeable costs" than, as the alternative, in "non-flexible and non-changeable costs" and hence occurring costs for agility.

These here called agility costs can be defined as additional one-time or ongoing costs that arise only to allow for a general greater adaptability of the network to known and unknown influencing factors and which would not occur without distinct agility measures. In this context, particular attention must be paid to high, fixed one-time invests to increase agility e.g. by minimizing latency, like monitoring systems. Although they also aim at increasing adaptability, the high additional fixed costs could contradict exactly their purpose, if a change of the costs themselves is necessary in the adaption process. Thus, agility costs themselves could hinder agility.

In comparison, flexibility costs are understood as additional costs with the purpose of increasing responsiveness in a defined horizon of parameters based on assumptions and probability estimates.

The idea of increasing costs without a direct, comprehensible and calculated purpose, because of the unpredictability of the influencing factors, might be the biggest obstacle in practice. In terms of flexibility and expandability many companies understand today the necessity of investing in their future. However, both of the mentioned are far more tangible than agility, especially if it comes to cost-benefit ratio. The main problem here is which agility benefit, for an unknown scenario, justifies an increase in real costs today?

To approach this problem quantitatively and rectify costs with savings in the future it is necessary to quantify the agility costs and the agility benefit. Even though an exact distinction and allocation of agility costs could be a challenge in some cases, their determination is possible like mentioned above. On the other hand, the quantification of agility benefit is much more difficult. Agility can be beneficial in many different aspects like quick identification of a need to change or the fast implementation of change requests. Nonetheless, the focus of the paper is the avoidance of occurring sticky costs after a change by managing fixed costs. Sticky costs are usually a temporary factor (rescheduling, change, etc.), so both the amount and the time until dismantling must be estimated in order to calculate an impact. This is complicated but could be done. Thus, it is for example possible to set the agility cost per fixed asset in relation to the possible occurring sticky costs per asset using a threshold value of e.g. multiple times of the potential sticky costs to limit the agility costs. This could be a first and easy approach to determine the trade-off between agility costs and benefit.

Nevertheless, in order to make a detailed business calculation, in addition to the amount of potential damage the probability of occurrence is required, since sticky costs only occur in the event of a change. However, based on the basic assumption, in the VUCA world this probability is impossible to estimate realistically. Quantification by scenario technique is therefore practically impossible and other approximations are necessary.

Therefore, at least to confine the solution space the authors proposed an approach to predict not the value of the probability of an event itself but the general volatility of the underlying factor. Thus, a determination of affected design dimensions by a volatile factor would be possible, in which higher agility measures and by that higher agility cost could be beneficial. [16] Still the main question remains and is just limited by this approach.

4. Conclusion & outlook

In today's fast changing environment, companies need to rethink their manufacturing network design fundamentally. An optimization under predicted uncertainties is only beneficial in a short-term view. To reassure competitiveness the adaptability of a network needs to designed proactively. To at least some extent, an agile manufacturing network is inevitable. One major challenge in the design of an agile manufacturing network is the management of fixed costs to minimize the sticky cost effect after a change. Therefore, the paper presents and discusses approaches to reduce, convert or modify fixed and step-fixed costs to lower this effect. Subsequently, possibly arising agility costs are introduced and the main obstacle of their cost-benefit ratio is addressed.

In further research, especially this ratio needs to be further analyzed and a concrete quantification of agility benefits is needed. Moreover, other topics to achieve an agile network, such as the minimization of latency times by using the right organizational and operational structure, should be addressed to finally design a manufacturing network with a right, dedicated level of agility between adaptability and costs.

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