



Conference Paper

## Building Blocks for Volume-oriented Changeability of Assets in Production Plants

**Author(s):**

Rippel, Manuel; Schmiester, Johannes; Wandfluh, Matthias; Schönsleben, Paul

**Publication Date:**

2016

**Permanent Link:**

<https://doi.org/10.3929/ethz-b-000117149> →

**Originally published in:**

Procedia CIRP 41, <http://doi.org/10.1016/j.procir.2015.12.009> →

**Rights / License:**

[Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International](#) →

This page was generated automatically upon download from the [ETH Zurich Research Collection](#). For more information please consult the [Terms of use](#).

48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015

## Building blocks for volume-oriented changeability of assets in production plants

Manuel Rippel<sup>a,\*</sup>, Johannes Schmiester<sup>a</sup>, Matthias Wandfluh<sup>a</sup>, Paul Schönsleben<sup>a</sup>

<sup>a</sup>*BWI Center for Industrial Management Logistics, Operations and Supply Chain Management, D-MTEC, ETH Zurich, 8092 Zurich, Switzerland*

\* Corresponding author. Tel.: +41-44-6320537; fax: +41-44-6321040; E-mail address: [mrippel@ethz.ch](mailto:mrippel@ethz.ch)

### Abstract

Demand volatility and uncertainty in the business environment lead to an increasing relevance of volume-oriented changeability (VoC) for manufacturing companies. Strategic investment decisions are often based on forecasts and predictions, which more frequently fail to materialize due to obsolete assumptions or unpredictable events with extreme impact. If the production output fluctuates, fixed costs of production plants emerging from these investments result in high variance of unit costs, which has an impact on operational performance. Despite these demand and investment risks, managers on the strategic level must make capacity decisions without endangering the plant's performance both in growth and decline phases. Therefore, the paper conceptualizes building blocks for strategizing VoC of assets in production plants. These building blocks systemize capacity strategies for economical and dynamical up- and downscaling of production output. The paper depicts the impact on financial targets and analyzes contextual requirements and interdependencies with the organizational concept. By means of this decision support concept, managers of the production plant can select and combine interdisciplinary measures for developing an asset management strategy in the face of demand volatility and uncertainty.

© 2015 The Authors. Published by Elsevier B.V. This is an open access article under the CC BY-NC-ND license (<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

Peer-review under responsibility of the scientific committee of 48th CIRP Conference on MANUFACTURING SYSTEMS - CIRP CMS 2015

*Keywords:* Manufacturing; Decision making; Management; Uncertainty

### 1. Introduction

Manufacturing companies are currently facing an increase in volatility and uncertainty of market demands. The impact of volatility on production plants is high due to their asset and personnel intensive structure. The associated fixed costs characteristics endanger profitability and competitiveness. Demand uncertainty affects plants since the profitability of medium- and long-term strategic planning and managerial decisions is calculated on the basis of forecasts and prognoses, both of which collapse extremely fast in today's business dynamics. In the worst case, extreme events with major demand disturbances and disruptions can endanger the cash liquidity of manufacturing companies. Akkermans and Van Wassenhove claim to address in particular grey swan events as "very unlikely events that happen through a fluke combination of intrinsically fairly unlikely occurrences" in production research and to "research on how to make supply networks

agile enough to adapt to major disruptions in their environment" [1]. Accordingly, plants have to realign their functional strategies and establish the ability to adapt capacity and cost structure according to demand fluctuations and major disruptions, given the increasing prominence of volatility and uncertainty as well as the practical relevance.

### 2. Practical Need and Research Gap

The implications of demand volatility and uncertainty on asset management are significant. Asset management has the task to provide capacity for the production of a forecasted volume. These forecasts are based on sales projections, assumptions and expectations by sales and marketing departments for the time period of several years, covering at least either product-life-cycle, machine-life-cycle or the machine's depreciation period. During the forecast period, there are numerous uncertainties (e.g. growth rates of

quantities, maximum quantities, total quantity along and duration of the product-life-cycle). The newer a product, the lower the reliability of the data. This means that the degree of uncertainty for setting-up capacity of a new product is much higher than for extension or replacement of capacity of an established product. Additionally, volatility with demand fluctuations or even major disruption can occur during the considered, forecasted period. Neither the general occurrence, nor their extent, nor duration can be anticipated. Nevertheless, engineering and production have to develop a technical manufacturing concept and prove its economic feasibility based on the above mentioned questionable and fragile input data. However, assets for the manufacturing industry are commonly highly specific and rigid in their response to changes, which turn corresponding investments into sunk costs. In a volatile and uncertain environment, this is highly problematic since asset-related fixed costs can hardly be synchronized with volatile production volume and endangers a company's profitability. Asset-related under/overcapacities are equally destructive to a company, increase its vulnerability and endanger its continuity. Developing an asset management strategy in the face of demand volatility and uncertainty is highly complex and presents several obstacles due to multi-criteria interdependencies and dynamics.

Within the scope of the widely known concept of changeability [2], Rippel et al. [3] introduced the concept of volume-oriented changeability (VoC) in order to specifically focus on and address the challenges, requirements and solutions of handling volume fluctuations in industrial practice. VoC can be considered as the plant's strategic contribution to a company's demand-responsive supply chain. Rippel et al. [3] state that "the implementation of volume-oriented changeability in practice requires that the examination has to be extended to the contextual requirements, the organizational concept and the strategic plant level." On the **strategic plant level**, the main fixed costs have to be considered because manufacturing costs are highly sensitive due to fixed cost components [4]. In this regard, the research focus of this paper is on assets as an essential source of fixed costs. According to the systematics of changeability [5], assets under consideration are workplaces (production technology and means) as well as manufacturing, assembly and logistics systems (manufacturing organization and transport means). Taking into account the **organizational concept**, system-dependent contradictions and restrictions, which cause dynamic target conflicts [6], have to be considered. Thus, addressing assets as a manufacturing plant's main production factor requires a multi-dimensional perspective on resulting impacts, namely socio-technical, financial and respective impact relations. **Contextual requirements** address how strategizing projects are conducted in practice (e.g. workshop-based, time pressure, pragmatism, abstraction level) and what is applicable (e.g. data availability and reliability) [7]. Furthermore, contextual requirements encompass interdisciplinary and cross-hierarchical practices (e.g. within planning, deciding, executing, steering) and priorities (e.g. coherence and consistency of business, supply chain, plant and functional strategies). Although a variety of measures and approaches with regard to asset management exist in industrial practice and academia from different

disciplines (e.g. finance, sourcing, engineering and production) in addressing the basic underlying issue [2, 4, 8, 9], they differ in their objectives, purpose and mechanism of effect. The disciplines of engineering and factory planning address assets from a technical perspective, developing reconfigurable manufacturing concepts and systems as well as process architectures on different systemic levels of manufacturing companies [8]. At the intersection of finance and sourcing, alternative asset management approaches have been developed that address the fixed costs dilemma mentioned above (e.g. pay-on-production (PoP) or leasing models) [6]. In scientific literature, the intentions and main emphases of these two disciplinary streams differ: On the one hand, finance and sourcing address the alignment of companies' cost structures towards volatility by providing solutions that turn fixed costs into variable costs, improve cash position and offer alternatives to possess and finance assets. On the other hand, engineering and factory planning offer the technical opportunity to adjust capacity in changing environments by developing technological solutions. However, the approaches and concepts of the two disciplinary streams show interdependencies. In order to effectively enhance manufacturing plants' VoC, both disciplines should be considered in an integrative manner since VoC deals with synchronizing costs and capacity with demand fluctuations in phase, both in regard to volume range and time.

It became evident in recently conducted action research cases (over two years) about strategizing in industrial practice, that practitioners' require tools to realign the functional asset management strategy of a manufacturing plant in the face of demand volatility and uncertainty. However, there is a lack of attention in literature to provide such practical relevant tools addressing the above mentioned requirements.

### 3. Objective and Approach

Thus, the objective of this paper is to reveal strategic alternatives from different disciplines to adapt asset-related production capacity and associated costs in manufacturing plants according to demand fluctuations and major disruptions and to provide relevant information about priority topics in a condensed manner. The purpose of this paper is to support plant managers in strategizing projects with the objective to realign a plant's asset management strategy in the face of demand volatility and uncertainty. Within the divergent-convergent cycles of strategic planning [7], the building blocks support practitioners in capturing, exploration and selection of knowledge about potential levers and required enablers. The main contribution can be assigned to the generation of strategic alternatives (divergent phase) [10].

The findings of this paper have been developed through literature studies as well as insights and experiences, which were gained within the strategizing and implementation of VoC at four production plants of a company (construction & materials) within an action research case.

First, **fields of impact** are analyzed in order to clarify the intended result of applying the building blocks. The fields of impact are derived from the above described obstacles for an asset management strategy in face of demand volatility and uncertainty. Afterwards, the **building blocks** are

conceptualized in an interdisciplinary perspective. They are distinguished in **lever blocks** and **enabler blocks**. Nevertheless, the existence, direction and extent of building blocks depend on **influencing variables**, which are identified last of all. The relations between building blocks, influencing variables and fields of impact are schematically illustrated as a conceptual model in Fig. 1 and as detailed overview in Fig. 2.

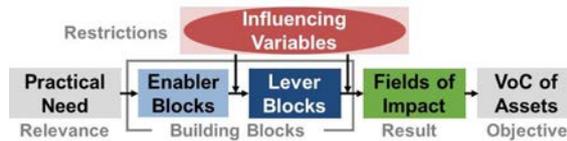


Fig. 1. Conceptual model of building blocks for VoC of assets.

#### 4. Analyzing fields of impact

From a technical perspective, assets are an essential factor for producing manufacturing outputs in the right quantity and quality. Hence, the required and available **capacity** is a major field of impact affected by the applied asset management measures because important parameters like delivery reliability, utilization and productivity are influenced. In addition, implications in the field of **capability** have to be considered. For example, speed covers the temporal aspects, which have an impact on the business' bottom line results. In particular, it is critical for market launches of new products. In the light of increasing strategic considerations of production concepts with regard to global footprints [11], transferability considers the possibility to relocate assets in an early stage within the investment process. Corporate considerations sometimes demand that the machine concepts and the relevant knowledge to operate them be relocated to other plants (e.g. from high-wage to low-wage countries). The applied manufacturing technology can contribute to product differentiation and innovation if there is an established backflow from manufacturing know-how into product development. If assets are significantly held by external partners and the associated manufacturing technology is not located in-house and also not proprietary anymore, the specific know-how and respectively the innovativeness of the plant could erode, and innovation processes might disrupt.

Assets constitute a significant burden to the plant's cash level and capital employed due to high initial investment. From a financial perspective, asset management measures have to be differentiated if they are cash-flow effective or profit-&-loss effective. Investments and divestment reduce or increase the plant's cash position respectively. Hence, **cash-flow effective building blocks** increase the plant's liquidity. **Profit-&-loss effective** measures additionally materialize in depreciation and finance costs as major cost blocks. The general production cost level is reduced and synchronized with produced volumes. Hence, production costs per unit are kept more stable in regard to volume fluctuations. While this might be the general overall effect of the proposed measures, an application of the design principles possibly have an increasing effect on the asset's acquisition price. Here, opposing forces are at work and trade-offs have to be governed.

#### 5. Conceptualizing building blocks

The measures and elements for VoC with regard to assets are aggregated and categorized (see Fig. 2). The systematized categories are named "building blocks" since the blocks facilitate practitioners in prioritizing, selecting, combining and configuring measures for building up volume-oriented changeability of their plant's assets on strategic level. Two different types of building blocks are introduced: The first type is called "**enablers**," which comprise the prerequisites for the set-up and execution of measures. The second type is named "**levers**," which systematize measures according to their impact characteristics and mechanism of effect contributing to VoC. The intention is to cover the most relevant categories of levers and enablers but not to be exhaustive. Based on the identified broad range of measures from several disciplines, practitioners can reformulate their asset management strategy by prioritizing and selecting their portfolio of measures on the strategic level. Afterwards, the selected measures can be configured and detailed on the operational level from assigned project teams. Required information and knowledge about the measures can be found in the literature of the respective disciplines.

##### 5.1. Enabler blocks

In this paper, three main enablers are identified that are understood as groups of fundamental principles to facilitate VoC of assets in manufacturing plants.

The first enabler comprises **integration principles**. Here, a contribution is made towards a holistic asset management. Assets ought to be managed along their complete lifecycle and the respective activities [12, 13]. The stages of an asset's lifecycle are: research and development, investment decision, finance, construction projecting, procurement, assembly, operation and disassembly [4]. During the asset's lifecycle, different departments (e.g. operations, maintenance, finance and accounting, sourcing) of the manufacturing plant as well as superior, corporate levels should be involved. Thereby, it should be clearly defined which departments must be consulted and should be heard for giving input or raising concerns out of their perspective and to collaboratively develop alternatives. Hence, communication and clear organizational structures are supportive for collaborative asset management. A process view can overcome organizational boundaries between departments and uncover all involved activities in regard to the asset's management. In addition, the interfaces towards suppliers like asset manufacturers or maintenance providers must be managed in order to secure asset performance [4]. To sum up, the differently prioritized impact fields during the life-cycle and according to the functional perspectives should be comprehensively considered in asset management by integrating the affected departments within and across the plant from the beginning [12]. Thereby, an optimization based on the priorities of only one perspective should be avoided.

Besides this horizontal collaboration among a plant's departments, the vertical structures within and across a plant must be aligned. The second enabler, **decision principles**, constitutes hierarchical, formal approval processes for

investment decisions as well as rules and standards pertaining to asset investments. One essential element is the formal approval process and the hierarchical involved stakeholders. Typically, it is clearly defined who has the final authority in the organization to decide about asset investments. Depending on the investment size, the de-/centralized structure of the organization and the respectively entities' autonomy, the decision can be assigned to the plant or to corporate authority. If the responsibility is transferred to another party after the decision is made, disadvantageous scenarios can emerge with regard to considering investments beneficial in the face of demand volatility and uncertainty. To cope with these dysfunctionalities, approval processes within asset management as well as investment rules and standards should be adapted so that they comprehensively incorporate strategic aspects of VoC. In particular, it should be clearly stated which expectations regarding abilities to handle demand volatility and uncertainty exist and which respective VoC potentials are demanded. These formulated expectations should depend on and reflect the "risk appetite" of the organization. In addition, the remaining risks, associated consequences and costs for preventively installed VoC potentials should be in the shared, long-term responsibility of the same, involved stakeholders.

Related to that, companies still avoid investing in changeable assets since common budgeting processes fail to adequately take the benefit of changeability into account and to justify higher expenses thereby [4]. As a second element, assessment methods and tools within decision making have to be established, which reflect the value of flexibility and changeability of assets within decision-making [14]. Total Cost

of Ownership (TCO), life cycle costs (LCC) or real option analysis (ROA) are examples of such methods that should be adapted to include flexibility and changeability. In addition to the acquisition costs, investments are analyzed in regard to their energy costs, maintenance costs, IT costs, and other costs during their operational lifespan. In addition, a change from a passive approach (e.g. discounted cash flow analysis) towards an active real option approach in regard to investments is applied. Furthermore, new, replacement or expansion investments should be assessed by means of their sensitivity regarding volatility, portfolio and product-life-cycle scenarios. The option with the lowest volatility-dependent business impact risk should be preferred, and investments should be approved only if they can definitely be utilized to a high degree under sustainable growth conditions.

The third enabler **design principles** include the well-known and sound technical changeability enablers from a factory planning and engineering perspective [5]. According to Wiendahl et al. [2] and Nyhuis et al. [8], assets contribute to a plant's changeability when they are universally usable in regard to products and technologies (universality), not localized (mobility), extendable and reducible (scalability), consisting of standardized elements (modularity) and compatible in respect to material, information and energy (compatibility). These design principles are to be regarded in addition to mere productivity-related issues and play an important role during the asset's entire lifespan. They should be considered during an asset's planning period and materialize their benefits when operated. In addition, they increase an asset's reusability at the end of its lifecycle [4].

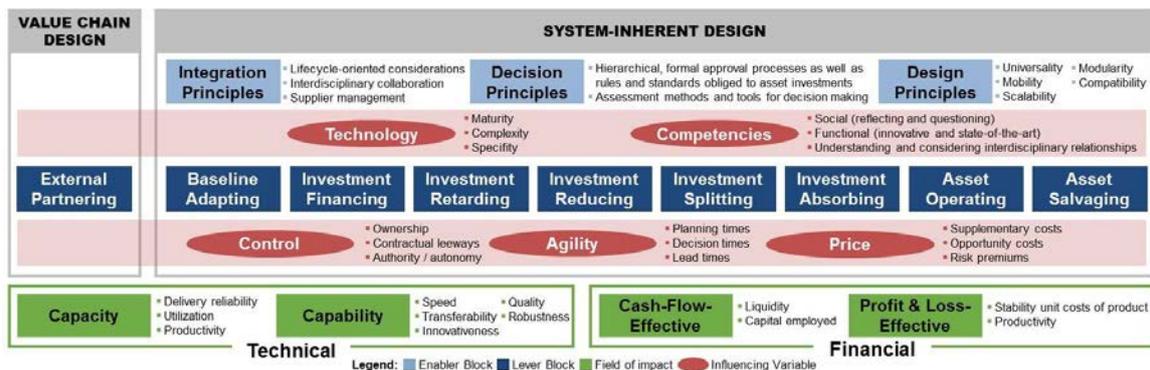


Fig. 2. Building blocks, influencing variables and fields of impact.

5.2. Lever blocks

While the enablers drive the VoC of asset management, the levers comprise concrete measures for adapting a manufacturing plant's VoC. Thereby, levers impinge on the manufacturing plant's capacity, cash-flow, cost position and its capabilities. In VoC, these four aspects ought to be synchronized in regard to volatile demand markets. Therefore, we call it the "Four Cs of Asset Management in the face of demand volatility and uncertainty." These four aspects are strongly interrelated and also function as a categorization scheme for the following types of levers.

The lever **external partnering** is part of the value chain design dimension and involves measures in regard to external providers. It comprises the contractual arrangements like all different variants of build-operate-transfer (BOT) concepts (e.g. pay-on-production) and the scope of products and services sourced from external partners. These measures mostly allow synchronized capacity, periodical operating cash-flow and costs with the demand continuously along the multiple periods. As an advantage, the initial investment cash-flow for purchasing can be avoided since the external party provides/purchase the asset. Thereby, the risk of asset ownership is transferred to an external party, wherefore a premium will be priced into the payable periodical rates, which disadvantageously affect the manufacturing costs.

Furthermore, there is potential revealed by the lever **investment financing**. Similar to external partnering, the risk and asset ownership does not lie at the manufacturing plant but with an external provider. However, the assets are located and operated at the plant's site. Financing concepts like leasing models belong to this lever. From the moment the measure is introduced, the effect on capacity is confined to this singular-period. In most cases, the capacity cannot be dynamically adapted to current demand fluctuations and is instead rather static. Even the adaptability in case of major disruptions depends on the contractual arrangement. The primary advantage consists in the possibility of avoiding the investment cash-flow and respectively the capital employed. The accumulated costs for the leasing fees during the entire utilization period might be higher in comparison to a purchased capacity and its periodical accruing depreciation. In particular, the costs will be much higher if there is leeway in the contract for an earlier termination.

The lever **baseline adapting** consists of the most traditional and radical measures in regard to assets, i.e. the investment or disinvestment of assets and the insourcing or outsourcing of processes (e.g. the required capacity in the upcoming periods is substituted by measures of external partnering). Their activation is a one-time action with a direct, singular impact on capacity and cash-flow but with an indirect impact on costs. The change of capacity is step-fixed with a singular effect.

The lever **investment retarding** refers to the temporarily postponement (until the demand uncertainty is lower) or even complete avoidance of new acquisitions, replacements and costly expansions of complete assets. The required capacity can be provided by exploiting alternatives in the existing asset structure of the plant or other corporate entities (e.g. increasing utilization, enhancing productivity, expanding or modifying existing assets or temporarily utilizing prototyping/laboratory equipment). By doing so, no build-up of new capacity takes place, and the cash-flow position is left unaffected, except for small investments into modifications of the existing assets. The measure is appropriate when forecasts indicate high uncertainty whether the forecasted demand volume will ever materialize and remain stable in the upcoming years. However, measure of this lever can be risky [13] since the options to exploit existing assets are limited. Supply bottlenecks and shortfalls could occur if the demand unexpectedly exceeds the forecasts and the lead time to build up or acquire the required capacity is very long. The failure risk of these existing assets could also increase in the long term due to the high intensity of utilization.

A less radical lever is **investment reducing**. Here, customization shall be minimalized and standardized components, modules or machinery shall be favored. Requirement specifications shall be revised and challenged by default in order to avoid exaggerated, costly requirements that are not absolutely necessary. In addition, the investment can be reduced by revising the sourcing strategy, (e.g. to question and challenge established suppliers for different types of machinery and to fully exploit options of global sourcing of machinery, modules and components). These measures keep the initially established capacity at the same level. However, the measure singularly impacts the investment cash-flow and reduces the periodical depreciations and respectively the cost level thereby.

It does not contribute to dynamically synchronizing capacity, operating cash-flow or costs according to demand fluctuations. However, it should be considered within a holistic set of asset management levers.

One of the most elaborate but also most powerful levers for VoC in the asset management strategy is **investment splitting**. This means that assets are designed according to the design principles as changeability enabler [9] so that capacity can be incrementally, step-wise scaled dependent upon the actual business development. Necessary expansions of the asset's capacity are spread over a time span in several expansion stages (e.g. by adding more modules of the particular bottleneck process steps of an expansion stage, by replacing bottleneck modules with modules of higher output, or by continuously upgrading process steps or working stations from manual to semi-automated to fully automated). Thereby, these measures comprehensively contribute to dynamically adapt capacity, cash-flow and costs according to demand during the whole lifecycle. Another important advantage is that the initial investment cash-flow can be reduced, and the risk of sunk costs due to overcapacity can be decreased. However, the costs for the asset's final capacity accumulated along the several expansion stages could be higher (e.g. additional interfaces have to be preventively installed or several separate, small investments over time are accumulated).

The assets in place are affected by the lever **asset operating**. This lever consists of the asset's maintenance management, including measures like Total Productive Maintenance (TPM), maintenance intervals according to factual utilization instead of fixed periodical cycles as well as continuous modernization of assets. In addition, the multitude of purposes the assets can be operated on is of importance because anti-cyclic demands of different product groups can be balanced and a constant utilization of the asset facilitated. Product-neutral and standardized components can be complemented by product-specific ones while manual and automatic processes can be coupled in order to increase operation's flexibility. Furthermore, variable routings of product components on the shop floor are another measure. Here again, the design principles essentially work as a changeability enabler [9]. The effect of these measures lies on the operating cash-flow and cost position while capacities remain mainly constant.

At the end of the asset's lifecycle, the lever **asset salvaging** becomes effective. Assets can be reused in the same or in other manufacturing plants or can be sold to external parties. In addition, components or modules can be transferred or sold, and the asset can be rescaled. This already has to be taken into account when assets are acquired. These measures have a partially and singular one-time effect on capacity, cash-flow and costs in contrast do baseline adapting.

For selected assets held by the manufacturing plant, the lever **investment absorbing** could be applied. Alternatives towards traditional depreciation models should be assessed with regard to feasibility. The objective would be to adapt the depreciation rates dependent upon the actual business development. While capacity and cash-flow would remain unchanged by these measures, the costs could be flexible along multiple periods. However, limitations and rules of financial and operational accounting have to be taken into account.

## 6. Identifying influencing variables

Influencing variables work as intermediate, intervening factors between enabler and levers and set up restrictions to the enabler's degree of impact on the above described fields.

Manufacturing **technology** plays an important role especially when it comes to translating the design principles as an enabler into concrete measures and including them within the design and engineering of machine concepts. Whether assets can be modularly designed, for instance, is dependent on whether the manufacturing technology provides the technological feasibility to do so. The technology's maturity, complexity and specificity can hamper more flexible or changeable alternatives (e.g. applying design principles).

Besides the technological feasibility, a manufacturing plant must have certain **competencies** at hand to translate the enablers into effective measures. A plant's personnel has to possess competency in the relevant disciplines (e.g. the engineering know-how for applying the design principles or understanding and utilizing more complex assessment methods that take the benefits of changeability into account). Besides, the employees have to take an interdisciplinary approach and need the required competence beyond their "native" discipline.

The influencing variable **control** plays an important role for asset management. This variable influences the effectiveness of levers on the fields of impact. At first, it is relevant to asset ownership, i.e. whether the plant itself possesses the asset and has capitalized it in its balance sheet. If the production capacity is not proprietary, contracts should be designed for VoC options. It should be possible to quickly adapt the order quantity and the respective payments. This means that commitments (e.g. like guaranteed purchase quantities) should be avoided as far as possible [3]. Furthermore, control in regard to the operation is important and so is the authority to conduct changes on its own responsibility if it is required. For example, official approvals of the manufacturing process and involved machinery can limit the scope for action.

The influencing variable **agility** considers reaction and lead times as important factors for the effectiveness of measures. It is important how long it takes to design, plan, build, change, replace, expand or relocate the capacity. For example, standardized and scalable assets can contribute to an acceleration of these processes. However, the required planning processes can become time consuming when all involved departments during asset's lifecycle are included and the design principles are applied. If the duration of the related lead times are long, managers have to decide earlier with more uncertainty. Whereas agility considers temporal aspects as a restriction, speed (in the impact field capability) represents a strategic objective, which contributes to the competitive position of the manufacturing plant (and the company).

Finally, the measures subsumed under the levers have an impact on the **price**, as for example risk premiums are accounted for by external partners such as lessors or suppliers of outsourcing services. Also, additional technical specifications like scalability might require higher asset prices. This additional cost for VoC negatively affects performance targets (e.g. productivity). The associated negative financial impacts hamper the willingness to implement levers.

## 7. Conclusion and outlook

The ability to synchronize production capacity and costs with the actual demand evolve into an important competitive advantage and could even be of vital significance for manufacturing companies. Building blocks are conceptualized for realigning a plant's asset management strategy in the face of demand volatility and uncertainty. They provide a transparent and consistent set of interdisciplinary measures for VoC of assets in a condensed manner for practitioners. The purpose is to adapt asset-related capacity and associated costs according to demand fluctuations and major disruptions. Hence, every building block has a positive influence either on the capacity, cash-flow or cost side of changeability and capabilities or a combination of the four. The outcome of applying the building blocks creates the basis for further operational studies and deriving a roadmap with detailed projects and implementation processes. Thereby, the research gap is addressed for strategizing volume-oriented changeability related to a production plant's assets in practice.

## References

- [1] Akkermans, H. A., Van Wassenhove, L. N., 2013. Searching for the Grey Swans: The Next 50 Years of Production Research, *International Journal of Production Research* 51, pp. 6746–6755.
- [2] Wiendahl, H.-P., ElMaraghy, H., Nyhuis, P., Zäh M., Wiendahl, H.-H., Duffie, N., Brieke, M., 2007. Changeable Manufacturing – Classification, Design and Operation, *Annals of the CIRP* 56, pp. 783–809.
- [3] Rippel, M., Lübke, J., Nyhuis, P., Schönseleben, P., 2014. Profiling as a means of implementing volume-oriented changeability in the context of strategic production management, *CIRP Annals - Manufacturing Technology* 63, pp. 445–448.
- [4] Wildemann, H., 2009. Fixkostenmanagement – Leitfaden zur Anpassung von Kostenstrukturen an volatile Märkte, TCW, München.
- [5] Hernández Morales, R., 2002. Systematik der Wandlungsfähigkeit in der Fabrikplanung, *Fortschritt-Berichte VDI*, Düsseldorf.
- [6] Bleicher, K., 2011. *Das Konzept Integriertes Management*, 8th ed. Campus Verlag, Frankfurt am Main.
- [7] Phaal, R., Kerr, C., Oughton, D., Probert, D., 2012. Towards a Modular Toolkit for Strategic Technology Management, *International Journal of Technology Intelligence and Planning* 8, pp. 161–181.
- [8] Nyhuis, P., Reinhart, G., Abele, E., 2008. *Wandlungsfähige Produktionssysteme. Heute die Industrie von morgen gestalten*, TEWISS Verlag, Garbsen.
- [9] ElMaraghy, H., Wiendahl, H.-P., 2009. Changeability – An Introduction. In ElMaraghy H. (Ed.) *Changeable and Reconfigurable Manufacturing Systems*, Springer Series in Advanced Manufacturing, Springer, London.
- [10] Ilevare, I. M., Probert, D., Phaal, R., 2014. Towards risk-aware roadmapping: Influencing factors and practical measures, *Technovation* 34, pp. 399–409.
- [11] Schönseleben, P., 2009. Changeability of Strategic and Tactical Production Concepts. *CIRP Annals – Manufacturing Technology* 58, pp. 383–386.
- [12] El Akruiti, K., Dwight, R., Zhang, T., 2013. The Strategic Role of Engineering Asset Management, *International Journal Production Economics* 146, pp. 227–239.
- [13] Schneider, J., Gaul, A. J., Neumann, C., Hogräfer, J., Wellbow, W., Schwan, M., Schnettler, A., 2006. Asset Management Techniques, *Electrical Power and Energy Systems* 28, pp. 643–654.
- [14] Yeo, K. T., Qiu, F., The Value of Management Flexibility—A Real Option Approach to Investment Evaluation, *International Journal of Project Management* 21, pp. 243–250.
- [15] Rippel, M., Budde, J.-W., Friemann, F., Schönseleben, P., 2014. Building blocks for volume-oriented changeability in personnel cost structure of manufacturing companies, *IFIP Advances in information and communication technology* 440, pp. 463–470.