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Future Scenarios of Value Creation in Mechanical Engineering – Derivation of Recommendations for Action

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Abstract

Increasing volatility and individualization has great impact on value creation, resulting in a complex and interdependent corporate environment. The analysis of possible developments of the future becomes a crucial success factor. By adopting the scenario technique this study aims at deriving future scenarios for value creation in the mechanical engineering context focusing on innovation leadership, differentiation through partnerships and hardware supplier status. The consistency is then evaluated and possible options for action are derived by mechanical engineering experts. The results not only support practitioners to understand future value creation but also inspires scientists conducting further research towards implementing futurology into strategy research.

Keywords: *Mechanical engineering; Futurology; Strategic Management; Business transformation*

1. Introduction

It is important for companies to be prepared for a rapidly changing business environment [1]. Reasons include accelerated technological progress, ever shorter product life cycles but also the increasing speed of innovation [2]. Porter mentioned in 1985 already that companies are under constant pressure to innovate in order to outperform competitors and to gain a competitive advantage [3]. Innovations enable significant improvement of products, services or processes, the development of new potential markets or the establishment of alternative organizational methods [4]. Digital Transformation currently induces cross-industry innovations and is primarily driven by information and communication technology. In B2C markets it has been shown that companies operating at the customer interface rely primarily on software rather than hardware. For B2B markets, this entails the risk of commoditization, i.e. the exchangeability of hardware [5,6]. Hence, the significance of the physical value-added contribution is declining. This transformation process also affects the technology-oriented and product-related sector of mechanical engineering [7]. The business model to date consists of selling products. It can be expanded by offering customer-specific, performance-enhancing and software-supported solutions including the product, thus creating greater added value for customers and companies [6]. Due to the growing volatility of environmental changes and the increasing complexity and dynamic of processes and systems, companies must act and think ahead to ensure flexibility and the ability to change. The cases of Nokia or Kodak demonstrate what can happen if new technologies or trends are misjudged or completely missed [8]. Deloitte, for example, conducted a study to examine scenarios for companies in the year 2030 in order to show trends, dangers and opportunities in a holistic view [9]. The German Engineering Federation (VDMA) uses scenario analyses on specific topics, such as supply chains [10], future materials [11] or machine learning [12], to show how the mechanical engineering industry can develop up to 2030.

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However, the literature has so far not explicitly examined how value creation in mechanical engineering will develop in the future. Value creation forms the basis for economic success and contributes to securing the existence of every company. The main objective of this study is to identify scenarios for value creation in mechanical engineering to enable long-term corporate planning. The following research question can be derived from the problem outlined, which will be investigated in this paper:

Which consistent future scenarios regarding value creation in mechanical engineering can be determined and which recommendations for action can be derived for companies?

2. Methodology

This section describes the methodological approach of this study, which is based on the milestones of the scenario technique according to Gausemeier and is shown in Figure 1 [13]. After each of the six activities to be dealt with chronologically, interim results are obtained which are necessary for the continuation of the study. The presented methodology was carried out by a team of three researchers and the results were evaluated in a large German engineering company with ten experts.

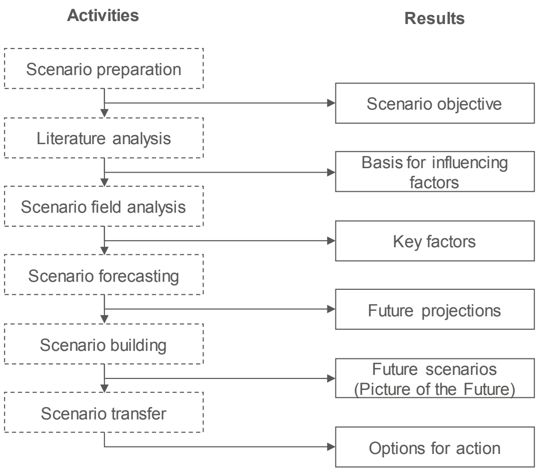

Figure 1. Scientific approach

Within the course of scenario preparation, the design field "value creation in mechanical engineering" is analyzed. The objective of determining future scenarios for the period 2030+ is defined. Scenario development considers both external environmental variables, such as political or social factors, and internal control variables, such as industry-specific factors. With the help of a literature analysis, current trends having a direct influence on value creation in mechanical engineering are identified. In the scenario field analysis, the trends are merged with the help of an affinity analysis to similar categories with suitable generic terms. All generic terms are influencing factors for the design field value creation. The influencing factors are limited to 15 key factors in order to guarantee the optimal quality of the derived scenarios [13,14]. These 15 key factors are analyzed by means of an impact analysis, i.e. how strongly the factors influence each other, and a relevance analysis, i.e. how important the factors are for the design field. In both analyses the influencing factors are compared and evaluated in a matrix (Fig. 2). The aim of the scenario forecasting is to identify future projections of the 15 key factors. For each key factor, two to three future projections with a time horizon of approximately >10 years are described. For derivation, logical as well as extreme but conceivable future projections are considered. The previously identified trends serve as the basis for the description of the future projections. The goal of scenario building is to generate four consistent scenarios from a bundle of mutually consistent future projections. A scenario is composed of exactly one future projection per key factor. Consistency is important for the credibility of a scenario. In order to obtain conclusive scenarios, all future projections are mutually evaluated for consistency and inconsistency in a pairwise comparison. This evaluation is carried out in a consistency matrix. A scale from -3 (inconsistent) to +3 (consistent) is used to assess consistency. +3 means that if one projection occurs, the other projection will also occur. -3 means the opposite. 0 means the projections are independent from each other. The analysis of the consistency matrix was carried out with the help of the software "Parmenides EIDOS". The software calculates all possible combinations of future projections. Each scenario has a consistency value. The consistency value is the sum of the consistency ratings of all future projection pairs in a scenario divided by the number of all future projection pairs in a scenario. The consistency value can reach a maximum of three. In the last step, "scenario transfer", the four scenarios are used to identify the effects of the individual scenarios and derive potential options for action with the help of expert workshops.

3. Theoretical basis

3.1. Change in value creation in mechanical engineering

The structural change in mechanical engineering is nowadays mainly driven by digitalization. The progressive development of information and communication technologies (ICT) will bring about a dramatic structural change [15] by the networking of physical things or objects with the Internet [16]. Modern ICT leads to new forms of value creation and business models with a disruptive character [17]. In this study, value is defined as "the amount that buyers are willing to pay for what a company provides them" [3]. The goal of value creation is to achieve a more valuable output compared to the inputs previously made [3]. It describes the totality of activities in a company that directly or supportively contribute to the strategic and long-term development of companies, to the achievement of operational goals [18]. In order to achieve these goals, during the various industrial revolutions new relevant value creation criteria such as efficiency, process orientation or customer orientation were introduced to further improve the input-output ratio. In particular, the development of digital products and services is on the one hand an important factor for intensifying customer relationships, differentiating oneself from the competition and realizing new digital business models with significantly higher efficiency and revenue increases [19–21]. On the other hand, it is an option to increase resource effectivity and efficiency across the entire value network in order to meet sustainability requirements [17]. This change means that value creation through collaboration in networks is becoming increasingly important in order to compensate for and build up missing competencies and exchange necessary information [22].

3.2. Fundamentals of futurology

Futurology is defined as "the scientific examination of possible, desirable and probable future developments and design options as well as their prerequisites in the past and present" [23]. The assumption of modern futurology is that, in principle, the future cannot be clearly determined. Several future developments are possible and can be shaped. The basis of futurology is the perception that there are many possible futures, but not an unlimited number. Modern futurology is subject to all the quality criteria that science sets for strategies and models. These include relevance, logical consistency, simplicity, verifiability, terminological clarity, specification of the scope, explication of the premises and boundary conditions, transparency and practical manageability [24]. Systems, companies and industries are increasingly networked and interact with each other under mutual dependencies. The number of direct and indirect factors that can influence the business of companies is increasing [2]. One of the most important success factors for companies is the ability to simulate possible future scenarios, to anticipate them and thus influence developments in the business environment and the corporate world. This enables the company to recognize opportunities and risks proactively and gives it a decisive time advantage over its competitors [1,25].

3.3. Key trends in mechanical engineering

Apart from isolated scientific publications only three trend reports could be identified. The VDMA's "Trendradar" study shows 160 relevant trends of a technological and non-technological nature. These trends were determined in cooperation with companies, VDMA experts and researchers and offer a broad overview of a wide range of topics [26]. The Fraunhofer "Foresight" study shows 51 relevant topics for research in the year 2030, which were analyzed by Fraunhofer experts and reviewed by international experts from science and industry [27]. The annual report of the Future Today Institute presents current technology trends. They analyzed 315 technology trends [28]. From these three reports and other identified literature, trends were derived that are relevant to the field of value creation. The trend analysis focused on the five megatrends "Digital Transformation", "Globalization", "Individualization", "Change in the Business World" and "Climate Change and Sustainability", as these have a direct impact on value creation. The selected trends were specified and described with the help of additional statistics, studies, publications and literature. The result of the trend analysis serves as a basis for identifying influencing factors for value creation.

4. Results

Section 4 presents the results of this study. Section 4.1 describes the key factors and their future projections. Section 4.2 then presents the future scenarios of value creation. In section 4.3, possible options for action and implications for the management of mechanical engineering companies are explained in more detail in order to finally answer the formulated research question.

4.1. Key factors of the scenario field and their future projections

Figure 2 shows the result of the relevance and impact analysis. Both axes are scaled by ranks. If a factor influences many other factors, this factor is very active and has a high rank. The passive sum can be neglected when selecting the 15 key factors. The circle diameters represent the result of the relevance analysis. The larger the circle diameter, the more important is the relevance of the factor influencing the design field. The circles shown in green are the 15 key factors that most actively influence the field of value creation in mechanical engineering. The influencing factors shown in grey are not key factors.

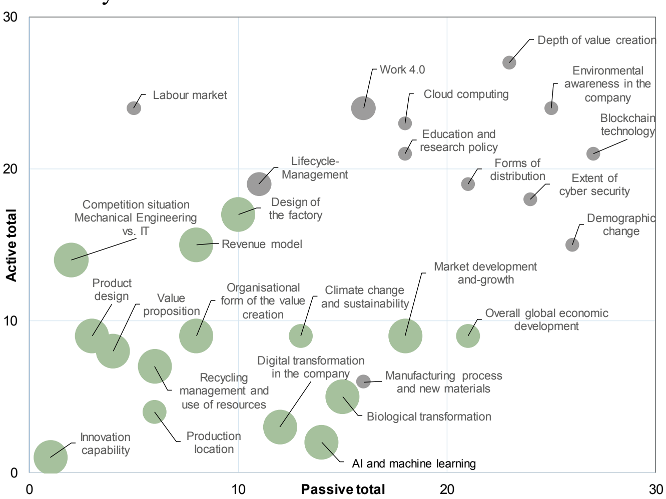

Figure 2. Results from impact and relevance analysis

The 15 key factors form the basis for scenario building and are explained in the following section. *The respective future projections are also mentioned:*

Climate change and sustainability is determined by the development of the global climate and describes the increase in temperature compared to the pre-industrial period and identifies the measures and causes of this development. *Climate targets clearly missed - Climate targets narrowly missed - Climate targets exceeded.*

Recycling management and use of resources describes the efforts of industry to implement a cycle-oriented economy. The goal of the closed-loop economy is to use products, materials and resources longer, to minimize the utilization of resources, and to avoid and recycle waste. *Linear economy - Transition to a circular economy - Circular economy.*

Overall global economic development is determined by trade policy and provides the framework in terms of the nature and extent of government intervention to achieve economic policy benefits. *Global protectionism - Protectionist trains & EU unit - Global open trade.*

Market development and growth is determined by the increase in economic output and describes the size of product demand on the market. The unit of measurement here is the percentage change of the gross domestic product. *Emerging countries dominate - Emerging & industrialized countries equal - Industrial countries dominate.*

Production location describes whether a company produces centrally in its own country or decentralized in other countries.

Decentralized production - Decentralized & centralized production - Centralized production.

Innovative capacity is a decisive factor for the competitiveness of a company and describes the process by which companies generate innovations. *Low - Consistent - High.*

Artificial intelligence (AI) and machine learning describe the degree of implementation and proficiency of AI techniques and applications in the company. *Arrears - Fixed component.*

Digital transformation in the company is determined by the degree of digitalization and interconnectivity in the company. *Subordinate role of data - Data supported - Data driven.*

Biological transformation determines the degree of integration of biological principles in technical and informational systems with the aim of a more sustainable creation of value. *No significance - Transfer of bioinspiration - Integration of biology.*

Competitive situation mechanical engineering vs. IT determines the degree of integration of IT companies in mechanical engineering and how strongly they influence the competition with their solutions. *IT companies dominate - Core competencies clearly distributed - Mechanical engineering dominates.*

Organizational form of value creation specifies which companies are involved in value creation and how they are arranged and coordinated to provide added value for the customer. *Efficient supply chains - static value creation networks - Adaptive ecosystems.*

Factory design describes the progress of automatization and how value creation processes in the factory function. *Digitalization - Connectivity - Autonomy.*

Value proposition describes the value that a company offers its customers with a service, a product or a combination of both. *Low customer orientation - Customer oriented product - Customized solution.*

Product design describes the product design, which product characteristics are demanded by the customer on the market. *Good-enough - High-tech & good-enough - High-tech.*

Revenue model indicates through which sources and in which way a company generates its turnover. *Product sale - Pay-per-use - Pay-per-result.*

4.2. Future scenarios of value creation

The following sections provide summaries of the four scenarios. The software EIDOS has calculated 9,565,938 possible scenarios based on the evaluated future projections. From the 1000 most consistent scenarios, four different scenarios were selected based on their characteristics (Fig. 3). The scenario with the highest consistency has a consistency value of 2.17. A high consistency is between the values 2 and 3. The respective consistency of the scenarios is indicated.

Global innovation leader (2.17):

In 2030+, Mechanical engineers are global innovation leaders, future shapers and role models for many other industries. New disruptive innovations in industry are created collaboratively and ecological. Worldwide open trade has led to global ecosystem-like value-added networks, whereby the recycling economy has been integrated. Production is decentralized and close to the customer. In CO_2-neutral, autonomous factories where smart concepts such as logistics, mobility and grid converge innovative products are manufactured. Biology is integrated into the value chain and enables efficient processes, technologies and products. Companies cooperate in industrial eco-parks and achieve economic advantages. As a result, entire ecosystems compete. The ability to innovate has increased through interdisciplinary cooperation across sectors. Through collaboration and openness, value-creating ideas are implemented on the market. AI is an integral part of business and production processes and products. Decisions are based on data. IT companies have tried to gain a foothold in the B2B market but failed, due to the lack of domain-specific know-how. Differentiation takes place via smart services, which helps to retain customers in the long term. The service share of the generated turnover has increased, a large part is generated by the sale of pay-per-result models.

Hardware supplier (2.02):

Mechanical engineers were downgraded to product or hardware supplier by 2030+. Original high-tech locations, such as Germany, are now one production location among many and have not used their opportunities in the digital age. Despite strong growth in emerging markets, the markets for commodity and entry-level products are fiercely contested and the innovative ability is low, due to the increasing isolation of the companies and the worldwide protectionism of industrial nations. Machines are often overengineered and do not solve the specific customer problem. Penalties or boycotting of products and services make market access more difficult. When it comes to AI, manufacturers lack experience. The economic potential of data-driven services and digitized business processes cannot be fully exploited. Strategic decisions in companies are made independently of findings from data analyses. Digital business models have not been consistently analyzed and implemented. IT companies seized the opportunity and acquired industry-specific knowledge. They offer smart services and process solutions on their platforms and act directly at the customer interface.

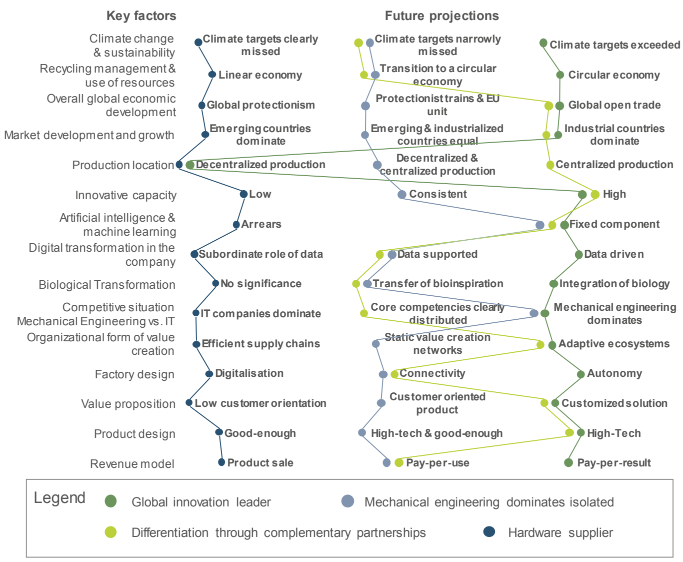

Figure 3. Characteristics of the respective scenarios

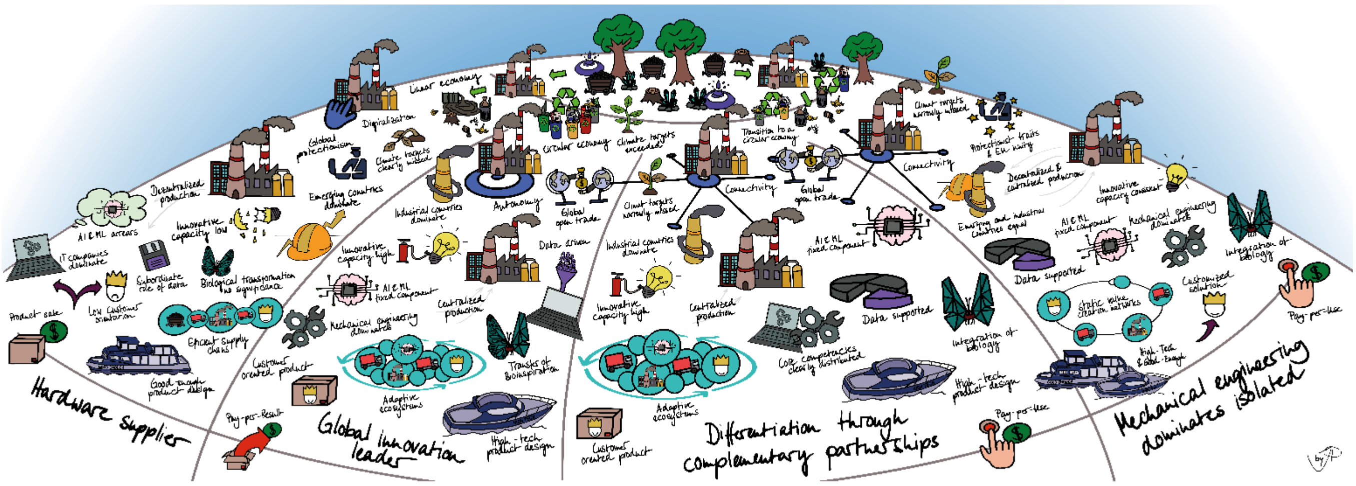

Figure 4. Picture of the future of value creation in mechanical engineering (illustrated by Juliane Pilster)

Differentiation through complementary partnerships (1.94): Value creation is digitalized, efficient and collaborative until 2030+. It takes place in ecosystems, as skills from different industries are needed to create added value for customers. Through worldwide open trade, the transition from linear to circular economy is in full swing. Production takes place in efficient smart factories. Mechanical engineers are aware that biology plays an important role in the creation of value. They are increasingly inspired by it. The ability to innovate has increased significantly through interdisciplinary cooperation across sectors, so that new value-adding ideas can be implemented on the market. AI is an integral part of processes and products. Cyber-physical systems (CPS) generate large amounts of data which are analyzed and interpreted. IT companies provide ideal infrastructures for the exploitation of data so that smart services and products can be offered via their platforms. Manufacturers concentrate on their core competencies and maintain the customer interface through their customized scalable solutions. Differentiation takes place through customer-specific development of smart process solutions and services, which results in long-term customer loyalty. The service share of total sales has increased and is largely generated by offering availability (pay-per-use).

Mechanical engineering dominates isolated (1.89):

Due to the efficient and digitalized value creation and the industry's own platform economy, the market position can be maintained and the position at the international top can be secured by 2030+. Depending on market requirements, products are manufactured centrally or decentralized in static value creation networks. Outside the EU, products and services are boycotted in some places by protectionist policies. The transition to a circular economy has been heralded. Incremental innovations are generated through loose cooperation with customers and users. AI is an integral part of processes and products. CPS generate substantial amounts of data which are analyzed and interpreted. Humans continue to make decisions, which are enriched by information from data. IT companies have tried to gain a foothold in the B2B market but have failed due to the lack of domain-specific know-how. Customers can thus be retained in the long term. There is a balanced demand on the market for high-tech products - industrial countries - and good-enough products - emerging markets. Sales are generated by billing the use of the product or system (pay-per-use).

4.3. Options for action for mechanical engineering companies

From the statements and results of the ten expert workshops, the team of three researchers was able to derive four concrete options for action that can be specifically addressed by the mechanical engineers within the scope of their value creation. With the help of these adjustment levers, they can consciously transform towards one of the scenarios or take steps to move in a different direction. These four derived options for action are explained in more detail in the following section.

Ecological awareness:

Mechanical engineers could become independent of both regulations and volatile raw material prices and thus produce ecologically neutral products. The foundation for this is the creation of an ecological awareness. As a result, measures can be taken to save resources and minimize waste. A first step is the analysis of the CO_2 emissions of individual companies. Based on these values, plans can be made to reduce energy consumption, increase energy efficiency and thus reduce CO_2 emissions. In the course of the current debate on a possible CO_2 tax, reducing CO_2 emissions would contribute to environmental protection and save costs. Furthermore, products need "new ecological functions" such as recyclability or the consideration of energy efficiency, which are important influencing factors, especially in research and development. Initial pilot projects can be used to test whether economic added value can be achieved through recycling management principles. This makes it possible to develop inexpensive, green products that are competitive. Partnerships and collaboration are a prerequisite for the implementation of ecological goals.

Product-Service-Design: By means of an intelligent product-service design, mechanical engineers can further expand customer loyalty and secure a competitive advantage by offering services. It is important to observe the development of pay-per-x models on the market and prepare suitable business models for them. In order to implement this, modular product concepts with intelligently adaptable functions as well as the measurability of final quality and degree of fulfillment are required. Mechanical engineers can introduce these models as soon as external conditions – such as the public infrastructure – make this possible and customers as well as stakeholders are willing to use such offerings. In addition, further requirements and clear strategic steps must be derived for the expansion of a fully autonomous factory.

Inter- and intraorganizational Transformation: In the future, innovations will more often be generated across industries in value creation networks or flexible ecosystems. For this reason, the development of strategic partnerships is essential for the company in the mechanical engineering sector. Existing relationships with business partners can be strengthened and intensified at all levels. The promotion of intra-company cooperation must be further intensified, and employees must be prepared for the change towards an ecosystem approach. A further step establishes cross-industry partnerships in order to gain access to the skills and resources needed to create future value.

New competencies and core competencies: New value-adding competencies can be developed by mechanical engineers, especially in the areas of networking, IT, software and data analysis. This requires knowledge about data handling. The role of data engineers is becoming increasingly important for value creation. The company's competencies are shifting from hardware production to software focus. The company is thus adapting the value-added structure of a software company to a large extent. Therefore, it is necessary to find a balance between previous core competencies in a high-tech context and newly required competencies of IT and software. Through these measures, mechanical engineers can combine machines with complementary software to form integrated solution bundles and thus offer customers new value propositions. Mechanical engineering companies also need these new competencies for the implementation of digital business models.

5. Discussion

The content of the scenarios is partly influenced by global factors that cannot be manipulated by companies themselves and is therefore has restrictions. The developments are very dynamic and characterized by many uncertainties. This makes a reliable forecast of the most likely developments difficult. A disadvantage of the scenario technique can be the subjective assessment of the people involved and the information provided. In this case, three comprehensive trend analyses, which were additionally enriched with further information were used. The reliability of the results depends on the professional qualifications, the ability to think holistically and the creativity of the people involved. However, it is clearly stated how complex and versatile future value creation can be. The recording of comprehensible future scenarios of value creation offers added value to companies in the mechanical engineering industry. The scenarios and options for action identified can provide the basis for formulating long-term strategies and implementing a roadmap into the future, thereby mitigating possible future effects for the company. This can provide a competitive advantage. The scenarios are influenced by emerging trends; thus, it is important to check the scenarios and future projections for changes at regular intervals.

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