Challenges and Research Needs in the Offer Phase of Special-Purpose Machinery and Plant Engineering: A Qualitative Study With Industry Experts

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***Abstract*—*Customization is an important competitive factor that enables companies to serve their customers better and succeed in an increasingly demanding and diverse market world. Instead of producing mass products for a broad target group, products or services are designed and produced to meet customers' individual needs and preferences. However, this also confronts companies with the challenge of meeting the diversity of customer needs. The special-purpose machinery and plant engineering industry, a major European and especially German industry, is the industry considered in this article. To analyze the challenges in more detail, the authors conduct an interview study with experts from this industry. This article examines the challenges faced by the experts during the offer phase, when the first design of a customized machine is created, and the phase that determines the company's success. Relevant literature is discussed, and gaps in research are identified.*

Key words: Bid management, challenges, interviews, lot size 1, mechanical engineering, offer phase, plant engineering, research opportunities, special purpose machinery, technical sales.

I. Introduction

The mechanical engineering sector is of great importance in Germany and is a part of the industrial goods market. In the European Union (EU), EUR 908 billion in sales were generated in the mechanical engineering sector in 2023. Germany generated the largest share of any single country with sales of EUR 263 billion. In terms of machinery exports, Germany also occupies first place in the EU [1]. As a result, well-organized and target-oriented offer management in technical sales is crucial for mechanical engineering companies in order to maintain a good economic position. In special-purpose mechanical engineering, complex machines and systems are designed that are individually tailored to the customer. Due to this high degree of specification, the products and, thus, their offers cannot be sold to just any customer, which means that large expenditures represent a higher risk [2]. However, individualization enables companies to stand out from the competition. In highly competitive markets, the ability to offer customized solutions can help win customers and achieve higher prices for products or services [3], [4]. On the other hand, such a demarcation increases the cost of the development and its complexity [3].

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The variety of product variants, thus, leads to an increase in the complexity of business processes, such as the offer phase in technical sales [5].

Furthermore, customers are increasingly driving the digitalization of products. This digitalization from the customer's perspective also influences the offer phase [6]. At the same time, the use of artificial intelligence (AI) in mechanical engineering is being promoted. AI can be used to plan special-purpose machines by automatically comparing past machines with the requirements of the new customer and making recommendations for implementation [7]. Design programs can also be linked to AI, suggesting potential assemblies and making design more time-efficient. Intelligent data analysis can optimize maintenance times and detect failures earlier. This technology offers both benefits and challenges [8].

From an environmental perspective, the issue of sustainability can also be addressed in this context. According to a recent study by VDMA and McKinsey, striving for greater sustainability is currently the biggest growth opportunity for the mechanical and plant engineering industry. The German mechanical engineering industry has a crucial role to play in achieving the European Green Deal's goal of reducing CO_2 emissions by 55% by 2030 and 100% by 2050. However, German mechanical engineering companies can only expand their technology leadership and tap into this new market potential through targeted measures to promote research and development [9].

Accordingly, an interview study was conducted by the Fraunhofer Institute for Mechatronic Systems Design IEM to uncover the challenges associated with this high degree of individualization and to identify potential approaches for managing complexity in the offer phase. The interviewed experts identify themselves as manufacturers of special-purpose machines and systems. This interview study provides the data for the exploratory analysis. The aim of the analysis is, on the one hand, to clearly determine the most serious challenges for the offer phase in special machinery and plant engineering, as these lead to significant reductions in efficiency. On the other hand, the current status of aspects, such as the use of methods and information technology (IT), will be highlighted. On this basis, it is possible to identify the existing potential and possible areas for improvement. In order to identify this potential, this article examines the challenges faced by professionals in the offer phase. With this aim in mind, 14 semistructured interviews with industry experts were conducted. The authors used the approach suggested by Mayring to structure the interviews and to categorize the challenges described by the interviewees.

The rest of this article is organized as follows. Section II summarizes the state of the art. Section III presents the interview methodology, followed by the interview results in Section IV. The results include findings coded directly from the interviews with the participants, such as internal and external challenges, trends, competencies, and potential for improvement in special-purpose machinery and plant engineering. In addition, the stakeholders "technical sales" and "customers" in special-purpose machinery and plant engineering are analyzed and characterized by the results of the interviews. These findings are discussed in Section V. There is also a review of the literature. Finally, Section VI concludes this article.

In the context of this article, offer and bid management will be considered as being interchangeable terminology. Although the term offer management is favored by the authors.

II. State of the Art

Customers in special-purpose machinery and plant engineering sector expect an individual solution that optimally meets their requirements [3], [10]. Accordingly, these custom-build products are machines or systems in small quantities, which are often produced in batch size 1. This results in high costs and large time expenditures already in the early planning phase. These points result from the intensive involvement of the customer. With the help of a personal approach and individual interaction, customer-specific requirements are to be identified and integrated into the machine or system [3]. Machine builders focus on the development of individual technical systems for isolated subproblems [10], [11]. It is a special application that changes an object during processing. In comparison, plant engineers solve several subproblems with the plant [11], [12]. The overall solution consists of a combination of standardized and customized performance components, whereby the respective degree can vary. The goal is a synchronized plant system, which is a closed solution concept of several partial solutions [11]. The individual product adaptation is characterized by a larger and partly open solution space [3]. It is also a characteristic that the solution space can be supplemented at any time by new, creative approaches. For example, dimensions, materials, or orientations can be changed [3]. Special-purpose machinery and plant engineering can be assigned to the business-type plant business [13]. According to this business type, the technical sales department structures the offer process. The focus is on the individual customer. Their specific needs play an important role in the design of the service. Thus, the exact machine or plant does not yet exist at the time of marketing and the customer cannot fully determine the quality of the service in advance [13]. In order to

market these trustworthy goods successfully, however, intensive consulting and communication activities are required on the part of the technical sales department [13], [14].

However, the sales conditions for these individualized machines have changed in recent years. Globalization and digitization have made the sales markets much more global. In addition, customers have higher expectations due to more opportunities to compare different offers. They expect products that meet their needs in the best possible way [3]. The interaction of these factors increases the degree of complexity within development, production, and sales activities to a considerable extent [3].

There are a number of IT systems on the market that can be used to support technical sales. Sales activities can be supported by setting up customer relationship management (CRM) systems, which bundle customer information in a central point. Enterprise resource planning (ERP) systems are similar programs, which are used for resource planning in different business units and are linked to a common database [15]. Production planning systems (PPSs) can provide relevant data on material consumption for costing through their information on operating resources and production orders. PPS systems are programs for monitoring the planning of production processes in accordance with quantities, deadlines, and capacities [16]. Technical drawings and 3-D models are created using computer-aided design (CAD) programs, which are used for software-supported modeling of the product structure [4]. Model-based systems engineering (MBSE) software can also be used. MBSE is defined by the end-to-end conceptualization of a system to be developed, from description to analysis, using models throughout the entire product lifecycle [17].

Mechanical engineering is placed in a general context in the literature, with no focus on special-purpose machinery and plant engineering. Accordingly, the sources mentioned are too unspecific to examine the exact circumstances of special-purpose machinery and plant engineering. They define much more the standard of processes in the general industrial goods business. Findings about challenges and trends in special-purpose machinery and plant engineering can only be made to a limited extent with the help of the literature. In addition, the Association of German Engineers' publications [Verein Deutscher Ingenieure (VDI)] on offer management, which is intended to guide companies, is out of date. A study carried out by the VDI in 2008 also used a survey to investigate the potential for improvement in offer management. This refers to various industries and not explicitly to mechanical engineering or special-purpose machinery and plant engineering [18]. As a result, it is not possible to draw any precise conclusions about the current conditions and aids in the offer phase. The motivation for this study, and thus, for an exact and up-to-date view of the special-purpose machine and plant construction in Germany, arose from the arguments mentioned above.

III. Research Design

The research design includes the presentation of the interview study conducted and the method used to analyze the transcripts. Accordingly, this is a qualitative study.

A. Presentation of the Study

With the scope of the study, expert interviews were conducted with 14 different industrial companies that located themselves in the special-purpose machinery and plant engineering sector. The interviewees actively responded to a call for tenders or were specifically contacted with the help of the owl maschinenbau e.V. and OWL ViProSim e.V. networks. Despite the reference to special-purpose machinery and plant engineering, the companies manufacture machines for very different industries. For example, the companies work with customers from the food, wood, furniture, automotive, and aviation industries. Detailed information about the companies can be found in Table 1.

Table 1. Information About the Companies.

Company	Machines or plant construction for	Founding year	Number of employees
1	logistics	1945	140
2	electrical and pharmaceutical industry	1951	75
3	food industry	1950	110
4	automotive industry, aerospace	1930	240
5	construction industry, cosmetics, pharmaceutical, food industry	1938	500
6	infrastructure, energy, automotive industry	1945	130
7	furniture industry	1981	200
8	automotive industry, aerospace	1934	150
9	wood, furniture industry	1885	130
10	supplier for various mechanical engineering companies	1972	500
11	supplier for various mechanical engineering and infrastructure companies	1958	25
12	food industry	1981	1500
13	wood, furniture industry	1925	500
14	food industry	1898	150

Furthermore, a focus on mechanical or plant engineering can be differentiated between the companies. Machine builders are characterized by a focus on modeling the system structure. Plant engineers are characterized by a focus on modeling the process sequence [19]. A breakdown of the companies surveyed is shown in Table 2. It can be seen that 57% of the companies belong to the plant engineering sector and 43% to the mechanical engineering sector.

The interviews are semistructured to allow the respondents to express themselves freely and to identify the individual challenges. The interviews cover the following topics.

1) Definition of special-purpose machinery and plant engineering.
2) Process flow of the offer phase.
3) Use of methods and tools.
4) Challenges and potential for improvement.
5) Trends in special-purpose machinery and plant engineering.
6) Qualifications of the technical sales department.

By analogy with these topics, the following research questions are to be answered through the interviews and the subsequent analysis.

1) What are the main characteristics of special-purpose machinery and plant engineering?
2) What tools and methods are used in the bidding process?
3) What challenges does special-purpose machinery and plant engineering face in the offer phase?
4) What potential for improvement exists for these challenges?
5) What trends can be identified in the field of special-purpose machinery and plant engineering?
6) What qualifications does the technical sales department in special-purpose machinery and plant engineering need?

Table 2. Characterization of the Companies.

Company	Machine or plant construction firm
1	plant construction
2	plant construction
3	machine construction
4	machine construction
5	machine construction
6	plant construction
7	plant construction
8	machine construction
9	plant construction
10	machine construction
11	machine construction
12	plant construction
13	plant construction
14	plant construction

Table 3. Information About the Interview Participants.

Company	Gender	Position within the company
1	male	managing director
	male	head of internal sales
2	male	head of sales
3	male	head of construction
	female	team leader construction
4	male	sales in the area of digitalization and automation
5	male	head of sales and marketing
6	male	head of sales special-purpose machinery
	male	sales and project planning
7	male	sales
8	male	head of sales
	male	sales drilling technology
	male	production optimization
9	male	managing director and head of sales

The interview participants pursue various professions, all related to technical sales. For example, sales managers, managing directors, sales representatives, and product developers were represented. In addition, the Chairman of the "Technical Sales and Product Management" Department of the VDI was interviewed. A detailed list of the interviewees can be found in Table 3.

B. Method After the interviews have been conducted, they are transcribed into text documents. With the help of the IT program MAXQDA, a qualitative content analysis according to Mayring is carried out. This involves a structured procedure that systematically reduces texts and filters out defined content [20]. The basis of the qualitative content analysis is the category system. Each category can contain any number of subcategories and reflects exactly which parameters are measured during the analysis. Categories were developed both deductively in advance based on the existing literature and inductively based on the passage through the text [21]. The deductive categories were identified based on a literature review on the topics of "technical sales" and "offer management/processing." The specialist literature was analyzed for decisive keywords, which were included as categories. The fact that the keywords were very present in the

literature suggested that they would also be relevant in the interviews. The category system is further expanded during the analysis with inductive categories. The inductive categories are identified based on the transcribed interviews. They are reviewed individually, and text segments are either assigned to the existing deductive categories or new inductive categories are created based on the text content. As the inductive categories are developed, the already coded interviews are reviewed again for matches. This process is repeated until a complete code system is created that represents all statements and topics. This circular procedure is based on so-called feedback loops [22]. The process is shown in Figure 1.

To ensure intercoder reliability, relevant excerpts of the interview transcripts are reviewed by two people and coded using the following categories. Subsequently, taking intracoder reliability into account, the transcripts are edited again by one coder independently of the first coding [23]. After reviewing the category system, inductive categories are added if necessary, and categories are reassigned or subassigned. The added categories are applied to all further transcriptions to ensure complete coding. If there is more than 80% overlap and both coders agree on the naming and assignment of categories, the full category system can be represented. Qualitative category creation is followed by the aspects of category assignment that are more quantitative, such as frequency and correlation analysis [24].

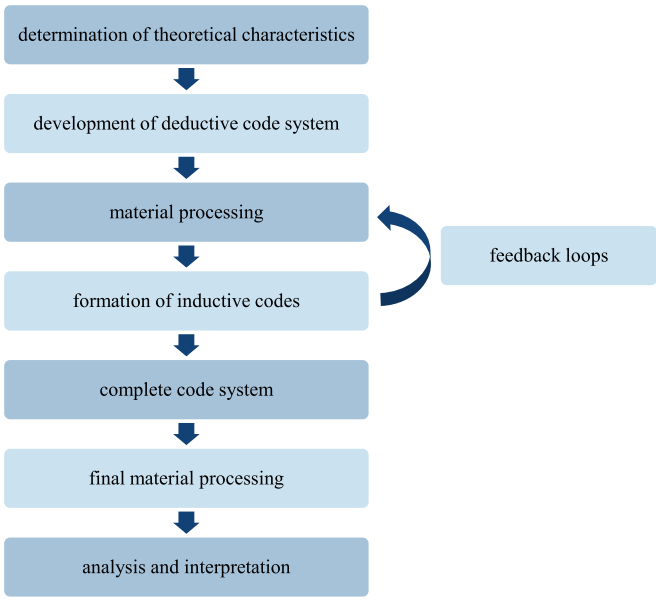


Figure 1. Process of qualitative content analysis.

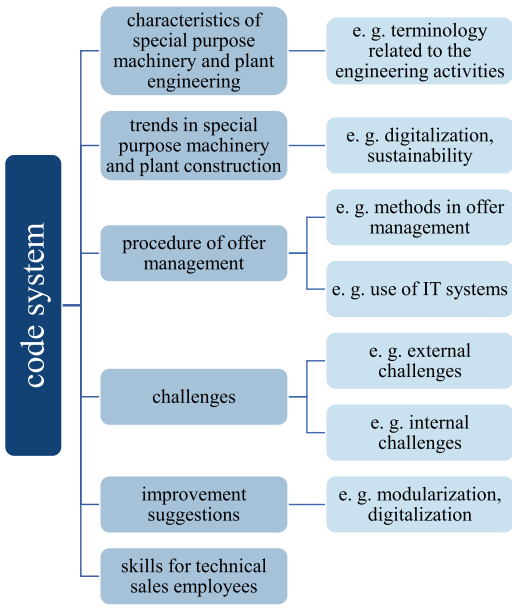


Figure 2. Excerpt from the coding system.

IV. Results

The results of the qualitative content analysis according to Mayring represent various areas of the offer phase of special-purpose machinery and plant engineering. The results are recorded using inductively and deductively formed categories that are aligned with the topic areas of the interview structure. The main categories "characteristics of special-purpose machinery and plant engineering," "trends in special-purpose machinery and plant engineering," "procedure of offer management," "challenges," "improvement suggestions," and "skills for technical sales employees" are developed. These main categories have further subcategories, such as "methods in offer management," "use of IT systems," "external challenges," and "internal challenges" (cf., Figure 2).

The results of the six main categories (cf., Figure 2) are presented in the following. In this context, the subcategories are also discussed. In addition, as mentioned above, the two stakeholders, technical sales

and customers, are characterized based on the interviews. Literature references are provided in each section.

A. Characteristics of Special-Purpose Machinery and Plant Engineering

There are several characteristics of the special machinery industry that were highlighted during the interviews with the experts. In connection with the engineering activities, i.e., the expected engineering effort, the subcategories "customized machine," "machine with the same basic structure," and "new construction" emerge (cf., Figure 3). The most frequently mentioned definition is a "customized machine" that is specifically tailored to the customer's needs. A total of 11 companies use this definition for a special-purpose machine or plant. The 10 of the 14 interview participants refer to a machine with a basic structure. Nine companies define a special-purpose machine or plant as a completely new construction.

Looking at the overlap of the different development activities at each company, it is noticeable that terms from multiple categories are often used together to describe the development of a special-purpose machine or plant. The 10 of the 14 respondents use at least two of the categories "customized machine," "machine with the same basic structure," or "new construction." Seven respondents used all three categories. From this, it can be concluded that there is no clear definition of terms within the companies or that it is not clearly defined which characteristics a special-purpose machine or plant has to fulfill. This illustrates the diversity of characteristics of a special-purpose machine or plant.

All three characteristics of development activities are also described in the literature. Lindemann et al. [3] name basic product structures, which represent the fixed areas of a machine and, thus, serve as a basis for further adaptations. This is comparable with the category "machine with the same basic structure." The further adaptations of the basic product structures refer to customer-specific requirements, which complete the machine. According to Lindemann et al. [3], the finished technical solution meets the individual needs of the customer. This description is comparable to the category "customized machine." According to Pahl et al. [25], an individual product adaptation with a very open solution space is a new construction This new construction passes all design steps and is based on new solution principles. According to Feldhusen and Grote [4], the new design is developed with the help of customer requirements. These specifications are comparable with the category "new construction." Depending on the extent of the individual customer requirements, the development activities correspond to the expenses for a special-purpose machine or plant. In advance, none of the development activities for a special-purpose machine or plant can be excluded, as it depends on the respective engineering effort. Based on the evaluation and the literature, the consideration of customer requirements is common to all three categories. They differ only in the degree of individuality and the type of solution principles that may be known or new.

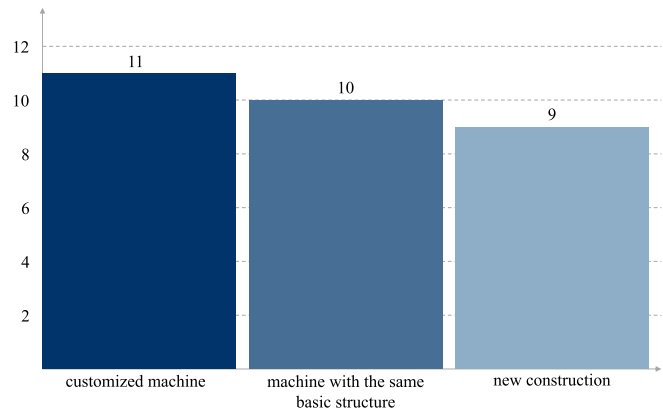


Figure 3. Terminology related to the development activities.

In addition, a frequently mentioned characteristic is the handling of iterations. The 10 of the 14 interviewed companies stated that they completed several iteration loops within the offer phase. The exact figures range from 4 to 15 iteration loops per offer.

Another characteristic of the special-purpose machine and plant manufacturers is their willingness to innovate. It describes the openness to new solutions and requests that have not yet been dealt with internally. The 4 of the 14 companies claim to be open to innovation.

The 4 of the 14 companies also stated that they had already received requests for the next one to three years, for which they intend to prepare offers. Accordingly, the forward-planning offer situation can be characterized as a further characteristic.

B. Trends in Special-Purpose Machinery and Plant Engineering

The most common response to the question about current trends in special-purpose machinery and plant engineering was digitalization. The 10 of the 14 companies report that digitization requirements are increasing (cf., Figure 4).

Sustainability in various aspects, such as energy-saving motors, is stated by six companies. The increasing complexity of machines and processes is named as a trend by five companies. The complexity of machines is increasing, e.g., due to modern controls that are networked with other machines, and the reduction of interfaces to multiple machines, i.e., one machine should perform as many different services as possible in a single machine. Three companies identify complementary services, such as maintenance for their machines as a leading trend. Two companies mention standardization as a trend. One company mentions ease of use because, according to the company, operators are increasingly being staffed by unskilled rather than skilled workers.

A comparison of the trends mentioned shows that digitization and sustainability are mentioned by five companies in connection with each other. Together with digitization, three companies also mention the increasing complexity of machines and processes. In addition, two experts mentioned services and digitization in combination. The trend toward digitization is, therefore, related to these trends, and the aspects of digitization are probably necessary for the implementation of the other trends.

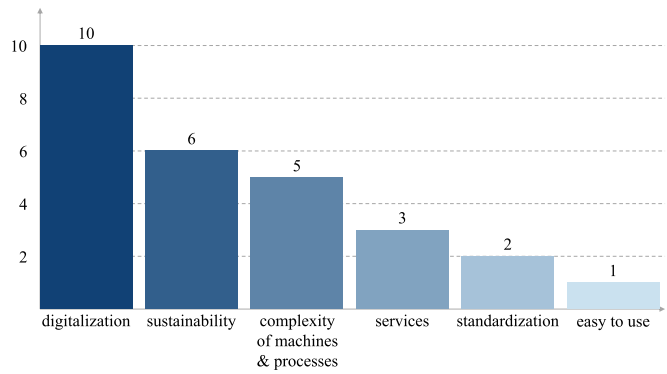


Figure 4. Trends in special-purpose machinery and plant engineering.

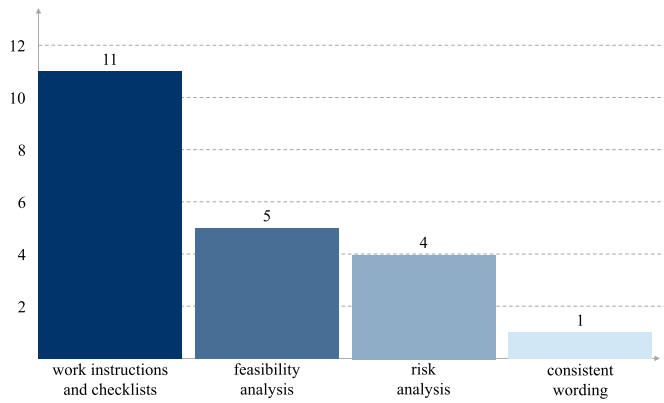


Figure 5. Methods in offer management.

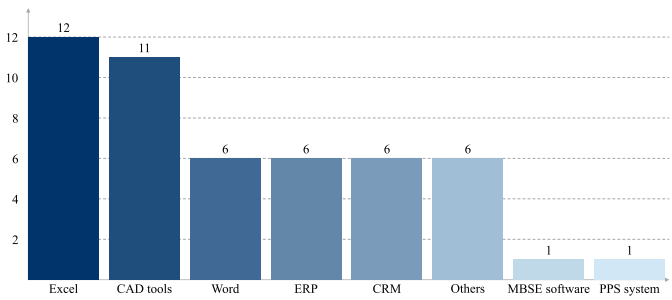


Figure 6. Use of IT systems.

C. Procedure of Offer Management

Companies use a variety of methods and IT systems to support the offer process. The most common method of offer processing is the use of work instructions and checklists (cf., Figure 5).

The 11 of the 14 companies use these during the offer phase. The use of work instructions and checklists is also recommended in a VDI guideline and other literature to support employees in the completeness of information [26], [27]. In this case, the recommendations in the literature coincide with the practical implementation. Five companies perform a feasibility analysis before preparing the offer. Four companies perform a risk analysis for the project. Only one company uses uniform wording when writing the offer, i.e., uniform terms are used for the different technical specifications and solution spaces defined in advance.

The use of evaluation models, such as the scoring model or the Kambartel value number procedure, is recommended in the literature as a method for systematically evaluating customer inquiries based on the defined criteria [27], [28]. However, none of the companies surveyed used such a model during the offer phase.

All of the companies are supported by different IT systems (cf., Figure 6). Excel is the most used program. A total of 12 companies report using this program. The 8 of the 12 companies use Excel for price

calculation. The results support the literature's recommendation to use Excel as a pricing tool, as two-thirds of the companies that use Excel do so for calculation purposes [29]. A total of 11 companies use CAD tools. Both CRM systems and Word are used in six companies. Six companies also make use of other IT systems, which are not named in detail. In two companies, it is a special SharePoint, in one company a ticketing system, in one company a program for cycle time calculation, in one company a design tool for machines, and in one company an offer configurator that allows to create a simplified layout. Furthermore, six companies work with an ERP system. One company states that an MBSE software and a PPS system are used for support. These PPS systems are also mentioned in the literature as facilitating calculation [16]. There is a discrepancy here between literature and practice. In 2010, the VDI recommended the use of CRM and ERP systems during the offer phase [26]. However, only less than half of the companies follow this advice. This suggests that there is still a lot of potential for companies to benefit.

The 12 of the 14 companies use past offer documents as a source of information. Thus, past offers are also a frequent aid in the preparation of offers.

The treasure trove of employee plays an important role in all of the companies surveyed. All of them state that they rely on the experience of their employees at various stages of the offer process. In eight companies, the technical solution is created on the basis of experience and knowledge. Experience knowledge is also used to determine the feasibility of a machine in eight companies. In six companies, experience knowledge is used in the price calculation. The literature confirms that this form of pricing by estimation is still frequently used in companies, although the procedure is risky [16]. Both the assessment of the seriousness of a customer request and the verification of the completeness of a request are based on the knowledge of the employees in each company (cf., Figure 7).

The companies also provide information on the process flow of the offer phase. Total 50% of the companies classify their approach as an individual process flow, which can vary greatly from inquiry to inquiry. Weibel's dissertation on sales in the industrial goods business deals with the general sales process in the various business types. In contrast to the individual process flow of the companies, it was determined that the processes should be as standardized with regard to customer processing. This processing should be carried out using standardized procedures according to customer requirements in order to minimize the risk of misconstructions [2]. According to the literature reference, the individual process flows are an obstacle for the respondent companies and should be standardized.

In order to create and present the offer, companies use different methods to acquire customers for their offer (cf., Figure 8). There are some special characteristics of customer acquisition that the companies consider to be success factors. Ten companies use 3-D tools in their presentations to attract customers. One of these companies supports this digital presentation with a printed 3-D model (prototype). Three of these companies not only use optical 3-D models but also carry out simulations on a digital twin (digital replica of the machine). For three companies, the real machine in form of a video or an on-site visit has a convincing effect on the

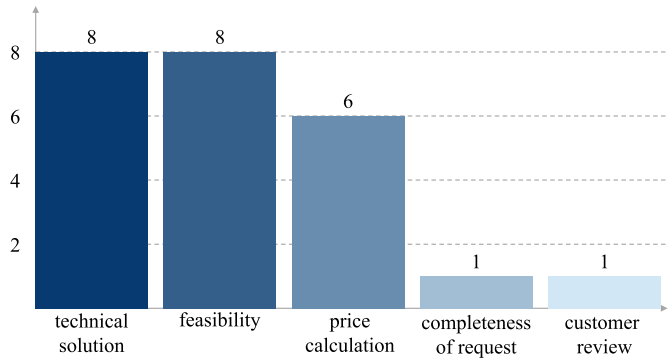


Figure 7. Use of in-depth knowledge.

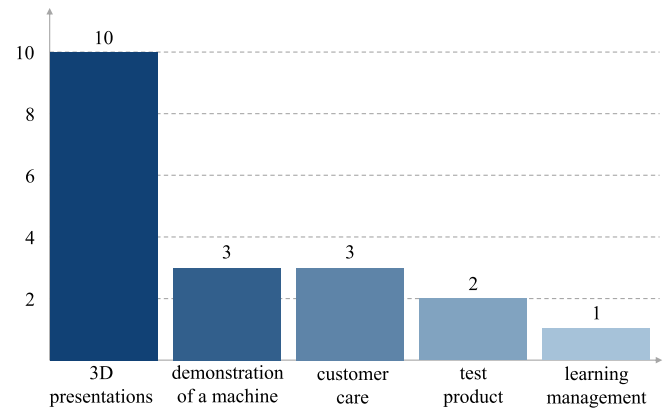


Figure 8. Use for customer acquisition.

customer. Three companies consider customer care to be a key component in customer acquisition. Test products or samples for customers are crucial to the success of two companies. One company uses learning management as a success factor. A learning management system contains a wealth of information, explanations, and videos that help salespeople to build specialist knowledge and, thus, win customers (cf., Figure 8).

D. Challenges in the Offer Phase

The companies characterize internal and external challenges related to the offer phase in special-purpose machinery and plant engineering.

Companies face external challenges due to various forms of customer behavior (cf., Figure 9). The 13 of 14 companies cite problems in areas of customer behavior. The most frequently mentioned behavior (12 out of 14 companies) is the occurrence of iterations and change requests from the customer. These changes occur after the fact and result, for example, in increased offer preparation time due to increased design effort. Several reasons for the occurrence of iterations were identified. Approximately, 80% of companies named customer change requests as one reason. Other reasons include the customer's inaccurate perception of the machine, and missing and incorrect data provided by the customer, such as differences between drawings of the end products and samples. Missing or late requirements are also a challenge. If the customer's requirements are not within the cost budget, iterations must also be performed. Since the offer phase is a lengthy process, changing customer requirements, such as new or modified products, can lead to further iterations. Lack of material availability was also mentioned as a reason for iterations. In addition to external factors, there are also internal reasons for iterations. Lack of or inaccurate documentation of requirements, poor communication between departments, such as mechanical and electronic design, and internal disagreements about the technical implementation with regard to various suggestions for improvement all lead to iterations within special machine and plant manufacturers. Requirements or other conditions for the offer process are inaccurately documented or not made available to everyone during the initial steps, and errors and changes will occur later in the process. In 7 out of 14 companies, a lack of prior knowledge on the part of the customer leads to a lengthy exchange of requirements with the customer, delaying further steps in the process. Data transparency is also a problem for half of the companies, as they do not immediately receive all relevant data from customers. For 50% of the companies surveyed, the increasing pressure to customize is a major challenge. Customers increasingly expect individualized solutions that are specifically tailored to their needs, but this requires significant effort on the part of companies. Despite these challenges, companies are expected to offer as much external variance in their product portfolios as possible. As one company points out "A major problem is the relatively high variance of the components we offer to our customers." Even small changes in customer requirements can result in new variants that require significant design effort for the special-purpose machine manufacturer. Communication with the customer is a challenge for six companies, for example, because there is no specific contact person. Five companies state that comparing offers is a challenge. Customers compare the offers they receive with competitors' offers and no order is placed. Two companies cite building trust with the customer as a challenge (cf., Figure 9).

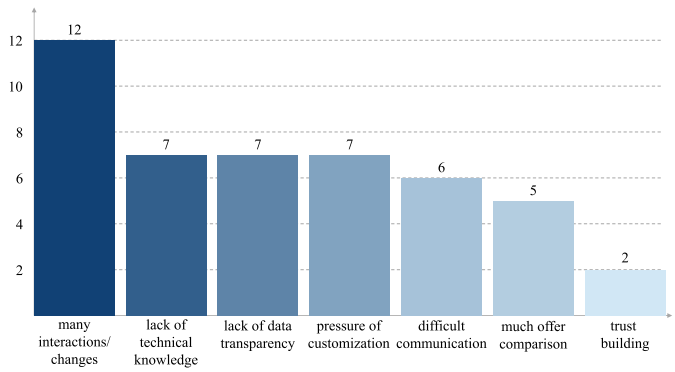


Figure 9. Customer behavior.

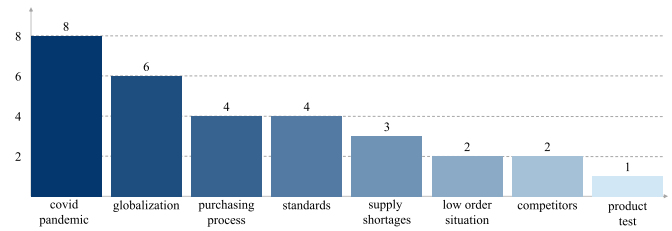


Figure 10. External challenges (without customer behavior).

In addition to the challenge of customer behavior, the companies mentioned other external challenges, such as the Covid pandemic, globalization, and the purchasing process. The number of responses from the companies can be seen in Figure 10. The challenges of globalization, limited resources, and

demographic change are often cited in the literature as drivers that force companies to remain competitive [30]. This is compounded by the rapid technological change [31].

It is noticeable that some challenges overlap when the companies' responses to the external challenges are checked for intersections. A total of 11 challenges always occur together with the challenge of "many iterations/changes." These challenges are trust building, difficult communication, lack of data transparency, pressure of customization, globalization, Covid pandemic, supply shortages, low-order situation, competitors, standards, and product test. As a result, it can be assumed that these 11 challenges are influenced by iterations and changes and vice-versa.

Looking at the internal challenges, effort–benefit ratio (cf., Figure 12) and various forms of interdisciplinary working (cf., Figure 11) methods are the most common internal challenges. Estimating the cost–benefit of preparing offers is a challenge for eight companies. It is unclear in advance whether the company will receive the order as a result of the offer. For salespeople, this raises the question of: How much effort do I put into an offer to make it worthwhile? Interdisciplinary working is a challenge in various forms for 12 of the 14 companies (cf., Figure 11). In some companies, the general interdisciplinary way of working is problematic, e.g., because there are tensions between departments or because different employees have different levels of knowledge. In the other companies, interdisciplinary work can be differentiated into subcategories (cf., Figure 11). In 7 of the 12 companies, disagreements about the resulting solution for the customer regularly cause considerable discussion among employees. The 6 of the 12 companies recognize the lack of data transparency between employees and individual departments as a source of problems. Communication between employees is described as a challenge by 50% of the 12 companies. Communication is a problem; e.g., too little information is shared due to lack of time and inadequate explanations that are not understood by other employees. Two of these seven companies highlighted the lack of standardized wording during the offer phase as a particular challenge. This means that there is no consistent terminology for technical terms within the company and that there are differences in wording and naming when dealing with foreign languages. Five companies identified the acceptance of new tools and methods among employees as a disruptive factor because older employees have prejudices against the programs (in three companies), or employees have a negative attitude toward change due to a lack of change management or increased stress (in two companies). The 2 of the 12 companies criticize a lack of accuracy in the way employees work. Different characters in the workforce, who prefer to work freely with customers and want to follow few guidelines, create challenges for one company (cf., Figure 11). In their study "Management of Hybrid Value Creation," Ganz and Bienzeisler [32] point out the consequences of insufficient communication with the specialist departments in the offer phase. In fact, it leads to unrealistic deadlines and delays. The 2023 Manufacturing X study identifies the need for research into solutions that improve collaboration in the engineering process, such as enabling lossless data exchange between different engineering tool families or using data from the shop floor for the next generation of products [31]. According to Dispan and Schwarz-Kocher [6], digital transformation goes hand in hand with cultural change, which requires empowering and engaging employees. As a part of the latest Acatech expertise of the Industry 4.0 Research Advisory Board, in addition to external collaboration with customers, efficient collaboration between different disciplines is also emphasized. This raises the research question of what a model could look like that enables the interdisciplinary

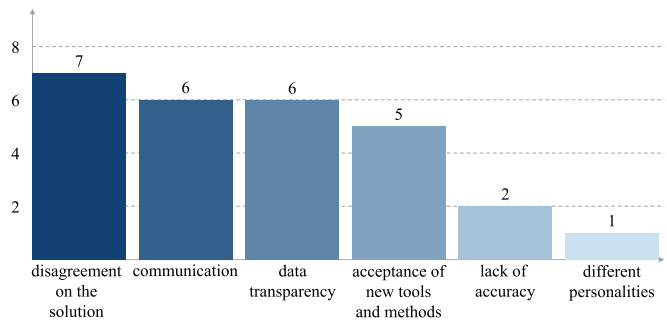


Figure 11. Interdisciplinary work.

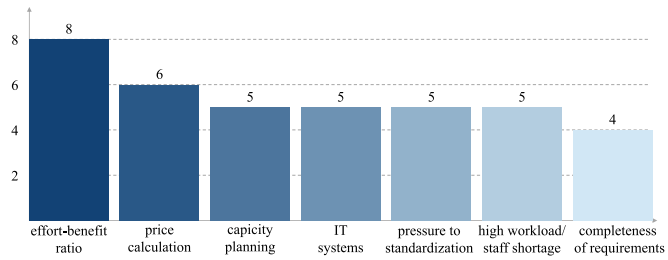


Figure 12. Internal challenges (without interdisciplinary work).

engineering of production systems and maps the data in the form of a system model [33].

Turning to the other internal challenges (cf., Figure 12), 4 of the 14 companies cite completeness of requirements as a challenge. For example, they state that for complex machines with which they have little experience, requirements are easily overlooked or customer requirements cannot be fully met.

Price calculation is also cited as a challenge by six companies. For example, they point to the estimation of design costs and the estimation of vertical integration as a particular difficulty in calculating prices. Five companies see capacity planning for future projects as a disruptive factor. In this context, the companies cite the difficulty of keeping design and production equally busy at the same time, and of compensating for periods when fewer orders are placed. The literature also reports on capacity planning as a challenge [34]. In addition, 5 of the 14 companies surveyed consider inadequate IT systems to be a source of problems. For example, they are not interlinked within the company, are too confusing for the complex presentation of all data or are not automated enough. Five companies see high workload or shortage of staff as a challenge (cf., Figure 12). Internal pressure to standardize is seen by five companies as an obstacle to the development of customer-specific solutions. In particular, managing the internal diversity of variants is a challenge, as too much diversity is difficult to manage, for example, in terms of archiving all variants. One company using a modular system stated "Our modular system serves as a basis, but it is rare that we simply take a module and build a complete machine from it." These statements clearly show the tension between individualization and standardization in which technical sales are caught. According to Dispan [35], it is necessary for sales not only to act purely customer oriented and try to satisfy every customer request but also to consistently take into account the interests of the company.

When the information on the internal challenges provided by the companies is examined for overlaps, it is noticeable that three challenges always occur together with the "effort–benefit ratio" challenge. These challenges are capacity planning, lack of accuracy, and lack of standardized wording. In the interviews, companies that mention these challenges also report a lack of clarity about the cost–benefit ratio as a challenge. Accordingly, it can be assumed that these three challenges are influenced by the cost–benefit ratio and vice-versa.

Furthermore, MAXQDA offers the possibility to mark the occurrence of two codes in close proximity within a document. The category systems "methods in offer management" (cf., Figure 5) and "challenges" are compared. The system checks whether codes are mentioned together within a maximum distance of two lines of the interview script. The external challenge "lack of technical knowledge" (cf., Figure 9) has eight overlaps with the category "use of work instructions and checklists" (cf., Figure 5). The external challenge "many iterations/changes" (cf., Figure 9) and the category "ERP system" (cf., Figure 6) have seven common overlaps. Six common overlaps occur between the external challenge "many iterations/changes" and the categories "use of work instructions and checklists" (cf., Figure 5) and "Excel" (cf., Figure 6). The "Excel" category has five common overlaps with both the internal challenge "effort–benefit ratio" (cf., Figure 12) and the internal challenge "IT systems" (cf., Figure 5). It can be assumed that the respective challenge occurs especially with these methods and tools. The IT program Excel and the use of work instructions and checklists are particularly susceptible to causing challenges. These process components should ideally be optimized, as they are particularly susceptible to problems that lead to challenges for companies.

E. Potential for Improvement From a Technical Sales Perspective The companies interviewed identified several areas of improvement that they believe would lead to significant increases in efficiency. The 12 of the 14 companies see the greatest potential for improvement in various aspects of digitalization (cf., Figure 13).

Two companies see potential for improvement through a general increase in the digitalization of the offer process. One company could imagine the automatic translation of international inquiries and requirements. Three companies see significant potential for improvement through a digital library/toolkit. According to the information provided, templates for recurring

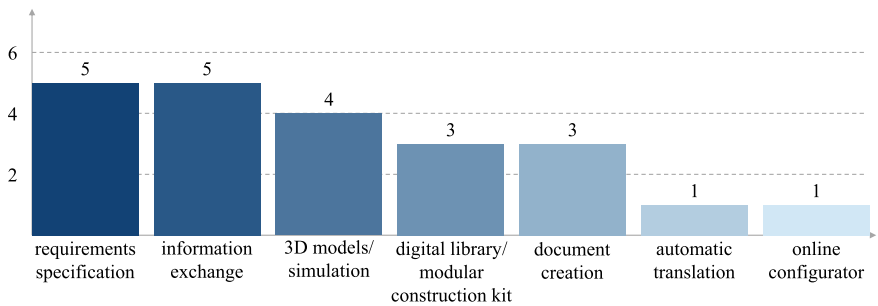


Figure 13. Digitalization.

main components of the machines as well as templates for texts of the offer document should be stored there. The 5 of the 14 companies state that the recording of requirements could be optimized. With regard to the preparation of the offer document, three companies would like to see improvements through IT systems. In addition, five of the companies stated that the exchange of information between employees and departments should be improved. Five companies see the potential for improvement through 3-D models or 3-D simulations for the presentation of offers, such as a program that displays the special-purpose machine or system in the production hall. The use of augmented reality (AR) to enhance 3-D presentations is also recommended in the literature and may become more widely known in the future as it continues to expand [36]. In addition, one company could imagine improvements through an online configurator for its machines. This online configurator works by first requesting technical data in the form of a checklist. The customer is then automatically offered a product and a price. If they are still interested, they can contact a sales representative.

The companies also mention other areas for improvement, such as an internal structuring of departments, online communication, and modularization. The numbers of the companies' responses can be seen in Figure 14.

The potential for improvement in companies can be addressed by a variety of approaches. At this point, we will briefly outline how the authors have attempted to address the challenges so far. It has been identified that the integration of systems engineering (SE) and MBSE offers significant opportunities for the offer phase in special-purpose machinery and plant engineering by providing a consistent system model [37]. Within the scope of this approach, established SE potentials were transferred to the offer phase. Use cases were developed that improve the traceability of processes and the systematic way of working [38]. This facilitates the understanding of requirements in the offer phase and the exchange of up-to-date information during development [38]. As a second approach to addressing the challenges in the offer phase, a model-based configuration tool was developed in collaboration with a special-purpose machinery and plant engineering company [39]. This configurator offers the possibility to handle external customer variance to systematically document the customer's requirements and to assign them to the internal variance, i.e., the internally standardized solution elements, without losing the possibility of individualizing the solution. This model is a mixture of a digital library, a modular construction kit, and an online configurator. A third approach of the authors presents a collaboration model that is designed to promote interdisciplinary cooperation and transparent working methods [40]. The process description of VDI 4504 has been modified for this purpose. The model contains a systematic overview of which stakeholders are responsible and when, and which IT systems should be used at which point in time. Furthermore, a model-based approach was integrated using the MBSE modeling language CONSENS. Various partial models support technical sales. For example, additional requirements can be easily captured using an environment model. The model was approved and tested in a validation with industry stakeholders to determine how it can be integrated into the offer phase. This allows processes to be improved and ways of working to be systematically restructured. The approaches show successful implementation of the suggested improvements, especially regarding the integration of SE into technical sales.

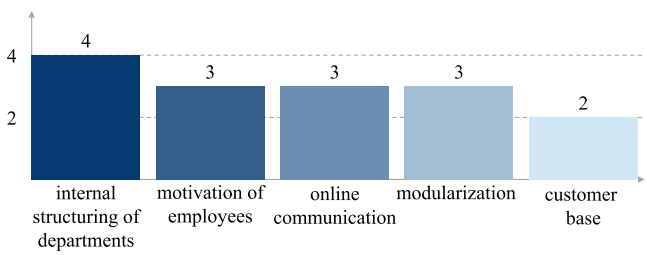


Figure 14. Improvement suggestions (without digitalization).

F. Qualifications of the Technical Sales Department The 5 of the 14 companies cite soft skills, such as social skills, determination, or communication skills as important qualifications for technical sales. The 13 of the 14 companies cite hard skills, such as design knowledge or relevant market knowledge, as an essential requirement. The 11 of these 13 companies only attach importance to technical knowledge. Accordingly, technical hard skills are most important for companies in the special-purpose machinery and plant engineering sector.

G. Characterization of Technical Sales With the help of all the findings from the interview study, an initial characterization of technical sales in special-purpose machinery and plant engineering companies can be made. According to companies 9, 10, 12, and 13, technical sales' employees are characterized by a greater willingness to innovate, as they deal with very individual customer inquiries. They also have to deal with iterations during the offer

process due to the high degree of individualization. As a result, they play an important intermediary role between customers and the company's internal development departments. The 50% of companies report that technical sales typically handle requests in an individualized process, without a standardized procedure, depending on the customer's request. Occasionally, methods, such as checklists, are used to record requirements. In most cases, the technical sales' employees in special-purpose machinery and plant engineering use simple IT tools, such as Excel by 12 companies and Word by six companies, which have no links to other programs and have to be filled in manually. Technical sales currently rely on a lot of experience and mental knowledge. In particular, the creation of technical solutions, feasibility decisions, and price calculations is based on past knowledge. Employees, therefore, need a high level of technical understanding, which is more important than commercial understanding and soft skills. Another important skill is estimating the effort–benefit ratio of an offer because preparing an offer for a special-purpose machine or system is time-consuming, and without an order, the costs must be spread over other projects. To prepare a successful offer, they must also coordinate the completeness of customer requirements and monitor compliance with all requirements.

Some claims can also be found in the literature. Kleinaltenkamp and Plinke [41] ascribe a key role to technical sales in communicating with the customer. Technical sales build a bridge between the customer and the internal technical and business departments of the company. Baumberger [42] explains the importance of the customer in product customization. A detailed exchange between technical sales and the customer is, therefore, essential. According to Blecker et al. [43], customers are not able to fully identify all their requirements due to their limited expert knowledge or are not explicitly aware of them. Misunderstandings between technical sales and the customer can arise. This can lead to products that meet the expressed requirements but not the actual ones [42]. As a result, there are more iterations and change requests [44].

H. Characterization of Customers in Special-Purpose Machinery and Plant Engineering

Customers in the special-purpose machinery and plant engineering sector are typically divided into industrial customers and key accounts, as the business area is in the business-to-business sector. Customers make large investments due to the high volume of the projects. They often specify changes when preparing offers, which leads to iterations. In the case of highly technical machines or innovative processes, customers often lack prior knowledge, which makes the requirements gathering process more protracted. Lack of data transparency is also a problem when recording requirements, as some customers are reluctant to share necessary data, such as drawings or samples. In addition, customers demand a high degree of customization to best meet their needs. These three issues are addressed by 50% of companies. If there is no specific contact person on the customer side, communication is difficult unless there is a long-term partnership. Companies 6 and 9–12 emphasize the comparison of offers as a characteristic that some customers make with regard to competitors. Baumberger's [42] dissertation also characterizes customers by individual demands, which they require at a low price. The main focus and the most time in the customer-specific product definition are placed on the specific customer requirements and their interpretation. This makes it clear that the requirements are quite complex and difficult to implement. Furthermore, customers have a stronger bond with the provider due to this high degree of individualization [42].

V. Discussion

The results of this study are based on 14 in-depth interviews with experts from the business-to-business sector. The companies surveyed are intended to be representative of the special-purpose machine and plant engineering industry. However, it is possible that, in a further study with other companies that identify themselves as special machine builders, different frequencies of challenges may occur or new challenges may be added. Also, due to rather small sample size, no statistical representation of the results can be claimed. It is not possible to provide a definitive answer to all the challenges facing the special-purpose machinery and plant engineering industry, as it cannot be guaranteed that all relevant challenges were mentioned during the expert interviews. It is possible that a subjective perception of the companies surveyed was included in the information provided. At this point, it is recommended to further investigate the challenges in the special-purpose machinery and plant engineering sector. This could, for example, be a quantitative survey to confirm the challenges identified or to classify them as minor. The survey could include a large number of companies that identify themselves as specialty machinery companies. Furthermore, other perspectives on the offer phase could be brought into the study. Other interview partners, such as customers or other specialist departments (design, technical purchasing, etc.), could be interviewed in order to decipher further challenges and gain a broader view of the process. As only technical sales people were interviewed, this could result in a biased perspective.

VI. Conclusion

In this article, we have discussed important aspects of special-purpose machinery and plant engineering from a technical sales perspective. A comprehensive overview of the opportunities and challenges that exist in the offer phase in the special-purpose machinery and plant engineering industry is given in this article. In the following, the most important findings of this article are summarized based on the research questions.

What are the main characteristics of special-purpose machinery and plant engineering?

Special-purpose machinery and plant engineering is characterized by being caught between individualization and standardization, trying to find a balance between external and internal variance. The main characteristics in the offer phase are the occurrence of iterations and the customized aspect of a special-purpose machine or plant. It was not possible to clarify conclusively whether a special-purpose machine or plant is just a product with basic components, a new design or a customized machine. Based on the information provided by the companies and comparisons with the literature, it is much more likely to be a mixture of these three construction types, with a focus on customer requirements.

What trends can be identified in the sector of special-purpose machinery and plant engineering?

The most decisive trend discovered in the analysis is the aspect of digitalization. This trend appears to have an impact on other trends, such as sustainability.

Which tools and methods are used in the offer process?

A key systematic method of the offer phase is the use of work instructions and checklists. However, the most important methods mentioned by companies are the use of previous offer documents and the use of employees' experience. Experience is mainly used in the creation of technical solutions and in the assessment of feasibility. The most commonly used IT systems are Excel and CAD tools. In general, therefore, experience is more important than a systematic approach in special-purpose machinery and plant engineering.

What challenges does special-purpose machinery and plant engineering face in the offer phase?

The main challenges for special-purpose machinery and plant engineering, especially for technical sales, are iterations and changes in the external area and interdisciplinary working methods in various forms in the internal area. It can be assumed that different challenges influence each other. It is also likely that some challenges also have a negative impact on parts of the process, as the challenges were mentioned in connection with the process steps.

What potential for improvement exists for these challenges?

Companies primarily identify the aspects of digitalization as the main potential for improvement. Technical sales should be supported by tools, especially for requirements recording and information exchange.

What qualifications does the technical sales department in special-purpose machinery and plant engineering need?

According to the interview study, the most important qualifications for a technical salesperson are hard skills. Soft skills tend to fade into the background. Within the hard skills, technical expertise is more important than commercial knowledge in special machinery and plant engineering.

Characterization of technical sales

In summary, technical sales must go through many iterations together with the customer. In this process, they are supported by a small number of methods and by simple IT tools. Technical sales must have a lot of technical experience in order to be able to assess the effort–benefit ratio, for example.

Characterization of customers in special-purpose machinery and plant engineering

In summary, customers often report changes due to knowledge gaps, low data transparency, and a high degree of customization. As a result, it is difficult to fully incorporate customer requirements. In addition, there is often a lack of specific contact persons on the customer side.

Which factors influence the preparation of customized offers in special-purpose machinery and plant engineering the most?

Summarizing the most common answers, the most frequently mentioned points are interdisciplinary working methods, customer behavior, digitalization, and the use of in-depth knowledge. These four points have the greatest impact on the creation of customized offers.

There is, therefore, potential for research in the form of approaches that support interdisciplinary work, both internally and externally with customers across companies, to address these challenges. The same

applies to approaches that support technical sales with its extensive knowledge in the processing of offers. These can be digital solutions on the one hand, but also systematic and methodical approaches for structuring the complex work. Future research should focus on addressing the challenges and potential for improvement. With regard to the SE approach followed by the authors of this article (cf., Section IV-D), it should be investigated which methods already exist and how these can be transferred to special machinery and plant engineering. In addition, model-based support should be developed and established. The approaches can then be introduced step-by-step [45].

The article shows that the way technical sales works today is no longer suitable for increasingly complex requests and upcoming trends. Challenges often remain unanswered. These must first be consciously addressed. As machines become more digital, the offer process should also take up this digitalization. Companies need approaches and support that promote experiential knowledge and interdisciplinary collaboration.

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