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UNRAVELING COMPLEXITY: SHAPING THE FUTURE OF PROCESS IMPROVEMENT IN HIGHLY AUTOMATED PRODUCTION WITH DIGITAL INNOVATION

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Abstract: Companies must continually evolve to meet dynamic conditions and sustain competitiveness, necessitating fundamental shifts in organizational structure, employee mindset, and ongoing improvement of internal processes across direct and indirect areas. This complexity is particularly pronounced in highly automated production settings, challenging further enhancements to existing processes. This paper explores the evolving role of process improvement in highly automated production and the relevance of emerging digital technologies in boosting productivity.

To address this research inquiry, virtual focus groups were selected as a qualitative approach, with seven executives from German large-scale enterprises evaluating the future role of process improvements in highly automated manufacturing. The findings indicate a significant potential for process improvements in manufacturing. While the integration of continuous process improvement aims for incremental enhancements, new technologies offer avenues to address existing inefficiencies, unscheduled downtimes, and excessive rework by tackling previously unresolved issues.

Keywords: Continuous Process Improvement, Process Optimization, Focus Group

INTRODUCTION

In the face of a dynamically changing business environment, continuously increasing global competition, saturated markets, and diverse customer requirements (Bea & Haas, 2012), companies struggle with the escalating complexity of their surroundings (Nadarajah & Sharifah, 2014). Globalization and technological advancements further contribute to an increasingly dynamic market (Griffith & Yalcinkaya, 2018). The concurrent challenges of shortened product life cycles and heightened customer demands ask for a continuous commitment to process improvement for companies to stay competitive (Dombrowksi & Crespo, 2008). Utilizing process optimization methods becomes essential in identifying and rectifying process weaknesses (Gericke, Bayer, Kühn, Rausch, & Strobl, 2013).

Conversely, digital innovations offer the potential to uncover new opportunities and address aspects of business processes previously unknown, demanding a fundamental redesign of these processes for effective and efficient fulfillment of customer demands.

Large-scale enterprises, in particular, have devoted considerable resources to optimizing and automating their production and business-relevant processes in recent years. Currently confronted with the task of enhancing productivity through the implementation of business improvements or digital innovations. Consequently, the question arises regarding how executives of these enterprises evaluate the future role of process improvement in highly automated manufacturing.

PROCESS OPTIMIZATION

The term “process optimization methods” denotes the enhancement of existing business processes through the application of specific methods to achieve success in the market (Kruse, 2009). Addressing crucial customer requirements, such as high product quality, involves identifying and improving weaknesses within a process, and process optimization methods are instrumental in this regard.

However, sustainable process improvement transcends the use of a singular process optimization method; instead, it necessitates the initiation of a continuous improvement process (CIP) (Gisi, 2018). It is imperative to maintain employee motivation and their ability to consistently work towards desired improvements (Benner & Tushman, 2003).

One conceptual framework for continuous improvement is the Japanese philosophy Kaizen, translated as 'change for the better' (Gorecki & Pautsch, 2013). Kaizen involves changing existing processes with the active participation of all employees involved, leading to increased motivation and the utilization of employee experience and knowledge (Pohanka, 2014). Kaizen serves as the foundation of the Toyota Production System (TPS), internationally recognized for waste reduction through optimization methods (Santos, Wysk, & Torres, 2006).

In addition to production systems, quality concepts contribute to process improvement. These concepts, including the zero-error principle and early error detection, aim to eliminate waste. An example is the Total Quality Management (TQM) approach, seeking enhanced quality to differentiate from competitors and simultaneously boost customer satisfaction (Dilworth, 1996). This ensures that CIP effectively leverages employee knowledge, enhancing the inimitability of manufacturing processes. Therefore, a key factor for CIP success lies in ensuring employees' interest in pursuing optimization (Upton, 1996).

EXPERIMENTAL RESEARCH DESIGN

The objective of this research was to elucidate insights into the experiential, perceptual, and belief-oriented dimensions of process improvement methodologies within the context of continuous manufacturing. Due to the inherently qualitative nature of the required data, focus groups emerged as a pertinent methodological choice for dynamic exploration. Leveraging nonverbal feedback and encouraging group interaction, the aim was to effectively challenge and scrutinize the viewpoints of the seven participants. This methodological choice was made with the intention of fostering a more profound comprehension of the challenges and possibilities associated with process improvements in the realm of manufacturing.

VIRTUAL FOCUS GROUPS AS A QUALITATIVE RESEARCH METHOD

Despite the historical application of focus groups in research since the mid-20th century (Morgan, 1997), it remains a relatively unconventional approach within the qualitative research domain (Barbour & Kitzinger, 1999). Traditionally employed in user-centered design to discuss products and their use within the target demographic, focus groups entail group interviews utilizing a semi-structured approach to guide discussions (Krueger & Casey, 2015). Diverging from conventional group interviews with a traditional inquiry-response cycle, the researcher employs open-ended questions, allowing group interactions to navigate through the loosely structured content (Kidd & Parshall, 2000; Morgan, 1996).Consequently, focus groups prove particularly adept at consolidating existing knowledge and delving into the depth and nuance of individuals' opinions and experiences (Litsoelliti, 2003; Gill, Stewart, Treasure, & Chadwick, 2008).In contrast to alternative group methodologies, participants in focus groups have the opportunity to express verbal, as well as non-verbal, approval, disagreement, or supplement statements made by fellow participants with additional information based on personal beliefs and experiences (Ledermann, 2000; Kitzinger, 1994). Moreover, the interactive nature compels respondents to reconsider and reevaluate their own contributions to the discussion (Gibbs, 1997). Consequently, focus group are not just the aggregation of individuals contributions (Osborne & Collins, 2001).

Traditional focus groups are typically

conducted in a laboratory setting, limiting their applicability to target groups available in sufficient numbers near the laboratory location (Berg, 2001; Barbour, 2018). To address this constraint, virtual focus groups present a viable alternative. It is essential to distinguish between synchronous and asynchronous virtual focus groups. Hofmann et al. (2012) observed more in-depth discussions and increased group dynamics in synchronous virtual focus groups, as participants in a face-to-face version tend to engage in excessive monologues. Synchronous virtual focus groups yield both rational and emotional insights and tend to be more problem-oriented compared to traditional or asynchronous virtual focus groups.

SELECTION OF EXPERTS AND ETHICAL CONSIDERATIONS

The careful selection of experts constitutes a critical aspect of assembling focus groups, given their reliance on participants' verbal contributions and interactions (Morgan, 1997). Nevertheless, the research design does not allow for to statistical representativeness. The emphasis is placed more on the representability of content rather than individual opinions and personal experiences within the highly automated manufacturing environment. This presupposes that participants serve as representatives of the group under investigation rather than representing individual cases. Hence, the purposeful selection of typical cases becomes crucial (Gill, Stewart, Treasure, & Chadwick, 2008; Mayer, 2012).

In crafting the composition of the target group, careful consideration was given to including a mix of hierarchical levels to gain insights from various perspectives and promote discussions across different experience levels and areas of responsibility. In addition to senior managers, project managers, and team leaders possessing substantial experience in process improvements and digitization within manufacturing, an in-house consultant was also included to contribute additional viewpoints. The preliminary screening of experts was conducted via brief telephone interviews, with the dual purpose of assessing participants' qualifications beforehand and identifying crucial personality traits to enhance the moderator's facilitation of the focus group Precautions were taken to ensure that there were no direct professional relationships among the participants, thus aiming for unbiased results.

Expert		Company		
Code	Position	Sector	Revenue [Bio €]	Em-ployees
E1	Senior Manager Mechanical Manufacturing	Automotive	38,2	82900
E2	Production Manager Chip-Manufacturing	Automotive Supplier	4,9	9900
E3	Project Manager Manufacturing	Automotive Supplier	12,1	77000
E4	In-house Consultant	Automotive	-	110
E5	Team-Leader Production Planning	Pharma Industry	19,2	51000
E6	Project Manager Industrialisation	Automotive Supplier	3,8	17300
E7	Senior Manager Cast House	Iron and Steal Manufacturing	9,3	28800

Table 1. Overview of selected experts

Given that focus groups subject participants' verbal contributions to group judgment (Walker, 2018), obtaining consent becomes a crucial ethical consideration that justifies the moderator's efforts to encourage participants to divulge intimate beliefs, personal experiences, and feelings (Green & Hart, 1999). All participants provided written consent to engage on a voluntary basis, following a comprehensive explanation by researchers regarding the use of collected data and the extent to which it would be disclosed to third parties. To safeguard the confidentiality of the collected data, an anonymized analysis of transcripts and additional access restrictions were implemented. However, it is important to note that the study was neither registered nor subjected to review by an ethics committee.

DATA COLLECTION AND PROCEDURE OF THE FOCUS GROUP

The virtual focus group transpired on November 2nd via Microsoft Teams and extended for approximately 130 minutes until reaching saturation point, as outlined by Barbour in "Doing Focus Groups" (2018). The proceedings were documented through audio and video recording, aiming not only to analyze the verbal discourse but also to assess non-verbal cues, gestures, and facial expressions. Employing a semi-structured guideline, the session commenced with a brief introduction to the topic, followed by an initial exploration of participants' experiences with process improvement measures. The moderator subsequently employed open-ended questions to navigate the discussion toward key topics, elucidating participants' perspectives on the significance of process improvement in highly automated manufacturing, sharing perceived obstacles, and recounting experiences with pitfalls. Participants were also prompted to evaluate the potential for further improvements in manufacturing. Lastly, the significance of new technologies, particularly digital transformation, for process improvements was discussed and elaborated upon.

While virtual focus groups afford the convenience of recording sessions for subsequent analysis of non-verbal communication (Hoffmann, Olschner, & Schubert, 2012), the involvement of multiple researchers was necessary to address technical issues during the session. A skilled moderator played a crucial role in guiding the discussion and ensuring comprehensive coverage of all relevant topics outlined in the semi-structured guideline. Particular attention was dedicated to the development of relationships among participants and encouraging the interaction of all group members (Rosentahl, 2016; Allen, 2014). Additionally, strategic summarizations were employed to facilitate refinement of the group's perspective and individual explanations.

The verbatim, anonymized transcript was subsequently cross-referenced with notable non-verbal signals from the screen recording and analyzed using the method outlined by Kuckartz (2012). In essence, the records were categorized into thematic main groups, further divided into subcategories, with statements from the focus groups assigned accordingly. The final phase involved visualizing and interpreting the categorized information.

RESULTS AND FINDINGS

The findings from the focus group with executives from German large-scale enterprises can be grouped into the following categories:

- Executive views of the siginificance of process improvement in manufacturing
- Perceived cheallenges when implementing process improvement
- Perspective on the potential of efficiency and effectivity
- The role of new technologies to enhance productivity

SIGNIFICANCE OF ENHANCING PROCESSES IN HIGHLY AUTOMATED MANUFACTURING

The pursuit of effectiveness and efficiency in highly automated manufacturing has driven substantial process improvement efforts in recent years. The dynamically changing environmental conditions and the pursuit of flexibility have resulted in highly complex structures, making efficient implementation of production processes unattainable without continuous improvement efforts. Process improvements stand out as the pivotal factor for long-term success, addressing the need to prevent unscheduled downtimes, inefficiencies, and waste, while ensuring elevated product quality. Notably, process analysis serves as the decisive tool to guarantee that optimizing individual process components, such as machinery, does not adversely impact the efficiency of upstream and downstream components (E3, E6).

In the realm of modernization and innovation projects, process analysis and the corresponding optimization play a crucial role in recognizing dependencies at an early stage. Technical processes and their products undergo optimization with varied objectives, encompassing costs, quality, safety, ergonomics, and environmental considerations that are increasingly gaining prominence (E4, E7). Process security naturally remains the foremost concern for process operators. Consequently, the promise of successful process optimization lies in considering all criteria throughout the optimization process. Hence, only continuous and sustainable implementations can be achieved, making process improvements a significant undertaking for highly automated manufacturing.

CHALLENGES PERCEIVED IN THE IMPROVEMENT OF MANUFACTURING PROCESSES

Despite concerted efforts, various automation solutions persist in the majority of production plants. Given this context, the comprehensive and unbiased documentation of comples processes across different systems poses a significant challenge when analyzing and enhancing existing procedures. Due to the heterogeneity and complexity involved, employing suitable methods and additional tools is essential in the optimization of processes (E6, E2). There was a divergence of opinions regarding whether the local machine should serve as the starting point for improvement efforts or if all optimization potentials should be approached from a global perspective. Nevertheless, it is crucial that the dynamic behavior of processes be ultimately documented at key characteristic points (E7). Another challenge lies in the comprehensive identification of critical measuring points. Problems arise, particularly in the analysis and subsequent improvement efforts, when the interactions between individual process components lack transparency. Internal program flows are typically not observable in detail from an external perspective; usually, only their effects are visible (E3). Additionally, drawing conclusions about the internal software processes from the observable behavior of the process itself is challenging. Typically, the units under consideration are distributed systems, involving multiple processing systems. Multiple concurrent software programs interact through various communication mechanisms on multiple controls, resulting in chronological and functional interactions that further amplify complexity. Here, there is also "…a clear lack of standardization and overarching system components evident" (E4).Furthermore, reproducibility in highly automated technical processes is quite challenging. This implies a lack of time determinism, as task runtimes in controls heavily depend on factors such as process status, current production conditions, external environmental influences, or the current system status, including wear and tear. This complexity reaches a level that humans can no longer manage without digital aids. Consequently, additional tools are required to synchronously record various process data.

This is where additional challenges arise in practical application. Diverse analog and digital signals must be consistently and synchronously recorded in a fail-safe manner. To analyze the vast amounts of recorded data, interactive, multimedia analysis tools are essential. People emerge as another potential source of error in this context (E2). The creative challenge of process optimization also introduces the risk of a biased perspective from involved engineers. A key success principle is the identification of specific areas of action for identified weaknesses, necessitating a global perspective. However, the introduction of innovation workshops involving interdisciplinary teams and creative techniques continues to face resistance and incomprehension from the well-established workforce (E1, E5, E7). A well-organized and rigorous moderation of the entire process improvement process is therefore indispensable but simultaneously poses a significant challenge (E4).

The sustainable implementation of process improvement methods, particularly the selection of suitable methods and resources, represents an additional hurdle. Participants identify issues, particularly with the operational implementation and the willingness to endure necessary changes in the long term. On the flip side, this is viewed as a crucial opportunity for a sustainable improvement project, especially as ergonomics and environmental considerations take on increased significance. In the era of Industry 4.0, human involvement is deemed the paramount factor in the operational process. In the hierarchy of improvement stages, individuals take precedence over both processes and equipment (E1). While equipment or processes can be readily replaced or modified in response to performance issues, the same does not hold true for individuals. Although personnel can be substituted in a process, altering the mindset of those individuals proves to be a more challenging endeavour (E7).

Ultimately, the heightened adoption of digital innovations to enhance productivity often necessitates the redesign of existing processes to fully realize its potential. Striking the right balance between process improvement and innovation presents a challenge. Currently, we lack structured approaches, methods, and tools to maintain a clear focus on customer demand while integrating the latest technologies for optimal satisfaction. This imperative should cover both process improvement and innovation. “Unfortunately, it tends to be an either-or situation, leading to subsequent adjustments and poorly coordinated processes” (E3).

PERSPECTIVES ON UNLOCKING EFFICIENCY AND EFFECTIVENESS

Despite significant efforts to optimize production processes over the past decades, there is a consensus that substantial potential for further improvement exists. This begins with the need to optimize information flows, indirect areas, and supporting processes and extends to the adoption of new technologies, unlocking new dimensions for improvement. A need for action still persists in the implementation of continuous improvement processes. Particularly, the interface between indirect areas and production offers significant room for improvement to fully realize the effects of prior process optimization efforts in manufacturing (E2, E6). Overall, the estimated improvement potential ranges from 6 to 15 percent, contingent on the specific field of responsibility and its integration into the product creation process.

The most promising approach to significantly enhance efficiency and effectiveness in highly automated, large-scale manufacturing enterprises is expected to be decentralized improvement processes (E1, E4, E7). Previous efforts have primarily concentrated on optimizing the technical aspects of production methodology, limiting the exploitation of existing efficiency potential. Consequently, companies must strive for the integration of human capital in process improvement, emphasizing the importance of incorporating management and behavioral aspects into decentralized optimization initiatives. The operational implementation of continuous improvement processes should become the responsibility of workers, with managers retaining accountability for the outcomes of improvement efforts.

HARNESSING THE POWER OF EMERGING TECHNOLOGIES TO UNLEASH PRODUCTIVITY POTENTIAL

The participants anticipate notable boosts in productivity with the progression of digitization. Specifically, two key areas are identified to contribute to productivity enhancement in the medium term:

- The use of worker assistance systems on the shop floor

- The use of Big Data Analytics to investigate the cause of errors

As the trajectory towards increased automation and the refinement of production lines and processes becomes inevitable, experts discern significant prospects in the realm of digitization for addressinghitherto unresolved issues.

A central aim involves minimizing unscheduled downtime and inefficiencies, coupled with the decrease in excessive rework.A primary challenge lies in the identification of the root causes of errors. Despite the apparent manifestation of issues,the highly complex processes often pose a hindrance to the direct identification of the actual causative factors (E3, E7). This is not least due to the fact that the current inability to comprehensively digitally record and monitor individual process steps. "At this point, a handful of black boxes transform into a black box enveloping the entire process"(E1). Digitization is anticipated to offer assistance; however, experts contend that continuous digital recording is not always feasible. Particularly in instances where a component undergoes a change in its physical state during the machining process, direct recording and modeling of data become exceedingly challenging. The preferable course of action lies in exclusively monitoring environmental variables (E7). As stated, "The unraveling of cause-effect chains becomes a speculative endeavor" (E3). Consequently, there is consens that manufacturers should increasingly rely on big data analytics to address a cascade of issues leading to unscheduled downtime, inefficiency, and excessive rework.. Six Sigma stands as a well-established and customer-centric improvement approach, emphasizing the analysis of company processes to eliminate the root causes of errors and process deviations. With the surge in machine-generated data and the subsequent escalation in data volume, relying solely on Six Sigma is no longer viable for establishing cause-effect relationships between variables. Machine learning methods serve as a valuable augmentation to the Six Sigma statistical toolbox, particularly in the analysis of intricate processes with numerous influencing parameters.

Therefor leveraging existing technologies is crucial to eliminate humans as a potential source of error. The adoption of worker assistance systems carries significant expectations, aiming not only to diminish error rates through supplementary in-process controls and precise work instructions (E6) but also to enhance precise documentation, consequently strengthening the predictability of personnel placement (E1, E2). Customizable systems enable optimal training, motivation, and deployment of employees. This marks a crucial advancement in integrating human capital for process improvement (E5, E1). Moreover, there will be an enhancement in production flexibility, marking a significant progression towards smaller batch sizes. A key element in achieving flexibility involves the decentralization of responsibilities and decision-making tasks from the management level to the shop floor, along with the streamlining of escalation loops (E2). However, the vast volume of available data poses a near-impossible challenge for human comprehension. AI-based decision support systems can assist workers on the shop floor by presenting evaluated action options. Additionally, specific warnings, as opposed to daily reminders, can contribute to an improved work safety environment (E7).

On the flip side, there are concerns that necessary process changes may encounter resistance from employees, and work councils may impede their implementation. Many worker assistance systems come equipped with numerous sensors, generating extensive data that may evoke a sense of monitoring and control among employees (E4). While extensive data acquisition may foster competition among employees and potentially boost performance, it also introduces psychological pressure with adverse effects. Monotony and cognitive underutilization in overly restrictive, controlling systems can trigger negative impacts on motivation, health, and long-term work capability (E1, E4). The primary challenge lies in ensuring the ethically justifiable use of these technologies to unlock their full potential for productivity enhancement. This highlights the need for a sustainable approach to social welfare that takes into account the well-being of workers, privacy concerns, and other relevant factors. It involves implementing measures to foster a balanced relationship between humans and machines in the era of Industry 5.0.

CONCLUSION

While large-scale enterprises have already invested significantly in automating and optimizing their manufacturing processes, there is still considerable room for improvement. Continuous process improvement aims for gradual enhancements, while new technologies like big data analytics and worker assistant systems offer opportunities to address existing inefficiencies, unscheduled downtimes, and excessive rework by solving previously unsolved problems. The complexity introduced by highly automated manufacturing requires additional digital tools for data gathering and analysis, where human involvement becomes a potential source of error.

Process optimization, being a creative challenge, requires preventing one-sided perspectives to identify the best measures. A global perspective, incorporating digitalized solutions, is essential. However, it's not enough to just digitally transform manufacturing; the entire organization needs to be digital to identify all bottlenecks in automated manufacturing. Achieving the right balance between process improvement and innovation necessitates structured approaches, methods, and tools to maintain a clear focus on customer demand while integrating the latest technologies for optimal satisfaction.

Therefore, both digitalization and

continuous improvement depend on fundamental organizational change and the adoption of a suitable mindset. Every employee should support the transformation and be involved in decentralized improvement processes, considered the most promising approach for efficiency and effectiveness. Efforts have primarily focused on optimizing technical aspects of production methodology, limiting the exploitation of existing efficiency potential. Future research should concentrate on integrating human capital for process improvement and finding ways to implement a suitable mindset, incorporating management and behavioural aspects into decentralized optimization efforts, also elaborating on its long-term impact on human resources.

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