Production Planning and Scheduling Challenges in the Engineer-to-Order Manufacturing Segment—A Literature Study

Ninan Theradapuzha Mathew* and Björn Johansson

***Abstract*—Production planning and scheduling is a significant activity for manufacturing companies that follow an engineer-to-order (ETO) manufacturing strategy. The volatile nature of customer demands and the primary requirement to produce highly customized products generate numerous challenges that affect the efficiency of planning and scheduling operations in engineer-to-order manufacturing. The article presents a literature study to identify the main challenges in production planning and scheduling in engineer-to-order manufacturing. The article also provides a classification of the identified challenges into four different categories. The categorization of challenges strongly suggests replanning or rescheduling as a critical requirement in the engineer-to-order manufacturing segment to attain resilience in uncertain environments.**

***Index Terms*—Challenges, engineer-to-order, literature study, production planning and scheduling**

I. Introduction

Challenges are part of our day-to-day life. The best example is the Covid-19 pandemic period. The human population has gone through tough times over the past few years. The human community learned and practiced resilience during these past years, which helped us to overcome the pandemic. Similarly, production companies all over the world face numerous challenges every day. Manufacturing organizations must be resilient enough to overcome the uncertainties they face regarding market trends, product requirements, changes in customer behavior, raw material scarcity, environmental laws and regulations, and rapid technological advances. Generally, manufacturing companies have different strategies according to their products, resource capacity, and the customer market.

Each manufacturing organization's customer order decoupling point (hereafter CODP) could differ based on the manufacturing strategy [1]. CODP is also known as the order decoupling point or order penetration point (OPP) [1]. CODP is defined as the point in the flow of goods where the production process is separated into forecast-driven and customer-order-driven production [1]. The decoupling point lies in the manufacturing organization's engineering or design phases with an engineer-to-order manufacturing strategy [1–3]. Thus, the engineer-to-order (hereafter ETO) manufacturing strategy is different from other manufacturing strategies like make-to-order (hereafter MTO), assemble-to-order (hereafter ATO) or make-to-stock (hereafter MTS) as the products to produce or the production plan are not predetermined or forecasted well in advance [4]. Hence, the ETO products are generally highly customized according to individual customer requirements and nonrepetitive to a large extent [3–6]. Highly customized products are sometimes considered one-of-a-kind (OKP) [3, 4]. Therefore, ETO manufacturing is also referred to as one-of-a-kind production [4].

As products are highly customized and manufactured according to customer specifications, usually, there is much uncertainty in the production planning and scheduling for manufacturing organizations that follow the ETO manufacturing strategy [7, 8]. Inefficient production planning leads to loss of productivity, which causes delivery concerns to the customers. Late deliveries mostly lead to financial penalties [7–11]. On the other hand, early completion of products before their due dates could lead to high holding costs and thereby increases the overall manufacturing costs [10]. Therefore, the ETO industry is under constant pressure to optimize its production planning and scheduling operations and improve delivery reliability [12]. Hence, production planning and scheduling is a significant and time-consuming activity in ETO manufacturing organizations.

One way of becoming resilient enough to face production planning and scheduling challenges is understanding the significant problems that manufacturing companies face in the ETO segment. Scientific articles published regarding manufacturing activities in the ETO segment are an excellent source to identify the main challenges regarding production planning and scheduling in the ETO segment. Hence, the authors in this article have employed a literature study to highlight the main challenges and complex scenarios that ETO manufacturing organizations must endure regarding production planning and scheduling operations. Awareness of the most significant problems would help organizations be proactive and equip themselves to embrace such difficult scenarios. This will not only help the organizations to improve their efficiency in production planning and scheduling but will also help them to reduce their overall manufacturing costs and customer satisfaction.

The article presents information regarding the main challenges in the production planning and scheduling process in the ETO segment. The remaining chapters of the article are categorized in the following manner. The methodology adopted in the literature study is explained in Section II. The findings or results from the literature study are presented in

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Section III, and the author's inferences and reflections on the results are expressed in Section IV. Section V concludes the article, followed by acknowledgement and a bibliography.

II. Methods

The literature study was based on a research question matching the article's main idea.

- Research question: What are the main challenges in production planning and scheduling for manufacturing organizations that follow an engineer-to-order strategy?

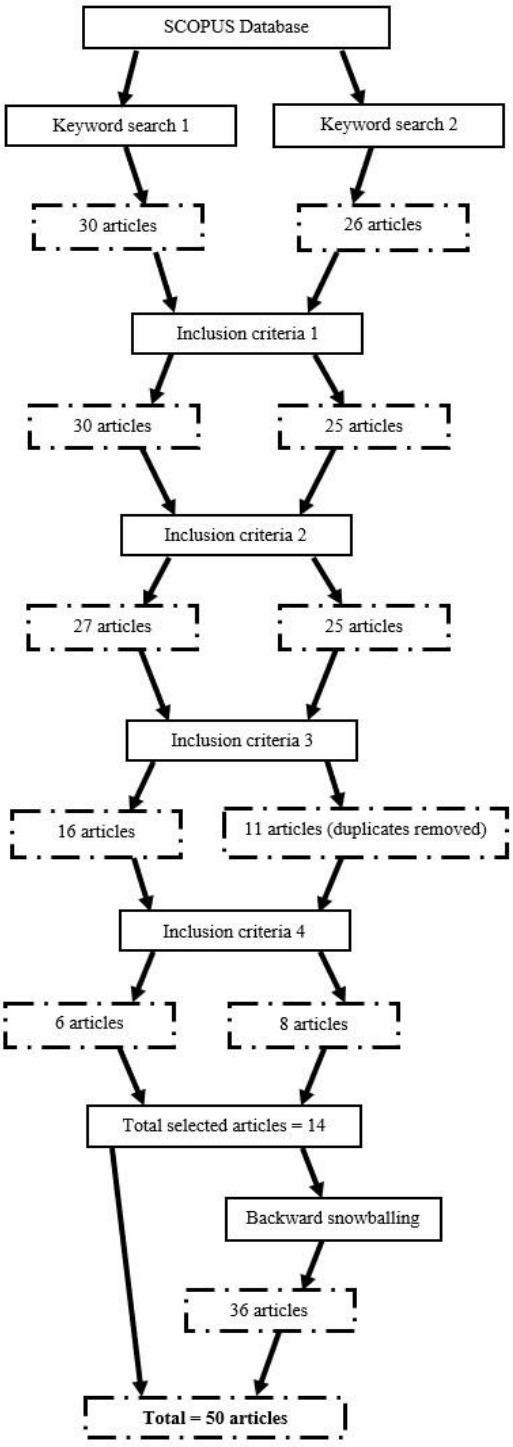

Fig. 1. Literature study method.

The Scopus database was used to find the relevant literature. Other databases like Google Scholar and Chalmers University of Technology library website were used to find the soft copies of the selected literature if it was difficult to download the articles from their published websites. As mentioned earlier, the ETO manufacturing strategy is also known as one-of-a-kind production. Hence, both terminologies were included in the keyword search. The keywords with the Boolean operators used for the literature search are given below:

- Keyword 1: production planning and scheduling AND engineer-to-order
- Keyword 2: production planning and scheduling AND one-of-a-kind

The inclusion criteria of the articles are given below:

- Inclusion criteria 1: Articles published only in the English language.
- Inclusion criteria 2: Articles published in the last 30 years - between 1992 and 2022.
- Inclusion criteria 3: Article selection based on the relevance of the information available in the title and abstract
- Inclusion criteria 4: Article selection based on the relevance of the information available in the introduction and conclusion section with the research question.

After these four screening levels, the remaining articles were subjected to full-text reading. After the final screening (fourth level of screening), 14 articles were selected for the literature study. Backward snowballing was performed to identify more relevant articles from the reference list of the selected articles. 36 articles were identified through the backward snowballing process. Fig. 1 shows the summary of article selection based on each keyword and inclusion criteria.

III. Results

The results chapter describes the challenges in production planning and scheduling in the ETO manufacturing industry identified from the literature study.

Many articles have mentioned the volatile and uncertain nature of customer orders and product volumes in ETO manufacturing compared to traditional manufacturing systems [4, 13, 14]. The article [15] states that in traditional manufacturing systems like MTS, MTO, and ATO, forecasting helps to determine the volume of customer orders in advance and thereby makes it possible to prearrange the materials and parts required to manufacture these products with suppliers and other parties in the supply chain. As mentioned in the introduction section, the customer decoupling point in ETO manufacturing is in the engineering or design stage. Therefore, each production order, materials required, and production process in the ETO sector could differ based on customer specifications and requirements [16, 17]. As a result, the overall production planning and control activities in the ETO segment are characterized mainly into two stages, a nonphysical stage, and a physical stage [1, 5]. The nonphysical stage consists of activities including tendering, design, engineering, and project planning, and the physical stage includes activities like manufacturing, assembly, delivery, and installation [1, 5]. For the ETO

manufacturing sector, it is common to have late changes in the product's design (close to the planned production date) as the customer is involved in the product design and engineering stages [3, 18, 19]. Sometimes the customer influences the product specifications or structure until the product delivery stage [3, 18]. Therefore, the production planning team in an ETO segment generates initial production plans mainly based on estimated lead times of individual parts needed for the production process [15]. The initial production plans or schedules are frequently subjected to replanning or rescheduling due to unexpected production disturbances in the ETO sector [16, 20].

Many articles have provided information regarding the frequently occurring production disturbances that cause deviations from the initial production plan or schedule [10, 20, 21]. Some frequently occurring problems are the lack of resources which could be operators, equipment, or materials; variation in work processes due to changes in design; modification in target times; priority orders; changes in delivery dates; incorrect sequencing and so on [10, 20, 21]. Hence, the production plans or schedules developed should facilitate easy replanning or rescheduling [22]. In an ETO environment, every product is engineered and customized according to customer specifications [14, 18, 23, 24]. When considering the production plan in an ETO environment, both the routing and the bill of materials would be different for each product, making the work of a production planner highly complex in an ETO environment [23, 25]. Generally, in production planning and scheduling operations, planners tend to neglect the information available from the planning system, and this mentality seems to increase in complex and uncertain manufacturing environments [26]. In uncertain situations, to have the flexibility to make changes in the production plan or production schedule, it is quite common for organizations to provide such autonomy to employees working with production planning and scheduling [18]. When humans perform the planning, the quality of the production plan mainly depends on the mental ability and experience of the planners [22]. The skill level and experience of production planners or production schedulers have a significant role in achieving productivity and flexibility, especially in complex planning environments [18, 26, 27]. Frequent replanning or rescheduling could increase the workload and stress level of the planners, which can further lead to a decrease in the production plan's quality and reliability [28].

Another planning problem in uncertain environments is the lead-time syndrome [23, 29]. In uncertain environments, to increase the due date reliability, planners tend to add safety time and release the production orders earlier than the actual plan [23, 29]. However, this preventive action may increase work-in-progress (hereafter WIP) and thereby increase the lead time, which will further result in a downward spiral of replanning or rescheduling and thus further worsen the due date reliability and cause delivery problems [23, 29].

Production plans and schedules are developed to guide manufacturing organizations in efficiently executing customer orders. The quality of production plans always depends on the quality of data used for creating the plans. Reliable production plans require accurate measurement and reporting of data regarding operation times and raw material availability [30]. Several metrics can be used to measure the quality or performance of a production plan or production schedule [31]. Standard metrics examples include utilization, tardiness, cost, and WIP [31]. However, it isn't easy to measure the overall performance of a production plan or production schedule by combining these metrics, as they could contradict each other [28]. For example, it is impossible to have a high resource utilization and simultaneously a low WIP [28].

Many articles emphasize flexibility as an essential characteristic of companies in the ETO sector [3, 19, 32–34]. One article mentions that flexibility is required in various aspects like product volume, product mix, suppliers, delivery dates, workforce flexibility, assembly procedures, and setup times [32]. Other articles put forward the significance of flexibility in terms of product types, processes, and product volume in the case of manufacturing organizations that follow the ETO strategy [3, 19, 33, 34]. However, attaining flexibility in all these aspects could be difficult for any manufacturing organization. Therefore, companies will use trade-offs or combinations among important flexibility aspects to satisfy customer needs as much as possible [32]. For example, in engineer-to-order manufacturing, delivery date flexibility is an important aspect affecting customer satisfaction [11]. Hence ETO companies generally work to have both delivery reliability (delivering products to customers according to due dates) and delivery speed (promising early delivery dates to customers during the order procurement process) [3, 11]. However, suppose the customer is given early delivery dates without considering the capacity of the manufacturing system and the availability of raw materials thoroughly; in that case, it could affect delivery reliability and leads to customer dissatisfaction [11]. In the same manner, if late delivery dates are given to the customers to make the production processes smooth and less complex, there are chances to lose customer orders to competitors [11]. Therefore, simultaneously attaining flexibility in delivery reliability and speed could be very difficult for ETO manufacturing companies [11].

Another aspect pointed out in many articles is the need for a more comprehensive production planning and scheduling framework in the ETO manufacturing segment [35–38]. One article state that there are only a few reference models for production planning and control (hereafter PPC) in the literature regarding the ETO segment [35]. The planning frameworks that are available for manufacturing companies that produce customized products either cannot support the complete ETO production planning and execution process or could be only used for individual process flows within the entire ETO supply chain [36–38]. Another article mentions that from a research perspective, the number of studies or the volume of literature regarding the requirements and needs in ETO manufacturing is lower than the literature available on other manufacturing strategies like MTS, MTO, and ATO [39].

Many articles have emphasized the incapability of available production planning and scheduling tools to satisfy the requirements in the ETO segment [25, 40–42]. One article mentions that the material requirements planning (hereafter MRP) systems need to be more competent in handling the

volatility in the ETO segment [40]. The authors indicate that most MRP systems are not built to support the needs of manufacturing companies that produce customized products [40]. The article [41] proposes a model which shows the inadequacy of master production scheduling tools to satisfy the conditions of ETO manufacturing. Another article [25] mentions that it may be practically impossible to use conventional manufacturing resource planning and just-in-time methods for production planning and scheduling when it comes to ETO or OKP manufacturing systems [25]. Due to the complexity of an ETO environment, production planning and scheduling tools implemented in other manufacturing environments like MTS, MTO, and ATO may not be sufficient and possibly would not provide the same results [42].

Enterprise Resource Planning (hereafter ERP) systems are used to develop, maintain, and execute production plans or production schedules in manufacturing environments. Hence, selecting the appropriate ERP System is critical for manufacturing companies to perform their business operations smoothly and efficiently [43]. However, most ERP systems currently available assume fixed lead times and work on deterministic approaches to develop and execute the production schedules [44, 45]. This makes most ERP systems incapable of completely handling ETO environments where there is a lot of uncertainty [46]. One article that compares ETO and MTS manufacturing strategies suggests that in ETO manufacturing, the production plans are mostly partially updated or incomplete while being fed into information systems [47]. Hence, for efficient production planning and scheduling in the ETO segment, there is a requirement for ERP systems or manufacturing execution systems that could allow input of partially updated data or incomplete data [47]. Another article points out that an ERP system suitable for the ETO segment should have high agility and adaptability as it will be subjected to volatility and uncertainty [48]. To summarize, finding an appropriate ERP system for production planning and scheduling is a significant concern in an ETO environment.

As a result, it is common to use external tools to develop, execute, and visualize production plans in an ETO environment to compensate for the incapability of current available ERP systems [46]. Another article mentioned the practice of manufacturing companies using additional information and communication technology (hereafter ICT) tools apart from the company ERP system to effectively share and visualize production plans for necessary decision-making and collaboration [16]. In the case of production scheduling, even though there are some advantages to using external ICT tools, the implementation and use of stand-alone software have been found to be problematic, especially in manufacturing environments with high uncertainty and volatility [49]. One article state that using several IT systems simultaneously causes overall data inconsistencies, which are resolved manually later [9]. The article [16] provides information that these additional tools usually act as independent applications due to the difficulty in integrating the same with the company ERP system. Another article stated that using external tools sometimes makes the company's ERP systems less important, and thus eventually, the data in the ERP systems become outdated or incorrect [46]. This makes it difficult for other parts of the supply chain to work efficiently, leading to increased inventories, manufacturing costs, and lead times, thus affecting customer deliveries [46]. Accordingly, there needs to be more clarity in determining the correct ICT tools for the ETO manufacturing segment [16].

Due to the possibility of many unprecedented production disturbances, much coordination and collaboration are required to effectively handle ETO products' design, production, and delivery [50]. Other articles suggest that the production of engineer-to-order products is an inter-organizational activity [18, 24]. Multiple projects are executed simultaneously in an ETO environment [16]. These projects could have varied material requirements, purchasing orders, production schedules, production flow routes, lead times, and continuous updates from the design and product development departments [16]. Hence, in an ETO environment, production planning and scheduling is a multifunctional activity where personnel belonging to different organizational functions are involved in the decision-making and execution of the production schedule [50]. Apart from that, to perform production planning and scheduling in the ETO segment in an efficient manner, there is a constant requirement for information regarding the current production status from the shop floor [45]. Most tools available today for planning in the ETO environment do not provide information on the current production status [45]. When there is no proper update on the production activity, it becomes challenging for planning personnel to coordinate and execute the much-needed replanning or rescheduling and communicate the updated production plans in an ETO environment [45].

IV. Discussion

From the literature study, it has been evident that the ETO manufacturing segment faces many challenges when compared to other manufacturing segments. The results from the literature study could be segregated into four categories of challenges for production planning and scheduling. Classifying challenges into distinct criteria has its benefits. The categorization of challenges would help to understand the interconnection between the challenges in a better manner and help in identifying the common root causes and addressing them. Apart from that, grouping challenges would provide equal importance and effort in resolving all sorts of challenges.

The first category comprises the challenges from a manufacturing strategy perspective. The second category consists of challenges from a planning tools and technology perspective. The third category corresponds to challenges associated with personnel (human resources) involved in production planning and scheduling. The fourth category considers limitations of the availability of research material in the ETO segment. The remaining subsections of the discussion chapter consist of the author's reflection on the four categories of challenges, management implications from the research study, a subsection on how improving production

planning and scheduling process affects sustainable development in ETO manufacturing and the last subsection regarding the limitations of the article with an outlook on future research.

TABLE I: CHALLENGES FROM A MANUFACTURING STRATEGY PERSPECTIVE

Challenges from a manufacturing strategy perspective	
1	Variation in product volumes or customer demands (volatile markets)
2	Late changes in product design or structure
3	The critical need for flexibility in multiple aspects (for example like product volume, product mix, suppliers, workforce, manufacturing processes, and assembly procedures) in the ETO segment and the difficulty for manufacturing companies to attain flexibility in multiple aspects simultaneously, resulting in tradeoffs
4	Late deliveries leading to financial penalties and early deliveries increasing holding costs
5	Frequent replanning or rescheduling of initial production plans or schedules

A. Challenges from a Manufacturing Strategy Perspective

The main challenges from a manufacturing strategy perspective in the ETO segment are given in Table I.

From a manufacturing strategy perspective, the common challenge in ETO manufacturing is the variation in customer demands affecting product volume. Hence, ETO manufacturing companies should be flexible enough to avoid increasing manufacturing costs due to overutilizing or underutilizing resources. In addition, the customer's ability to make late product design changes also calls for more flexibility and adaptability in production planning and scheduling operations. Moreover, the literature also points out that ETO manufacturing companies cannot afford either late deliveries or early completion of customer orders. Both scenarios will lead to an increase in overall manufacturing costs. All the above challenges point to the critical need for flexibility and resilience, which the ETO manufacturing companies generally attain through replanning or rescheduling. Therefore, the authors suggest that from a manufacturing strategy perspective, the ability to replan or reschedule the production orders without affecting productivity, resource efficiency, and delivery reliability is the most crucial requirement for ETO manufacturing companies.

B. Challenges from a Planning Tools and Technology Perspective

The main challenges from a planning tool and technology perspective are given in Table II. From the categorization table, it is easier to identify the critical requirements for planning and scheduling tools in ETO manufacturing.

An ideal planning tool in the ETO segment should be compatible with the existing ERP system and should assist the ERP system in the production planning and scheduling process. At the same time, the planning tool must be able to access information about the current production status and inform the planning personnel regarding the same. This is very important because, in an ETO environment, the initial production plan is made based on estimated data as the product structure or design is incomplete and the probable need for replanning or rescheduling is unavoidable. Information regarding the current production status is essential to perform replanning efficiently. Therefore, planning and scheduling tools used for ETO manufacturing should facilitate the planning and replanning processes.

TABLE II: CHALLENGES FROM A PLANNING TOOL AND TECHNOLOGY PERSPECTIVE

Challenges from a planning tool and technology perspective	
1	Need for ERP systems that could allow input of partially updated data or incomplete data
2	Compatibility problems between external tools and the existing ERP system leading to data inconsistencies
3	The practice of using external tools making data in the ERP systems outdated which affects the whole supply chain
4	Lack of tools to provide in formation on the current production status
5	General lack of clarity in determining the correct ICT tools for ETO

C. Challenges from a Human Resources Perspective

Human resources have always been a critical aspect of production planning and scheduling. The main challenges from a human resources perspective are given in Table III.

TABLE III: CHALLENGES FROM A HUMAN RESOURCES PERSPECTIVE

Challenges from a human resources perspective	
1	The unique routing and bill of materials for each product, makes the work of a production planner highly complex in an ETO environment
2	The quality of the plan depends on the knowledge, skill level, and experience of the planners in ETO
3	Lead-time syndrome, which further results in replanning or rescheduling
4	Frequent replanning or rescheduling could increase the workload and affect the stress level and mental ability of the personnel involved in planning
5	The constant need for communication and collaboration between different functional groups for planning and replanning in ETO environment

From the literature study, production planning and scheduling in an ETO environment is a complex and challenging task for the personnel involved. Even worse, replanning or rescheduling would be more arduous. During replanning, the planning personnel should try to squeeze the new plan into the current production without affecting the delivery reliability of the other customer orders. In addition, problems like lead time syndrome further pave the way for more replanning. So, the planning personnel in an ETO environment need support for the initial planning and replanning processes. Therefore, the most significant challenge from a planner's perspective could be to find a system or tool that could enable easy planning and replanning, at the same time, provide them with the necessary means to upload the information to the company ERP system and communicate the newly changed plan to all those involved in the planning process in real-time.

D. Challenges from a Research Perspective

Industry-oriented research studies have always helped to find solutions for problems in the manufacturing domain. The main challenges in production planning and scheduling from a research perspective are given in Table IV.

TABLE IV: CHALLENGES FROM A RESEARCH PERSPECTIVE

Challenges from a research perspective	
1	Lack of comprehensive framework to support the whole ETO production planning and execution process
2	Less number of studies or literature regarding the requirements and needs in ETO manufacturing

Many articles in the literature study mentioned the difference in the volume of academic literature available between the ETO manufacturing strategy and other manufacturing strategies. Hence through this article, the authors aim to contribute towards the ETO segment. Another challenge from the literature study is the need for comprehensive production planning and control framework. Therefore, the authors believe that more industry-oriented case studies are required in the ETO segment.

E. Management Implications

The categorization of challenges from the literature study has helped to identify replanning or rescheduling as a significant concern in the ETO manufacturing segment. Due to uncertainty and volatility in the ETO segment, replanning or rescheduling has become essential. However, replanning or rescheduling could be arduous for companies in the ETO segment as it causes a lot of internal and external collaboration, communication, and additional person-hours. Hence, the study's most important management implication is the need to attain resilience through replanning or rescheduling to improve overall production planning and scheduling efficiency in the ETO manufacturing segment.

Considering other managerial implications, the critical ones are from the manufacturing strategy perspective and human resources perspective. From a manufacturing strategy perspective, it is vital for manufacturing companies in the ETO segment to have flexible resources (could be workforce, machinery, tools, or equipment) that could adapt according to the requirements of the replanned or rescheduled orders [19]. From a human resources perspective, it would be significant to ensure that the production planning team can replan and reschedule rapidly and competently based on the occurrence of various production disturbances. As mentioned earlier, the production planning and scheduling process in ETO manufacturing is a collaborative process involving multiple organizational teams and functions. Hence, from a planning tools and technology perspective, it is necessary from a managerial standpoint to ensure that the production planning team has the right tools, technology, or facility to communicate the information about the replanned or rescheduled orders.

However, from a human resources perspective, along with the right tools, technology, and facility, the people should also have the right skills and knowledge to handle the available resources effectively. Industry 4.0 facilitates introducing and using new tools for the production planning and scheduling process, which could solve problems in an innovative and efficient manner [25]. The World Economic Forum's Future of Jobs Report 2020 projected that as the adoption of technology increases half of the workforce all over the world would require reskilling by 2025 [51]. Therefore, upskilling or reskilling the people to a required degree which provides them with the expertise to utilize the newer planning tools and technology, is also a critical aspect from a managerial perspective [52].

F. Sustainable Development

Sustainable development is essential for manufacturing companies worldwide, irrespective of their manufacturing strategies. To ensure overall sustainable growth and development, manufacturing companies should improve their products and as well as their operations [53]. If not dealt with carefully, production planning and scheduling operations could have a massive impact on all three pillars of sustainable development—economy, society, and environment.

The impact on economic aspects is more straightforward regarding production planning and scheduling. Delivery reliability is a significant performance factor for ETO manufacturing companies. As mentioned earlier, inaccurate production plans could lead to delivery concerns and cause financial penalties [7–11]. Increased penalties affect economic sustainability and lead to reduced customer satisfaction. Inefficient production planning and scheduling could increase the need for additional work hours to meet customer delivery deadlines. Extra working hours could result in material and energy wastage and affect environmental sustainability [54]. Finally, when it comes to social sustainability, as described earlier, frequent replanning or rescheduling could lead to increased work intensity of employees involved with production planning and scheduling and result in employee exhaustion [54]. High work intensity could increase sickness rates in the long term [54]. Therefore, the authors recommend that the literature study results regarding the challenges in production planning and scheduling could be considered improvement opportunities for enhancing overall sustainability in the ETO segment.

G. Limitations and Future Research

One of the main limitations of this research study from a methodology perspective is that the article results are solely based on the findings from the existing literature available in the ETO segment. Therefore, the challenges identified in the article consist of a nonexhaustive list. In their future research, the authors would like to conduct qualitative interviews and quantitative surveys with personnel from ETO manufacturing companies from various manufacturing domains to evaluate and compare the challenges in production planning and replanning more from an industrial perspective.

V. CONCLUSION

The article's primary objective has been to provide an overview of the significant challenges regarding production planning and scheduling in manufacturing companies with an ETO strategy. The results from the literature study conducted have helped to achieve this objective. By reviewing scientific

articles in the ETO segment, the authors show that flexibility in production planning and scheduling operations is an essential requirement in the ETO segment as the production plans or production schedule is highly vulnerable to uncertain situations. The literature study results show that there is less research material available for manufacturing companies with the ETO strategy compared to the volume of research material available for manufacturing companies that follow other manufacturing strategies like MTS, MTO, and ATO. Thus, the authors would like to contribute towards the ETO segment through this literature study article. The authors also recommend that acting on the challenges identified in production planning and scheduling from the literature study could enable sustainable development in manufacturing companies with an ETO strategy. The improvements regarding production planning and scheduling challenges directly impact economic, societal, and environmental aspects of sustainability.

The authors have also classified the identified challenges into four categories – challenges from a manufacturing strategy perspective, challenges from a planning tool and technology perspective, challenges from a human resources perspective, and challenges from a research perspective. Through this categorization, the authors have shown that replanning or rescheduling is a paramount concern in the ETO segment. The categorization of challenges has also enabled the authors to identify the critical requirements for a planning tool in the ETO segment. Based on the literature study, the authors propose that the ideal planning tool in the ETO segment should facilitate planning and replanning processes. The planning tool should also help the planning personnel quickly communicate the updated plans with everyone involved in the planning process and update the changes in the company ERP system. Most importantly, the planning tool should provide real-time production status from the shop floor to help planners in their overall decision-making.

From a future research perspective, the authors propose the need for more industry-oriented case studies with manufacturing companies with ETO strategy. More industry-oriented research will also help to find the best suitable ICT tools for production planning and scheduling in the ETO segment. Finally, the authors suggest that industrial and academic experts consider the importance of replanning or rescheduling and thereby help manufacturing companies in the ETO segment to have more resilience in uncertain situations.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Ninan Theradapuzha Mathew wrote the paper and conducted the literature study; Björn Johansson supervised the research; all authors had approved the final version.

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