Cognition, Technology & Work
https://doi.org/10.1007/s10111-024-00785-3

RESEARCH

Human factors and emerging needs in aerospace manufacturing planning and scheduling

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Received: 6 June 2024 / Accepted: 6 November 2024

Abstract

Planning and Scheduling (P&S) are critical components of organizational management that influence efficiency, overall performance, and human factors in the workplace. The aerospace manufacturing industry is experiencing rapid changes, marked by heightened demands for new aircraft and the need for precise task execution to accommodate increasing air traffic and rigorous safety regulations. This study explores the human factors and emerging needs in the P&S processes within aerospace manufacturing. A qualitative research approach was employed, featuring semi-structured interviews with 15 professionals from a prominent European organization. The participants, actively engaged in P&S operations, were chosen to offer diverse perspectives on their roles and the industry's specific requirements. Results indicate that planners/schedulers, IT experts, and operations team leaders are crucial in ensuring efficiency throughout the various stages of P&S operations. The findings reveal that emerging needs encompass workforce and customer management (i.e., allocating human resources, responding to client requests, and addressing workforce resistance to new technology adoption), prioritization (i.e., scheduling tasks based on urgency, error susceptibility, and cost efficiency), and contingency handling (i.e., machinery availability, time constraints, quality issues, human performance variability, and weather conditions). These needs highlight the importance of considering human factors and cognitive aspects when designing and implementing P&S systems. The study underscores the challenges the aerospace manufacturing industry faces as it adapts to technological advancements and evolving market conditions. The findings emphasize the necessity of advanced P&S systems that integrate innovative technological solutions with an understanding of human factors and cognition.

Keywords Aerospace manufacturing · Planning and scheduling · Human factors · Job roles · Needs

1 Introduction

Planning and Scheduling (P&S) are crucial aspects of organizational management that significantly impact efficiency and overall performance. Planning involves the development of strategies to achieve specific goals, while scheduling means assigning and managing tasks within a given timeframe to execute those plans effectively (Snoo et al. 2010; Tyagi et al. 2013). Both are crucial in ensuring that resources are utilized optimally and objectives are met.

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In manufacturing, planning forecasts demand and allocates resources, setting a timeline for production. Scheduling translates these plans into actionable sequences, aligning tasks to meet production targets (Sunday et al. 2021). This coordinated approach, encompassing resource allocation and task sequencing, supports operational flow and productivity (Kallrath 2002; Tyagi et al. 2013). Given the complexity of P&S, specialized frameworks address common issues like schedule delays, cost overruns, and quality control, which are particularly challenging in aerospace manufacturing.

In aerospace, these P&S challenges are amplified by the need for precision and adaptability in high-stakes environments. Integrating human factors with advanced P&S technologies, such as AI-assisted systems, is essential for managing the industry's unique demands. Despite advancements in P&S research, critical gaps remain in addressing the unique demands of aerospace manufacturing,

Published online: 23 November 2024

particularly in integrating human factors within complex, technology-driven environments. As technologies like AI-assisted systems become integral to P&S, understanding how they interact with human decision-making and adaptability becomes essential. While human factors are widely recognized for managing dynamic and complex tasks, there is limited research on their role in helping aerospace professionals navigate the specific challenges of P&S in this industry, indicating a need for focused investigation.

Across industries, human factors research has shown that adaptability and decision-making are vital for efficiency and resilience. However, the aerospace sector faces distinct, evolving challenges—such as stringent safety requirements, fluctuating demands, and complex task coordination—that require dedicated insights into how human factors can enhance P&S under these high-stakes conditions. As aerospace manufacturing adapts to rising global air traffic, shifting market demands, and advancing technologies, the need for P&S systems that integrate human factors has become more pressing. This study addresses this need by exploring aerospace-specific P&S dynamics, emphasizing how human factors can optimize these processes and illuminate the complexities industry professionals face in sustaining operational performance.

2 Background and related work

Research on P&S has traditionally emphasized the role of technology in optimizing manufacturing processes. However, the importance of human factors—particularly in complex, high-stakes environments such as aerospace—has gained renewed attention. This section provides an overview of the key contributions from the literature on human factors in P&S and addresses the specific challenges and recent advancements in aerospace manufacturing.

2.1 Human factors in planning and scheduling

The role of human factors in Planning and Scheduling (P&S) has long been recognized as essential in managing complex and dynamic industrial environments. Early studies (e.g., Dutton 1962, 1964) laid the foundation, demonstrating that human involvement is crucial in handling adaptable, nuanced decisions, especially when routine systems face unexpected challenges. Research in the 1980s and 1990s expanded on these concepts, with Sanderson's work highlighting human intuition and adaptability as critical assets in overcoming unforeseen scheduling disruptions. Such adaptability is particularly relevant to aerospace manufacturing, where rapid technological advances require P&S professionals to combine human flexibility with high-tech solutions.

The importance of human problem-solving in P&S was further validated by studies in the 1990s, such as those by Nakamura and Salvendy (1994), McKay (1995), and Wiers and Van Der Schaaf (1997). These researchers demonstrated that human schedulers excel in complex environments, often surpassing automated systems by applying unique problem-solving and adaptive skills in high-stakes scenarios.

Building on this groundwork, recent research increasingly focuses on integrating human factors with advanced P&S technologies, particularly in aerospace and high-stakes environments.

Parnell and colleagues (2021) compared methods for generating design recommendations for new technological features, starting with the premise that human factors methods should prevent new technologies from introducing new user errors. They found that involving end-users in structured human factors methods is critical for creating practical and usable technological systems.

A recent study by Subramanya et al. (2022) emphasizes the importance of skilled workers in aerospace manufacturing, particularly in process planning activities like interpreting part designs and selecting appropriate manufacturing processes. This study highlights the essential role of specialized knowledge in optimizing P&S activities, reinforcing the view that human expertise is crucial in this high-stakes industry.

Comberti et al. (2019) analyzed different workstations' physical and mental workload requirements, offering insights into how better resource allocation can enhance performance and reduce errors. They found that effective workload management significantly influences overall performance, reducing errors and improving output quality. Complementing these aspects, Ahmed (2019) and Nawi et al. (2023) underscored the importance of effective time management as a critical factor in staff well-being and operational safety, especially in large-scale manufacturing environments characterized by continuous operations and demanding schedules.

2.2 Planning and scheduling in Aerospace Manufacturing

In the last decades, the aerospace manufacturing industry has faced increased demands and a surge in traffic volume, placing significant pressure on manufacturers to deliver aircraft to airlines on time. Recent research indicates that worldwide air traffic has been steadily increasing, which is expected to continue in the coming decades (Wensveen 2023). As a result, the demand for new aircraft is rising, creating a need for manufacturers to ramp up production to meet these demands. This increased demand is driven by population growth, economic development, and the expansion of air travel networks (Wensveen 2023). This inevitably leads to the need to manage the new challenges posed to aerospace workers who, as Cahill and colleagues (2023) claim, are facing considerable issues due to the increased workload.

Aerospace manufacturers constantly aim to improve their production processes and efficiency to keep up with the growing demand. They invest in automation and digital manufacturing technologies to streamline operations and increase productivity. These advancements enable manufacturers to optimize processes, reduce production time, and enhance quality (Liu and Jin 2020). However, meeting the increased demands and delivering aircraft on time is still challenging. The market constantly evolves, with demands such as more passengers, greater cruise range, new engines, and environmental considerations. Manufacturers should adapt to these changing requirements and incorporate them into their design and production processes. Moreover, it is noteworthy that the need for stringent safety and quality standards in aircraft manufacturing also poses significant hurdles for manufacturers (Nelson and Drews 2008).

Furthermore, the industry is witnessing significant challenges related to fluctuating raw material costs and supply chain bottlenecks, which affect production timelines and cost efficiency (Bao et al. 2023). To mitigate these risks, manufacturers are exploring more resilient supply chain strategies and diversifying their supplier base. The push towards sustainability and reducing carbon emissions reshapes the industry. Innovations in lightweight materials, fuel-efficient engines, and alternative fuel sources are becoming increasingly important in designing and producing new aircrafts. Hence, aerospace manufacturers face the challenge of scaling up production, innovating, and adapting to a rapidly changing global landscape (Bao et al. 2023). Furthermore, additive manufacturing and other AI-based technologies are also raising the importance of continuous learning for employees to maintain and enhance operational standards and to keep the workforce up-to-date with current practices (Najmon et al. 2019; Chen et al. 2019).

A recent review by Nwasuka and Nwaiwu (2024) highlights the potential of integrating line balancing and process plan selection in Smart Manufacturing Systems to enhance production efficiency. This integration can reduce downtime and improve resource utilization while supporting data-driven decision-making and optimization strategies. These advancements seek to streamline processes and meet the growing demands of the industry.

Planners and schedulers in the aerospace manufacturing industry must manage constraints linked to the operational complexities inherent in the field, requiring skillful navigation to maintain efficiency and adhere to stringent production schedules. As Yang et al. (2019) highlighted, resource constraints underscore the delicate balance in managing the workforce, machines, and materials. For example, a shortage of technicians, considering their breaks, worksheets, holidays, or absences, can make planners reassess and reallocate resources to meet tight production schedules. Temporal constraints, identified by Azami et al. (2018), emphasize the time-sensitive nature of manufacturing processes. Delays in receiving critical components, such as engine parts, can disrupt the entire production chain, necessitating swift and strategic replanning to avoid cascading delays.

The aerospace manufacturing industry also contends with capacity constraints involving specialized machinery with fixed limits (Azami et al. 2018). These constraints can lead to bottlenecks, particularly when demand surpasses available machinery capacity, pushing planners to optimize resource utilization while minimizing production downtime. Dependency constraints add another layer of complexity to the scheduling process. Herrmann et al. (2001) illustrate that the interdependence of tasks means that a delay in one area, such as avionics installation, can have a domino effect on subsequent processes, including aircraft painting or cabin furnishing. Moreover, weather constraints, which refer to limitations arising from unfavorable weather conditions, can disrupt outdoor testing and parts transportation. This necessitates contingency planning and robust scheduling flexibility to accommodate unpredictable external factors.

Yang et al. (2023) recently presented a new way to optimize the P&S of making complex parts for aerospace companies, dealing with challenges like different processing requirements, limited resources, and changing demands. The method uses a unique algorithm called the “honey-bee mating optimization algorithm,” inspired by how honey bees mate. The algorithm mimics the mating process of a queen bee with drones, using strategies to avoid problems and find the best solutions. The researchers tested their method on genuine aerospace parts and found that it effectively shortened the production time and reduced the cost.

In recent years, advanced analytical models and predictive analytics have become increasingly significant in aerospace manufacturing (Hueber et al. 2019). These analytical tools enable manufacturers to anticipate potential delays and bottlenecks, allowing for proactive adjustments in the production schedule. Furthermore, integrated planning systems are being developed to synchronize various aspects of manufacturing, from supply chain management to assembly line operations (Yang et al. 2019). As noted by Monek and Fischer’s research (2023), these systems facilitate real-time monitoring and adjustments, enhancing the agility and responsiveness of the manufacturing process (Monek and Fischer 2023). These and other recent technological advancements laid the foundation for real-time scheduling in aerospace manufacturing. According to Akhtar et al. (2019) real-time scheduling directly addresses the industry's need for efficiency and adaptability in an environment with limited resources, high product variability, and stringent timelines. Real-time scheduling systems enable the dynamic allocation of tasks and resources, allowing manufacturers to respond instantly to shifts in production requirements or unforeseen disruptions. These systems, especially when integrated with autonomous control and agent-based models, help streamline operations on the shop floor by optimizing machine utilization, reducing idle times, and enhancing operator productivity. A comprehensive review by Ma et al. (2023) helps to highlight the key technological advancements that allowed real-time scheduling to be deployed in the aerospace manufacturing industry. Central to these advancements are multi-objective scheduling techniques, for instance, using Genetic Algorithms (GA), Ant Colony Optimization (ACO), and Particle Swarm Optimization (PSO) to create adaptive scheduling systems that can handle unexpected issues, such as equipment malfunctions or urgent changes. Digital twin and edge computing integration further enhance scheduling precision by synchronizing virtual and physical production environments. This enables real-time monitoring, fault detection, predictive maintenance, and streamlined responses to production changes with localized data processing that reduces latency (Ma et al. 2023). The Industrial Internet of Things (IIoT) is pivotal in connecting machines, sensors, and operators, creating a highly communicative and responsive production environment where real-time data flows help maintain continuous operation and prevent delays. Additionally, hybrid heuristic algorithms blend multiple optimization strategies to tackle complex scheduling issues, ensuring energy-efficient, delay-minimized operations that optimize machine workloads. Finally, the quality of Human-machine interaction (HMI) is a critical component highlighted by Ma et al. (2023) in enabling real-time scheduling within aerospace manufacturing. Integrating HMI with technologies like Digital Twin, IIoT, and intelligent control systems, HMI bridges the gap between automated systems and human operators, allowing for seamless collaboration.

The present literature also highlights the aerospace manufacturing industry's need for highly skilled planners and schedulers. The market demand requires, for instance, a high reactivity between teams in charge of the aircraft's design and production system. One way to increase this reactivity is to help the design architects understand how the aircraft is produced and the bottlenecks in the manufacturing process and to help them evaluate the impact of a design modification on the production system (Pralet et al. 2018).

2.3 Research objectives

Although there has been considerable research on P&S processes within manufacturing industries, there are notable gaps in understanding the distinct roles and requirements of planners and schedulers in aerospace manufacturing. This is especially pertinent given the recent shifts and complexities within the sector.

While existing studies have explored the influence of human factors and operational constraints on P&S effectiveness, there is a clear need for further research dedicated to addressing the specific challenges encountered by planners and schedulers in this dynamic and evolving industry. Specifically, the literature lacks detailed insight into how planners and schedulers adapt to emerging technologies, handle complex stakeholder interactions, and navigate evolving operational challenges in aerospace manufacturing. There is a need to investigate how these roles interact with other key stakeholders, such as customers and production teams, to optimize the manufacturing process and address bottlenecks in the face of these new challenges.

> Conducting a qualitative study on the roles and needs of planners and schedulers in aerospace manufacturing would bridge these research gaps and provide novel insights into enhancing P&S effectiveness in the context of the industry's ongoing transformation.

This study examines the key roles and requirements within aerospace manufacturing, focusing on critical aspects that influence P&S processes and overall operational performance. To this end, three research objectives were pursued: (1) to provide a detailed description of the main professional roles related to P&S processes, as well as the responsibilities and tasks, filling current gaps in the literature; (2) to analyze the planners and schedulers emerging needs, identifying areas for improvement and optimization; and (3) to explore the different dimensions of the challenges encountered by professionals in the P&S process and the role of human factors in facing them, thus providing insights for practitioners aiming to improve overall production efficiency.

> This work is part of the Horizon Europe project TUPLES (https://tuples.ai/), aiming to provide new technical approaches for P&S. This project addresses the P&S challenges in a context characterized by uncertain task durations, fluctuating resource availability, and the diverse skill sets of the workforce.

3 Method

The method employed in this study is summarized in Fig. 1, which provides a visual overview of the main research phases, including the approach definition, the development of materials, participant recruitment, data collection, and data analysis.

3.1 Participants

This study recruited 15 professionals (3 females, 12 males) from a leading European aerospace manufacturing organization in Germany, Spain, the United Kingdom, and France. The company's participant selection process was guided by industry experts to ensure representativeness and relevance to P&S operations. To qualify for the study, participants had to be current employees actively involved in aircraft manufacturing, assembly, or logistics, occupying roles related explicitly to P&S. Additionally, participants were required to be potential end-users of new P&S systems, possessing a minimum of 4 years of experience in these processes, which provided them with the necessary expertise to offer perspectives and insights into the roles, challenges, and requirements of P&S operations. This selection process ensured that the sample represented the broader aerospace manufacturing industry, particularly regarding P&S involvement and experience. Including professionals from different geographical sites and functional areas further contributed to a comprehensive understanding of the P&S processes across various contexts.

3.2 Materials

The present study adopts a qualitative approach, employing semi-structured interviews to explore the participants' perspectives and experiences (Adams 2015). To ensure thoroughness in data collection, the semi-structured interview protocol was prepared according to the framework proposed by Kallio et al. (2016) and following five phases: (1) identification of prerequisites according to the objective of the study; (2) retrieving and using previous knowledge from the literature; (3) preparing a preliminary semi-structured interview guide; 4) pilot testing the interview guide with one participant; and (5) drafting the final semi-structured interview guide. The interview pilot was crucial for estimating the time needed for the session and assessing the participants' level of engagement with P&S processes and tasks. Consequently, the researchers fine-tuned the protocol to fit within a maximum duration of one hour and adjusted the questions to ensure relevance to the target audience. Given the pilot interview's success in gathering the expected data, it was included in the interview pool. The final semi-structured interview protocol contained questions designed to elicit detailed insights about the roles, tasks, and skills of aerospace manufacturing planners and schedulers. It also explored the organizational challenges they encounter and the constraints to overcome them effectively.

3.3 Procedure

Participants were recruited using an ad-hoc invitation document sent directly via email. This invitation was

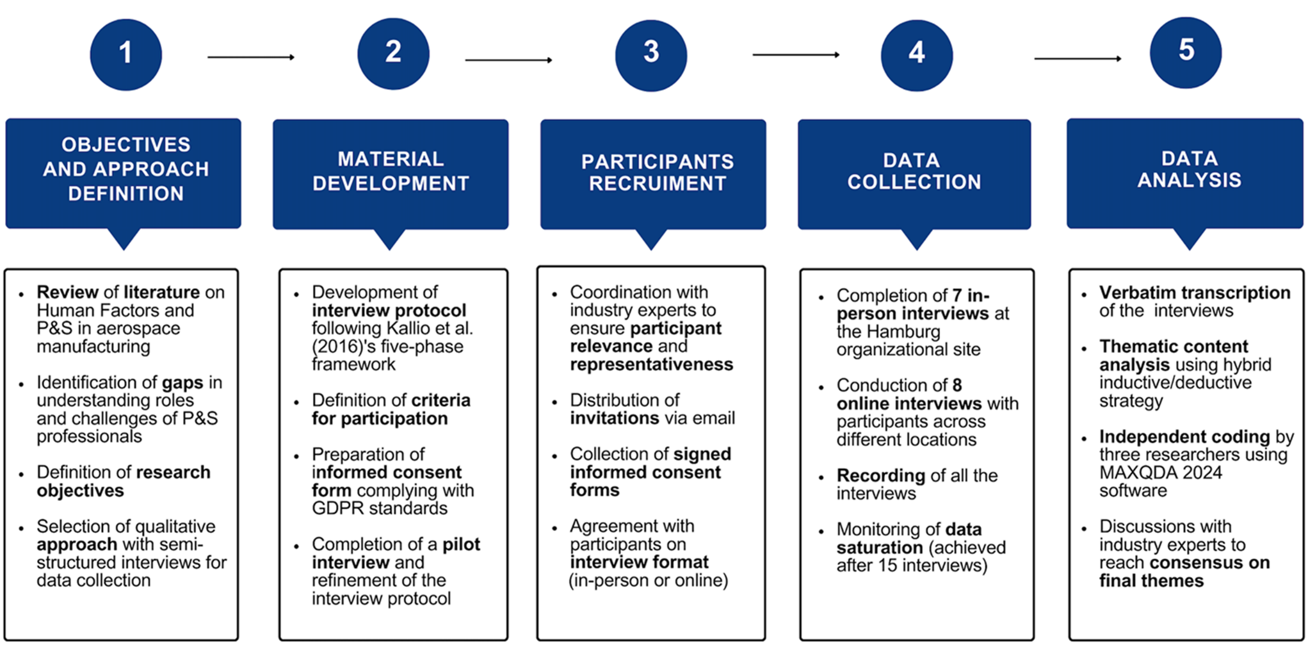

Fig. 1 Overview of the research method and key steps

disseminated within the organization, targeting experienced employees engaged in P&S processes. The invitation document outlined: (i) the research objectives; (ii) the study's relevance; (iii) participation requirements; (iv) a description of the data collection methods and timelines; (v) contact information of the researchers; and (vi) a request for confirmation of availability to participate in the study.

A dedicated document was prepared to ensure compliance with the General Data Protection Regulation (GDPR), explaining how participants' data would be handled according to GDPR standards. This included a consent form for participants to sign, allowing their interviews to be recorded and the data to be used in the study while ensuring privacy and data protection. Finally, the participants were contacted after collecting and reviewing applications that met the participation criteria and obtaining GDPR consent. This final step involved scheduling the interviews.

The 15 interviews were conducted between October 2023 and January 2024. Seven interviews were conducted in person at the organization's sites in Hamburg (Germany). By accommodating the language preferences of the participants, four sessions were carried out in English, while three in German with the assistance of a native-speaking interpreter. The other seven interviews were conducted online with English-speaking participants only. This decision was based on the premise that including an interpreter in online interview settings might introduce unnecessary complexity and potential noise in the data collection process. Data saturation was monitored during the interview process and was deemed achieved after 15 interviews. The consistency of the findings across participants indicated that the main themes had been thoroughly explored, and no new themes or insights emerged in the final interviews. This confirmed that the data collected were sufficient to support the study's conclusions. With the consent of the participants, all interviews were audio-recorded.

3.4 Data analysis

The recorded interviews were transcribed verbatim. Subsequently, a thematic content analysis was conducted utilizing the MAXQDA 2024 software (Gizzi and Rädiker 2021), adhering to the methodology described by Braun and Clarke (2006). The analysis adopted a hybrid inductive/deductive strategy, integrating predefined categories with identifying new emerging sub-themes (Armat et al. 2018). This approach ensured the analysis was grounded in theoretical principles and reflective of the participants' perspectives.

Three researchers independently coded the transcripts to ensure consistency and reliability in the coding process. Each researcher analyzed the data separately, identifying relevant segments based on predefined categories and emergent themes. After this phase, the researchers convened to compare their coding outcomes and address any discrepancies. Discrepancies were resolved through consensus-building discussions, during which the team revisited the relevant transcript sections and deliberated on the rationale behind differing coding decisions. This process continued until a mutual agreement was reached. When necessary, the theoretical framework was referenced to ensure that the coding aligned with the research objectives and that the analysis remained consistent with the data. A peer debriefing session was conducted with two industry experts, offering an additional layer of verification and confirming that the identified themes accurately reflected the data.

4 Results

The results of the study are presented in three main sections. First, we describe the three primary job roles (Planners and Schedulers, IT/software engineers, and Operations team leaders) and their associated responsibilities and tasks. Second, we present an analysis of the main themes that emerged from the interviews, including managing the workforce and customers, prioritizing tasks, and handling contingencies. Finally, we discuss the various sub-themes within each main theme, representing the diverse dimensions of the challenges professionals encounter in the P&S process.

4.1 Job roles and critical tasks

In our study, we identified three leading job roles and their corresponding tasks involved in the P&S process in aerospace manufacturing. Table 1 provides a synthetic description of each identified role and lists their primary tasks.

Planners and Schedulers are responsible for both long-term and short-term planning. Their main tasks involve considering comprehensive factors to control planning activities for 18 months. The interviewees emphasized balancing various operational timelines and resource allocations to ensure smooth production processes.

The IT/software engineers interviewed reported that their primary focus is maintaining and deploying P&S software to enhance process optimization. They mentioned their role in evaluating current tools against future needs and implementing new systems to improve efficiency. The participants also highlighted the significance of their contributions to streamlining the P&S process through technological solutions.

The manufacturing operations team leaders who participated in the interviews stated that their primary responsibilities included allocating tasks and human resources, coordinating operations to ensure efficient workflow, and

Table 1 Roles and tasks of employees engaged in the P&S process

Roles	Description	Key tasks
Planners and Schedulers	Planners and Schedulers are responsible for long- and short-term planning, maintaining control over production processes for up to 18 months, and continuously adjusting schedules to align with daily manufacturing goals.	Long and short-term planning Daily tracking and adjusting of schedules
IT and software engineers	IT and Software Engineers oversee the integration and management of production planning tools, ensuring compatibility with other software systems, and assess tools for future needs to optimize P&S processes.	Tool maintenance New tools development
Operations team leaders	Operations Team Leaders coordinate workforce operations, manage workforce allocation, and ensure efficient workflow to meet production goals.	Tasks and workforce allocation Coordination of workforce operations

managing significant numbers of personnel. They emphasized the importance of effective communication and coordination among team members to maintain a smooth production process. The interviewees also mentioned their challenges in managing a large workforce while ensuring adherence to production schedules and quality standards.

4.1.1 Planners and schedulers

The interviewees underscored the importance of maintaining control over the planning process for an extended period, typically 18 months. Effective P&S in aerospace manufacturing requires a strategic and forward-looking approach, considering not only the immediate production requirements but also the long-term goals and objectives of the organization.

> The main goal of this role is to have the planning for the next 18 months under control.

Participants described creating a production plan based on a specific delivery target, in this case, 50 aircraft deliveries in 2024. The planner needs to consider various factors, such as the delivery schedule (e.g., specific dates in January, February, etc.), calendar constraints, inventory targets, and time limitations. This highlights the complexity of the planning process in aerospace manufacturing, as it involves integrating multiple variables and constraints to develop an optimal production plan. Furthermore, participants emphasized the importance of formalizing the plan once it has been devised, suggesting that the documentation and communication of the plan are crucial steps in the planning process.

> For example, consider that for 2024, you aim to achieve 50 aircraft deliveries, each scheduled for a specific date—some in January, others in February, and so on. With this information, we construct our production plan, considering various factors. This includes our calendar, inventory targets, time constraints, and other similar parameters. Once you have devised what you believe to be the optimal plan, the next step is to formalize it.

Planners and schedulers must continuously monitor the production progress and compare it to the original plan, which requires sustained attention and the ability to detect deviations. This cognitive process involves information processing, as the planner gathers and interprets data from various sources to assess the alignment between the actual production and the planned objectives.

When a misalignment is detected, the planner devises a tactical plan to realign production with the original objectives. This process involves generating alternative solutions, evaluating their feasibility, and selecting the most appropriate action. Planners engage in mental simulation to anticipate the potential outcomes of different tactical plans and their impact on the overall production goals.

> Once the plan is entered into the system, you need to monitor daily whether production aligns with this plan. If not, you must devise a tactical plan to realign with the original objectives. Essentially, this becomes a cyclical process.

Planners and schedulers use complex calculations and estimations to determine the resources required for specific tasks or identify feasible functions within constraints. They make informed decisions based on incomplete or ambiguous information, considering the trade-offs between different scheduling options. This process involves risk assessment and the ability to prioritize competing demands, such as resource allocation, time constraints, and cost-effectiveness.

> The second step focuses on detailed scheduling, determining how many resources are needed to complete a given task, or identifying what kind of task can be achieved within the constraints of a valid cost function.

The cyclical nature of this process suggests that planners possess cognitive flexibility and the ability to switch between different modes of thinking, such as strategic planning and tactical problem-solving. This constant adaptation to changing circumstances can lead to cognitive workload and mental fatigue, which highlights the importance of designing work systems that support the cognitive needs of planners and schedulers.

4.1.2 IT and software engineers

IT and software engineers oversee the production planning tool and manage its integration with other software systems. They need to have a holistic understanding of how different tools and systems interact and impact each other and ensure that the production planning tool is seamlessly integrated with other software used across the organization. This requires cognitive skills such as problem-solving, decision-making, and the ability to anticipate and mitigate potential issues arising from the interaction between different systems.

The primary tasks described by the participant, such as identifying production stations, ensuring they are accounted for in the system, and determining the starting and ending points at each station, involve great attention to detail and spatial reasoning.

> My team consists of various experts who specialize in different tools. I oversee the tools used for production planning. I manage the interface and connections between this tool and other software utilized across the organization. My primary tasks include identifying the production stations, ensuring they are accounted for in the system, and then determining the starting and ending points at each station.

Participants' roles and tasks extend beyond primary planning responsibilities and include technical expertise, problem-solving, communication, and interpersonal skills. The operator's ability to manage tool interfaces, ensure software connectivity, and provide guidance and support to colleagues is crucial to the smooth functioning of the P&S process.

> I am often contacted to ensure the tool interfaces function correctly, as issues sometimes arise with the connections between different software. Occasionally, colleagues report that the information I have entered into the system has not properly cascaded into the software for some reason. When they observe this, I guide how to work with the software more effectively.

The software engineer's central role is to assess the current tools used by the organization and determine their suitability for future needs. This responsibility involves a strategic and forward-thinking approach, as the engineer anticipates the evolving requirements of the P&S process and makes informed decisions about whether to continue using existing tools or transition to new ones. This role requires a deep understanding of the capabilities and limitations of various software tools and the ability to evaluate their alignment with the organization's goals and objectives. Identifying business needs and coordinating resources for successful implementation requires close interaction with various stakeholders, including planners, schedulers, and other team members. Engineers need to communicate effectively the benefits and potential challenges of new tools and technologies and build consensus around the implementation strategy.

> I am focusing on the tool side, evaluating not only the tools we currently use, which I support; but also considering future needs to determine whether we should continue with the same tools or transition to different. My current role primarily involves identifying opportunities within the business to deploy new tools, including artificial intelligence and other advanced technologies. Once the business needs are identified, I organize and coordinate the necessary resources to fulfill those needs and generate value for the company. Depending on the specific technology, software, or prerequisites required for deployment, I ensure that the right resources are secured for successful implementation.

4.1.3 Operations team leaders

Operations team leaders are focused on understanding each team member's skills, capabilities, and experience, as well as the specific requirements of each task. The team leader tries to match the right person to the right task, ensuring that the work is completed efficiently and to the required quality standards. This process involves decision-making skills, as the team leader prioritizes tasks and allocates resources based on the schedule and any potential constraints or challenges.

> When I have the schedule in hand, I [as the team leader] look at the various tasks and assign people accordingly.

This responsibility involves a proactive approach to resource management, as the operations team leader anticipates potential absences or other issues that may impact the team's ability to complete the scheduled work. By checking the availability of personnel, the team leader can make informed decisions about task allocation and adjust the schedule as needed to accommodate any changes in resource availability.

> We check the availability of personnel of our teams to understand whether they are present at work and ready to perform the task we assign to them.

Another relevant responsibility of the operations team leader is managing the production operations of large teams. This role requires strong organizational and leadership skills, as the team leader coordinates the efforts of a substantial number of individuals, ensuring that everyone is working towards common goals and objectives. Managing such large teams also involves effective communication, delegation, and motivating and inspiring team members to perform at their best. The operations team leaders' role in supporting and managing all aircraft activities at the airport underscores the critical nature of their work in ensuring the smooth operation of the aerospace manufacturing process. This responsibility requires a comprehensive understanding of the various tasks and processes involved in aircraft production and maintenance and the ability to coordinate and prioritize activities across multiple teams and shifts.

The operations team leaders coordinate various activities, such as transporting entire aircraft or aircraft parts between different locations within the manufacturing facility. The team leader has a strong understanding of the logistics involved in such operations and the ability to communicate and collaborate effectively with other teams and departments.

> I manage the [production] operations of two large teams and the shifts of two large groups of 50 people each.
> We are four team leaders in my department and around 110 blue-collar employees. We [as team leaders] support and manage all aircraft activities at the airport.
> I coordinate my team, which is responsible for transporting entire aircraft, which can be split into two halves or further into two pieces. For example, we can transport a part of an aircraft from Hangar 14 to the paint hangars.

While the planner and scheduler primarily focus on macro-level planning, the operations team leader is immersed in micro-level management. The planner and scheduler role is critical in aligning all tasks with the overarching goals of aircraft production, ensuring a strategic and cohesive workflow. This position demands a deep understanding of planning software and a comprehensive knowledge of manufacturing processes, reflecting a robust technical proficiency. In contrast, the operations' team leader role involves the direct oversight of plan execution and the hands-on management of personnel on the production floor. Operations team leaders possess a fundamental understanding of planning tools but place greater emphasis on the technical aspects of task execution.

4.2 Main themes in the P&S process

Results from the interviews allowed us to identify critical themes related to the needs of the professionals involved in the P&S process. For each theme, diverse sub-themes emerged, representing the challenges faced by those professionals. These needs are classified into three primary themes: managing the workforce and customers, prioritizing tasks, and handling contingencies.

Firstly, the need to manage the workforce and customers is highlighted as pivotal, with workforce management being a significant concern cited by operations team leaders and planners/schedulers. Secondly, the need to prioritize is evidenced by the necessity to manage task dependencies, criticality, and associated costs—each dimension reflecting the operational nuances of aerospace manufacturing. Lastly, the need to handle contingencies involves several dimensions that planners and schedulers must navigate to mitigate risks associated with manufacturing disruptions. Table 2 provides an overview of the identified needs and dimensions, providing an operational framework that accommodates both human factors and technical elements of the roles involved in P&S. Each need and dimension are detailed in this section.

4.2.1 Managing workforce and customers

Workforce management is highlighted by planners/schedulers and team leaders as critical, with the need to account for human variables such as errors, illnesses, and qualifications, requiring strategic allocation and reallocation of resources. Another challenge for planners/schedulers is meeting customer requests, which often surge towards the end of the day, leading to peak demand for new products by the next day. For planners/schedulers and team leaders, prioritization emerges as another significant topic in this theme, where the decision-making process involves identifying immediate tasks and strategizing on task assignments to optimize workflow and productivity. Lastly, the acceptance of new tools within IT/software engineers presents a challenge in encouraging the adoption of innovative solutions for scheduling and planning, emphasizing the need for demonstrating benefits and managing organizational change.

4.2.1.1 Allocating human resources Human resources management is a critical factor in the successful allocation of work. Participants acknowledge that due to the scale of the production plan, they are expected to face situations where the exact resources needed are only sometimes avail-

Table 2 Overview of the study's identified themes and related dimensions

Themes	Dimensions	Definition and references	*N*	Roles
Managing workforce and customers	Allocating human resources	The strategic distribution and redistribution of human assets to fulfill production needs and address fluctuations in human performance (Doumic et al. 2017)	9	Operations team leaders, Planners/scheduler
	Meeting customer requests	The management of task volumes and operational capabilities, responding to client deadlines and expectations (Sommer 2014)	7	Planners/schedulers
	Handling workers' resistances	The management of team members' reluctance to adopt new technologies, aiding in the integration of these tools into their workflow (Ito et al. 2021)	3	IT/software engineers
Prioritize	Task dependency	The criteria for scheduling tasks based on task urgency and interdependencies (Wang et al. 2019)	3	Planners/scheduler Operations team leaders
	Task criticality	The criteria for scheduling tasks based on the error susceptibility of the tasks themselves (Sruti et al. 2018)	2	Planners/scheduler Operations team leaders
	Revenue potential	The criteria for scheduling tasks based on the cost efficiency of the specific activities (Gohareh et al. 2017)	2	Planners/scheduler Operations team leaders
Handle contingencies	Machinery availability	Possible disruptions related to the accessibility and functioning of equipment (Azami et al. 2018)	6	Planners/scheduler Operations team leaders
	Time limitations	Handling production timings to meet customer demands, delays can severely disrupt operations (Azami et al. 2018)	5	All
	Quality issues	Possible disruptions related to the quality of components or the work carried out not meeting the standards (Nelson and Drews 2008)	4	Planners/scheduler Operations team leaders
	Human performance variability	Need to handle inconsistencies in human behavior and performance that can lead to errors affecting manufacturing processes (Yang et al. 2019)	3	All
	Weather conditions	Disruption of tasks related to adverse weather conditions prevents to carry out specific tasks (Yang 2023)	3	Planners/scheduler Operations team leaders

able. This reality requires the leader to engage in daily allocation and reallocating the available resources in different ways to meet the demands of the production process. This responsibility involves a high degree of flexibility, adaptability, and problem-solving skills, as the leader continuously assesses the changing needs of the production line and makes strategic decisions to optimize the use of available human resources.

> Human resources, that is key. For allocating work in a particular way, normally, it is not that you don't have the exact resources you need because of the scale of the plan. So, you are daily allocating and reallocating your resources in different ways.

A participant provided a specific example of team leaders' resource allocation challenges in the aerospace manufacturing process. Different areas may compete for resources. These areas constantly vie for critical resources, such as towing teams, which are essential for moving aircraft between different stages of production and testing.

> For ground support, there are essentially two areas competing for resources. One is the final assembly line where the aircraft is still being assembled, and the other is ground operations, for example, test flights. These areas are constantly competing for resources, such as towing teams.

Manufacturing team leaders try to manage the workforce considering the inherent variability in human performance, which can be influenced by factors such as fatigue, stress, or distractions. Workers may face additional challenges, such as illnesses or equipment problems, which can further impact their ability to perform their tasks effectively. This understanding is crucial for team leaders, as it allows them to create a supportive and accommodating work environment that considers their team members' well-being and individual circumstances.

> I always need to remember that the workers on production lines are human and can make mistakes. They also have to deal with illnesses or problems with the equipment.

Another complexity of the team leader's role in workforce management is ensuring that the right workers are assigned to the right tasks at the right time. This responsibility involves understanding each worker's skills, qualifications, experience, and ability to match these attributes to the specific requirements of each task or workstation. Team leaders also consider scheduling, training, and cross-functional collaboration to ensure the production process runs smoothly and efficiently.

> So, the hardest part is ensuring that my blue-collar workers are in the right place, at the right time, with the right qualifications.

Finally, the need for a more skilled workforce can significantly impact the manufacturing process's efficiency, productivity, and quality, as well as the well-being and performance of production teams. When there are not enough qualified workers to fill the available positions, production teams may experience increased workload, stress, and fatigue, leading to decreased performance, higher error rates, or even safety risks. Additionally, the need for more skilled workers can limit the company's ability to expand production, take on new projects, or implement new technologies or processes.

> The unemployment rate in the area where we operate is below 4%. When it drops to about 3% you reach a point where there is a baseline of people who are typically unemployable at least for manual or operator work. So, we are facing a shortage of people. The gap between 3% and 4%, less than 4%, represents the turnover of people changing jobs and renewing their contracts with different companies.

Another challenge in workforce management is team diversity, with people from different sites and cultures working together. Participants recognized that individuals may have other ways of working, which can create challenges in achieving a homogenized or standardized approach to tasks and processes. This diversity can stem from differences in cultural norms, values, communication styles, and problem-solving techniques, among other factors. A participant emphasized the need for a nuanced approach to managing diversity and promoting standardization. Simply imposing a predefined process on a diverse team is unlikely to be effective.

> We have a lot of people from different sites and cultures; they work differently, and we try to get everything homogenized, but sometimes it is hard.
> Due to diversity constraints and the way of working on the sites, simply telling them, 'OK, this is supposed to be the process,' is not going to be effective. Therefore, we must assist them in finding the right way of working.

4.2.1.2 Meeting customer's requests Participants highlighted the importance of timely aircraft delivery in the aerospace manufacturing industry. The leaders address their customers' demands to ensure aircraft are delivered on schedule. This requires careful planning and a delicate balance between workload and capacity. When faced with a high volume of customer requests and tight deadlines, workers may experience increased stress, workload, and time pressure, which can lead to decreased job satisfaction, motivation, and quality of work. Additionally, the inability to meet customer demands consistently can strain relationships and trust between the manufacturer and their clients, potentially impacting long-term business prospects.

> We must address our customer's demands because timely aircraft delivery is crucial. This is where planning comes into play. We must calculate the workload and achieve a balance with our capacity. The complexity of these requests is quite extensive.
> Often, customers tell me they need a task completed by a particular time. The problem is that I can only sometimes accommodate the requests, maybe because we're short-staffed or due to other factors.

A typical scenario is when the team experiences a surge in customer requests towards the end of the day. The leader noted that every customer wants a new product for the next day, which creates a peak in demand and a significant challenge for the production team. This situation highlights the importance of effective P&S to ensure the team can manage the increased workload and meet customer expectations.

> Normally, we get some peaks towards the end of the day because every customer wants a new product

for the next day. The main challenge is that we often receive too many tasks from different customers.

4.2.1.3 Handling workers' resistances Some participants reported that a challenge is encouraging people to be willing to use any tool for the scheduling and planning process. In some cases, planners, schedulers, and production team leaders may need more support from team members when adopting new tools or technologies. This resistance can stem from factors such as a lack of familiarity with the tool, concerns about the learning curve, or a general aversion to change.

Convincing workers to embrace a new tool is a complex task and requires effective communication and change management strategies. This involves clearly articulating the potential advantages of the tool, such as increased efficiency, improved accuracy, or better decision-making capabilities, and helping team members understand how these benefits can positively impact their work and the overall production process.

> The first challenge for me would be to encourage people to be willing to use any tool for the scheduling and planning process.
> We need to demonstrate the expected benefits of the tool, which can be quite challenging. It is not only about convincing people but also about managing change within our organization.

The challenges described in the extracts underscore the importance of considering the human element when introducing new tools or technologies in the workplace. People may have different levels of comfort, experience, and motivation when adopting new tools, and leaders must be sensitive to these individual differences. Resistance to change can also be influenced by job security concerns, fear of failure, or a lack of trust in the organization's ability to manage the transition effectively.

4.2.2 Prioritize

This theme includes criteria for which P&S professionals prioritize activities in everyday operations. Task dependency emerges as the most common criterion, evidenced by the participant's need to maintain synchronization between the various stations on the assembly line, ensuring that no phase creates a bottleneck for the others. Another is task criticality, emphasizing that in situations with similar levels of importance in outcomes, priority is given to the most safety-critical tasks to manage the overall risk effectively. Lastly, costs play a crucial role in prioritization. The capacity of a program to generate profit often determines its prioritization, with a preference for the most efficient or profitable programs for the organization.

4.2.2.1 Task dependency One of the complexities of task prioritization in manufacturing is that some functions can be performed concurrently and in any sequence, others follow a more rigid sequence defined by a "critical path." The critical path refers to the most extended sequence of dependent tasks that must be completed on time to avoid delays in the overall production schedule. This combination of flexibility and rigidity can create challenges in understanding the rationale behind prioritizing one task over another, as the impact on the overall production process may not always be immediately apparent.

> While we may have an obvious critical path, many tasks can be performed concurrently and in any sequence. This creates difficulty in understanding the rationale behind prioritizing one task over another.

Participants highlighted the complexity of prioritization decisions in the manufacturing process. A typical scenario is where two activities must be completed by a specific deadline, one for the final assembly line and the other for outstanding work. Participants stated that the final assembly line would always take precedence in this case. This decision reflects the importance of maintaining the integrity and efficiency of the primary production process, even if it means deprioritizing other tasks or activities.

> If two activities need to be completed by 6:00 PM, one for the final assembly line and the other for outstanding work, the final assembly line would always take precedence. So, I guess there are also issues of task interdependencies. So, for example, one task can only start if another task has been completed.

Moreover, participants reported the need to identify the tasks that should be completed first, which requires a clear understanding of the overall production goals, deadlines, and dependencies. It may sometimes be more advantageous to take on a task that was initially assigned to another colleague but has yet to begin. This suggests that leaders should be flexible and adaptable in their approach to task allocation, considering not only the predefined assignments but also the real-time status and urgency of different tasks.

> I have to identify the tasks that need to be completed first and consider whether it might be more

> advantageous to undertake a task assigned to another colleague that has yet to begin.

A participant introduced the concept of a "pulse line," a type of assembly line commonly used in aircraft manufacturing. In a pulse line, production is divided into a series of workstations, ten in this case, where each station must progress in a synchronized manner to maintain the flow of assembly. The line moves at set intervals, such as every three days, with all stations advancing simultaneously. If, for instance, on the second day, certain tasks at one or more stations are not progressing as expected, those tasks must be prioritized to prevent bottlenecks. Failure to synchronize progress across stations could disrupt the entire pulse line, causing delays in the production schedule.

> For prioritization, the key point here is that we normally work with assembly lines called a pulse line. So, imagine you have ten different stations, and these ten different stations should move simultaneously, synchronized. So, if you move every three days, for example, and on the second day, you see that some phases at some of the stations are not burning the same percentage of work that they should be, you prioritize this phase not to create a bottleneck for the other stations.

This highlights the critical role of real-time monitoring and adaptive prioritization in ensuring the smooth flow of work and minimizing delays or disruptions.

4.2.2.2 Task criticality The interviews showed that when deciding between tasks of equal importance, participants prioritize based on the potential for errors. Task criticality involves assessing potential error rates of functions within the manufacturing process to determine prioritization, focusing mainly on tasks with a higher risk of mistakes or safety issues and deprioritizing tasks where delays would have minimal impact on overall outcomes or employees' safety.

> However, if the tasks are equivalent in terms of the activities they unlock, the deciding factor might be which task is more prone to errors. In such cases, I would prioritize the task with a higher risk of mistakes. So, I would lean towards managing safety risks without direct task dependencies.

This prioritization strategy is particularly relevant in scenarios where tasks are not interdependent. Additionally, postponing a task does not significantly impact the overall results or customer satisfaction, and if the risk of errors is minimal, such tasks can be deferred. This approach underscores a strategic prioritization that balances error minimization with the practicalities of scheduling and task dependencies.

> If delaying one task doesn't significantly impact the results and can be completed later, that is okay. If it affects the customer or the risk of errors is minimal compared to the other task, we prioritize the other task.

4.2.2.3 Revenue potential As in most manufacturing companies, in aerospace manufacturing, prioritization is significantly influenced by the financial aspects of different production programs. Participants highlighted that decisions often revolve around economic efficiency and revenue. Some programs, noted for their revenue generation, usually receive prioritization in resource allocation and scheduling decisions. The focus on costs as a crucial factor in task prioritization reflects a deeply strategic aspect of aerospace manufacturing. It is not just about meeting deadlines and maintaining quality but also ensuring that the operation's financial health is considered, aligning operational activities with the economic realities of the industry. It underscores the comprehensive management strategy of planners and schedulers, where financial awareness plays a crucial role.

> Another factor [for prioritization] is related to money. We have different programs here: the A320, the A330, etc. The A320 program is the most efficient one here. This is where we generate the most revenue.

Additionally, costs are critical in daily operational planning and the strategic development of new baseline plans, where budget constraints are balanced against inventory needs. This statement emphasizes a financial-driven strategy in P&S to optimize profitability and resource utilization.

> Decisions are made by considering these costs, resembling a daily or tactical plan. Moreover, costs are considered alongside the inventory when creating a new baseline plan.

4.2.3 Need to manage contingencies

Most interviewees highlight the importance of managing contingencies and the potential impact of unexpected disruptions on the aerospace manufacturing process.

4.2.3.1 Machinery availability A significant one is the availability of machinery. Equipment malfunctions or misplacements often cause slowdowns in operational work processes. This suggests that the smooth workflow in the manufacturing process heavily depends on critical machinery and equipment's reliability and proper functioning. For example, a misplaced bracket or crane in the wrong location can cascade the production process.

> The machine needs a crane to move it, and for instance, we discovered that overnight, someone had not cleared some brackets, and the crane was in the wrong place.

One of the interviewees mentioned maintenance problems with equipment or instruments as a common waste time source. Their comments highlight that the reliability and proper functioning of production assets are critical for meeting the demanding time requirements of the final assembly process.

> We encounter issues in the final assembly line where the time constraint is severe. Sometimes, we waste time due to maintenance problems with the equipment or instruments.

Participants illustrated the potential impact of supply chain disruptions on the manufacturing process. One interviewee described a scenario where a missing aircraft part from a supplier could halt production at a specific station. This underscores the critical importance of effective supply chain management and the need for contingency plans to mitigate the risk of part shortages or delivery delays.

> Sometimes the supplier doesn't deliver a [aircraft] part, halting production at a specific station. The point is that every production plan has a critical path. If an item on this critical path is missing, you cannot proceed with anything else.

From a human factors perspective, the challenges described in the extracts highlight the cognitive and emotional demands of manufacturing team leaders and workers in managing contingencies and adapting to unexpected disruptions. Dealing with equipment malfunctions, misplacements, or supply chain issues requires high situational awareness, problem-solving skills, and the ability to make rapid decisions under pressure.

4.2.3.2 Time limitations Time limitations further exacerbate operational pressures, requiring strict adherence to production schedules and cycle times. Any delay or wasted time in the assembly line can significantly affect the production schedule. Another example relates to the concept of "cycle time," which is the maximum time allowed to produce one product unit on a specific production line. The team must complete all the necessary tasks and processes to make one product within that timeframe. This directly impacts the overall production rate and the ability to meet customer demands.

> The production rate is associated with cycle time, which is sometimes minimal. For instance, we may decide that on Line C, we must produce one product every six hours, which defines our cycle time, to which we must adhere.

From a human factors point of view, the challenges described in the extracts place significant time pressure and cognitive demands on manufacturing team leaders and workers. Meeting strict cycle times requires high coordination, efficiency, and attention to detail, as even minor delays or errors can quickly accumulate and put the entire production schedule at risk. The pressure to work swiftly and accurately can also contribute to increased stress, fatigue, and the risk of human error, potentially compromising the quality and safety of the manufacturing process.

4.2.3.3 Quality issues Quality issues significantly cause delays and changes in the production process. These issues can arise from various sources, such as operator errors, system failures, or machine breakdowns. Ensuring consistent quality throughout the manufacturing process is a complex and multifaceted challenge that requires attention to both human and technical factors.

> A major cause of delay and changes is related to quality issues. This could be due to various reasons, such as the operator, the system, or a machine breakdown. Any lapse in quality creates extra work compared to the original plan.

When a product or component fails to meet the required quality standards, it must be actively addressed and corrected, often through time-consuming and labor-intensive processes.

> Non-quality issues may occur that require additional effort for rework or repair.

Quality issues can also manifest in the assembly line, such as a nonconformity that may require stopping the production process and reacting with extra, unplanned work. Quality problems are disruptive and can derail even the most carefully planned production schedules.

> A cause is related to quality problems. In this case, sometimes there is a nonconformity in the assembly line, and perhaps it is necessary to stop and react or do extra work that was not planned.

4.2.3.4 Human performance variability Human performance variability, including miscommunication and planning mistakes, contributes to operational delays. Human errors at the individual task level can have cascading effects on the more extensive manufacturing process. Operators start a task, and in case of human failures in evaluation or judgment, they need to wait for further instructions on how to proceed.

> Someone has started a task but then made a mistake, and now he must wait for instructions on what to do next in that specific work.

This highlights the need for clear, standardized work instructions and protocols to guide operators in correctly executing tasks and the importance of real-time support and problem-solving when errors or deviations occur.

Breakdowns in information sharing between different teams or departments can lead to conflicting demands and resource allocation issues. Without clear and timely communication about the status and location of critical resources, such as aircraft sections, teams may inadvertently work at cross-purposes, leading to delays, confusion, and wasted effort.

> Typically, due to human errors in tactical planning, different hangars end up requiring the same section because of a lack of communication. They forget that the section is still in one hangar. Even if we had the capacity, delivery wouldn't be possible because the work on it hasn't been completed, preventing us from moving it to the next hangar.

The challenges underscore the complex interplay of cognitive, social, and organizational factors that can contribute to communication breakdowns and errors in the manufacturing process. This can be particularly challenging in large, distributed organizations where team members may have different backgrounds, expertise, and working methods.

4.2.3.5 Weather conditions Many operations in aerospace manufacturing need to be carried out outside buildings, and weather conditions emerge as a distinct cause of changes and delays. The vulnerability of certain manufacturing activities to external environmental factors is largely beyond the organization's control. For instance, winter operations necessitate strategic adjustments due to temperature-sensitive tasks. Specific tasks or processes in the final assembly stage are highly dependent on maintaining particular temperature ranges, and exposure to cold outdoor temperatures could compromise the quality or integrity of the work.

> During winter, on the final assembly lines, we need to coordinate activities with the closing times of the gates due to tasks sensitive to temperature. Opening the gates is not permitted at these times, an additional factor we must consider because it leads to plan changes.

Among other environmental conditions affecting the P&S operations, wind can also directly impact the manufacturing process. Specifically, high wind speeds can halt the transport of tall components, leading to delays in the assembly schedule.

> Weather is an issue. For instance, last week, we encountered significant issues with wind. The sections, as well as the VTP (Vertical Tail Plane) and similar components, being quite tall, are especially susceptible to wind. So, when the wind strength reaches a certain kilometer range, transporting these parts becomes impossible, and the product assembly is delayed.

5 Discussion

This study explored P&S processes in the aerospace manufacturing industry, revealing distinct roles and emerging needs of professionals engaged in these processes. The findings highlight the critical interaction between human factors and operational needs, contributing new insights to the existing literature.

Our results extend the understanding of key roles within aerospace manufacturing P&S, aligning with previous research emphasizing human intuition and adaptability in managing unforeseen challenges (Sanderson 1989; Nakamura and Salvendy 1994).

Our examination of the roles and key tasks of Planners and Schedulers, IT/software engineers, and Operations team leaders demonstrates the evolving nature of these responsibilities in response to technological advancements and operational complexities. For instance, the strategic oversight provided by Planners and Schedulers over extended planning periods requires a capacity for foresight and adaptability, mirroring the critical human skills identified in McKay's (1995) research. The role of IT/software engineers has become increasingly integral in maintaining and integrating advanced P&S tools, reflecting the sector's growing reliance on technology to enhance process optimization. This finding extends the work of McKay by illustrating the modern shift towards technological solutions in P&S processes. Additionally, operations team leaders are crucial in real-time task assignment and resource management, bridging the gap between strategic planning and operational execution. This underscores the necessity for robust leadership skills, aligning with the emphasis on human factors in effective resource management (Othman et al. 2012).

Emerging workforce and customer management needs, task prioritization, and contingency handling were prominent themes in our findings. Effective human resource management was highlighted as essential to meet escalating production demands, with participants describing scenarios where sudden shifts in production schedules or unexpected employee absences required swift task reallocation. This need for flexibility and adaptability in workforce management aligns with Othman et al.'s (2012) emphasis on considering human factors such as skills, training, and fatigue in workforce scheduling.

Task prioritization emerged as a complex but vital process, with participants emphasizing the need to prioritize based on task dependencies, criticality, and revenue potential. This finding extends the existing literature by linking prioritization strategies directly with operational efficiency and financial outcomes in aerospace manufacturing. The necessity to prioritize tasks effectively to maintain production flow and meet critical deadlines underscores the logistical and strategic complexities inherent in contemporary aerospace manufacturing contexts.

Contingency management also surfaced as a crucial aspect, particularly in dealing with machinery availability and quality issues. Participants noted that unexpected machinery breakdowns or lapses in quality could significantly disrupt production timelines, necessitating robust contingency plans and flexible scheduling systems capable of real-time adjustments. This finding supports the work of Azami et al. (2018) and highlights the need for systems that can adapt to unforeseen disruptions, integrating human decision-making skills with technological tools.

The interaction between human factors and technological tools in P&S processes emerged as a critical area, suggesting the need for systems that support human adaptability and technological efficiency. For instance, the ability to manage contingencies, prioritize tasks, and handle workforce and customer demand highlights the multifaceted challenges faced by professionals in this field, suggesting the potential of integrating Artificial Intelligence or predictive analytics technologies to support these processes. As Hueber et al. (2019) suggested, these tools can assist in task prioritization and help planners anticipate delays, enabling proactive adjustments to production schedules. By facilitating synchronization across various stages of production, advanced data-driven technologies can help planners and schedulers manage the complexities of aerospace manufacturing, minimizing the risk of bottlenecks and enhancing overall efficiency.

This study contributes uniquely to the literature by providing empirical data on the specific roles and needs within aerospace manufacturing P&S, an area previously underexplored. It also offers actionable implications for practitioners. Insights into task prioritization and workforce flexibility highlight the need for training programs to enhance decision-making under pressure and improve adaptability in dynamic production environments. Additionally, the emphasis on contingency handling highlights the need for P&S software that allows for real-time adjustments and the integration of human input to adapt to disruptions effectively. Practitioners can use these insights to refine workflow management strategies, ensuring that leadership roles emphasize human oversight and technological collaboration to maintain operational efficiency.

While this study offers valuable insights, it has limitations. The research was focused on a specific segment of the aerospace manufacturing industry, which may limit the generalizability of the findings to other sectors with different operational dynamics. Moreover, the sample size of fifteen participants, drawn from a limited geographical area, may introduce potential geographical bias, as the perspectives might not fully represent the global aerospace industry. As a result, the reliance on qualitative data from this sample may not capture the full spectrum of experiences across the broader industry, suggesting the need for further research to extend these findings.

Future research should explore these factors further, expanding data collection to other high-risk production contexts and investigating the challenges of implementing AI-driven P&S tools in high-risk manufacturing environments. Understanding the long-term impact of integrating human factors into P&S systems will provide deeper insights into enhancing operational performance and workforce satisfaction.

6 Conclusion

This study on the P&S processes within aerospace manufacturing has provided insights into the critical roles and emerging needs necessary for the industry's advancement. By examining human factors, key job roles, and workforce operational needs, it becomes clear that integrating adaptable P&S tools is essential in the aerospace manufacturing sector. The findings suggest that advanced P&S systems should prioritize human-centered design principles to ensure these tools are intuitive and align seamlessly with the users' workflow. Systems must support the cognitive processes of planners and schedulers by providing real-time data and analytics that facilitate informed decision-making. Incorporating user feedback during the design phase can enhance both the usability and acceptance of these systems.

Moreover, the integration of human factors is crucial. The systems should be designed to accommodate human variability and adaptability, vital for improving overall efficiency and reducing errors. Moreover, incorporating advanced analytical models and predictive analytics into P&S systems can significantly enhance their ability to anticipate potential delays and bottlenecks. These tools provide planners and schedulers with insights into optimal resource allocation and scheduling adjustments, enabling proactive management of production schedules. The capability to manage contingencies, such as machinery availability and quality issues, underscores the need for flexible and adaptive systems. These systems must be capable of real-time adjustments, allowing for swift reallocation of resources and schedule modifications in response to unforeseen disruptions.

The study also highlights the importance of enhancing collaboration and communication among different roles, such as planners, schedulers, IT/software engineers, and operations team leaders. P&S systems should include features that facilitate seamless information sharing and coordination among team members, ensuring alignment with production goals and timelines. Integrating cutting-edge technology and human insights is critical to developing P&S solutions that are both effective and supportive of sustainable industrial practices. By aligning closely with worker needs and industry challenges, advanced P&S systems can help aerospace manufacturers make more informed decisions, improve operational efficiency, and maintain high quality and safety standards.

As the era of Industry 5.0 approaches, it is evident that aerospace manufacturing is rapidly evolving. Developing advanced human-centered P&S systems will help aerospace manufacturers navigate future challenges and remain at the forefront of industrial innovation. Combining technology and human-centric strategies ensures that the sector can adapt to changing demands while fostering environments that support innovation and workforce well-being.

Author contributions L.P, S.M., and F.F. wrote the main manuscript text. M.H. and S.Q. contributed to the design and the implementation of the study. All authors reviewed the manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Competing interests The authors declare no competing interests.

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