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Using Concept of Operations to Design Human-Centric Manufacturing Systems for Novel Products—A Comprehensive Prescriptive Case Study

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ABSTRACT

Efficient production systems are necessary for the realization of products that fulfill customer needs and delivery requirements. However, the process of designing the production system has received little academic attention, and today's manufacturing system design processes and architecture are still based on traditional engineering methods. This paper covers a case study using the systems engineering method Concept of Operations and Operational Concept for the design of a human-centric production system for a novel product. A comprehensive prescriptive study was designed, combined with attempts to verify the methods used. The case study applies design methods defined in ISO/IEC/IEEE 15288. A total of six workshops, the development of Concepts of Operations, three levels of Operational Concept, and two validation studies are documented. A total of 166 persons participated, and up to 15 persons participated in the validation workshops. The analysis shows that the design methods addressed gaps identified in literature: (1) the lack of systematic and effective systems engineering design methods in production system design, and (2) the lack of inclusion of human aspects in the production system design. The gaps in the effectiveness of the methods remain to be fully evaluated as the project is still running and will not be concluded until 2025. Recommendations for future work include exploring how ConOps/OpsCon method can be more widely spread and adopted by engineering as a significant artifact for systems understanding for the design of more human-centric, resilient production systems.

1 | Introduction

Efficient production systems are necessary for the realization of products that fulfill customer needs and delivery requirements [1, 2]. Bellgran continues: "Designing a production system is a unique and complex task in which many parameters should be taken into account during the process of creating, evaluating and selecting the proper alternative." The importance of design, in particular as an industrial activity and the increasingly complex and dynamic context in which it takes place, has led to the desire to improve the effectiveness and efficiency of design practice [3]. This also applies to the design of production systems. However, the process of designing the production system has received little academic attention, ignoring its potential for gaining a competitive edge [1, 4].

Islam et al. state that "there is still a lack of empirical studies on how to conduct a production system design that targets the operational performance objectives already during the design phase, considering this a research gap" [5]. Vielhaber and Stoffels identified that in academia, there is a greater focus on product development than on production development. In particular, methodologies and process models dedicated to

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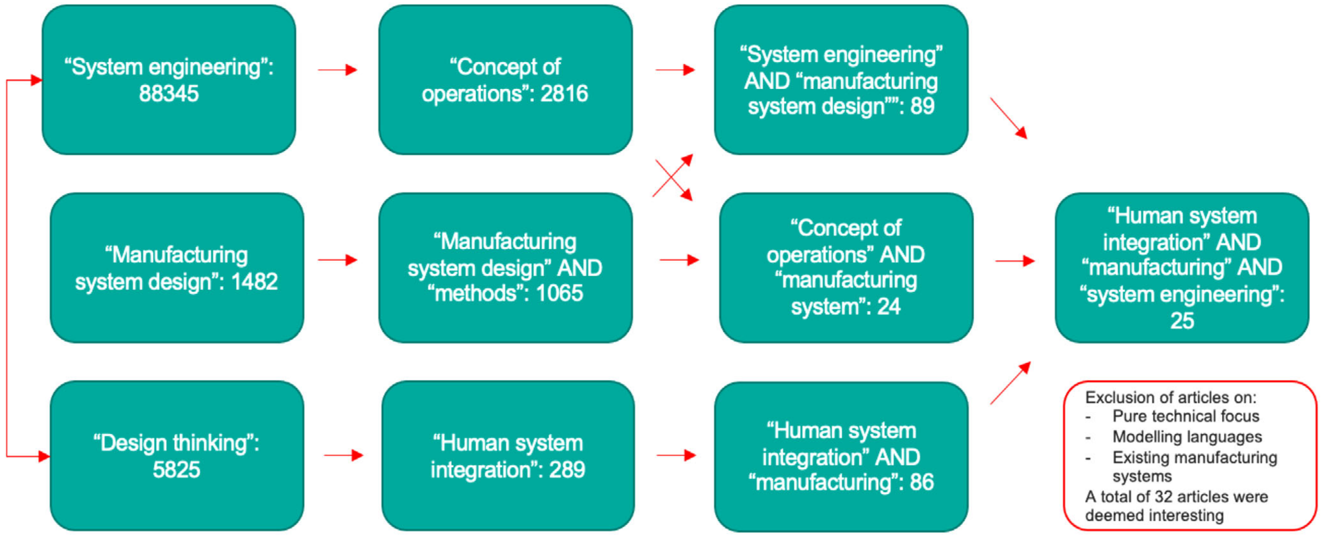

FIGURE 1 | Search strings for literature review with a summary of the number of records in the results and a summary of how the 32 relevant articles were identified.

production equipment have lower scientific coverage than their product-oriented counterparts [6].

Product development methods have been explored and adapted over many years. Within the systems engineering (as well as the engineering design) community, several methods have been developed to reduce complexity and manage risk from engineering institutions such as NASA [7] and INCOSE [8] as well as key researchers in the field [9]. However, these methods have not yet been fully adopted by the manufacturing engineering community [10]. Stark et al. [11] state: "Today's manufacturing system design processes and architecture are still based on traditional engineering methods and can hardly cope with increased system complexity." Stark et al. continue: "In reality, the manufacturing system design barely even follows a systematic design approach; it is still common practice to let each design engineer work within his or her own discipline by using specific design and engineering models (…) without any true systems engineering design opportunity."

Several researchers have addressed the need to extend the focus of the design of industrial systems to the whole sociotechnical system (e.g., [12–18]). They claim that human actors are often greatly simplified in model-based design, thus disregarding individual personality and skill profiles. In complex systems, humans are often part of the complex system as opposed to being just users of the system, and current systems engineering practices tend to address human considerations as an afterthought [16]. The objective of human-centered model-based systems engineering is to incorporate human actions in multiple viewpoints [16].

This paper covers a case study using the systems engineering method Concept of Operations and Operational Concept for the design of a human-centric production system for a novel product. The research questions are formulated as follows:

RQ1: How can the systems engineering methods of Concept of Operations and Operational Concept be used to design human-centric manufacturing systems for novel products?

RQ2: What can be learnt by applying Concept of Operations and Operational Concept in the design of human-centric manufacturing systems for novel products?

2 | Frame of Reference

A literature study to understand the current state of application of ConOps and human-centricity in manufacturing systems design was performed during the research process. The method of reviewing the literature varied throughout the process. Three databases were used: Scopus, Web of Science, and Access Science, complemented by Google Scholar. The keywords were combined into search strings with Boolean operators, along with a summary of the number of records produced by each search string, with results limited to peer-reviewed full text and the scope of the years 2015–2023. Snowballing was used in several instances. The search was limited to the title, abstract, and keywords of the records, and a selection of 32 articles was considered relevant. Since the same search strings were used in more than one database, duplicates occurred in the searches in the different databases. Where the titles were relevant, the abstract and keywords were read and added to the list of papers to be read in full. The main criterion for exclusion and inclusion was a connection to the manufacturing industry or engineering. Articles focusing on pure technology, modeling languages, and existing manufacturing systems were excluded. In addition, only published articles, conference papers, books, and book chapters were included, and another criterion was a clear link to the research questions. An important note is that the latter criterion involves a risk of bias in terms of subjectivity, as it relies on the researcher's interpretation of whether or not a paper is connected to the research question. Twenty-five papers were considered relevant and of sufficient quality for further analysis. The keywords are described in Figure 1 below.

2.1 | Design of Production Systems

The production system design requires a holistic perspective where the sub-parts of the system with their internal relations

TABLE 1 | Overview of established approaches and methodologies within the domain of production system development, based on Stoffels et al. [22].

	Specification	Concept development	Component development	System integration
Eversheim (2002), Minolla (1975)		Workflow planning	Work system planning/ production resource design	
REFA (1990)	Preliminary planning	Rough planning	Detail planning	
Wu (1994)	Analysis of situation	Concept development	Design	
Spur (1994)		Production system planning	Production system design	
Suh (1995)	Definition of requirements	Concept development	Decomposition of concept	
Gu et al. (2001)	Definition of requirements	Concept and configuration development	Detailed design	Design evaluation
VDI4499 (2008)		Concept development	Component design	Virtual commissioning
Bellgran and Säfsten (2010)	Preparation/analysis	Concept development	Detailing	

contribute to realizing the transformation. Facilities, people and equipment (e.g., machines), software, and procedures are considered to be elements of the production system, which all have relations to each other [19]. Whereas engineering design is traditionally seen from a physical product perspective, Pahl and Beitz [20] state that "design tasks related to production machines, jigs and fixtures and inspections equipment (…) fulfilling the functional requirements and technological constraints are equally important." They also mention the importance of a systematic methodology being in place to ensure designers reach potential solutions quickly and directly, and for design methodology to foster and guide the abilities of designers, encourage creativity, and at the same time focus on the need for objective evaluation of results. The development of a production system follows the product development steps [21] with the main methods and authors described in Table 1.

2.2 | Concept of Operations

The terms ConOps and OpsCon are used in slightly different ways in literature, sometimes interchangeably. For the purposes of this study, ConOps refers to the intended function of the enterprise, and OpsCon describes how the system works from the operator's perspective. These two artifacts stem from ISO/IEC/IEEE 15288 [23], which includes 14 technical processes; the role of the first four is described in Figure 2.

The ConOps/OpsCon method was introduced by Fairley and Thayer [24] as a bridge from operational requirements to technical specifications. The key task in the development of a ConOps/OpsCon is the allocation of functions and stakeholder requirements to elements of the proposed system on a high level. ConOps/OpsCon documents have been developed in many domains, such as the military, health care, traffic control, space exploration, and financial services, as well as various industries such as nuclear power, pharmaceuticals, and medicine. The document is a user-oriented document that describes a system's operational characteristics from the end user's viewpoint. It is used to communicate overall quantitative and qualitative system characteristics among the main stakeholders. ConOps/OpsCon documents are typically based on textual descriptions, but they may include informal graphics that aim to portray the key features of the proposed system, for example, its objectives, operating processes, and main system elements. ConOps/OpsCon can be considered a transitional design artifact that plays a role in the requirements specification during the early stages of the design and involves various stakeholders [16, 25]. The authors rank the method as "a promising method and design tool that provides means to describe different actors and interdependencies between them. Compared to earlier methods based on modeling, it better supports both the dynamic nature of the overall system and co-design and development activities with relevant stakeholders."

During the ConOps/OpsCon development process, each actor can be described in more detail and can be used in co-designing activities when defining, for example, the operator role in a new system. As Mostashari et al. [26] describe the ideal ConOps development process, they highlight the importance of:

- Involve relevant stakeholders in all phases of the ConOps development process.
- To embed visualization within a ConOps development tool.
- To facilitate agility through the display of complex data and the ability to easily make modifications by large numbers of stakeholders with varying roles.
- Assist shared mental model formation throughout the development process by leveraging an integrated toolset that enables stakeholder participation.

When completed, the ConOps/OpsCon can be presented with different levels of detail, so that by zooming in and out of the hierarchy, different elements of the system come into focus, and

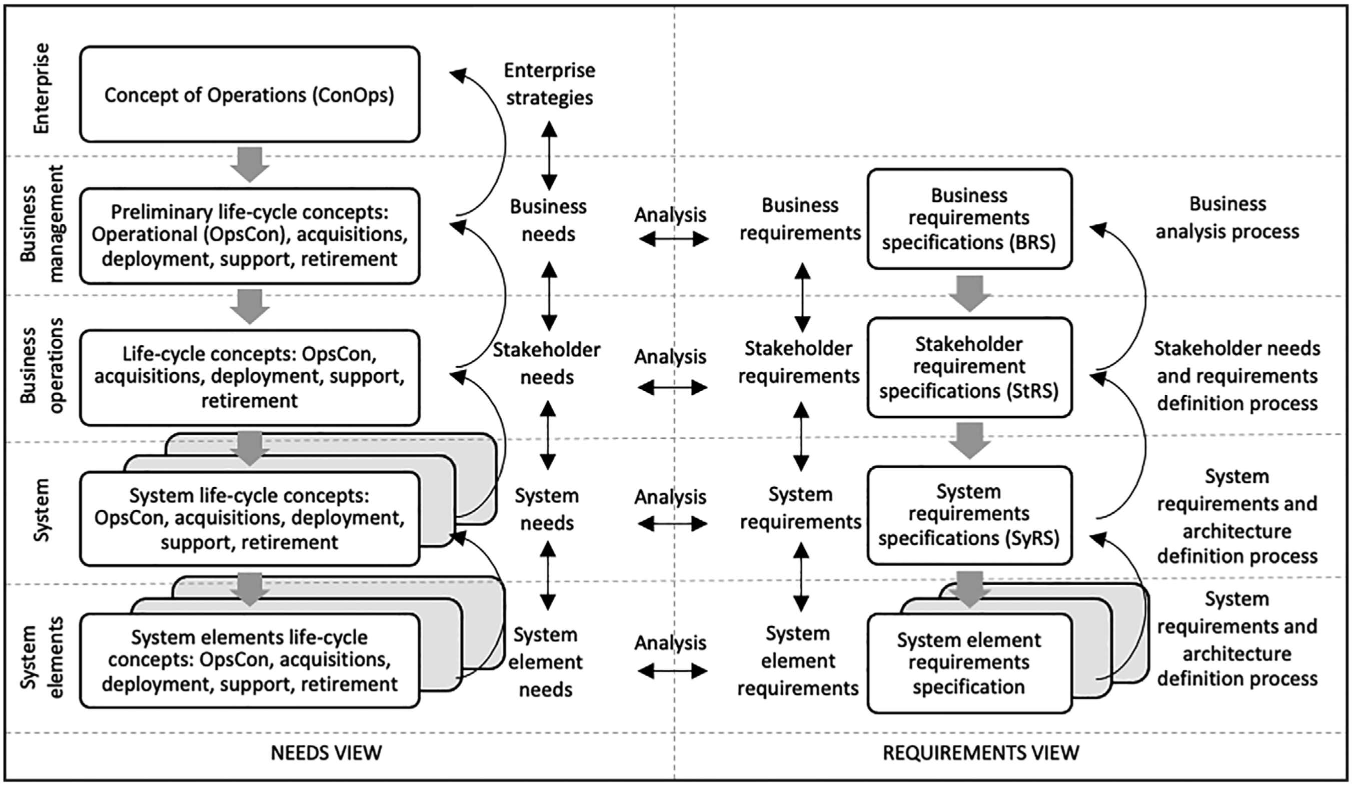

FIGURE 2 | Transformation of needs into requirements. Adapted from INCOSE Handbook [8].

FIGURE 3 | Summary of key ConOps/OpsCon characteristics.

is a boundary object promoting communication and knowledge sharing [25]. It is worth noting that some companies perceive the development of ConOps/OpsCon as demanding and resource-intensive [26]. A summary of key characteristics is shown in Figure 3.

2.3 | Human-Centric Industrial Systems Engineering

Several researchers have addressed the need to extend the focus of the design of industrial systems to the whole sociotechnical system (e.g., [12–18]). They claim that human actors are often greatly simplified in model-based design, thus disregarding individual personality and skill profiles. Jones et al. [27] identify the actors in Industry 5.0 manufacturing systems as human, organizational, and technology-based agents. In complex systems, humans are often part of the complex system as opposed to being just users of the system, and current systems engineering practices tend to address human considerations as an afterthought [16]. Madni et al. state the reasons as being a difference in terminology between the human factor engineering community and traditional engineering, as well as shortcomings in presenting the value proposition of human system integration (HSI). In the design of socio-technical systems, the technical, contextual, and human factors viewpoints should be considered [25]. Human factors engineering is a scientific approach to the application of knowledge regarding human factors to the design of complex technical systems and can typically be divided into four groups: analysis, design, assessment, and implementation/operation [25]. Kaasinen et al. state that one of the first tasks in the analysis step is to perform a Concept of Operations, a ConOps.

The objective of human-centered model-based systems engineering is to incorporate human actions in multiple viewpoints [16]. Madni et al. state that a limitation of current HSI modeling tools is that they are independent of the architecture process and the decision-making in the conceptual design of the system, and that no holistic approach for HSI exists. In today's systems engineering practice, the integration of humans into production systems is only pursued retrospectively, that is, after the architectures have already been specified and designed [15]. The authors continue: "Model-based development offers the potential to improve the integration of human needs into early system design." The human is the most important and unique element in a system, as well as the weakest link and potentially the highest risk [28], and should therefore be included and appropriately modeled [16]. The origin of human factors started in ergonomics but is now increasingly transitioning into systems engineering language [12]. The human-centered design describes concepts to include workers with different skills, ages, labor, and education in productions [15]. Due to new requirements within the Industry 5.0 scope, larger amounts of data and knowledge are required, which in turn results in new requirements, such as for more decision-making capabilities, more social interactions and a broader variety of skills [29].

HSI is "a technical and management process for integrating human considerations within and across all system elements; an essential enabler to systems engineering practice" [8]. NASA's HIS Practitioner's Guide defines HIS as "an interdisciplinary science, craft, and art to integrate humans, technical systems, and organisations into efficient, safe and user-friendly systems" [30]. According to Neumann and Dul [31], the careful consideration of the human being in the design can improve productivity, quality, and technology implementation and can have intangible benefits for operations while also improving worker well-being and working conditions. There is clearly a need to develop work allocation and teamwork in human-machine teams so that human workers feel they are in the loop and human jobs remain meaningful and manageable [25]. Workers' rights to varied and challenging work, good working conditions, learning opportunities, scope for decision-making, good training and supervision, and advancement opportunities are in line with the initial value system in sociotechnical design, even though technology and organizational structures might change in industry [32]. Neglecting human factors can lead to performance degradation because the human and machine components of the production systems are not coordinated effectively [15].

3 | Research Approach

To be able to answer the research questions, literature studies supported by prescriptive case studies were selected as a research approach. The case studies included both qualitative and quantitative research methods.

3.1 | The Case Company

The case company is a global actor in the transport solution industry with about 100,000 employees worldwide. Several brands are represented in the portfolio, as well as a variety of vehicles, from excavators to buses and trucks. The company was set up by several organizations, all of which interact on an operational level. The company has factories in 18 countries. In addition to its production sites, its global industrial operations include several product development centers and several part distribution and logistics centers. Furthermore, there are assembly plants operated by independent companies at 10 locations around the world.

The case study selected for this study is a project to set up a new production line for a new disruptive product using production processes previously unknown to the engineering departments. The author followed the production management part of a battery assembly industrial plant project for 18 months. The plan is to establish a battery cell production plant about 40 km from the battery assembly plant. The battery assembly plant is located within the compound of the already existing production facility of combustion engines, with the ability to take advantage of the vast and highly established industrial setup. The battery assembly plant will distribute the batteries to the truck plants in the industrial system of the case company. The industrial flow is described in Figure 4, with the focus of this study circled.

In June 2022, the initiative started up by holding sessions with the future production manager to gain understanding of the situation in the projects and the challenges going forward. The overarching assignment was to create a production plant producing a disruptive product that was not fully designed, using processes not known beforehand and with the aim to align to Industry 5.0 with the focus on human-centricity. Results from earlier projects had shown that the engineering focus was more equipment-oriented than production system-oriented. This issue was something that this project aimed to address. The challenges were identified and summarized as (a) creating a human-centric system, (b) establishing a management system for preparing, ramping up, and running production, and finally (c) setting up the digital and physical flow. The focus of this paper is on challenge (a); the other two challenges are described in additional papers by the authors.

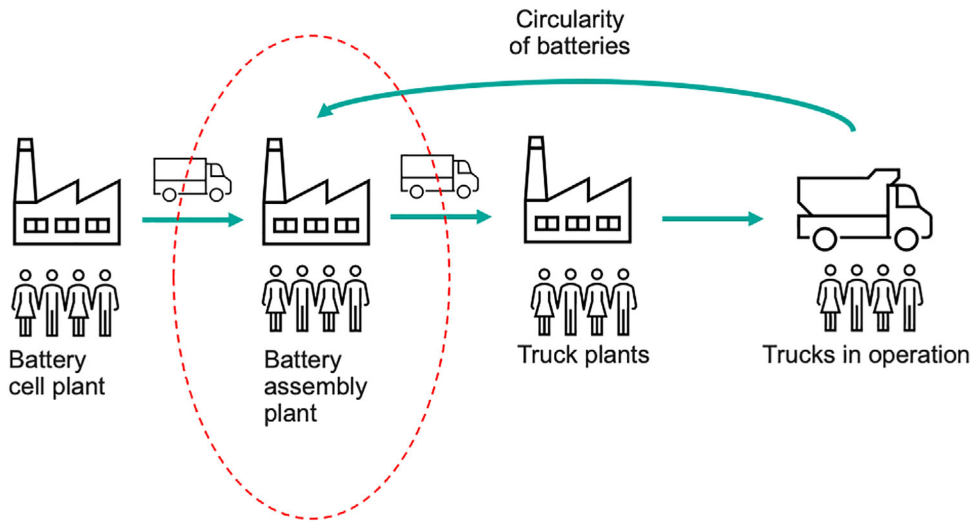

FIGURE 4 | The planned industrial flow in the battery production system project with the focus of this study circled.

TABLE 2 | Main steps in the comprehensive prescriptive study stage, from Blessing and Chakrabati [3].

Topic	Sub-topics
Task clarification	Results from earlier projects
	Reference model
	Literature on similar goals
	Intended impact model
Conceptualization	Functions of intended support
	Intended introduction plan
Elaboration	Existing literature on Intended support
	Intended support fully described
	Intended Impact Model finalized
Realization	Core functionalities of intended support
	Actual support developed
	Actual impact model
Support evaluation	Actual support evaluated and modified if necessary

3.2 | Comprehensive Prescriptive Study

To understand how the ConOps method can be used to design a human-centric production system for novel products, a comprehensive prescriptive study was designed combined with attempts to verify the methods used, as it results in support that is realized to such an extent that its core functionality can be evaluated. The design guidelines and methods applied were selected from design thinking and ConOps. The model used is based on the comprehensive prescriptive study process, described in Table 2.

The analysis method is based on the comprehensive predictive study logic on how to evaluate the success of the indented impact model. The analysis is developed from the hierarchy of Project goals → Engineering goals → Goals breakdown → Intended Impact Model. How well the design support corresponds to the Project goals, Engineering goals, and goals breakdown defines the success of the developed method.

3.3 | Workshop Design

Mostashari et al. [26] recommend that the ConOps development process design should:

- Involve relevant stakeholders in all phases of the ConOps development process.
- Embed visualization within a development tool to facilitate agility through the display of complex data and the ability to easily make modifications by large numbers of stakeholders with varying roles.
- Assist shared mental model formation throughout the development process by leveraging an integrated toolset that enables stakeholder participation.

From these recommendations, cross-functional workshops focusing on model visualization were selected as the research approach to use the Concept of Operations from a human-centric angle.

The workshops are described in terms of the number of participants, theme, organizations represented, organizational hierarchy, and the output from each workshop. Table 3 summarizes the output of each workshop. the number of participants, the theme of each workshop, organizations represented, and organizational hierarchy.

As the author has a managerial role at the case company, there is a risk of bias from the respondents. To start with, access to the project would not have been granted to an external researcher, so already from the start the researcher was embedded. To mitigate potential biases, half of the feedback data in the studies was collected anonymously through Menti.

TABLE 3 | Summary of workshops held with the number of participants, theme of each workshop, organizations represented, organizational hierarchy, and output from workshop.

Workshop #	Theme	Organizations represented	Organizational hierarchy	Output from workshop
1 (22 p)	Alignment reference group	Production, Logistics, Engineering, Logistics Engineering, Maintenance, Planning, IT	Sr leadership, middle management, project members	Co-created and shared visual models of alignment in requirements from the system
2 (44 p)	Empathizing with the people in the system	Production, Logistics, Engineering, Logistics engineering, Maintenance, Planning, IT, operators, maintenance technicians, circular operations	Sr leadership, middle management, project members, operators	Co-created and shared visual models of six personas identified with their requirements on the future system
3 (22 p)	Management aspects of preparing, ramping up and running production	Production, Logistics, Engineering, Logistics engineering, Maintenance, Planning, IT	Middle management, project members	Co-created and shared three descriptions on the most important aspects from management
4 (28 p)	Staff functions, humans in the system	Quality, engineering, maintenance, logistics	Middle management, project members	Co-created and shared five personas identified with their requirements on the future system
5 (38 p)	Digital and physical flow	Customers and suppliers in the end-to end flow, Production, Logistics, Engineering, Logistics Engineering, Maintenance, Planning, IT	Middle management, project members	Co-created and shared visual models of the main risks in the end-to-end digital and physical flow
6 (12 p)	Digital flow deep dive	Production, IT, Engineering	Middle management, operators	60 new demands from production to IT

4 | Results

The results from the comprehensive predictive study are presented below with a summary of the results in Section 4.7.

4.1 | Task Clarification

For this study, the project goal was limited to (a) creating a human-centric system. Proposals for methods going forward were presented, and ConOps was selected primarily as a recommendation from the researcher. From the project goals, the engineering goals, the goals breakdown, and the intended impact model were described at a high-level, as described in Figure 5.

4.2 | Conceptualization

The intended support description was generated from the task clarification documented in the intended impact model. The intended support description describes the support in terms of the need or problems addressed, the goals and objectives of the support, its elements, how it works, the underlying concepts, theory, assumptions, and rationale, and how it is to be realized. This was generated together with a reference group at the case company, through brainstorming. A workshop model was developed focusing on cross-functionality, requirements documentation, visualization, and common system understanding. The requirements development is further described in another paper [33]. From literature, ConOps and design thinking were studied and adopted. The intended support description is described in Table 4.

4.3 | Elaboration

The intended impact model and intended support description were iterated, and an Intended introduction plan was generated, consisting of six workshops with various actors invited as seen in Figure 6.

The workshops were designed to be 3–4 h long and with the format described in Figure 7.

The focus of the intended design support is to ensure how to get a satisfactory quality of input from all actors in the future system. Hence, the documentation and visualization of the models were to be performed by the researchers and experts.

4.4 | Realization

In the realization phase, the core functionalities of intended support, actual support, and actual impact model are elaborated

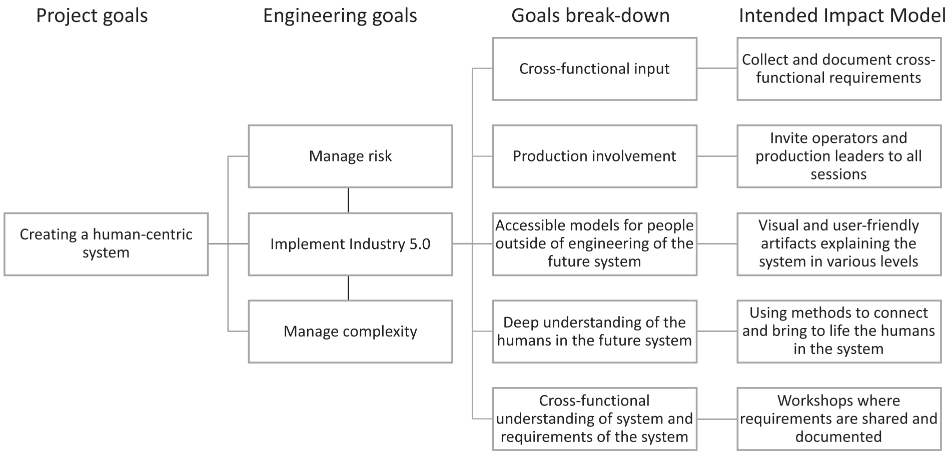

FIGURE 5 | Logic of development of intended impact model for the comprehensive predictive study.

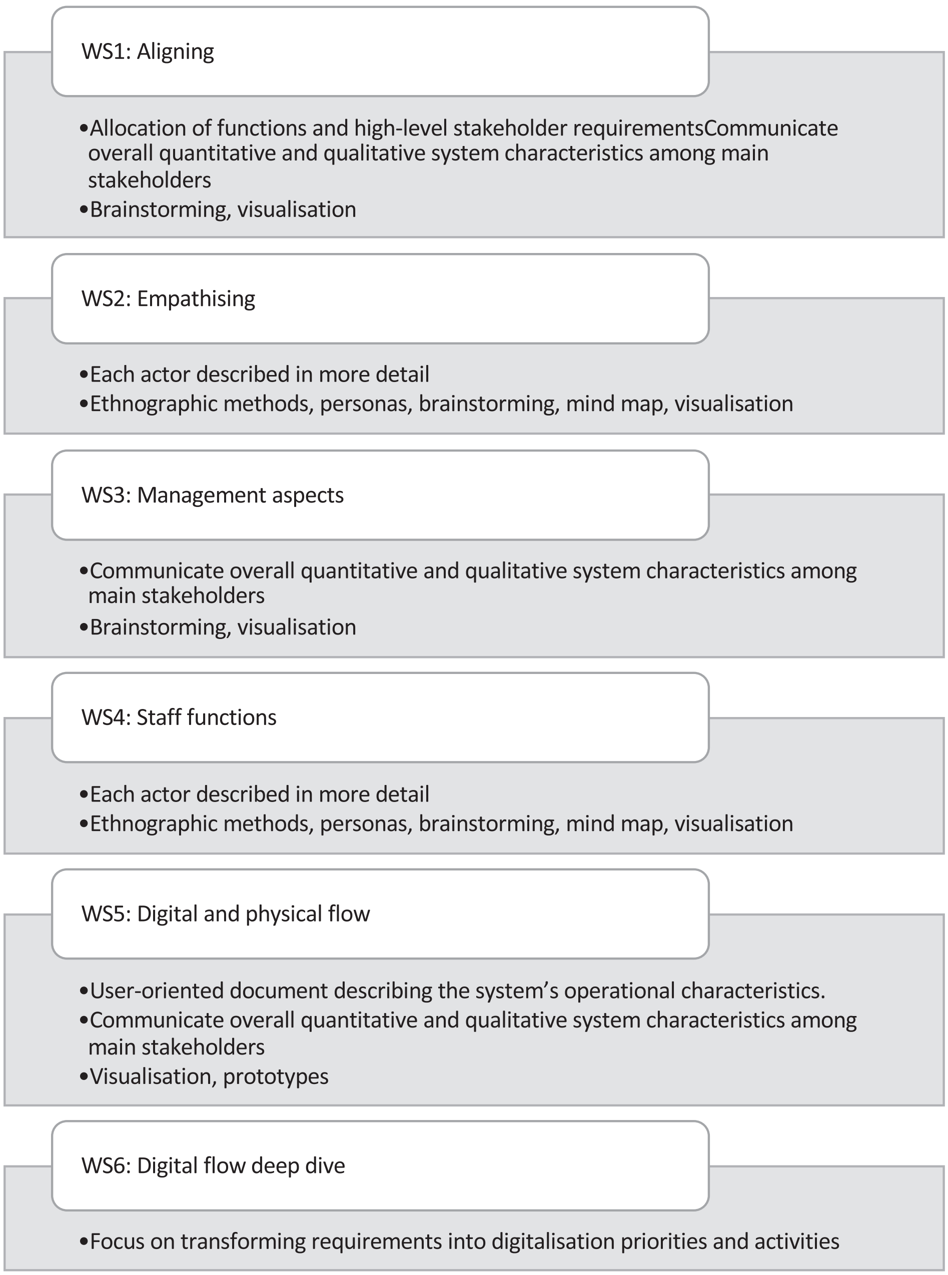

FIGURE 6 | Elaborated intended support description with intended implementation plan.

TABLE 4 | Intended support description.

Intended support components	Intended support description
Assumptions and rationale	Provide methods for engineering to develop a human-centric production system
Need or problems addressed	• Support to manage complexity • Support to manage risk • Support the implementation of Industry 5.0
Goals and objectives of the support	• Deep understanding of humans in the system • Aligned cross-functional understanding of the system
Its elements	• Workshop format • Persona guidelines • Participation list • Documenting methods • Documenting tools
How it works	• Cross-functional workshops • Production involvement • Documentation of requirements • Transformed into visual models in different levels
The underlying concepts	• Accessible visual system models for the entire organization • Bring the humans in the future system to life
Theory	• System engineering • Production system development • ConOps • Design thinking
How it is to be realized	• Management commitment • Training sessions on theory and underlying concepts • Access to modeling experts • Follow-up

on. The input from the developed workshop framework was used to develop and refine the ConOps and OpsCon with different levels of abstraction. The ConOps is used to get a shared picture in the entire organization of how the business will operate. The ConOps is described below, with Figure 8 describing the enterprise-level end-to-end flow for the entire system, including the circular flow.

Figure 9 visualizes the system from a production facility perspective.

To describe the OpsCon Level 1, simulation expertise and software were used to model the flow to run simulations. This method is used to identify bottlenecks but is also a powerful way to visualize the system for the organization to gain understanding of the production pace, and hence where potential problems can occur. Figure 10 describes OpsCon Level 1.

To describe OpsCon Level 2, 3D experts were used to build a virtual film from the digital twin of the plant. The purpose of this is, again, to make the future more present and real for the people acting in the system, and also to identify risks from a layout perspective. For confidentiality reasons, only a selection of screenshots is displayed in Figure 11.

4.5 | Support Evaluation

To confirm that the ConOps/OpsCon development was verified as relevant for engineering practices, data was collected at the end of two workshops to validate the actual impact model from the engineering goals as described in Figure 5. The data from session one was collected and documented, and testimonial sessions were documented by the researcher from session two.

Written Feedback Based on Questions 1–3 Below:

Of 20 participants, 15 gave their response, a response rate of 75%. The questions were:

1. Does this approach help to manage complexity? If so, in what way?
2. Does this approach help to manage risks? If so, in what way?
3. Does this approach support the implementation of Industry 5.0? If so, in what way?

All respondents responded Yes to the three questions, except one who stated that it was not clear if the methods help to manage complexity. The statement to this response was, *"Perhaps it is not detailed enough to just have workshops of this brainstorming characteristics."* Statements from question 1, regarding complexity management, touched on several aspects that reflect the ambition of systems engineering and design thinking: *"A very good way to document things we only talked about before," "(…) is a way to make the person in the system more real," "This way makes it easier to understand," "The collaboration and brainstorming in the workshops makes us build our reasoning and makes the whole system better," "I feel that I can influence the system and my future."* Statements from the respondents for 2, regarding risk management, were: *"This method helps us to identify risks early," "This helps us understand the overarching ideas to be used in our production preparation," "This helps us understand the overarching ideas to be used in our production preparation," "I learned things I didn't consider before," "With better methods like this, better collaboration and focus on flow we can minimise the risks," "Great to work cross-functionally like this," "With this way we can develop more precisely our concepts," "Great to mix competences and aspects," "Collects and simplifies demands, as well as makes them more concrete."*

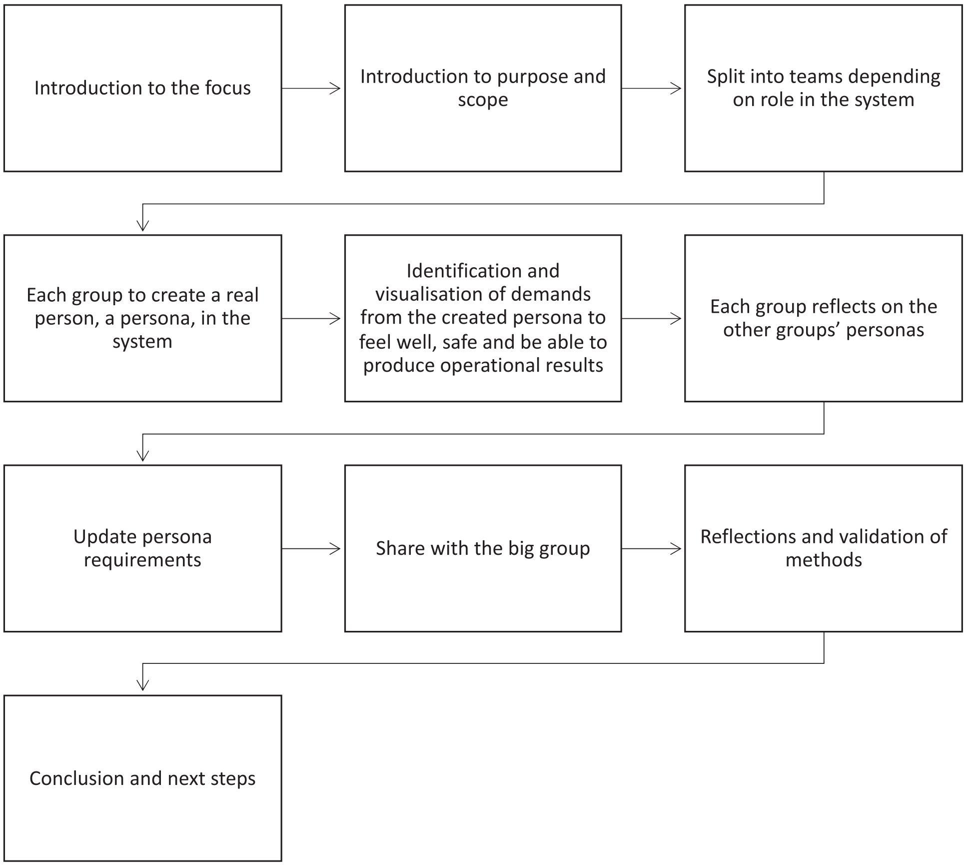

FIGURE 7 | Workshop design for the six workshops.

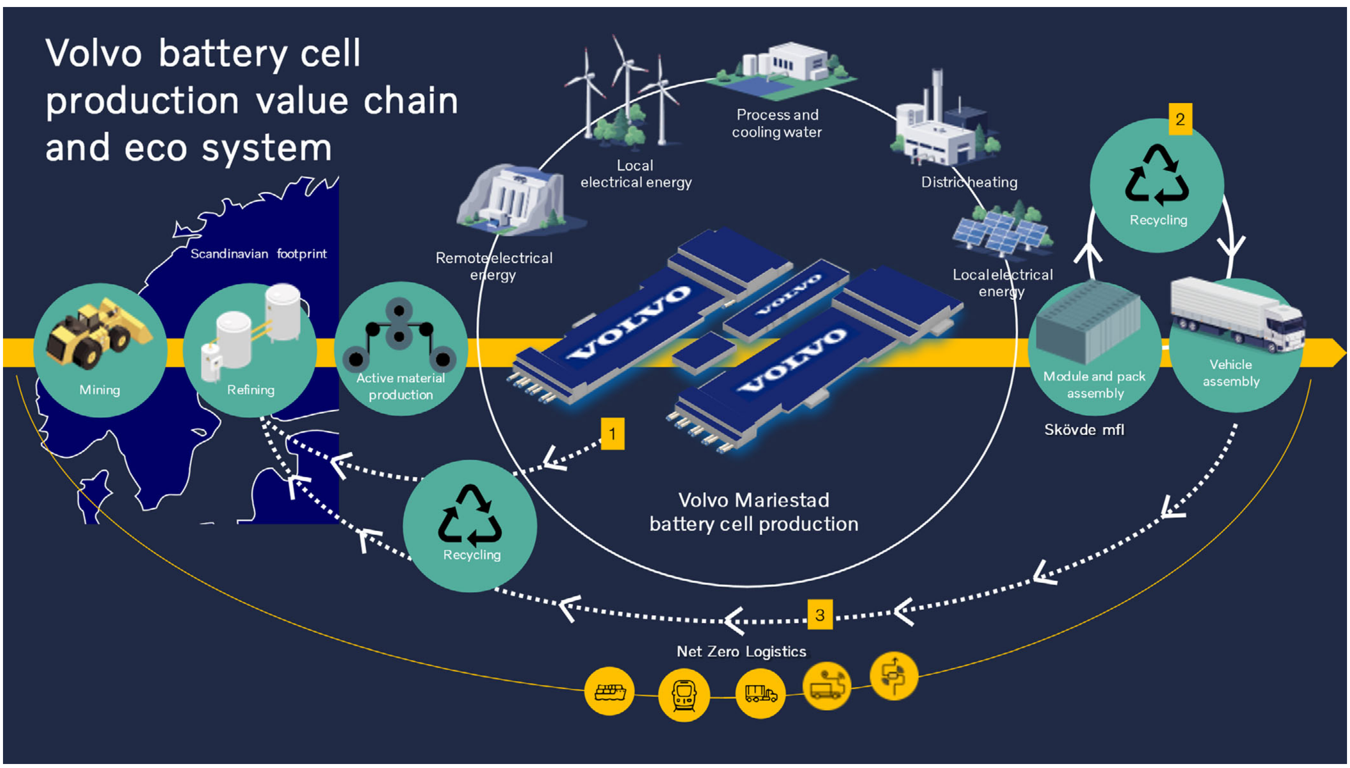

FIGURE 8 | ConOps enterprise level end-to-end flow for the entire system, including circular flow.

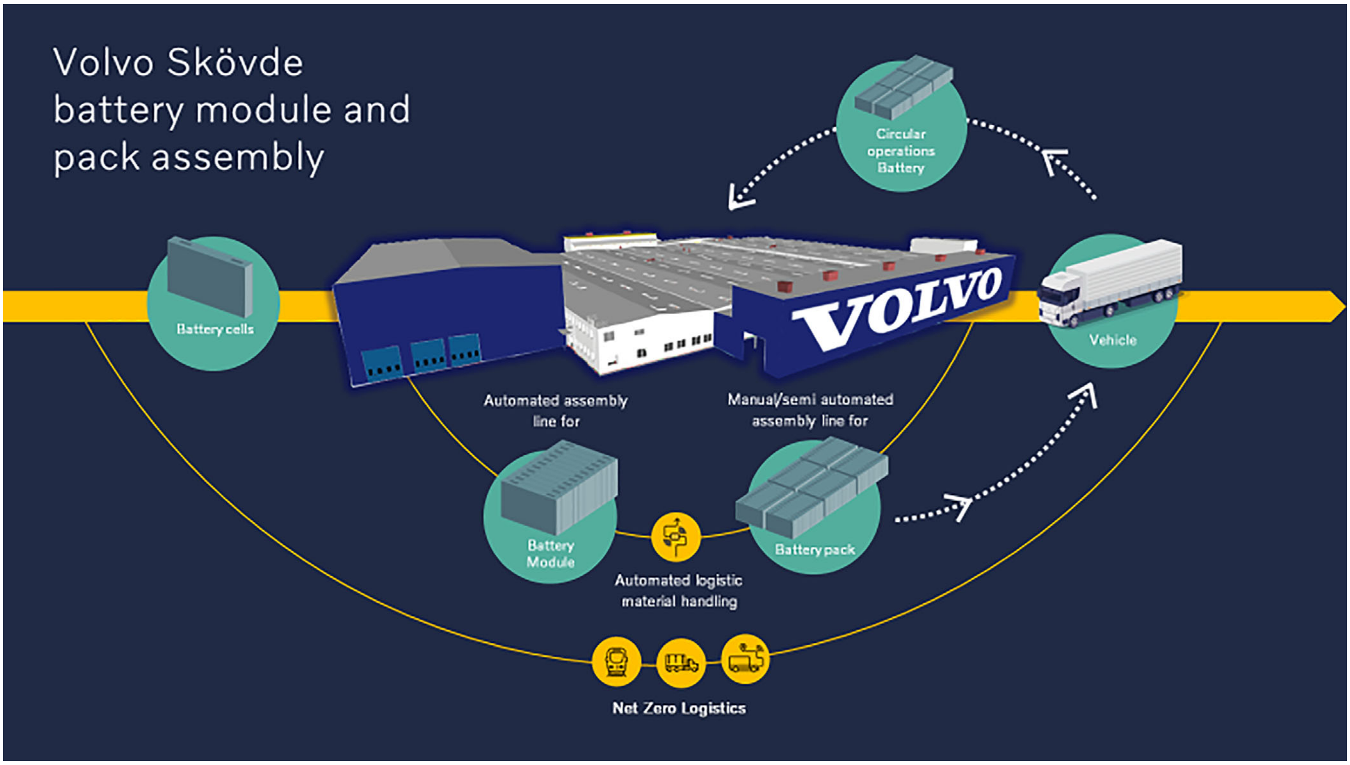

FIGURE 9 | ConOps production facility perspective.

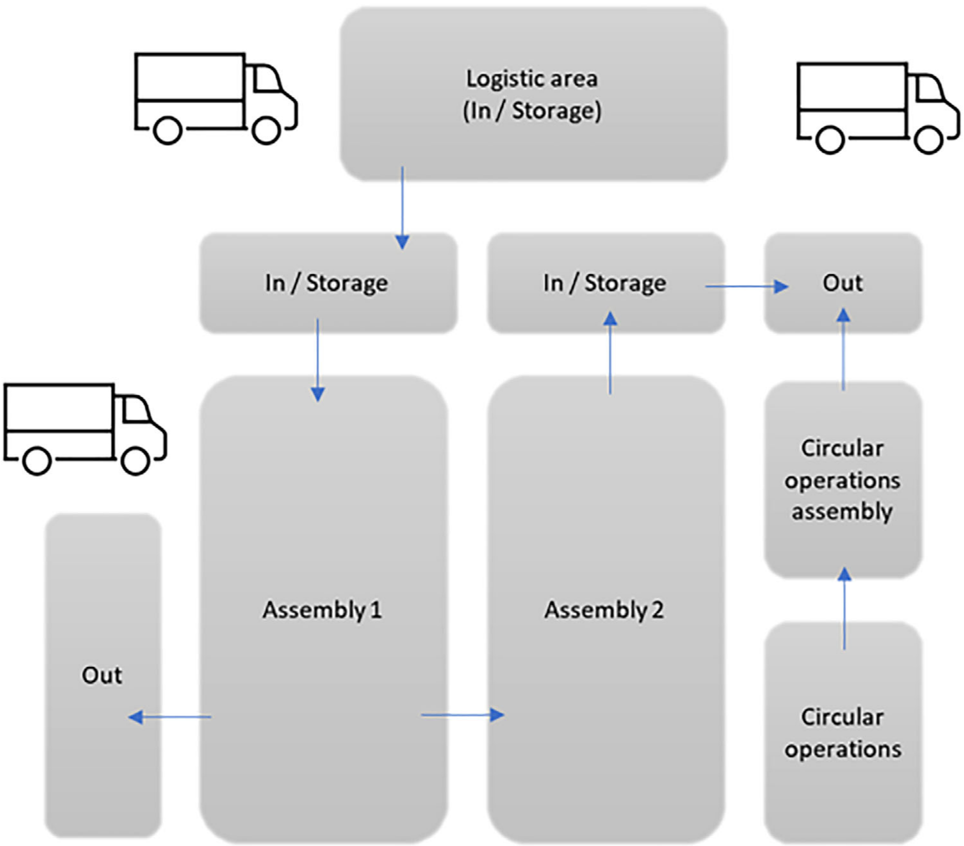

FIGURE 10 | ConOps Level 1, a visual system model to gain understanding of the production pace, and hence where potential problems can occur. Cannot be displayed for confidentiality reasons.

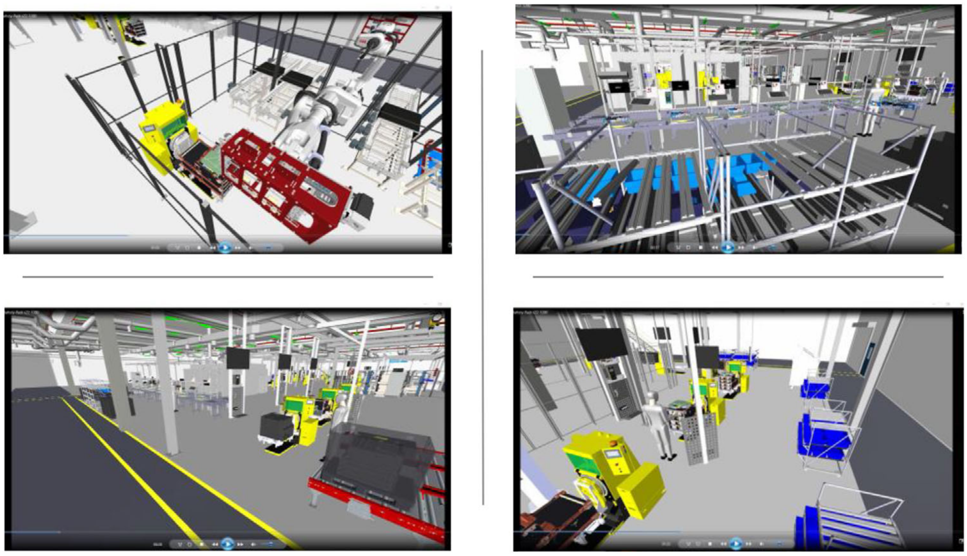

FIGURE 11 | OpsCon Level 2, four frames from a virtual film based on the 3D digital twin of the future factory. Cannot be shown for confidentiality reasons.

TABLE 5 | Fulfillment by the actual design support to the engineering goals.

		Total	Yes	No	Confirming statement (selection)	Challenges
Engineering goals	Manage complexity	15	14	1	"The collaboration and brainstorming in the workshops make us build our reasoning and makes the whole system better"	*"Perhaps it is not detailed enough to just have workshops of this brainstorming characteristics"*
	Manage risk	15	15	—	*"This method helps us to identify risks early"*	*Not mentioned*
	Implement I5.0	15	15	—	*"This is human centric for real! To start from a specific person's needs in the flow / system."*	*Not mentioned*

Some statements from question 3, regarding the implementation of Industry 5.0, were: "It is a great way to visualise the life in the plant," "We were missing the people focus before," "This is human centric for real! To start from a specific person's needs in the flow / system."

Testimonials in Meeting Documented by the Researcher:

In this session, 15 people shared their reflections orally in a group session on the approach. A selection of positive testimonials were: *"Great that it was only a few hours with high tempo—we could do a lot!," "It was great to see the connections in the system," "Slightly different deliveries from the teams but together it becomes a great result," "It is fun to challenge the traditional roles and focus more on the competences that are needed," "This way of working is great: we are breaking down something huge into manageable slices. This makes us feel that we are making progress and not standing still worrying."* Two statements focused on the challenges of the approach: *"It takes a while to understand the framework"* and *"Difficult to get down to the details."*

4.6 | Summary of Actual Design Support Validation

The fulfillment by the actual design support to the engineering goals is described in Table 5.

The fulfillment by the actual design support to the intended impact model are described in Table 6.

4.7 | Summary of Comprehensive Predictive Study Results

A summary of the results is described in Table 7 below.

5 | Discussion

The findings from the study show promising results when it comes to addressing the engineering goals of managing

TABLE 6 | Fulfillment by the actual design support to intended impact model.

Intended impact model	Confirming statement (selection)	Challenges
Collect and document cross-functional requirements	"With this way we can develop more precisely our concepts," "A very good way to document things we only talked about before," "Great to work cross-functionally like this," "Great to mix competences and aspects"	"It takes a while to understand the framework," "Difficult to get down to the details."
Invite operators and production leaders to all sessions	"With better methods like this, better collaboration and focus on flow we can minimise the risks," "I feel that I can influence the system and my future"	
Visual and user-friendly artifacts explaining the system in various levels	"This way makes it easier to understand" "This helps us understand the overarching ideas to be used in our production preparation," "It is a great way to visualise the life in the plant," "It was great to see the connections in the system"	
Using methods to connect and bring to life the humans in the system	"(…) is a way to make the person in the system more real," "We were missing the people focus before," "This way of working is great: we are breaking down something huge into manageable slices. This makes us feel that we are making progress and not standing still worrying."	
Workshops where requirements are shared and documented	"Collects and simplifies demands, as well as makes them more concrete," "I learned things I didn't consider before"	

TABLE 7 | Summary of research results for the comprehensive predictive study.

Topic	Sub-topics	Fulfillment
Task clarification	Results from earlier projects	Results from earlier projects had shown that the engineering focus was more equipment-oriented than production system-oriented.
	Reference model	ConOps and design thinking.
	Literature on similar goals	Described in the frame of reference.
	Intended impact model	Intended Impact model described.
Conceptualization	Functions of intended support	Intended support description is described.
	Intended introduction plan	The concept was tested in the study in six workshops.
Elaboration	Existing literature on intended support	Described in the frame of reference.
	Intended support fully described	The documentation and visualization of the models were to be performed by the researchers and experts.
	Intended impact model finalized	Intended impact model described.
Realization	Core functionalities of intended support	The ConOps is used to get a shared picture in the entire organization of how the business will operate.
	Actual support developed	ConOps method developed with actual ConOps as examples.
	Actual impact model	Intended impact model fulfilled by actual impact model.
Support evaluation	Actual support evaluated and modified if necessary	To confirm that the ConOps/OpsCon development was verified as relevant for engineering practices, data was collected at the end of two workshops and validated the actual impact model from the Engineering Goals.

risk, implementing human-centricity, and managing complexity within the scope of concept development of the production management part of a battery assembly industrial plant project. The comprehensive prescriptive study approach was considered appropriate for this type of research. However, as the project is still at an abstract concept level, the goals are not as precise and measurable as the theory of the research methods proposes. From this perspective, the generalizability can be more difficult to prove, which would be highly beneficial to explore further, ideally with a control group on a parallel project. On the other hand, Design Research is also important in the very early stages of development, where the concepts are still to be developed.

Main Observations From the Study:

- Many of the technical methods and concepts that were used to develop the ConOps/OpsCon artifacts, such as simulation models and 3D-generated films, have been used before, but in other perspectives and with a smaller and more limited group of people, the engineers. What is new in this project is that all the actors in the production system are invited from production.
- Normally it is the engineering department that invites what is referred to as "stakeholders" to bring input in specific phases in projects. Traditionally, the human aspects are not specifically highlighted. However, in this project, operators were involved from the beginning.
- The method that was applied involved working with personas to empathize with the humans in the system. Previously, personas have only been used from the central HR team.
- Working with and emphasizing the importance of visual models for gaining understanding from all actors is something new for the organization.
- Still, one gap that was identified in the literature review was the insufficient commitment from functional departments. Their presence was increased in this project, although still not up to expected levels.

Unexpected Findings From the Study:

- The feedback and validations were surprisingly positive for the researchers. Reasons for this could be that the teams felt it was fun to be part of a research project and that they received a lot of attention, and also that the researchers are managers at the plant, which could mean that participants felt pressure to show enthusiasm. This means that there is a potential for bias in participant feedback. The overwhelmingly positive answers on the initial yes/no questions could also mean that there were not qualifiers to the extent that the researcher intended, that participants wanted to be polite, or that deeper reflection did not occur.
- The participants felt that this was such a new way of working. These concepts have been available for a long time, but as the literature review also states, it appears that they haven't yet reached the engineering community in production system design. One reason for this could be that the company's product design department gets a lot of resources—10 times the amount of resources in production system design—even though investments in the production systems are also large in scale. One reason why product development is prioritized could be bias from management: that the products themselves are far more important than the production system that should deliver these products at world-class levels for perhaps 20 years.

From managerial aspects, it is important to challenge the current ways of working and make sure the organization is up to date on the methods and skills used to deliver the future industrial systems. This study was only a case study; a lot is required in terms of management and organization ability to get the engineering community to the point of using systematic, state-of-the-art methods. These systems should support a resilient production system, not only over time but also within the planetary boundaries, while embracing the full scope of a human-centric approach.

6 | Conclusions and Recommendations

The conclusions from the work and recommendations for future work are described below per research question.

6.1 | Conclusion of RQ1

RQ1: How can the systems engineering methods of Concept of Operations and Operational Concept be used to design human-centric manufacturing systems for novel products?

The design support concept method to develop the Concept of Operations was developed and delivered three artifacts on three levels of abstraction. This approach addressed issues identified in literature that complement the existing methods with new perspectives that encouraged creativity and cross-functionality. The approach supported the transfer of knowledge within and between development teams. The approach provided support in building models that are more clearly understood by designers, and the work also helped identify issues that were not addressed by any other team. This approach supported the inclusion of humans in the systems right from the beginning, thus addressing the issue often seen in engineering of treating human aspects as an afterthought. Through this approach, several aspects were identified that were not addressed, and work groups were set up to design solutions. However, it has not yet been possible to identify the gaps in the effectiveness of the methods the project will still be running for a few more years. Additionally, the findings should be seen as preliminary evidence, as this is one case study and hence not tested broadly nor included a control group.

6.2 | Conclusion RQ2

RQ2: What can be learnt by applying Concept of Operations and Operational Concept in the design of human-centric manufacturing systems for novel products?

The main learnings from the interviews with the participants in the workshops is that all except one person thought that using these methods helps to manage complexity. It was also appreciated as being more rigorous in terms of documentation than previous projects, since one focus of the workshops was to document the concepts selected and develop a system concept for the input. It was stated that the workshops made the entire operation easier to understand as a system, and that it was possible to influence the development. Regarding the management of risks, the input was equally supportive, stating that this method helps to identify and mitigate risks early in the project. Participants mentioned the importance of gaining an overview that they had previously lacked, and the importance of cross-functionality, collaboration, and flow thinking supports this finding. Other statements included that this approach enables us to develop our concepts more precisely, and that the demands become more tangible. Some participants mentioned that it takes some effort to understand the methods and that it can be too simplistic to use a more intuitive approach. These are important aspects to consider going forward. Again, the findings should be seen as preliminary evidence, as this is one case study and hence not tested broadly nor included a control group.

6.3 | Recommendations for Future Work

Recommendations for future work would be to further explore how the ConOps/OpsCon method can be more widely spread and adopted by engineering as a significant artifact for systems understanding for the design of more human-centric, resilient production systems. Additionally, future studies would benefit from more robust analysis with control groups to strengthen the validation and generalizability of the findings. Further on, the aspects of how ConOps/OpsCon can be used to establish organizational knowledge, both within project teams and between teams, are relevant to explore. It is recommended to include controlled comparative studies of different production system design methodologies, more rigorous evaluation metrics, methods to control for response bias in feedback collection, and longitudinal studies tracking actual production system outcomes to further validate the findings. Finally, it is recommended to investigate further what the production system design engineering community could harvest from the product development community, if these methods would have any actual impact on project cost and leadtime overruns, the workload of engineers, and better production systems in terms of resilience, sustainability, and human factors.

Data Availability Statement

Research data are not shared.

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