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Bridging planning silos: A cross-functional decision support system for capacity, order, and supplier decisions in global production networks

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ABSTRACT

The complexity and dynamism of global production networks require interlocked decision-making processes, including planning production capacity and capabilities, allocating orders, and selecting supplier options. In large companies, these planning processes are spread over several functions, leading to inefficient global decisions and increased coordination costs. This work proposes an integrated planning process for multi-echelon production networks that includes all three decision types mentioned. A systematic design process is developed and implemented as an optimisation problem. The results from an automotive supplier use case demonstrate significant advantages over the existing fragmented planning approach, as well as improvements in decision-making time.

1. Introduction

The transition to electric mobility poses a major challenge for incumbent automotive suppliers, who must both adapt their product portfolio and drastically reduce overall costs to remain competitive against new market players [1,2]. Hence, efficient planning of their global production networks (GPNs) becomes indispensable [3]. Hereby, planning and controlling GPNs involve coordinating and assigning activities within industrial value creation processes, ensuring that resources are acquired and utilised efficiently. Organisations have created specialised functional departments to enhance operational planning efficiency, such as logistics, purchasing, and production network planning [4]. However, this poses a hurdle for cross-functional alignment, impedes cohesive and globally optimal decision-making, and leads to missed savings opportunities [5]. For large companies with a high degree of vertical integration and a high level of product and variant diversity, coordinated and quick planning ability is key for economic success and resilience [6]. Capacity and capability planning minimises investment costs for production sites and lines, considering the complex relationships between product features and production line capabilities, as well as factors such as logistics and production expenses. Based on this, order allocation assigns customer orders to specific production lines, optimising operational costs. Both tasks can require sequential planning in multi-echelon production networks, where production stages are divided across sites. Procurement planning selects suppliers and allocates volumes to ensure reliable and cost-effective supply. Such interconnected planning tasks involve multiple stakeholders with varying priorities, requiring hierarchical and sequential processes to align decisions.

Organisational functions utilise Decision Support Systems (DSSs) tailored to their specific needs to select alternatives in complex decision-making situations. However, the siloed use of DSSs can yield suboptimal results. To benefit the whole organisation, information must be exchanged across functional boundaries.

This paper proposes and demonstrates a cross-functional, DSS-based planning process for multi-echelon production networks that covers planning production capacity and capabilities, allocating orders, and selecting supplier options. The remainder of this paper is structured as follows. Section 2 discusses related work. Section 3 introduces the systematic multi-model design process used to develop a multi-model planning approach in Section 4. Section 5 shows the results of applying this approach in an automotive use case. Section 6 discusses the implications of this paper, and Section 7 provides a summary.

2. Related work

2.1. Production & procurement planning approaches

Relevant works can be categorised into production planning, procurement planning, and integrated supply-chain approaches.

Typical production planning approaches focus on costs and integrate configuration and allocation decisions [7]. proposes a multi-objective, two-stage stochastic optimisation model for site selection, capacity planning, inventory management, and shipping planning within the GPN [8]. designs a two-stage GPN with quantity discounts and transport mode selection using a MILP and Lagrange-based decomposition [9]. develops a production and distribution model for GPNs, optimising site selection, capacity expansion and reduction, production levels, and distribution strategies while accounting for exchange rates and tariffs [10]. explores robust GPN planning using

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Monte Carlo simulation and clustering methods for scenario generation and stochastic modelling.

Procurement planning approaches often consider multiple objectives. Several approaches consider resilience in multi-objective decision-making [11,12]. In contrast, cost minimisation approaches primarily differ from production planning in terms of the decision-relevant cost elements. E.g., [13] incorporates contractual costs related to supplier-held capacities and inventories, opportunity costs for lost sales, and transportation costs [14] includes surcharges for the consumption of contractual flexibility reserves.

These isolated production and procurement planning approaches neglect interdependencies along the value chain. Approaches like [15,16] integrate operational decisions concerning procurement volume allocation, production planning, and inventory management but forego configurative decisions [17] addresses structural decisions, e.g., regarding the selection of suppliers and production sites, but neglects short-term decisions such as order allocation based on the chosen network configuration. Furthermore, these approaches are dedicated solutions for specific problems where reusability is not the main focus.

2.2. Decision support systems

When such models are used repeatedly, they are considered decision support systems (DSS). DSSs are designed to aid users in complex, semi-structured decision-making [18]. Model-based DSSs represent real systems in predictive or prescriptive models and allow for targeted investigations of scenarios and decision alternatives [19]. To avoid the extensive data collection and preparation that is usually necessary, DSSs can be designed as digital twins of the respective system with a suitable data synchronisation pipeline [20]. This is particularly advantageous for cross-functional systems to exchange information regarding the systems' state and planned changes quickly. Recent works have developed asset administration shells and frameworks for digital twins of GPNs, thus providing the necessary IT infrastructure [21].

2.3. Multi-perspective decision support system design

For DSSs to be effective, task-specific design is crucial. Several conceptual modelling approaches have been developed, aiding the successful design of DSSs. However, most design approaches focus on specific methods, such as simulation or optimisation and do not consider the design of multiple integrated DSSs. Consequently, there are only a few contributions that implement multiple DSSs, such as [22], which proposes a bi-level system for production distribution planning and [23], which illustrates a dual-perspective system for multi-product site capacity planning. From a theoretical perspective, there are some approaches to classify multi-model interactions, such as [24], which distinguishes different forms of predictive model interaction and [25], which presents a comprehensive interaction model for predictive and prescriptive models. These works offer insights into complex model interactions; however, they focus on multiple models that form a single Decision Support System (DSS) for a specific type of user, rather than multiple interconnected models for multiple users. DSSs with multiple Users have been established under group decision support systems (GDSSs), but these systems usually focus on information provision and interpretation instead of predicting or optimising complex systems. For example, [26] presents a GDSS for supplier selection and [27] offers a task-specific DSS based on a common data infrastructure. Thus, further work on designing connected, prescriptive, multi-perspective DSS is necessary.

3. Systematic multi-model design

A systematic, three-step process, consisting of (i) decision type analysis, (ii) method composition, and (iii) model detailing, is used to design the integrated multi-perspective DSS. In the first step, the time horizon considered in the decision, the central system elements to consider, and the desired capability of the DSSs for each decision type are determined by considering the characteristics of the decisions, the decision process, organisation and the modelled system. In the second step, the methods forming the DSSs are selected, including methods to predict system behaviour, evaluate decisions, configure alternatives, and generate scenarios to best suit the decision characteristics analysed before. Additionally, interactions between the conceptualised DSSs are identified, and possible design alternatives for multi-DSS design are developed and evaluated to select a preferred multi-model architecture. In the third and last step, abstraction levels for modelled system elements, specific behaviour representations, and the system delimitation are chosen and designed.

The interaction between the DSSs is formalised by analysing the DSS decision variable sets and assigning them to sets fixed for the decision, subject of the decision, or inconsequential results. The latter two sets are further distinguished into predictive variables, which are determined as parameters of experiments and prescriptive variables, which the DSS determines. By comparing these sets, dependencies, locks, conflicts, and realisations of inconsequential results can be identified. An effective multi-DSS system can be designed by analysing these relationships and deriving suitable strategies to address them. The following section outlines the key steps of this process as applied to the problem described above.

4. Integrated production and procurement planning

This work aims to create a decision support system that jointly optimises production capacity, supplier selection and development and the allocation of orders to production sites and suppliers. It builds upon the previous work of [10], who introduce an approach for robust GPN planning, including digital twin concepts for data integration at the network level, and extend it to multiple production echelons and procurement. It is assumed that the company operates a large and complex production network, divided into multiple business units and product groups. The interests of organisational functions and business units are partially competing. Thus, intra-organisational communication is a challenge.

4.1. Multi-model interaction

In multi-echelon networks, dependencies exist between the echelons. The costs of material at a given echelon depend on the preceding echelon. To plan optimally, each echelon requires information from the surrounding echelons, forming information locks. Traditionally, these locks are resolved using an iterative procedure, where the most cost-intensive echelon is planned first, and then the results are propagated to the other echelons. This unidirectional procedure can be improved by reiterating each echelon in reverse order in a bidirectional procedure. However, these iterative procedures cannot ensure optimal results. Another option is to develop an integrated multi-echelon optimisation model, described in Section 4.3. Integrated procedures usually suffer from increased complexity, so model adaptation may be necessary.

A similar lock exists between each echelon. The allocation of production volumes depends on material costs, while the allocation of external orders depends on the delivery locations. As different organisational functions operate these models, this approach uses an iterative approach to resolve this lock, allowing procurement and production planning to retain control of their planning models. The procurement planning model and its interaction with the production planning model are described in Section 4.4. The resulting model interaction scheme is illustrated in Fig. 1.

4.2. Single-echelon capacity planning and order allocation

As this work is based on the single-echelon model introduced by [10], only the essential characteristics are discussed here. It plans production capacity and order allocation across $t \in T$ periods. The core task of the planning is to satisfy customer demand in the form of customer orders, which define both the end product variant and the quantity per period. These orders must be produced within the GPN under consideration, which consists of sites $s \in S$, containing both existing and potential production lines $l \in L$. Each line has a standard and a maximum capacity. Exceeding the former results in overutilisation costs. The latter must not be exceeded. Each line is equipped or may be

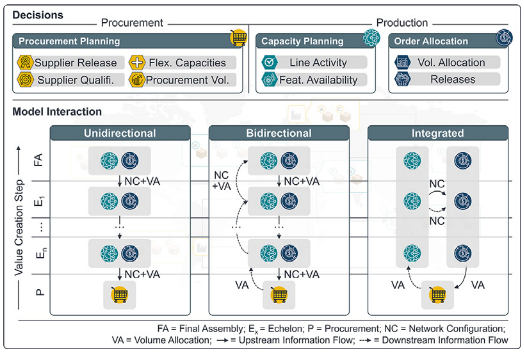

Fig. 1. Model interaction schemes for production and procurement.

upgraded with certain technical features $f \in F$ to produce specific orders. Similarly, each order specifies the technical features required to manufacture it. Due to technical reasons, not every line can be upgraded to include every feature, and lines may require customer releases to produce a particular order. Capacity planning and order allocation are optimised for minimal total costs. Fixed costs and variable costs are incurred for the operation of a line. In addition, the use of reserve capacity, i.e. exceeding the standard capacity, is penalised through overutilisation costs. Potential new lines may be bought, e.g., if capacities are insufficient. In addition, features can be added to lines, incurring upgrade costs. Delivery costs are also considered for each order based on the production site s and delivery location.

Several constraints are considered, including (i) demand volume satisfaction, (ii) capacity adherence on new and existing lines, (iii) line activity continuity, (iv) feature availability, (v) release availability, and (vi) strategic, non-negotiable constraints, such as site-specific production volumes.

4.3. Multi-echelon capacity planning and order allocation

The relationships between products and their components and the transport processes must be integrated into the model to plan production across multiple echelons. The relationships between products and their components, which are captured in the bill of material can be represented in a matrix $\Gamma^{|O| \times |O|}$ with $\gamma_{o,\sim o} = 1$ if order $o \in O$ requires order $\sim o \in O$ to be produced and $\gamma_{o,\sim o} = 0$ else.

Based on this, flow continuity constraints guarantee sufficient intermediary products $\sim o$ at supplied sites s, expressed as:

$$\Sigma_{\sim s \in S} q^{(TRN)}_{\sim o,\sim s,s,t} \geq \gamma_{\sim o,o} * \left(\Sigma_{l \in L} q^{(PRD)}_{o,l,t} * b_{l,s} \right) \tag{1}$$

Where $q^{(TRN)}_{\sim o,\sim s,s,t}$ denotes the transportation quantity of order $\sim o$ from site $\sim s$ to site s in period t to cover the production quantity $q^{(PRD)}_{o,l,t}$ of all lines located at a site ($b_{l,s}$) as required by the order confusion matrix. Moreover, maximum transportation volumes at supplying sites need to be adhered, formalized by:

$$\Sigma_{\sim s \in S} q^{(TRN)}_{\sim o,s,\sim s,t} \leq \Sigma_{l \in L} q^{(PRD)}_{o,l,t} * b_{l,s} \tag{2}$$

However, this integrated consideration can increase computational complexity, so the model may be split into two abstraction levels to ensure sufficient scalability. First, at a higher abstraction level, orders can be grouped into product clusters based on differentiation criteria, such as required features. Based on these clusters, decisions regarding capacity planning, such as line activity and upgrade decisions, can be made efficiently. On the second detailed level, customer orders are distributed within the boundaries set by the product clusters, and releases are defined accordingly.

4.4. Procurement planning

Procurement planning covers a corresponding horizon of $t \in T$ periods. In contrast to production planning, however, from the perspective of procurement planning, the production sites $s \in S$ serve as delivery locations whose demand for purchased raw materials and intermediate products $g \in G$ must be satisfied for all periods. A discrete number of extant or to-be developed suppliers $p \in P$ may provide these volumes.

The procurement planning model optimises the total costs, including supplier network configuration and direct procurement costs. Each supplier must be generally released and qualified to provide each product. Every production pause leads to reactivation costs for releases and qualifications. The production volume of a supplier is limited to a maximum and a nominal value. If the nominal capacity is exceeded, non-variable flexibility costs occur. During the production ramp-up, capacity may be lower. The direct procurement costs are based on a volume-dependent cost rate representing volume discounts. The planning is subject to several constraints, including (i) capacity restrictions, (ii) flexibility capacity extensions, (iii) demand fulfilment, (iv) supplier release and qualification availability and continuity and (v) discount constraints.

Additional model interactions arise when combining procurement and production planning. The allocation of production volumes of both end and intermediate products along the value creation chain in production planning serves as a starting point for comprehensive procurement planning. In particular, the demand for externally procured products is derived from the allocated volumes, which in turn requires the set of all suppliers to be considered for procurement planning. Similar to iterative production planning, the resulting procurement plan is fed back to production planning with adjusted sourcing costs for iterative refinement. This feedback procedure is used in the bidirectional and integrated planning processes. A fully integrated model was considered but rejected due to organisational ownership constraints.

5. Industrial case study

5.1. Description of the use case

The developed methodology is applied to plan the web-structured GPN work of a large tier-one automotive supplier. The company produces motor components in large-scale production 3-4*$10^{6,}$ and supplies globally spread customers under frame contracts. The plans are generated for sixteen half-year periods, prescribed by the iterative manual planning process used before. The GPN covers 4 sites in Europe and Asia, with 32 production lines across 5 echelons. In total, 30 features are required to produce all intermediates and final products to fulfil customer demand in 4 regions. Depending on the product, some echelons are skipped. Additionally, components may be delivered directly to customers. Furthermore, purchased products may be sourced from 3 (potential) suppliers and are in demand at 2 of the 5 echelons. The parameters for the case study are gathered from sales figures, master data, and estimates from GPN and procurement planners. To ensure anonymity, the results presented have been normalised.

5.2. Comparative analysis of multi-echelon planning methods

In the use case, multi-echelon production planning encompasses capacity planning and order allocation, and is conducted using unidirectional (UD), bidirectional (BD), and integrated (IG) procedures for comparison. Fig. 2 depicts the resulting inter-echelon flows for the unidirectional optimisation and highlights significant volume shifts and savings when switching to bi-directional and integrated planning, respectively. BD and IG planning shift the production volumes by 0.47% and 3.45%, respectively, compared to the unidirectional solution, resulting in 0.94% total cost savings for the IG solution. Interestingly, the shifts of production volume in BD and IG planning do not point in the same direction. For example, whereas BD increases E2 production volumes at Site 3, IG drastically reduces them in favour of other optimisations. This highlights the inability of iterative solutions to find global optima. Accounting for the high overall production costs, the savings are considerable. However, the capacity planning decisions remain largely the same. All three procedures significantly reduce planning times due to the elimination of information exchange.

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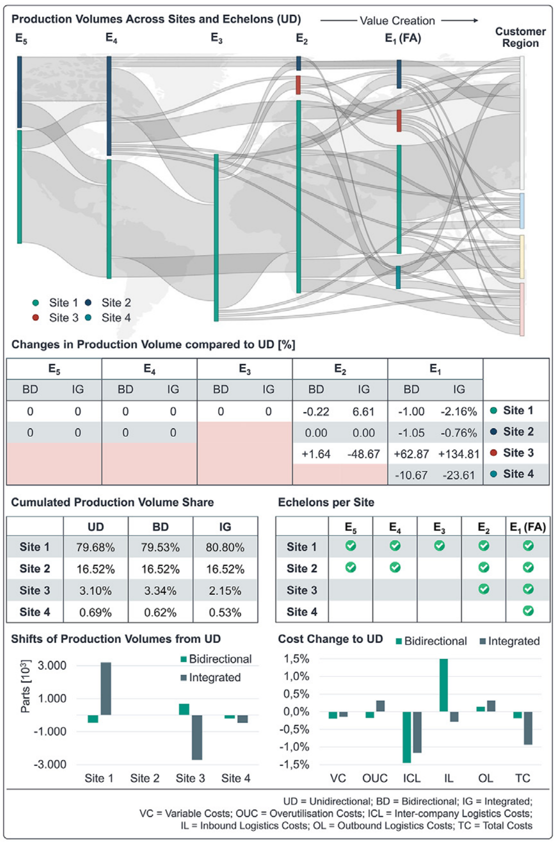

Fig. 2. Results from different production planning approaches.

5.3. Comparative analysis of procurement results

The procurement department can directly utilise the results of the production planning model as inputs for its procurement planning model. Compared to existing manual information transfer, this enables significantly faster planning. The comparison of procurement planning for the BD and IG production planning procedures, as depicted in Fig. 3, shows notable volume shifts as well. The IG planning can halt procurement from Supplier 2 one year before BD. These differences in supplier network configuration and shifts in procurement volumes result in a 0.07% decrease in overall procurement costs.

6. Discussion

The results underscore the potential of integrated cross-functional planning for GPNs. As existing work suggests, integrated approaches can improve decision quality compared to iterative approaches. In this study, the savings of the integrated method are more modest than those found in other studies. The anecdotal evidence from this use case suggests that the primary benefit of integrated decision-making lies in the speed and efficiency of the decision-making process, rather than in the decision itself, as integrating the planning tools allows for a reduction in planning times from weeks to hours. This requires suitable information interfaces and an underlying data structure. The systematic multi-DSS design process applied in this work is one crucial step in that direction.

The presented approach builds upon the existing manual data exchange and planning, highlighting the effectiveness of integrated decision-making. Even though this work focused on one use case, both experience from practical application and theoretical work on complex system optimisation suggest similar results can be expected in other cases. However, the chosen iterative integration of purchasing remains a necessary compromise due to the distributed planning responsibilities. Future work could investigate organisational solutions that allow functions to run integrated models across functional boundaries while minimising the development effort and organisational complexity. Secondly, considering multiple scenarios from the procurement and

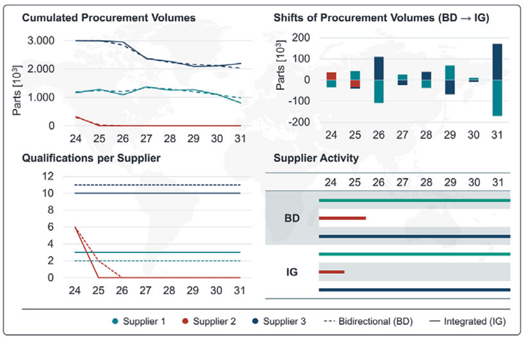

Fig. 3. Comparison of procurement planning results for BD and IG.

production domains would be valuable. This could lead to more robust decision-making overall. The findings are particularly relevant for large complex organisations. The benefits of creating complex cross-functional planning systems may not outweigh the costs for smaller organisations. Nevertheless, even iterative procedures with suitable interfaces can provide significant value. Finally, additional research is needed to test the generalisability of the results.

Overall, the results of this paper suggest that industrial organisations should develop and integrate their decision support capabilities, as it likely allows them to react more quickly to changes in their environment and to find globally optimal decisions.

7. Conclusion

This paper proposes a cross-functional decision support system for large-scale production companies that integrates capacity planning, order allocation, and procurement planning. The system is developed using a systematic design process, significantly improving the decision-making process and quality.

Future work may consider integration with additional planning processes, such as sales and strategic network planning. It may also offer decision-makers integrated tools to enable the optimisation of domains outside their function. Such integrated systems also need to consider uncertainty, cross-functional scenarios, and the consequences of increased information availability inside the organisation. Finally, the methodologies may be tested in different scenarios to advance the understanding of the benefits achievable through integrated planning processes.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Martin Benfer: Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Moritz Hörger:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

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Supplementary materials

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.cirp.2025.04.029.

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