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Dual-perspective capacity planning in interconnected multi-product production networks using stochastic optimisation

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ABSTRACT

Planning production capacities in multi-product production networks is challenging due to the multitude of decision factors, inter-organisational interests, and a high degree of uncertainty. Particularly, the organisational separation of different products that share sites induces planning complexity. This paper proposes an interactive-two model concept integrating product-specific network planning and a site capacity planning perspective. Stochastic mixed integer linear programming determines order allocations, line investments, and personnel plans. The potential to swiftly adapt plans while obeying local constraints is demonstrated with a large automotive supplier. The approach should allow quicker and more adaptive planning, leading to more resilient organisations.

1. Introduction

Today's global production networks (GPN) must constantly adapt to changing market conditions, often across multiple product families [1]. For large corporations with over 20 sites, orchestrating the efficient production of goods is a complex planning task involving several organisational functions. One process, capacity and capability planning, involves decisions regarding the set-up and decommissioning of production lines across the network of sites and changes in line capabilities. In high-volume, high-variant production, variant-specific capabilities can be differentiated across production lines to accommodate the product variance while limiting necessary investments. Capabilities are often not a one-to-one match of product variants to production line features but a complex relationship between product features and line features. Furthermore, variant allocation and investment decisions depend on customer preferences, logistics and production costs. In large organisations, investment decisions involve multiple stakeholders with different functional perspectives and goals. To coordinate these perspectives, hierarchical planning processes are often employed.

In recent years, increasing economic pressures on producers from high-wage countries and the volatility and complexity of global value chains have highlighted the need for better, faster, and uncertainty-cognisant planning. In semi-structured and semi-routine decision situations, such as those described above, decision support systems (DSS) are a powerful tool [2]. They help decision-makers to assess alternatives quickly and account for conflicting goals. They can increase the resilience of production networks by enhancing the speed at which adaptation needs are recognised and acted upon [3]. However, creating DSS for complex, multifaceted decisions involving multiple stakeholders remains challenging. Specifically, the recurring configuration of capability and capacity investments across various product families and sites remains a process with high manual efforts.

This paper proposes a dual-model approach to this problem, utilising stochastic optimisation and integrating the perspectives of network planners and site management in an iterative but targeted process. Combining two distinct DSSs enables both user groups to effectively provide their expertise while making decisions that are beneficial for the whole organisation.

The remainder of this paper is structured as follows. Chapter 2 provides insight into related work and fundamental concepts used. Chapter 3 illustrates the multi-model DSS concept, focusing on rolling order allocation and investment planning, site-specific capacity planning, and network adaptation options. The application of this approach is demonstrated using the example of a large automotive supplier in Chapter 4. Subsequently, Chapter 5 discusses the results before Chapter 6 summarises the findings and offers an outlook for future research.

2. Related work

Various previous approaches have considered network planning problems on the operational, tactical, and strategic levels. These approaches exhibit different foci, depending in part on the product characteristics and production network in question. A few particular works are noteworthy for capacity planning in a network of multiple products. [4] propose a two-stage stochastic mixed integer linear programming (MILP) model for capacity and flexibility planning in a production network. [5] use stochastic dynamic programming to plan demand flexibility in production networks. Another two-stage

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stochastic MILP for the integrated planning of production resources, logistics and outsourcing decisions is proposed by [6]. Other approaches by [7] and [8] also use stochastic MILPs for capacity planning in the network. The discussed approaches remain relatively strategic and are not concerned with specific product variant-related production capabilities. Managing multiple user types and their interaction with such DSS is not a focus of these works.

DSSs are interactive, computer-based information systems supporting the solution of decision problems [9]. This work focuses on model-based DSSs, which allow users to access and manipulate predictive and prescriptive models [2]. Several DSS in the context of GPN have been proposed, most notably by [10], who describe a framework for DSS, and [11], who offer a framework for DSS in supply chain decisions. [12] propose using DSS as digital twins of GPN with a shared and synchronised database.

While many multi-model systems are described in the literature, few works propose a systematisation. [13] describe an approach for using multi-model, multi-user systems in production planning and control. [14] propose a multi-model DSS for the assessment of disruption risks in supply chains. [15] describe a two-stage hierarchical planning system for a two-stage production system.

Taxonomies describing the interaction between simulation and optimisation for specific tasks exist [16]. Directly connected multi-model systems are more common in other scientific disciplines, such as weather and climate modelling [17]. However, those models are often only predictive and arguably face different challenges.

3. Multi-model concept and model details

In large multi-product networks, integrated optimisation of order allocation and investment planning can be infeasible and impractical as the network size makes computational costs prohibitive. The diversity of products and required knowledge can necessitate the interaction of multiple experts, limiting the usefulness of a singular DSS. Instead, this approach proposes a complex of two DSSs interacting with each other. Network planners responsible for product-specific production networks use the network planning DSS (NP-DSS). In contrast, the site-planning DSS (SP-DSS) is used by local site planners and centrally assigned network coordinators. Network-specific plans are originally forwarded from network planning to site planning and then iteratively adapted to meet local capacity restrictions at each site. Thus, decisions can be improved across several production networks. This overall concept is visualised in Fig. 1.

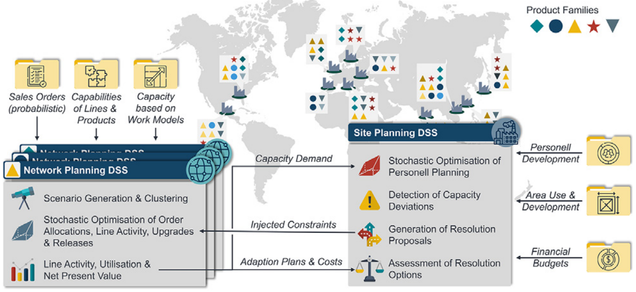

Fig. 1. Two-DSS concept for capacity planning.

As proposed by [12], a shared database is used to exchange information between the two models. The concept illustrated by [13] for distributed planning is used. Distributed planning across sites and networks requires data access management for the different users. This shall, however, not be the focus of this paper.

3.1. Order allocation and investment planning

In the here presented approach, an existing DSS using MILP for order allocation and investment planning presented initially in [18] is utilised. Thus, only the central aspects of this network planning DSS are discussed here.

The NP-DSS determines the activity of and investment in production lines, the acquisition of customer releases for specific products on specific lines, and the allocation of production volumes to line capacities. The net present value approach considers in- and outbound logistic costs, variable and fixed production, investment, and capital costs. Boundary conditions are order fulfilment, capacity restraints, fixed allocations, flexibility requirements, and line capability matching with product features. The considered time horizon is seven years, divided into 14 planning periods. As demand uncertainty represents the primary uncertain influence on this planning process, possible demand developments and order volumes are determined with Monte Carlo simulation. The scenarios are clustered and weighed for stochastic optimisation with partial recourse. A MILP problem is defined and solved with a commercial solver. The optimisation results in a set of scenarios for which allocation and investment plans are determined. Network planners use the NP-DSS to develop yearly allocation and investment plans, explore configuration alternatives, and react to changing conditions quickly.

3.2. Dynamic capacity planning

The NP-DSS optimises investments for each product family irrespective of the plans of other product families. However, necessary capacities such as personnel, production area, and investment capital are limited, so demand for and offer of capacity need to be matched. The SP-DSS aggregates the results from the NP-DSSs to determine the capacity demand. It further determines capacity offers using optimisation for personnel decisions and planning data for area and investments. As the planning on the site level is subject to the same uncertainty as network planning, the stochastic results of the NP-DSS are integrated into the SP-DSS.

The plans for each product k specific network are recorded in a set of scenarios $\omega \in \Omega_k$ contingent on sales development. Each scenario is given a weight w_ω, based on a likelihood estimate such that $\sum_{\omega \in \Omega_k} w_\omega = 1 \, \forall \, k \in K$. At each site p a set of networks K_p intersects. Thus, the index set of scenario combinations $\mathscr{x} \in \mathscr{X}_p$ at each site, assuming $\Omega_{k_1} \perp \Omega_{k_2} \, \forall \, k_1, k_2 \in K$, can be described as

$$\mathscr{X}_p = \prod_{k \in K_p} \Omega_k \tag{1}$$

Then the weight $w_\mathscr{x}$ of each unique combination is given by

$$w_\mathscr{x} = \prod_{\omega \in \mathscr{x}} w_\omega \quad \forall \, \mathscr{x} := (\omega_i) \in \mathscr{X}_p \tag{2}$$

Each network places capacity demands for direct and indirect personnel, area, and investments on the sites in the network. The site demands correspond to the sum of capacity demands placed on the site by each network.

Companies cannot directly determine the number of personnel. Instead, they can influence early retirements, layoffs, hired staff, and the number of subcontract employees. Thus, this approach uses stochastic optimisation for personnel capacity based on current staff, planned retirements and capacity demand as the product of line utilisation and nominal line personnel demand at full capacity. Early retirements, hired staff, and subcontractor numbers are dynamically adjusted to match the capacity demand. These decisions are shared between all scenario combinations for the first two periods, whereas decisions for later periods are recourse. Under- and overstaffing are modelled as soft constraints, accounting for the inflexibility of personnel capacity. Both hiring and the number of subcontractors are limited to a fixed share of overall personnel, replicating the sluggishness of personnel capacity adaption. Costs are determined for early retirements, hired staff, subcontractors, and under- and overstaffing. A MILP is used to solve the direct personnel planning for each $\mathscr{x}$.

The demand for indirect personnel is determined as a combination of scaling factors according to the profession of the personnel. Capacity demand can scale with the number of direct personnel, lines and distinct products. Linear scaling based on current quotas is assumed. Only production-related professions are considered. The resulting retirement, hiring, and subcontractor rates are determined analogously as direct personnel.

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It is assumed that demand for and offer of area can be matched as a scalar, and area utilisation efficiency remains constant. The area demand is determined by utilised lines and capability upgrades in the form of additional machines or stations. The area demand is defined as the sum of fixed area for lines, additional area for upgrades, and indirect areas with different scaling factors. The area occupied by a line remains reserved for one period after line shutdowns. Changes in the area are only introduced as premises, as such changes are typically large-scale projects. Investment demands are determined by the costs of new lines and upgrades and returns from line sales. Investments at each site can be limited.

The SP-DSS recognises four types of deviations: (i) overstaffing, (ii) understaffing, (iii) area violations, and (iv) budget violations. The criticality c_δ of a deviation δ is determined as a combination of severity of a violation and its likelihood:

$$c_\delta = \sum_{\mathscr{s} \in \mathscr{X}_p} \left(w_{\mathscr{s}} \left(\frac{\delta_{\mathscr{s}}}{\widehat{\delta}} \right) \right)^{g} \tag{3}$$

where $\widehat{\delta}$ denotes the criticality threshold for the deviation, $\delta_{\mathscr{s}}$ describes the deviation for each scenario combination and g expresses the stress put on exceptional deviations. Deviations are differentiated by site, period, and type. Using the criticality, deviations can be categorised and highlighted. Site capacity planners may use this to inform the adaptions they pursue.

3.3. Network adaption

To resolve severe deviations, the network planning of one or multiple products needs to be adapted. The site planning DSS determines necessary restrictions, which would lead to an elimination of the deviation. The NP-DSS can then estimate the resulting cost differences by optimising with injected constraints and examining additional costs. Although this approach cannot guarantee a global optimum, favourable networks to restrict can be established. With these first indications, site and network planners can initiate a targeted adaption of the allocation and investment plans.

The previously discussed aggregation logic is reversed to determine injected network constraints. The capacity constraint for network k at site p resolving a deviation δ is then expressed as

$$\sum_{l \in L_{k,p}} \kappa_l q_l^{(NEW)} \leq \min_{\mathscr{s} \in \mathscr{X}_p} \left(\sum_{l \in L_{k,p}} \kappa_l q_{l,\mathscr{s}} - \delta_{\mathscr{s}} \right) \tag{4}$$

Where $l \in L_{k,p}$ is the set of lines of network k allocated at p, κ_l is the capacity translation factor of l, $q_{l,\mathscr{s}}$ is the capacity demand of l in scenario combination $\mathscr{s}$, and $q_l^{(NEW)}$ are the new capacities. In cases where the right-hand side is smaller than zero, the network k cannot resolve the deviation on its own. Instead, a combination of multiple restrictions chosen by the user can be employed.

Regarding direct and indirect personnel, q_l specifies the line utilisation. For area restrictions, lines' activity is limited, and explicit monetary restrictions are placed for investments. Restrictions addressing the same site and issue in multiple periods are determined jointly.

The networks are optimised again to assess different resolution strategies with added restrictions. If the network planning problem becomes insolvable, the resolution strategy is inviable. Otherwise, the costs before and after adding restrictions can be compared to evaluate the cost increases caused by the networks.

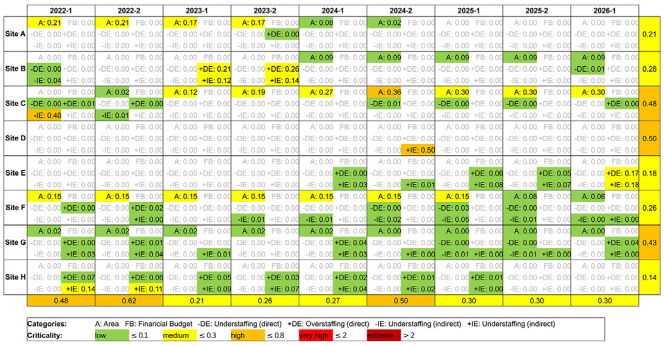
The SP-DSS may also be used to assess area expansions, production ramp-ups, and options to limit the consequences of economic downturns, for example, through reduced work times for personnel. In all of these cases, it primarily serves to focus, not entirely replace, more detailed and time-consuming analysis methods.

4. Industrial case study

The above-described concept was tested with a large automotive supplier with an extensive production network comprising several intersecting production networks of different product families. The company already uses a rolling hierarchical but highly manual planning approach to allocate planned order volumes, line investments and site planning. The parameters used for the SP-DSS, such as planned retirements and the area offer, are collected as part of the existing process or estimated by site planners. The presented data and results were altered for anonymity.

4.1. Capacity monitoring and planning

Fig. 2 shows an excerpt of deviation criticality c_δ across sites and planning periods. The types of deviations are indicated symbolically, and the highest criticality index for each site and period is colour coded. This overview allows manufacturing coordinators and site managers to monitor issues in capacity planning and their severity. $\widehat{\delta}$ was set as 0.05 globally and $g = 1.3$.



	2022-1		2022-2		2023-1		2023-2		2024-1		2024-2		2025-1		2025-2		2026-1		
Site A	A: 0.21	FB: 0.00	A: 0.21	FB: 0.00	A: 0.17	FB: 0.00	A: 0.17	FB: 0.00	A: 0.08	FB: 0.00	A: 0.02	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	0.21
	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	
	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	
Site B	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.09	FB: 0.00	A: 0.09	FB: 0.00	A: 0.09	FB: 0.00	A: 0.09	FB: 0.00	A: 0.09	FB: 0.00	0.28
	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.21	-DE: 0.00	+DE: 0.26	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.01	+DE: 0.00	
	-IE: 0.04	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.12	-IE: 0.00	+IE: 0.14	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	
Site C	A: 0.00	FB: 0.00	A: 0.02	FB: 0.00	A: 0.12	FB: 0.00	A: 0.19	FB: 0.00	A: 0.27	FB: 0.00	A: 0.36	FB: 0.00	A: 0.30	FB: 0.00	A: 0.30	FB: 0.00	A: 0.30	FB: 0.00	0.48
	-DE: 0.00	+DE: 0.01	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.01	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	
	-IE: 0.48	+IE: 0.00	-IE: 0.01	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	
Site D	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	0.50
	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	
	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.50	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	
Site E	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	0.18
	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.06	-DE: 0.00	+DE: 0.05	-DE: 0.00	+DE: 0.17	
	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.03	-IE: 0.00	+IE: 0.01	-IE: 0.00	+IE: 0.08	-IE: 0.00	+IE: 0.07	-IE: 0.00	+IE: 0.18	
Site F	A: 0.15	FB: 0.00	A: 0.15	FB: 0.00	A: 0.15	FB: 0.00	A: 0.15	FB: 0.00	A: 0.15	FB: 0.00	A: 0.15	FB: 0.00	A: 0.15	FB: 0.00	A: 0.08	FB: 0.00	A: 0.06	FB: 0.00	0.26
	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.02	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.03	+DE: 0.00	-DE: 0.00	+DE: 0.00	-DE: 0.00	+DE: 0.00	
	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.01	+IE: 0.00	-IE: 0.01	+IE: 0.00	-IE: 0.02	+IE: 0.00	-IE: 0.05	+IE: 0.00	-IE: 0.01	+IE: 0.00	-IE: 0.00	+IE: 0.00	
Site G	A: 0.02	FB: 0.00	A: 0.02	FB: 0.00	A: 0.02	FB: 0.00	A: 0.02	FB: 0.00	A: 0.02	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	0.43
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	-IE: 0.00	+IE: 0.03	-IE: 0.00	+IE: 0.04	-IE: 0.00	+IE: 0.01	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.03	-IE: 0.00	+IE: 0.00	-IE: 0.01	+IE: 0.00	-IE: 0.01	+IE: 0.00	-IE: 0.00	+IE: 0.00	
Site H	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	A: 0.00	FB: 0.00	0.14
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	-IE: 0.00	+IE: 0.14	-IE: 0.00	+IE: 0.11	-IE: 0.00	+IE: 0.09	-IE: 0.00	+IE: 0.07	-IE: 0.00	+IE: 0.04	-IE: 0.00	+IE: 0.02	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	-IE: 0.00	+IE: 0.00	
	0.48		0.62		0.21		0.26		0.27		0.50		0.30		0.30		0.30		

Categories:	A: Area	FB: Financial Budget	-DE: Understaffing (direct)	+DE: Overstaffing (direct)	-IE: Understaffing (indirect)	+IE: Understaffing (indirect)					
Criticality:	low	≤ 0.1	medium	≤ 0.3	high	≤ 0.8	very high	≤ 2	extreme	> 2	

Fig. 2. Monitoring of capacity deviations (excerpt).

As shown in Fig. 3, the personnel planning is optimised for the expected development of production volumes. This depiction shows the mean values for personnel demand and offer. The volatility in orders leads to over- and understaffing, as early retirements combined with newly hired staff can be more costly than transient overstaffing. The associated costs can be increased to avoid understaffing, likely leading to additional hired staff and some early retirements. For networks without demand data, here shown as 'Other Products', the planned capacity offer was used as a demand replacement.

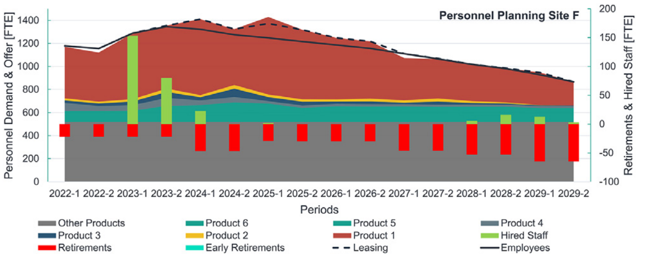

Fig. 3. Capacity adaptive personnel planning.

4.2. Network adaptions

Resolving capacity conflicts and exploring different network adaption options involves comparing their effects on network costs. Furthermore, changes in utilisation, resource activity and investments are relevant. Depending on the volume demand per scenario, these differences may or may not occur. Fig. 4 shows the mean costs and corresponding capital value of resolving the capacity area deviation at 'Site C', as shown in Fig. 2.

The example shows a significant difference between the production networks for 'Product 2′ and 'Product 3′, caused mainly by differences in variable costs at 'Site F' and 'Site G'. For the example shown, logistic cost values were unavailable and are thus omitted from this comparison. With this first indication, the network planners can start more detailed examinations.

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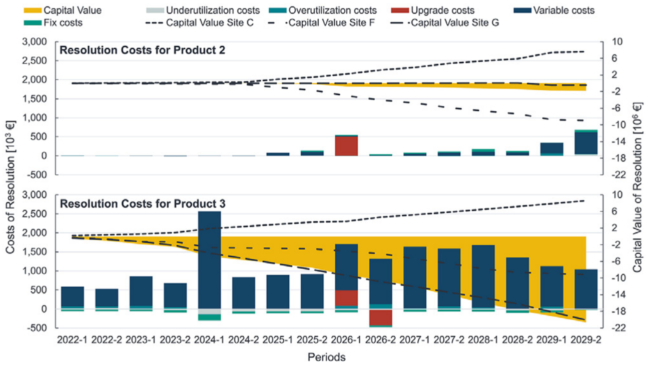

Fig. 4. Comparison of multiple network adaption options.

5. Discussion

The proposed approach improves upon manual planning processes but represents a compromise compared to complete network optimisation across different product families. This compromise is necessary due to computational capacity constraints and distributed user expertise. However, it results in an inability to find exact solutions to the overall network problem. This compromise seems warranted as the computational restrictions are severe, and the proposed approach can likely find a good solution to violations.

Within the capacity, some additional compromises needed to be made. The linear area capacity model is a significant simplification that neglects the influence of area shapes and logistic dependencies. However, more detailed, nonlinear area models with substantial improvements in quality are far more computationally demanding and require detailed data on available areas and their dependencie. The chosen linear model can provide a good first indication of capacity demand. Another assumption is the linear scaling of indirect areas and personnel. This assumption is commonly used but represents a significant simplification. However, more detailed models would have to dive deeper into organisational dependencies or be based upon more detailed empirical scaling models, which are largely absent in contemporary literature. Finally, it is assumed that scenarios are independent across networks, which is unlikely but a necessary simplification due to the distribution of relevant decision-makers in the organisation. It may lead to an underemphasis of drastic scenario combinations. Thus, extreme outcomes need to be taken especially seriously. In practice, a compensatory overemphasis is achieved by increasing g.

Overall, the industrial application simplifies planning processes and improves planning quality concerning uncertain future developments, as it allows uncertain planning information to be transmitted throughout the organisation. It integrates multiple users in large corporations in a comprehensive yet pragmatic, transparent planning process. The results obtained from the SP-DSS, especially concerning resolution options, serve as an indication and guide for more detailed examinations. The above-described abstractions are necessary to allow a quick process, but since the most promising options are detailed further, they should not negatively affect the decision quality. The results of the detailed planning processes can be reintegrated into the model, for example, as dynamic scaling parameters. The approach can enable faster reactions to changes and, thus, increased resilience. Whereas many extant approaches neglect the organisational complexity of the examined planning processes, this work represents a step towards connected uncertainty-cognisant capacity planning. This work also represents a first step towards multi-perspective multi-model DSS.

6. Conclusion

This paper proposes a multi-model approach to network capacity planning in large producing companies. The approach aggregates the optimisation results for multiple production networks across sites to identify and resolve capacity conflicts across multiple production networks. The concept of integrating models that are organisationally separated has shown its promise.

Future work may look into integrating additional models, such as a demand model, into the approach. The approach should also be tested in other use cases. Improvements in planning speed should be quantified, once comprehensive data across the network is available. Furthermore, a concept to maintain the covariance between scenarios for different networks could allow for a more realistic consideration of extreme scenarios. Finally, using meta-heuristics to find optimal resolution strategies for capacity conflicts may be worthwhile. This is particularly relevant for personnel deviations, which have the most complex cost response to variations in resolution strategies.

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.

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