Strategic capacity management in big-size, engineer-to-order supply chains*

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***Abstract*— Big-size products are usually highly customized and are typically developed under an engineer-to-order system. This makes capacity planning challenging due to heterogeneous operations, products with diverse configurations, and outsourcing that varies across systems. This article proposes a linear programming model to manage production and supply capacity planning in big-size product supply chains at the strategic decision level. This approach enables aggregated production planning and coordinated supply chain management. It is applied to a real case involving products, modules, parts, and sub-assemblies with modular customization. As a result, three resources were identified as bottlenecks. This demonstrates the model's ability to capture differences in workload stability and identify potential capacity constraints. Such findings underscore the need to anticipate specialized and customized resources.**

***Keywords*—Big-size products, engineer-to-order, supply chain, strategic capacity management, linear programming**

I. INTRODUCTION

The supply chain of big-size products exhibit distinctive characteristics compared to other products developed in engineer-to-order (ETO) environments and even more pronounced differences compared to mass-produced goods [1]. Despite being flexible in their characteristics, products can vary in design or features according to customer requirements. Their production involves multiple components and sub-assemblies that must be coordinated across a complex chain of specialized and often geographically dispersed suppliers and subcontractors (Figure 1). This dependence on customized and complex configurations across production systems, as well as on a supply chain structured around specialized resources and processes, limits the ability to respond efficiently to demand variability.

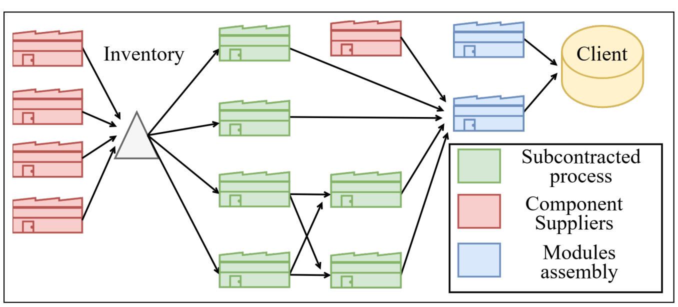

Fig. 1. An exemple of supply chain of big-size products

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ETO big-size products frequently implement modular and partially standardized product structures [2]. The combination of standardized and customized elements increases the complexity of supply chain planning. Planning must adapt to products with different engineering and production customer order decoupling points, using order-driven methods for customized items and forecast-driven methods for standardized ones [3]. Order-driven operations focus on non-standard items and follow project-based planning, whereas forecast-driven operations manage modules and standardized items using approaches that aggregate demand and capacity. Capacity planning methods, such as Sales and Operations Planning (S&OP), have been widely applied in forecast-driven environments but remain underexplored in ETO settings [4]. Despite the potential of this framework, practical methods for implementing strategic capacity planning in large-scale ETO supply chains are still limited, particularly in contexts characterized by product customization and coordination across multiple organizations.

This article develops a decision-making tool, based on a linear programming model, to assess the system's overall capacity at the strategic level for production and supply capacity planning in a big-size product supply chain within an ETO context. It identifies bottlenecks and provides insights into how capacity can be managed to meet demand. The remainder of this article is structured as follows. Section II reviews the relevant literature on supply and production capacity planning in the context of big-size products and ETO supply chain systems. Section III introduces the problem and presents the proposed linear model. Section IV details the model validation process and numerical results. Finally, Section V outlines the conclusions and perspectives of this paper.

II. LITERATURE REVIEW

A. *Characteristics of big-size products supply chains*

Big-size products are generally regarded as large-scale complex engineering systems, that are characterized by detailed technical specifications, a high degree of customization where customers actively participate in the design phase, low production volumes, and extended production cycle times [1]. Structurally, they consist of numerous non-standard components organized into large modules and multiple sub-assemblies, resulting in complex and highly structured product architectures. Big-size products are commonly found across several industrial sectors, including aerospace [5], construction [6], maritime industries [7] and the production of equipment to energy industry [8].

These product characteristics strongly influence manufacturing systems. In particular, stringent specifications and high customization often lead to complex and unique bills of materials (BOM). Such features, commonly associated with ETO and make-to-order (MTO) systems [9], impose specific operational and organizational requirements. These ETO systems are project-based organizations with parallelized processes, highly specialized labor [10], large production areas, dedicated equipment for handling materials across workstations and along the system [1]. As consequence, close coordination across sales, engineering, and production functions is also required to integrate customer requirements, engineering specifications, and production capabilities [4].

Driving these operational demands, big-size ETO companies must manage time-limited projects that, by their nature and scale, extend the operational boundaries of a single company, forming complex supply chains. These systems range from highly vertically integrated manufacturers that procure only raw materials and basic components to highly vertically disintegrated companies with fully outsourced production activities [11]. In these supply chains, it is common for corporate functions such as engineering, contracting, and production to be carried out by specialized and separate entities, with engineering and contracting firms coordinating multiple ad hoc production subcontractors. Thus, these supply chains coordinate multiple companies and production sites, integrating engineering, procurement, and manufacturing activities across organizational boundaries [12].

B. Capacity planning in ETO big-size products supply chains

To manage product complexity, ETO organizations adopt modular and partially standardized designs. Modularity relies on standardized, interchangeable, and often prefabricated units that are easy to assemble, enabling firms to anticipate certain production and supply activities and accelerate on-site assembly. In terms of production and supply management, modular designs facilitate the alignment of schedules, decision-making processes, and cross-functional coordination among engineering, supply, production, and testing phases commonly done by different companies [2]. In ETO supply chains for big-size products, this modularity can be interpreted through a two-dimensional Customer Order Decoupling Point (2D-CODP) framework , which allows the identification of different engineering and production process configurations [3].

To illustrate the 2D-CODP framework, Figure 2 presents the common ETO, Make-to-Order (MTO), Assemble-to-Order (ATO), and Make-to-Stock (MTS) configurations from a production perspective. In the context of big-size products, the figure depicts the different levels of engineering development and standardization of the supply chain of final products, modules, and components. Due to their size, final products (yellow) are typically composed of modules that facilitate handling, transportation, and storage. These modules (blue) may exhibit varying degrees of engineering standardization, ranging from fully customized designs to combinations of predefined design options. In turn, modules consist of components (pink) that generally involve lower levels of engineering development and higher levels of standardization.

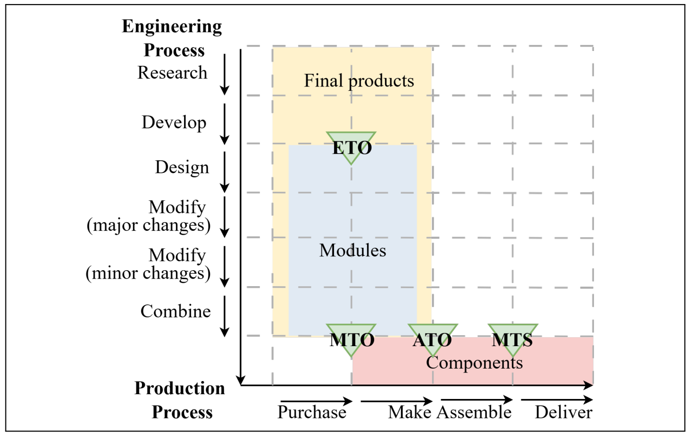

Fig. 2. 2D-CODP for big-size products. Adapted from [3]

The combination of standard and non-standard components and modules complicates supply chain planning, particularly when fabrication and assembly are outsourced. Supply chain planning therefore requires differentiated approaches, transitioning between order-driven and forecast-driven operations [3]. Order-driven operations involve non-standard items and follow project-based planning. It includes determining resource requirements by specific project characteristics and the coordination of materials, suppliers, and delivery schedules. These characteristics increase uncertainty and reduce planning visibility [13]. In contrast, forecast-driven operations, which manage modules and standard items, adopt planning approaches that aggregate demand and capacity, through methods such as S&OP. Such methods are well-established in mass-market environments; however, their application in ETO systems remains limited and insufficiently understood [4].

From a theoretical perspective, Bhalla et al. [4] propose an S&OP framework tailored to ETO environments, identifying four key sub-processes: sales planning, engineering planning, procurement planning, and production planning. Capacity planning is embedded across all four sub-processes and supports decision-making at each stage. In sales planning, capacity considerations inform the evaluation of incoming orders and the definition of project conditions, such as costs, lead times, and due dates. In engineering planning, capacity planning ensures the availability of appropriate engineering resources to perform knowledge-intensive activities following order confirmation. In supply planning, it supports the identification of capacity requirements for specialized suppliers based on the criticality of standard items. Finally, in production planning, capacity planning guides decisions on capacity allocation and outsourcing. This is especially important when product customization requires suppliers to gradually build expertise in both low-volume and large-scale production. Nevertheless, despite the relevance of this framework, there remains a need to develop approaches that operationalize capacity planning in big-size ETO supply chains and support its practical implementation in complex, multi-actor environments. To this end, in the next section a literature search is conducted to examine existing approaches for managing capacity planning problems in ETO supply chains.

C. Supply chain capacity planning problems and modeling approaches in ETO systems

The literature search was conducted in Web of Science to examine approaches for managing capacity planning problems in ETO supply chains. The search used the equation *("Capacity" AND ("Engineer-to-Order" OR "Engineering-to-Order" OR "Engineering to Order" OR "Engineer to Order") AND ("strategic" OR "tactical"))*, retrieving thirteen relevant papers, eleven of which were accessible and reviewed. The analysis of these studies identified four qualitative and six quantitative approaches, as well as a literature review. Qualitative studies relied on company surveys and case studies, while quantitative studies employed mathematical and simulation modeling techniques.

Within the qualitative approaches, Zorzini et al. [14] establish rules to assess the feasibility of accepting new orders and determining their due dates based on system workload and capacity. Whereas Zorzini et al. [15] formalize the decision-making framework for due date assignment in ETO contexts, introducing procedures contingent on the type of enquiry submission and the priority of the order. Complementing these approaches, Bhalla et al. [7] propose a theoretical model for assessing rough-cut capacity plannings for due date setting in relation with product, market, and manufacturing characteristics. While Shurrab et al. [6] identify the demand and supply characteristics associated with different CODP's and clear up their impact on supply chain complexity and demand-supply alignment. Lastly, Bhalla et al. [4], through a literature review, analyze how volume flexibility influences the customer enquiry management process and enables the provision of reliable delivery dates.

Regarding the qualitative studies, Table I summarizes their features in terms of product, system scope, decision level, and method. We identified three applied cases and two generic product cases, all of them in production systems in a tactical decision level. Concerning the product attributes among the applied studies, only Carvalho et al. [8], [16] address products that can be classified as big-size products, such as high-pressure boilers and reactors while Brachmann and Kolisch [17] focus on printed circuit boards. Several studies address tactical capacity planning problems in ETO production systems. Zschorn et al. [18] use Linear Programming (LP) to plan the required capacity of qualified personnel at a single station, to determine whether a production order can be completed within a given period. Alternatively, Brachmann and Kolisch [17] employ Mixed-Integer Programming (MIP) to schedule the start times, durations, and allocation of resources across multiple projects, accounting for flexible capacity, including deviations in working times and due dates. Carvalho et al. [8] develop a MIP model to adjust the master production plan determining the production capacity requirements that balance demand with available capacity, considering overtime, hiring, temporary workforce, subcontracting, and inventory.

TABLE I
QUANTITATIVE APPROACHES FOR ETO CAPACITY PLANNING

Ref.	Product	System Scope	Decision level	Method
[18]	Printed circuit boards	Production	Tactical	Exact: LP
[17]	Packaging machines	Production	Tactical	Exact: MIP
[8]	High-pressure boilers and reactors	Production	Tactical	Exact: MIP
[16]	High-pressure boilers and reactors	Production	Tactical	Monte-Carlo Simulation
[19]	Generic product with a deep structure	Production	Tactical	Simulation
[20]	Generic customized products	Production	Tactical / Operational	Heuristic-simulation: ALNS and GA

Based on their first work [8], Carvalho et al. [16] apply Monte Carlo simulation to account for uncertainties in production lead times whereas Hicks and Braiden [19] propose a manufacturing system simulation model for generic products with a deep product structure, integrating master scheduling, material requirements planning, assembly planning, inventory management, process planning, shop floor control, and they propose performance measurement to evaluate different scenarios. Finally, Hu et al. [20] employ heuristic simulation methods, combining Adaptive Large Neighborhood Search (ALNS) and Genetic Algorithms (GA) to determine tactical-level global resource allocation and scheduling in multi-mode ETO projects with predefined release and due dates.

Previous studies address this problem within the scope of individual production systems at a tactical level. However, none of these studies examine capacity planning from a supply chain perspective, particularly in the context of large-scale products. Due to their size and specialized processes, these products require a strategic perspective, where capacity constraints and decisions involve multiple interconnected actors. The majority of the reviewed studies focus on analyzing the impact of capacity planning on the sales planning sub-process from a project-based perspective. Their objective is to support the customer enquiry management function by evaluating incoming orders and setting due dates at the level of individual production resources. These studies have been developed for non-standard products and do not consider the management of standardized modules and components from an aggregated perspective. Therefore, this article aims to fill this gap by proposing a linear programming–based approach as a common method to represent system flows at a strategic level for production and supply capacity planning in supply chain systems, particularly for large-scale products in an ETO context.

III. LINEAR PROGRAMMING MODEL

The represented supply chain operates under an ETO strategy for big-size products. The model determines the quantities of components, sub-assemblies, modules, and finished products to study the workload of each supply and production resource. Subsection III-A describes the problem and its underlying assumptions. Subsection III-B presents the model notation. Subsection III-C details the mathematical model formulation.

A. Problem description

The problem tackles strategic-level capacity planning to support supply and production decisions in a four-tier supply chain. In this scenario a product is composed of modules, sub-assemblies parts and components. Figure 3 shows the relationship between modules, sub-assemblies parts and components through the BOM structure. The system relies entirely on outsourced procurement and production. Hence the model optimizes both inventory holding costs and the costs associated with subcontracted services and externally procured components. It considers predefined due dates, lead times, and overall product specifications.

The main objective of the model is to manage system capacity and evaluate workload distribution across supply and production resources to identify the need for additional or resized resources. In the context of big-size products, capacity management includes strategic decisions such as adding new subcontractors, engaging specialized suppliers, or establishing new large-surface warehouses. The model incorporates capacity constraints for each resource. Dummy variables are introduced to represent overload situations. Positive values of these dummy variables indicate capacity overloads in the corresponding resources, allowing potential bottlenecks to be identified. In the objective function, overload variables are assigned higher costs than real resources, reflecting the time and expense required to identify, develop, and ramp up these suppliers and subcontractors.

From a modeling perspective, although the system involves integer decision variables, it uses continuous variables as the objective is to support strategic supply and production planning rather than detailed operational scheduling. At the system level, big-size products are highly customized; however, they still share a set of well-defined and standardized production processes and components. The model adopts an aggregated representation by grouping common manufacturing processes and sharing critical components across product variants. Custom-made components are not considered. Moreover, input data variability is not considered, and all

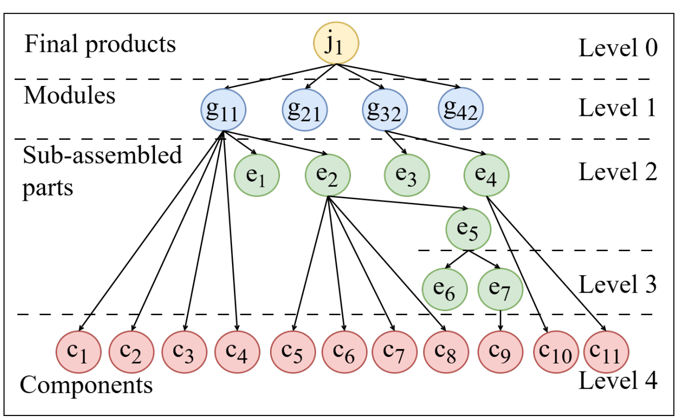

Fig. 3. Big-size product BOM (left) and its supply chain tiers (right)

parameters are treated as deterministic.

The supply chain represented operates with the following characteristics:

1) The products are large in size (approximately 120 m²).
2) The products exhibit a limited level of customization. From a production perspective, it means they are composed of differentiated modules and sub-assemblies with specific functional roles, assembled at various stages and then installed on site at the customer's location. Modules of the same type share a common BOM structure ; customized items are not considered.
3) Each predefined module may have different variants depending on customer requirements; therefore, a large number of product configurations can be processed within the supply chain system.
4) The modules follow predefined industrial process schemes with established lead times and precedence relationships. These precedences follow the structure of parents and children in the BOM, where a child can be a module, a sub-assembled parts, or a component.
5) Module and sub-assembled parts rely entirely on outsourced specialized ETO production resources. Each major process is carried out by a different company. They are often located in different geographical areas, and products are transported throughout.
6) Each company procures the main materials required for its operations according to detailed technical specifications, while key components are stored in a dedicated warehouse.
7) Due to the scale and specialization of the processes, redundant resources exist, meaning that multiple companies are capable of performing the same major production process.

B. Notations

Sets	
$\mathcal{T}$	Set of time periods (weeks)
$\mathcal{J}$	Set of finished products
$\mathcal{I}$	Set of modules
$\mathcal{G}_i$	Set of module variants for modules $i \in \mathcal{I}$
$\mathcal{E}$	Set of sub-assembled parts
$\mathcal{C}$	Set of components
$\mathcal{R}$	Set of resources (suppliers or subcontractors)
$\mathcal{P}$	Set of parents in BOM, $\mathcal{P} = \bigcup_{i \in \mathcal{I}} \mathcal{G}_i \cup \mathcal{J} \cup \mathcal{E}$
$\mathcal{K}$	Set of children in BOM, $\mathcal{K} = \bigcup_{i \in \mathcal{I}} \mathcal{G}_i \cup \mathcal{E} \cup \mathcal{C}$
$\mathcal{P}(k)$	Set of parents of a child $k \in \mathcal{K}$ in the BOM
$\mathcal{L}$	Set of parent-child pairs in the same resource location $\subset \mathcal{P} \times \mathcal{K}$
$\mathcal{T}_k^-$	Set of periods for which the lead time before period $t \in \mathcal{T}$ remains within horizon $\mathcal{T}$ $\mathcal{T}_k^- = \{t \in \mathcal{T} \mid t - LT_k \in \mathcal{T}\} \quad \forall k \in \mathcal{K}$
$\mathcal{T}_k^+$	Set of periods for which the lead time after period $t \in \mathcal{T}$ remains within horizon $\mathcal{T}$ $\mathcal{T}_k^+ = \{t \in \mathcal{T} \mid t + LT_k \in \mathcal{T}\} \quad \forall k \in \mathcal{K}$
Parameters	
LT_k	Production or procurement lead time of child $k \in \mathcal{K}$ (weeks)
$D_{j,t}$	Demand of finished product $j \in \mathcal{J}$ in period $t \in \mathcal{T}$ (units)
$\mathrm{BOM}_{p,k}$	Quantity of child $k \in \mathcal{K}$ required by parent $p \in \mathcal{P}$ (units)
$A_{k,r}$	=1 if child $k \in \mathcal{K}$ requires resource $r \in \mathcal{R}$, 0 otherwise
B_k	=1 if child $k \in \mathcal{K}$ is outsourced, 0 otherwise
V_r^{prod}	Capacity of resource $r \in \mathcal{R}$ (units)

S_i^{mod}	Storage space per unit of module $i \in \mathcal{I}$ (m²/unit)
S_k^{subcomp}	Storage space per unit of child $k \in \mathcal{E} \cup \mathcal{C}$ (m²/unit)
V_i^{mod}	Storage capacity for module $i \in \mathcal{I}$ (m²)
V_e^{sub}	Storage capacity for sub-assembled part $e \in \mathcal{E}$ (m²)
V^{comp}	Warehouse capacity for components (m²)
H_k	Inventory holding cost of child $k \in \mathcal{K}$ (€)
$O_{k,r}$	Sourcing/outsourcing cost of resource $r \in \mathcal{R}$ child $k \in \mathcal{K}$ (€)
II_k	Initial inventory of children $k \in \mathcal{K}$ (units)
Decision variables	
$f_{k,t}$	Quantity of child $k \in \mathcal{K}$ entering production at period $t \in \mathcal{T}$
$x_{k,t}$	Quantity of $k \in \mathcal{K}$ completing production at period $t \in \mathcal{T}$
$n_{k,r,t}$	Quantity of child $k \in \mathcal{K}$ sourced/outsourced from resource $r \in \mathcal{R}$ at period $t \in \mathcal{T}$
$q_{k,t}$	Inventory level of child $k \in \mathcal{K}$ at end of period $t \in \mathcal{T}$

C. Mathematical Model

$$\min \sum_{k\in\mathcal{K}}\sum_{t\in\mathcal{T}} H_k\, q_{k,t} + \sum_{k\in\mathcal{K}}\sum_{r\in\mathcal{R}}\sum_{t\in\mathcal{T}} O_{k,r}\, n_{k,r,t} \quad (1)$$

$$\text{s.t.} \quad x_{k,t} = f_{k,t-LT_k} \qquad \forall k \in \mathcal{K}, t \in \mathcal{T}_k^- \quad (2a)$$

$$x_{k,t} = 0 \qquad \forall k \in \mathcal{K}, t \in \mathcal{T} \setminus \mathcal{T}_k^- \quad (2b)$$

$$x_{k,t} + q_{k,t-1} = \sum_{p\in\mathcal{P}(k)} \text{BOM}_{p,k} D_{p,t} + q_{k,t} \quad \forall k \in \bigcup_{i\in\mathcal{I}} \mathcal{G}_i, t \in \mathcal{T} \quad (3a)$$

$$x_{k,t} + q_{k,t-1} = \sum_{p\in\mathcal{P}(k)} \text{BOM}_{p,k} f_{p,t} + q_{k,t} \quad \forall k \notin \bigcup_{i\in\mathcal{I}} \mathcal{G}_i, t \in \mathcal{T} \quad (3b)$$

$$q_{k,0} = II_k \qquad \forall k \in \mathcal{K} \quad (3c)$$

$$n_{k,r,t} = n_{p,r,t+LT_k} \qquad \forall (p,k) \in \mathcal{L}, r \in \mathcal{R}, t \in \mathcal{T}_k^+ \quad (4a)$$

$$n_{k,r,t} = 0 \qquad \forall k \in \mathcal{K}, r \in \mathcal{R}, t \in \mathcal{T} \setminus \mathcal{T}_k^+ \quad (4b)$$

$$f_{k,t} = \sum_{r\in\mathcal{R}} n_{k,r,t} \qquad \forall k \in \mathcal{K}, t \in \mathcal{T} \quad (5)$$

$$\sum_{k\in\mathcal{K}} \sum_{t'=t}^{t+B_k LT_k} n_{k,r,t'} \leq V_r^{\text{prod}} \qquad \forall r \in \mathcal{R}, t \in \mathcal{T} \quad (6)$$

$$n_{k,r,t} \leq A_{k,r} \qquad \forall r \in \mathcal{R}, k \in \mathcal{K}, t \in \mathcal{T} \quad (7)$$

$$\sum_{k\in\bigcup_{i\in\mathcal{I}}\mathcal{G}_i} S_i^{\text{mod}} q_{k,t} \leq V_i^{\text{mod}} \qquad \forall i \in \mathcal{I}, t \in \mathcal{T} \quad (8)$$

$$S_k^{\text{subcomp}} q_{e,t} \leq V_e^{\text{sub}} \qquad \forall e \in \mathcal{E}, t \in \mathcal{T} \quad (9)$$

$$\sum_{c\in\mathcal{C}} S_k^{\text{subcomp}} q_{c,t} \leq V^{\text{comp}} \qquad \forall t \in \mathcal{T} \quad (10)$$

$$f_{k,t},\ x_{k,t},\ n_{k,r,t},\ q_{k,t} \geq 0 \qquad \forall r \in \mathcal{R}, k \in \mathcal{K}, t \in \mathcal{T} \quad (11)$$

The objective function (1) minimizes inventory holding costs as well as purchasing and subcontracting costs of resources. Constraints (2) link variables f and x, representing the relationship between the quantity of a child $k \in \mathcal{K}$ entering and completing production, shifted by lead time LT_k. Flow balance ensures that demand requirements are satisfied: Constraints (3a) correspond to finished product demand, (3b) correspond to the dependent demand of modules, sub-assemblies, and components, and (3c) account for initial inventory. Constraints (4) enforce equality between two sub-assemblies (parent and child) in the set $\mathcal{L}$ that are processed by the same resource, these quantities shifted by the lead time. The relationship between the variables f, which initiate a production process, and the variables n, which represent the allocations of resources, is defined by constraints (5). The quantities of modules, sub-assemblies, and components are limited by the capacity of suppliers or subcontracted resources (6). Constraints (7) link each module, sub-assembly, and component to its corresponding resources. There are multiple resources capable to process the same item. Storage capacity constraints are imposed for modules (8), sub-assemblies (9), and components (10) stored in a shared warehouse. Finally, constraints (11) ensure the non-negativity of the decision variables.

IV. MODEL VALIDATION AND RESULTS

The mathematical model was tested using historical data from the supply chain of large and complex energy generation platforms and validated in collaboration with the company's planners. It was implemented as a linear optimization model using the Pyomo library in Python [21] and solved with the CBC solver. The model was run for a total of 52 weeks (one year), with an additional 27 weeks allocated for system preparation and stabilization. The company's portfolio included 19 final product configurations and 5 modules, each with up to 3 variants. Regarding resources, 26 subcontracted processes, 13 component suppliers, and 15 dummy resources were considered.

The model addresses decisions related to capacity: production and supply capacity, as well as storage capacity for modules, sub-assemblies, and components. Production and supply capacities (constraints 6) concern the workload of production resources, such as modules $i \in \mathcal{I}$, sub-assemblies $e \in \mathcal{E}$, as well as supply capacities of components $c \in \mathcal{C}$. Analyzing the results, 39 real resources were used, three of which (r_5, r_{15}, and r_{17}) experience slight overloads, indicating bottlenecks in the supply chain. Figure 4 illustrates the workload of resource r_5, which reaches a maximum overload of 4 units in period 59. Although additional capacity (represented by a dummy resource) is only needed from periods 59 to 62, the long lead times (28 weeks) require assigning the dummy resource in 51% of the periods starting from period 38 to ensure enough capacity by period 59. Similar analyses for resources r_{15} and r_{17} indicate maximum additional capacity needs of 4 and 1 units, respectively, which could be anticipated 5 and 6 periods in advance. The remaining 36 resources do not require additional capacity; however, during periods of maximum utilization, their workloads range from 20% to 95%, with five resources exceeding 50%. This demonstrates an imbalance in supply chain capacity usage and suggests that some resources could become bottlenecks in the future. This behavior was validated through discussions with the planners.

Regarding storage capacity (constraints 8 and 9), the model's decision is to assign zero values to the storage

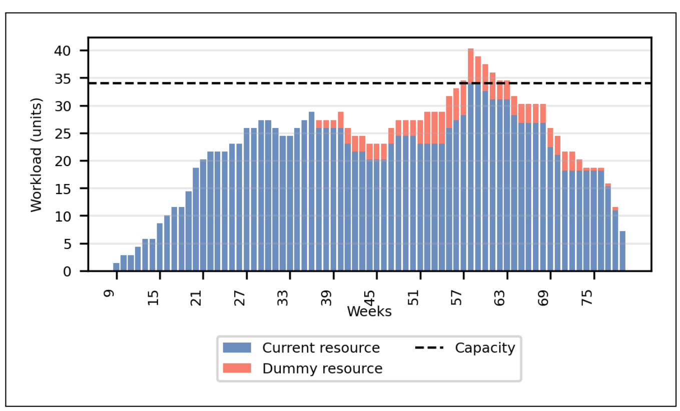

Fig. 4. Workload of resource r_5

variables q. This is explained by the high storage costs associated with these large-size products, making the storage of modules and sub-assemblies not viable. Similarly, the components storage capacity (constraint 10) is never reached. Since the model only considers key and critical components, which in reality share storage capacity with other non-critical items, the supply capacity of these suppliers is never exceeded, and the model does not plan inventory for these components.

V. CONCLUSIONS AND PERSPECTIVES

ETO big-size products require highly customized, complex supply chains, which demand specialized resources, extensive coordination, and integrated operational and organizational management. Capacity planning in these ETO supply chains is particularly challenging, as it must align demand, engineering, procurement, and production across multiple actors and outsourced activities. In this context, we do not consider any engineering tasks related to scheduling decisions. However, due to the modularity of big-size products, the production and supply of modules and standard items can be planned using approaches that aggregate demand and capacity.

Most existing studies on ETO capacity planning focus on tactical, single-system decisions, leaving a gap in strategic, supply chain-level approaches. This study addresses this gap by proposing a linear programming model for strategic capacity planning in supply chains producing big-size products. This approach to capacity management is applicable not only to finished products but also to modules, parts, and sub-assemblies with modular customization, enabling the planning of aggregated production and supply plans.

The results demonstrate the model's ability to identify both real and potential capacity bottlenecks and to analyze the workload across supply and production resources at a strategic level. These insights are crucial for supporting capacity planning and for identifying resources that may require capacity adjustments or enhanced production coordination.

From a future perspective, in the context of big-size ETO products, this model can serve as a stress-test simulator for capacity planning, allowing the evaluation of different demand scenarios and strategies to ensure long-term performance and resilience. It will support the strategic redesign of the supply chain structure in ramp-up situations. Future adaptations of the model should incorporate the capacities of critical components and order-driven components, as well as take supply uncertainty into account.

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