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Collaborative Planning in Non-Hierarchical Networks—An Intelligent Negotiation-Based Framework

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Abstract: In today's competing business market, companies are constantly challenged to dynamically adapt to customer expectations by diminishing the time response that goes from the beginning of the business opportunity to the satisfaction of the customer need. Simultaneously, there is increased recognition of the advantages that companies obtain in focusing on their core business and seeking other competencies through partnerships with other partners by forming collaborative networks. These new collaborative organizational structures require a new set of methods and tools to support the management of manufacturing processes across the entire supply chain. The present paper addresses the collaborative production planning problem in networks of non-hierarchical, decentralized, and independent companies. By proposing a collaborative planning intelligent framework composed of a web-based set of methods, tools, and technologies, the present study intends to provide network stakeholders with the necessary means to responsively and efficiently address each one of the market business opportunities. Through this new holistic framework, the managers of the networked companies can address the challenges posed during collaborative network formation and supply chain production planning.

Keywords: collaborative planning; intelligent collaborative decision making; multicriteria decision model; optimization; supply chain

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1. Introduction

As a result of the latest technological, economic, and financial changes, the market landscape has been altered, forcing company managers to reinvent the concept of enterprise. Over the past decade, a heightened level of complexity has emerged, compelling managers to place greater emphasis on the service levels they offer. This entails reducing response times and addressing the specific requirements of a growingly diverse customer base. Simultaneously, managers are comprehending the fact that market competition is shifting from company centered scenarios to supply chain networks with complex inter-organizational structures and intricate networked manufacturing processes. Consequently, the industrial sector is witnessing an increasing adoption of collaborative strategies to tackle the manufacturing complexity associated with highly customized products. This shift places a stronger emphasis on service levels and the urgent need to reduce response times.

The networked organizations that have emerged in this decade present immediate challenges in effectively managing material and information flows throughout the supply chain. These challenges are particularly crucial in demand-driven supply networks, especially for innovative and fashionable products, due to their inherent complexity and unpredictability.

The recent market characteristics are compelling independent manufacturing companies to seek out new forms of organizational structures to embody shorter lifetime existences. Due to the need for creating innovative products in shorter periods of time and with reduced costs, a new concept of cooperation between companies has surfaced, i.e., the concept of collaborative networks. This new organizational structure enhances a stronger commitment among independent companies to tackle a common business opportunity by using their complementary skills and capabilities [1–3].

Focused on integrating these collaborative networks, companies now face the challenge of organizing their internal business processes in an efficient way to promote integration and quick response inside the collaboration processes established with the other partners. These new business processes effectively demand new methods, tools, and technological solutions to cope with de networked operation environment [4].

Specifically, the business processes related to collaborative network formation and network production planning pose significant challenges. Collaborative production planning derives from the need for synchronization of a company's production plans and the necessity to manage the allocation of resources in an effective way to achieve the desired performance (price, delivery time, quality level, and others) [5,6]. Companies that embrace the challenges of distributed planning face complex and critical problems. In consequence, to maximize efficiency of their processes, they are heavily dependent on the appropriate decision support systems and optimization tools [7–9].

The main objective of the present paper, partially framed within the EU (European Union)-funded project CoReNet, is to present an intelligent collaborative planning framework for SMEs (small and medium enterprises) independent companies in collaborative networks to support network formation, network production planning, and knowledge sharing across the supply chain of innovative and fashionable products.

The present framework solution stands out for its innovative implementation of a non-hierarchical decentralized collaborative planning tool. In contrast to previous projects and research groups in the field, the current approach distinguishes itself by moving away from centralized planning decisions and embracing non-hierarchical negotiation. In reality, EU-funded projects such as OPIM (One Product Integrated Manufacturing), PRODNET II (Production Planning and Management in an Extended Enterprise), Globeman21 (Global Manufacturing in the 21st Century), ECOLEAD (European Collaborative Networked Organizations Leadership Initiative), BIVEE (Business Innovation and Virtual Enterprise Environment), and Glonet (Global Enterprise Network focusing on Customer-centric Collaboration) do not incorporate such human-assisted non-hierarchical negotiation in their planning processes.

The remainder of this paper is organized as follows: first the existing collaborative planning-related literature is reviewed as a technical background, followed by the proposal of the intelligent collaborative planning framework. Subsequently, a simplified industrial application case is presented with the follow-on case results and analysis. Lastly, conclusions and final remarks are presented concerning the intelligent collaborative planning framework's implementation and the subsequent steps planned for its improvement.

2. Collaborative Planning—Technical Background

This section presents a literature review regarding the collaborative planning approaches for hierarchical and non-hierarchical networks of companies.

2.1. Collaborative Networks

In today's fiercely competitive environment, markets are undergoing rapid transformations, fueled by customer-driven demands. Customers are seeking greater variety, uncompromising quality, exceptional service, and prompt, dependable delivery. Combined with this reality, technological developments are happening at an incredible speed, resulting in innovative products and radical transformation of manufacturing processes. These changes are shifting the way businesses and manufacturing operations are conducted in networked organizations [10,11].

In the beginning of the 2020s, companies realized the need to look beyond the borders of their own firm to their suppliers and their customers to improve market value through smarter approaches. This movement changed the company's focus from internal management of business and manufacturing processes to managing across the supply network [12].

Christopher & Peck [13] commented that one of the most profound changes in recent years was the recognition even from the largest business organizations, such as corporations, that they have only relatively few competencies in which they can be said to have a real differentiation. This recognition has resulted in a focus upon core business and a trend to seek the other competencies from other partners. The growth of partnerships has placed increasing emphasis on managing relations between partners in the organizational network.

Manders, Caniels et al. [14] summarized this new paradigm by pointing out that recent trends such as outsourcing and mass customization are forcing companies to find flexible ways to meet customer demand. This flexibility is forcing companies to migrate from traditional forms of functional commitment with focal companies in a network to scenarios where the focus is on the optimization of core activities for each partner to maximize the speed of response to changes in customer expectations.

In accordance, customer-driven supply chains are characterized by the speed at which the system can adjust its output within the available range of the external flexibility types: product, mix, volume, and delivery, in response to an external stimulus such as a customer order or a business opportunity.

Research on collaborative networks of innovative and fashionable products has identified six key phases that organizations must address to seize a specific market opportunity until the final dispatch to the customer (refer to Figure 1). Furthermore, it has revealed that each of these phases presents significant challenges in terms of time constraints, resource consumption, and complexity [15].

Figure 1. Collaborative networking manufacturing lifecycle phases.

In face of these critical impact phases, the prevailing market environment asks for flexible and reactive organizational structures which rapidly adjust to new manufacturing challenges and revise the business requirements accordingly. These new market characteristics are compelling manufacturing networks to embody shorter lifetime existences and take advantage of new infrastructure technologies to support distributed decision making, information sharing, and knowledge management [16].

2.2. Collaborative Planning

A major challenge for networked organizations in delivering products and services arises from the complexity of planning individual tasks for different operational processes. According to Proch, Worthmann, and Schlüchtermann [17], networked planning decisions include order releasing for procured material (procurement), lot sizing, production planning and scheduling, manufacturing execution control, and detailed definition of distribution flows, routes, and transport loads (distribution). Several instances of these activities are performed in different locations along each node of the supply chain. This means that each individual planning system must be aligned with the remaining systems in the network in order to deliver feasible plans. Traditionally, the only possible way to manage such supply chain planning integration was to assume a centralized planning approach that integrates all participating units. This approach relied on information systems called supply chain management (SCM) systems.

SCM systems were designed to handle data on incoming raw materials from outside suppliers, deliver data on distribution flows for customers, and synchronize internal work processes with outward flows. In practice this system is suitable for companies belonging to the same group or with a strong commitment to a supply chain "owner". On the other hand, SCM systems cannot be applied to external companies that compete in the same market and are independent.

A significant challenge arises when there is a need to link and coordinate the manufacturing operations between independent companies belonging to the same supply chain. Several authors argued in favor of a negotiated approach to achieve synchronization between production plans from each one of the companies participating in the supply chain [17–21].

Aligned with the negotiation concept, Stadler [22] introduced a coordinated scheme based on negotiations, wherein two or more decision-making units collaborate to develop synchronized production plans. This decentralized approach enables all network members to adjust their individual manufacturing plans, aiming to achieve a mutually acceptable overall plan for all supply chain partners. It emphasizes active contributions from all involved parties, in contrast to centralized planning approaches that disregard such involvement. This proposal aims to provide an overall optimized solution for a business opportunity that emerges within the context of the supply chain through effective coordination.

A consensual definition of collaborative planning (CP) was presented by Kilger and Reuter [23]. The authors defined collaborative planning as a linking of different local planning processes and domains that, through collaboration, achieve a common and mutually agreed network plan. To accomplish an overall collaborative plan, the partners share pertinent information, allowing a synchronous and accurate update of the planning results.

The main reason behind an integrated supply chain management solution for nonhierarchical and decentralized networks arises from the competitivity challenge. Through the collaborative planning approach, it is possible for these networked organizations address the following issues [24]:

- How to efficiently tackle each one of the business opportunities posed by the market with the joint competencies present in the network members.
- How to provide a transparent environment with problem solving mechanisms between the supply chain members.
- How to efficiently use the available capacity across the manufacturing stages along the supply chain.
- How to achieve global efficient solutions through the elimination nonoptimized activities.

This level of integration and coordination is only possible through the implementation of a collaborative approach among different stakeholders along the supply chain, being jointly responsible for network activities such as planning, flow management and manufacturing, and performance management. Collaborative relationships radically transform how information is shared among different partners and drives business processes to new challenges [25].

Research has shown that collaborative planning encompasses activities through which individuals coordinate their respective planning processes. Traditionally, individual companies primarily plan accordingly to their own goals; however, in cooperative relationships, they also try to take into consideration different scenarios to enable the optimization of other players' planning goals. Thus, collaborative planning processes usually consider views which enable individual managers to recognize that their own individual plans should be adjusted, not by their own selfish local criteria, but by optimized global planning goals. In essence, collaborative planning empowers individual companies to align their plans toward a shared objective, facilitating the joint optimization of planning activities across enterprise boundaries [26,27].

The journey toward adopting a collaborative planning approach has unveiled numerous challenges for individual organizations. Among these challenges, the concept of centralized planning emerges as the most significant. Typically, local production managers tend to project their own realities and argue in favor of implementing a centralized planning approach to ensure the overall success of the network planning function.

The seminal work from Breiter, Hegmanns et al. [28] raised pertinent questions regarding the suitability of a centralized planning approach, highlighting several major obstacles. The authors outlined the following challenges:

- Collaborative network partners' engagement in several supply chains: companies participate in several networks, which could generate interferences on their planning activities. To successfully manage these multi-supply-chain scenarios, a centralized approach requires to include in its planning scope all the networks involved.
- Balance between local and global plan objectives: each individual company manages their internal production plans to achieve the best performance. If these objectives are to be met, all the needed changes to obtain the global plan objectives must be negotiated and not imposed. This is especially true when the network is composed of independent companies.
- Reluctance to share information: to implement a centralized decision making, important and strategic information is needed from partners, concerning their resources and capabilities. This information is usually classified as confidential, and companies are unavailable to share it along their partners.
- Lack of acceptance of central authority models: the enforcement of central plans requires the capitulation of local autonomy, which is not welcome on the current business market.

Considering these major obstacles, the conclusion is that a centralized approach might not be the best approach to guarantee a global coordination among independent companies in complex supply chains. Alternatively, a decentralized approach without coordination mechanisms among partners might lead to nonoptimal solutions, because it will only reflect local solutions.

A dependable decentralized coordination mechanism based on negotiation might be the solution, because it aims to ensure information confidentiality, decision autonomy, and trust enrichment among supply chain partners.

When dealing with dynamic and intricate business scenarios, such as those found in the textile and footwear sectors, the centralized approach imposes various constraints. One notable constraint is the loss of local autonomy, which is typically rejected by most companies due to their segmentation, competitive nature, and rivalry.

2.3. Coordination and Collaboration through Negotiation

Several authors sustained that a decentralized planning approach with coordination among independent partners requires negotiation mechanisms [20,29,30].

Othman, Zgaya, Dotoli, and Hammadi [31] proposed an approach where they applied automated negotiations with companies or decision-making units represented as software agents as the mechanism to establish coordination in the supply chain. Negotiation is assumed as the process via which a group of agents communicate with one another to try and come to a mutually acceptable agreement on some matter.

Yang and Sun [30] also presented multiagent systems as a solution to deal with the negotiation process for collaborative planning. According to the authors, an agent is an autonomous, goal-oriented software process that operates asynchronously, communicating and coordinating with other agents as needed. The state of coordination is achieved when the agents find a jointly acceptable point in the agreement space.

Both models tackled the collaborative network coordination problem through the decomposition of the production planning model by a set of agents that represent each partner entity participating in the network. An iterative coordination scheme was proposed, defining the procedure for the exchange of the planning results, and these results were integrated as restrictions into the solving of the local models.

Although the way in which the authors dealt with the problem of decentralized negotiation was innovative, these multiagent approaches continue to face a major obstacle: partners' unwillingness to share confidential information, critical to their own business processes. Therefore, a more practical approach is required to address to the problem of decentralized production planning negotiation among independent networked companies.

3. Framework Proposal

Traditionally, for industrial companies, one of the most critical business processes is production planning. In networked organizations, the production planning function attains new levels of complexity and has a massive impact on the overall performance of the supply chain.

When addressing practical and intricate networked production planning scenarios involving innovative and fashionable products, such as those found in the textile or footwear sectors, several important issues come to the forefront. These include the preservation of local autonomy for each entity, the reluctance to subordinate to a central authority, ensuring confidentiality of business information, and fostering transparency in negotiation processes.

Starting with the issues and the requirements explained earlier regarding the decentralized collaborative problem, the present paper proposes an intelligent collaborative planning framework. The preliminary research work that resulted in the present proposal was initially based on the European Union-funded project "customer-oriented and eco-friendly networks for healthy fashionable goods (CoReNet)" that aimed to provide industry companies with the tools and methods to face the challenge of working in demand-driven and customer-oriented collaborative networks for innovative and fashionable product supply chains.

The proposed framework considered four main stages in the supply network's lifecycle (see Figure 2):

- Process planning: product designing with the identification of the internal and external components to establish the generic production process.
- Partner search: creation of a supply network, including the formalization of the contract with partners.
- Operation: collaborative planning, manufacturing, and delivery by the supply network.
- Dissolution: closure of the supply network.

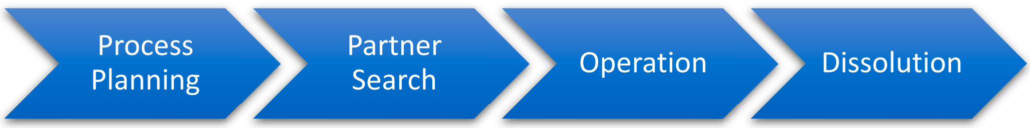

Figure 2. CoReNet framework for dynamic supply network operation.

Both the partner search and operation stages require planning procedures since a consistent and real quotation is needed to be presented to the customer, not only considering prices and materials, but also providing a delivery date or a production lead time. The related supply network planning operation needs to allow direct cooperation and collaboration among the involved partners.

The main features presented In this partner search tool are as follows:

- Search for partners on two different domains: internal (among already known suppliers) and external (internet).
- Use of syntactic and semantic engines to refine and filter search.
- Use of user-defined criteria to perform search.
- Use of mash-up services to filter results.
- Saving of results in different areas—staging area for results to be evaluated and partner area for to-be-used results.

When examining the operational phase of the supply network lifecycle, the proposed approach incorporates four primary phases within the planning sequence for supply networks:

- Partner search: creation of a supply network, including the formalization of the contract with partners and suppliers and overall process plan.

- Aggregate planning: rough production plan for customer quotation.
- Detailed planning: detailed production plan definition with optimization of costs.
- Dispatch: definition and dispatching of production orders for the entire supply network.

Both the aggregate and the detailed planning phases require decentralized collaborative planning procedures (see Figure 3) since a consistent and real quotation needs to be presented to the customer, not only considering prices and materials, but also providing a delivery date or a production lead time. The related supply network planning procedure needs to allow direct cooperation among the involved partners.

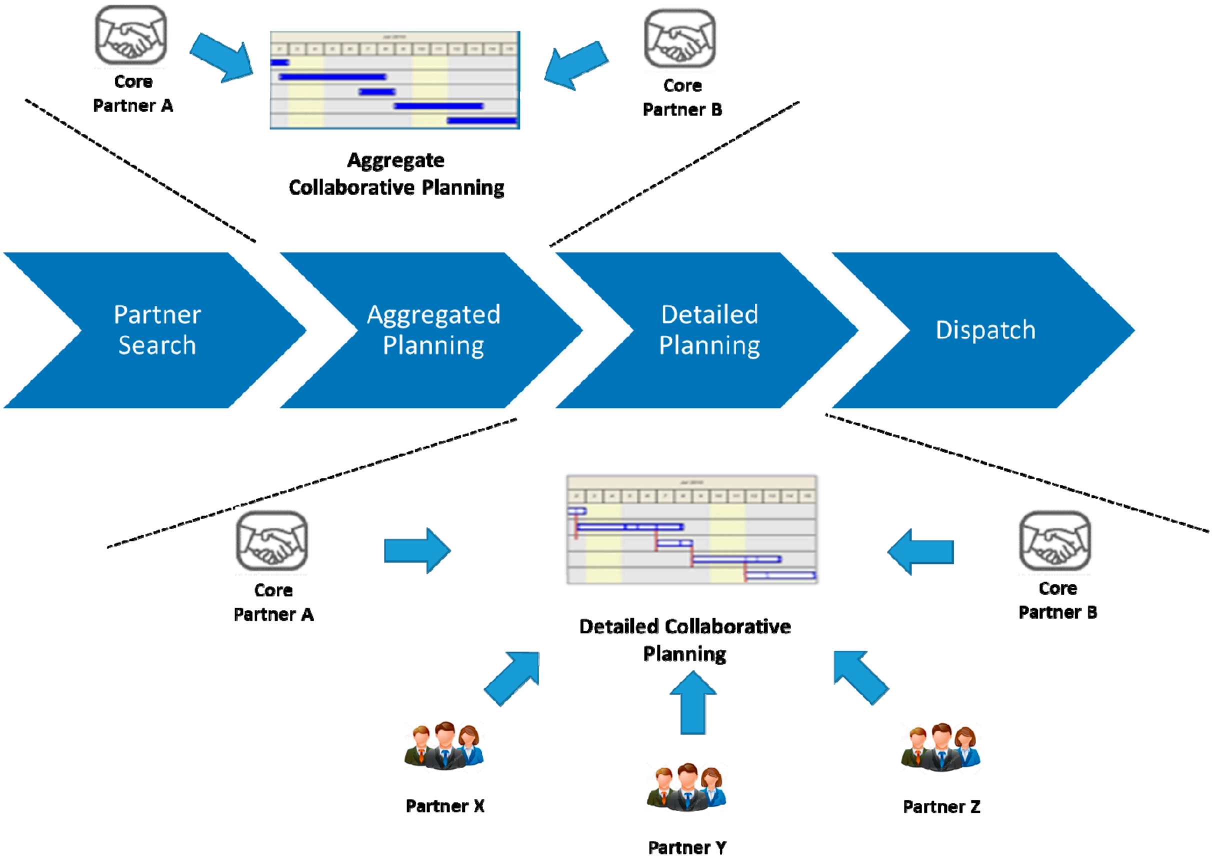

Figure 3. Description of the planning process during the supply network lifecycle.

The partner search tool developed in the project is based on the definition of partner profiles including both data provided by the supplier itself (e.g., administrative data, description of competences, and provided material or process) and data derived from the analysis of the suppliers' past behavior based on performance indicators such as the following:

- Collaboration degree: indicating how the supplier behaved in previous collaborations (e.g., number of collaborations held in the previous period and number of successful negotiations).
- Product quality: reflecting the quality of the provided products (e.g., number of defective products).
- Flexibility: describing the partner's ability to react rapidly and adapt to changes in the order or at production time.

The collaborative planning process plays a pivotal role in coordinating activities to ensure the harmonization of companies' plans, ultimately striving for collective optimization of planning across departmental boundaries. When navigating complex and practical business scenarios, such as those prevalent in the textile or footwear sectors, safeguarding the autonomy of each entity emerges as a crucial consideration. To address this concern, a novel collaborative planning concept is introduced within the framework. This concept is designed to facilitate intelligent decision making in supply network planning, drawing upon the requirements analysis gathered from the project's industrial partners.

This framework specifically targets the fulfillment of networked manufacturing requirements for innovative and complex products. The novel approach adopted is grounded in decentralized and cooperative actions, facilitated by a user-friendly interface that effectively connects stakeholders within the supply network. This web-based platform supports intricate negotiation practices, fostering collaboration among partners. Moreover, leveraging multicriteria analysis, the framework enables the establishment of assessment mechanisms for optimizing the overall supply network planning process.

The proposed approach is founded upon a decentralized negotiation model, enabling partners to suggest revised delivery dates and costs, visually represented in Figure 4.

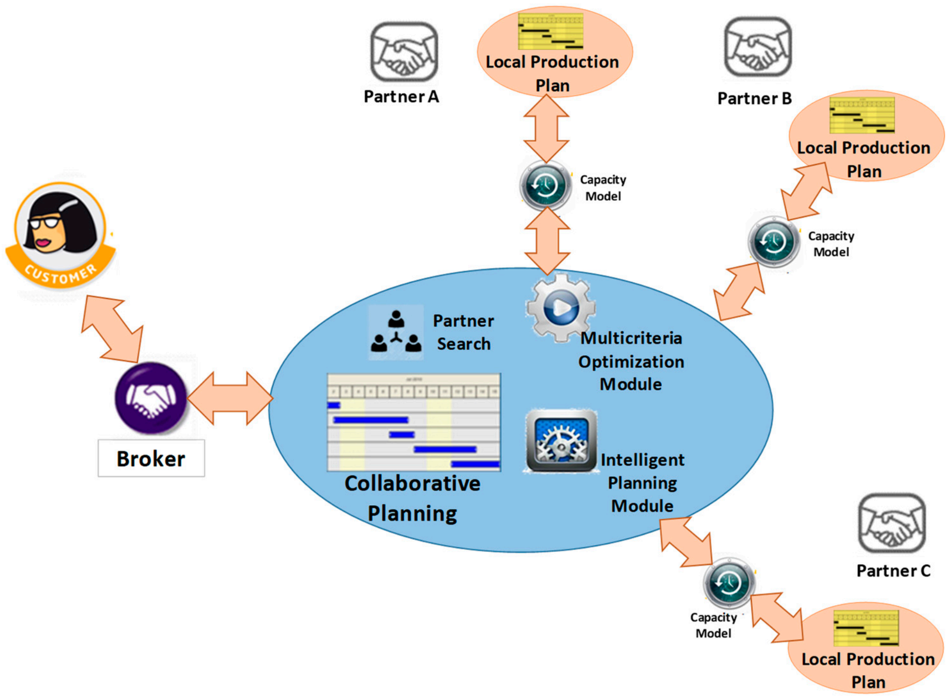

Figure 4. Decentralized collaborative planning approach architecture.

With the present approach, every business opportunity proposed by a customer can be tackled through a business front office that acts as a broker, interfacing with the collaborative network. The broker acts as a cloud service, providing the necessary tool access to assist the creation of the supply chain aimed to address the business opportunity. The event that triggers the start of the negotiation process is the submission by a partner of the technical specification form that details the characteristics of the new product and its manufacturing process on the negotiation platform. From this moment forward, the broker (web service) takes over the support of the entire negotiation process, ensuring compliance with the rules initially established in the business proposal definition. With this approach, the decision-making process is ensured on a decentralized non-hierarchical basis.

The broker starts by accessing the partner search module, which allows them to identify the list of potential partners that satisfy the business and technological requirements to participate in the collaborative network.

After the elicitation of the major requirements on the required custom-made product, the product concept/design is defined by the broker and by the new partners that are invited to join the supply network, according to their specific competencies and availability.

For the building of the collaborative plan, there are two steps: the first step aims to help the prospective partners to collaboratively define a realistic quotation and share prices, through a decentralized negotiation process, where dependencies and time overlapping between the required operations are defined.

Major problems to tackle in this planning phase are the priority rules (Who allocates? Who manages?) and the availability of partners. The planning objective is to minimize/maximize specific criteria, such as the overall cost of the supply network solution, partners' historic behavior regarding the collaboration degree, the manufacturing flexibility, and product quality, while simultaneously meeting the required delivery date.

To assure transparency in the subsequent negotiation process, the broker and the selected partners collaboratively define the criteria that will support subsequent decisions in the process, i.e., the multicriteria assessment of the plan proposals.

For the designated list of criteria items, it is possible to assign a level of significance by utilizing a percentage score as a weighting factor. This score serves as a representation of the importance assigned by the partners to each criterion, enabling them to be ranked accordingly.

The framework achieves two essential objectives through its collaborative approach to defining the criteria selection. Firstly, it enhances the transparency of the negotiation process by providing clarity on how the best solution is achieved and evaluated. Secondly, it increases the likelihood of incorporating criteria items that maximize both the potential gains for the customer's proposal and the internal efficiency of the network. This pivotal step ensures the conditions necessary for a non-hierarchical network.

Simultaneously, the networked partners mutually agree upon the conditions that determine the conclusion of the negotiation, including the designated end date and the maximum number of iterations permissible during the collaborative planning negotiation. Afterward, the broker, according to the product specification operation list, details an operation frame interval (with starting and finishing dates) for each production stage, generating an initial solution ("rough" plan).

Every partner is provided with an initial "rough" plan that outlines the time frames for each stage, accompanied by a set of requests for quotations, corresponding to the allocated operation stages. Subsequently, each partner conducts a local analysis of their production capacity to determine the feasibility of accepting the proposed dates and lead time for the specified quantity. On the basis of this assessment, a quotation is formulated, either accepting or rejecting the proposed plan, and suggesting one or more alternative options for the request.

Based on these quotation responses, the negotiation process continues through the identification of the possible best solutions and evaluating them according to the agreed criteria. Subsequently, leveraging the previous responses, the framework initiates another iteration by intelligently refining the proposal framing, taking into account the assessment of the available information. It then proceeds to send a new set of requests for quotations, allocating one for each operation stage to each partner.

The negotiation process continues until the end negotiation conditions are met, the negotiation period terminates, or the maximum number of iterations is completed. Subsequently, the best evaluated solution according to the agreed multiple criteria is selected, and the corresponding response to the customer is sent.

3.1. Intelligent Collaborative Planning Framework

The proposed intelligent collaborative planning framework is intended to help companies support the demand of short lifecycle products such as innovative and fashionable products. It is a result of a literature and sector case analysis and is focused on developing a practical operational alignment for supply chain configuration and operation planning at an aggregated level.

Figure 5 presents the overall view of the intelligent collaborative planning framework proposal presenting its main elements. The collaborative planning framework is composed of the actors or roles, the methods and functionalities, and the set of tools.

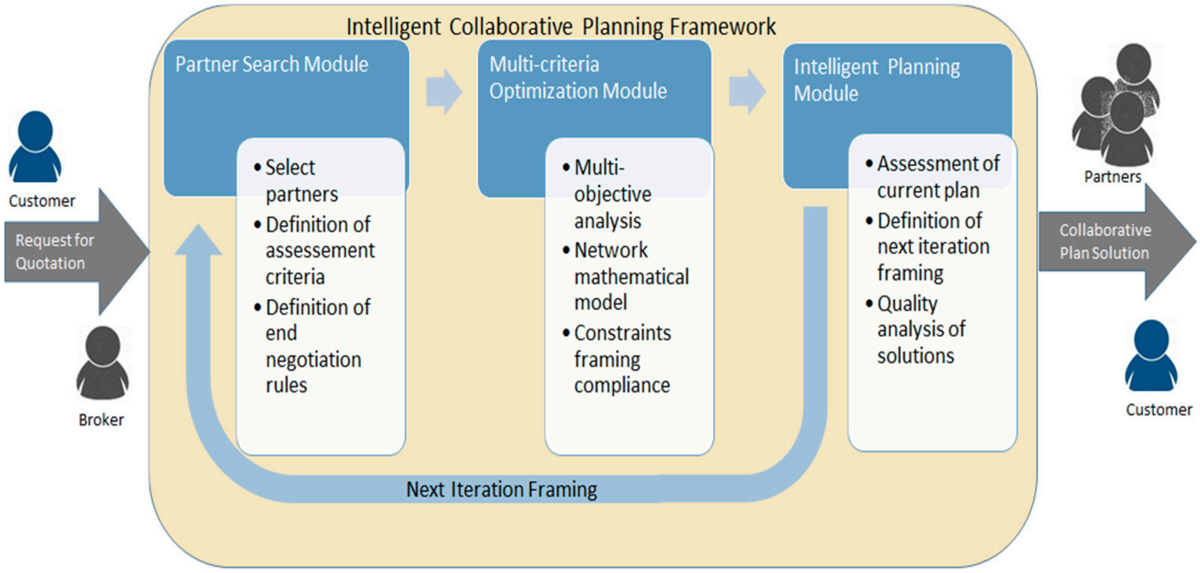

Figure 5. Intelligent collaborative planning framework.

The framework integrates the following elements:

- Actors—identifies and characterizes the entities that participate in the collaborative negotiation process and their role.
- Methods—comprises the procedures, techniques, and approaches required to implement the intended functionalities.
- Toolset—the set of software tools and modules that provide the required functionalities.
- Regarding the actors, the framework identifies the following roles:
- Customer—entity that generates the business opportunity by creating a quotation request for the collaborative network in which it is defined the product or service requirements;
- Broker—entity that acts as a front-office support with the customer and coordinates in a decentralized way the collaborative negotiation process;
- Partner—entity involved initially in the negotiation for the formation of the supply chain and subsequently with the participation in the networked manufacturing process.

Concerning the methods definition, the framework includes the following procedures:

- Partner selection—mechanism that supports partner profiling and searching capabilities to support the set-up of supply chains;
- Definition of assessment criteria—method that collaboratively establishes the criteria for the evaluation of the possible solutions;
- Definition of end negotiation rules—mechanism that allows the closing of the negotiation process when the established conditions are met;
- Multi-objective analysis—since the assessment of the possible planning solutions is based on a multicriteria approach, the multi-objective analysis provides the adequate evaluation;
- Network mathematical model—a multistage process mathematical model supports the identification of optimal solutions for the selected assessment criteria;
- Constraint framing compliance—given that production planning in collaborative networks involves multistage manufacturing operations, it is necessary to ensure that stage operations do not overlap, and that transit intervals are considered;
- Assessment of current plan—since the collaborative negotiation process is based on trust, the procedure assessment of each possible planning solutions is performed transparently using the defined criteria;
- Definition of next iteration framing—since the collaborative planning negotiation process is performed iteratively, and the challenge is to reduce the number of iterations (with the consequent request for quotation and response from each partner), the aim of

this procedure is to define an intelligent definition of next iteration multistage framing dates for each partner's request for quotation.

- Quality analysis of solutions—using the multi-objective analysis and the relevant data collected during the negotiation, this procedure allows a quality evaluation of the solutions obtained and a subsequent update of the relevant indicators for each partner.

Concerning the Toolset, the framework contains the following tools:

- The partner search module—tool that facilitates the search, negotiation, and selection of potential partners for each stage of the manufacturing process of the customer-requested product.
- Multicriteria optimization module—tool responsible for multicriteria analysis of the multistage partners' proposals using an optimization approach to identify the best solutions.
- Intelligent planning module—tool responsible for evaluating the multicriteria optimization solutions and propose new time frame proposals in the iterative negotiation process.

Below, the multicriteria optimization module and the intelligent planning module are explained in detail.

3.2. Multi-Objective Optimization Module

This module aims to seek optimal solutions in each phase of the negotiation, taking into account multiple assessment criteria such as cost, due date compliance, and partner KPIs. In each phase, each combination of partner proposals corresponds to an alternative plan. The selection of the alternative plans considering multiple conflicting criteria can be formulated as a multi-objective optimization problem. The multi-objective mathematical formulation of the partner's selection problem considering the cost, the collaboration degree, and the quality certification as criteria can be expressed as follows:

$$\text{Min} f_1(x) = \sum_{i=1}^{n} \sum_{j=1}^{m} \sum_{k=1}^{l} c_{ijk} x_{ijk} \text{ COST}, \tag{1}$$

$$\max f_2(x) = \sum_{i=1}^{n} \sum_{j=1}^{m} f_{ij} \sum_{k=1}^{l} x_{ijk} \text{ COLLABORATION}, \tag{2}$$

$$\max f_3(x) = \sum_{i=1}^{n} \sum_{j=1}^{m} q_{ij} \sum_{k=1}^{l} x_{ijk} \text{ QUALITY}, \tag{3}$$

where n is the number of partners, m is the number of phases, and l is the number of proposals of each partner in the stage. There are three objectives to optimize: minimization of the cost ($f_1(x)$), maximization of the collaboration degree ($f_2(x)$), and maximization of the quality certification ($f_3(x)$). In this model, c_{ijk} denotes the costs of proposal k in phase j and partner i; f_{ij} and q_{ij} are, respectively, the collaboration degree and quality certification of partner i in phase j. The binary decision variable x_{ijk} indicates if proposal k in phase j and partner i is selected.

The constraints of the model are as follows:

- To impose that just one proposal is selected for each phase,

$$\sum_{i=1}^{n} \sum_{k=1}^{l} x_{ijk} = 1, \ \forall j \in \{1, \ldots, m\}; \tag{4}$$

- To guarantee that the proposal selected in each phase does not overlap in time with the selected proposal of the next phase (precedence constraint),

$$\sum_{i=1}^{n} \sum_{k=1}^{l} \left(t_{ijk} + d_{ijk} \right) x_{ijk} \leq \sum_{i=1}^{n} \sum_{k=1}^{l} t_{ij+1k} x_{ij+1k} , \ \forall j \in \{1, \ldots, m-1\}, \tag{5}$$

where t_{ijk} and d_{ijk} are, respectively, the initial date and duration of the proposal k in phase j and partner i;

- To guarantee that the due date of the project (T) is satisfied,

$$\sum_{i=1}^{n}\sum_{k=1}^{l}(t_{imk}+d_{imk})x_{imk} \le T; \tag{6}$$

- To define the decision variables as binary values, where 1 means that the proposal is selected and 0 that the proposal is not selected,

$$x_{ijk} \in \{0,1\}\ \forall i = 1,\ldots,n\ \forall j = 1,\ldots,m\ \forall k = 1,\ldots,l. \tag{7}$$

This problem has a combinatorial nature, and the aim is to identify, from the set of all feasible alternative plans, those that are efficient. The multiple conflicting criteria of the problem give rise to the existence of a set of efficient solutions known as the Pareto-optimal set. A solution is Pareto-optimal if there is no other solution that dominates it, i.e., none of the objectives can be improved without deteriorating at least one of the other objectives. Pareto-optimal solutions are incomparable and define a Pareto-optimal frontier in the objective space representing different tradeoffs among objectives.

The multi-objective optimization problem can be reformulated as a single objective optimization problem using scalarization methods by introducing some weights. Different weight combinations allow computing an approximation to the Pareto-optimal set using a single objective optimization method [32]. In order to search for efficient plans, the weighted sum method with different combinations of normalized weights was implemented. Moreover, since the objectives have different magnitude scales, normalization was performed for each objective. The normalized objective function for objective s is given by

$$F_s(x) = \frac{f_s(x) - m_s}{M_s - m_s},\ \ s \in \{1,2,3\}, \tag{8}$$

where $f_s(x)$ is the s objective function for each objective (see Equations (1)–(3)), m_s and M_s are, respectively, approximations to the minimum and maximum values of $f_s(x)$. It should be stressed that these extreme values can correspond to infeasible solutions of the optimization problem, and they are computed just for normalization purposes. Thus, the normalized objective function for cost $F_1(x)$ is computed considering $m_1 = \sum_{j=1}^{m} \min_{i,k} c_{ijk}$ (the sum, for all phases, of the minimum cost values) and $M_1 = \sum_{j=1}^{m} \max_{i,k} c_{ijk}$ (the sum, for all phases, of the maximum cost values). A similar procedure is used to compute the normalized objective functions for collaboration degree $F_2(x)$ and quality certification $F_3(x)$, i.e., considering approximations to the extreme values of the objectives (for collaboration degree, $m_2 = \sum_{j=1}^{m} \min_{i} f_{ij}$ and $M_2 = \sum_{j=1}^{m} \max_{i} f_{ij}$; for quality certification, $m_3 = \sum_{j=1}^{m} \min_{i} q_{ij}$ and $M_3 = \sum_{j=1}^{m} \max_{i} q_{ij}$).

The single-objective optimization problem obtained by the application of the weighted sum method to the normalized objective functions corresponds to the minimization of the aggregated function $f_{\mathrm{a}}(x)$:

$$\min f_{\mathrm{a}}(x) = w_1F_1(x) - w_2F_2(x) - w_3F_3(x), \tag{9}$$

where w_1, w_2, and w_3 are the normalized weights ($w_1 + w_2 + w_3 = 1$). The maximization objectives were converted into minimization ones by negating the corresponding objective function. The solutions obtained for different combination of weights are taken into consideration to perform the decision-making process. It should be noted that the efficient set is, in general, a smaller set when compared with the set of all feasible solutions. Moreover, this set contains only nondominated solutions, i.e., the Pareto-optimal solutions that are the plan alternatives to be considered in the decision-making process. All the other feasible solutions (dominated solutions) are not relevant since they are not optimal alternatives. Therefore, in each iteration, multicriteria decision analysis is applied to select one of the solutions of the efficient set obtained by multi-objective optimization. This analysis takes into consideration the assessment criteria and the negotiation rules previously established with the partners.

3.3. Intelligent Planning Module

The intelligent planning module was designed to allow the decentralized collaborative planning negotiation process to improve as quickly as possible, in each iteration, the quality of the framing dates proposals and, as a result, achieve better solutions for the overall collaborative plan.

As each partner participating in the negotiation is not willing to disclosure their capacity model information to the network partners, the responses to the brokers' request for quotation are discreet and limited in number. This means that each partner is only available to participate in a small number of requests for quotation, and, when that number is exceeded, the partner loses interest in the negotiation process.

From the interviews on the industrial partners involved in the research project, it was concluded that, on average, each partner would only be available to respond to a maximum of five requests for quotation for each business opportunity.

Considering the presented requirements, to the collaborative planning framework provide improved solutions, it needs to present intelligent features that would allow, in a small number of iterations, to improve the collaborative plan solutions in terms of the multicriteria evaluation.

Aligned with this view, different strategies have been designed and evaluated for the intelligent planning module, using the limited information available on each iteration. Through this intelligent approach, it is possible to make the process of defining new framings more efficient when compared with the traditional random approach.

Table 1 presents the list of the implemented strategies for the intelligent planning module.

Table 1. Intelligent Planning Module Strategies.

Strategy	Next Frame Proposal Based in
Average	Average values of previous replies
Weighted average	Weighted average values of previous replies
Best proposal	Previous best proposal
Genetic approach	Crossover of previous best proposals

Each one of the implemented strategies takes into consideration specific aspects that potentially could generate a path of improvements in the collaborative planning solutions. The aspects that backed up the development of proposed strategies were as follows:

- Average—in the studied industrial sectors, a large number of partners present similar seasonal load patterns; therefore, the average value of the partners' quotation replies tends to converge to periods of lower load in the capacity models and as a consequence of lower cost;
- Weighted average—this strategy substantiation is similar to the average strategy but, in order to value the lower cost of responses, takes into account the weighted average of the inverse of the cost on each previous iteration response;
- Best proposal—this strategy assumes that the best previous iteration response is a good suggestion for the next framing iteration;
- Genetic approach—this strategy is inspired in the genetic algorithm (GA) metaheuristic approach. This strategy approach uses the bio-inspired selection and crossover operators. It starts by selecting the best previous iteration solutions and then performs a crossing over operation, mixing these best solutions in hope to obtain better solutions in the next iteration.

The developed strategies in the intelligent planning module were essentially conceived from the empirical experience of the planning managers of the collaborative networks studied.

This module integrated in the collaborative planning framework was designed as a decision support tool and allow the application of a set of strategies to define the stage intervals accordingly to the choice of the broker process manager.

3.4. Collaborative Planning Service

The collaborative planning service is a web-based tool implemented on the Liferay portlet container platform. It functions as a versatile portlet, providing distinct web-based views tailored for specific user groups/roles. These views facilitate user interaction through the collaborative planning tool, as illustrated in Figure 6.

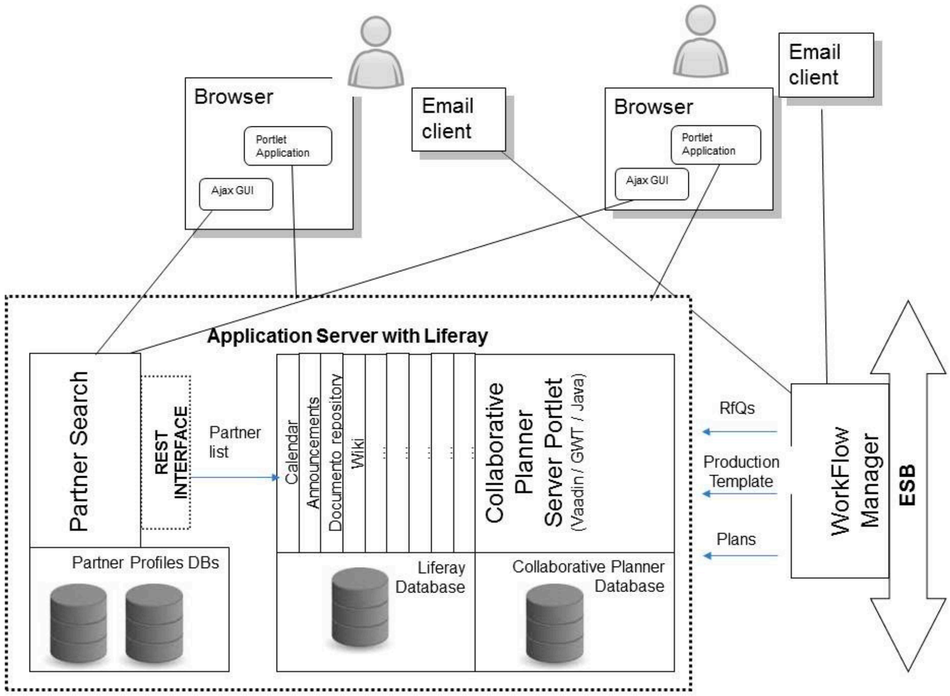

Figure 6. CoReNet framework architecture diagram.

The diagram illustrates the technical decisions made for the integration of the tools developed to facilitate the network design and setup for collaborative planning.

To provide end users with seamless access, the application was made available through a centralized access point, leveraging the capabilities of the Liferay portal. This portal enhances the services by incorporating social networking functionalities and advanced communication services, enabling activities such as commenting, ranking, reporting bugs, and seeking assistance.

The proposed approach offers numerous benefits to manufacturers and suppliers in the textile and footwear sectors seeking agile solutions for order management and collaborative production planning processes, particularly for the production of small series of innovative and fashionable products.

In fact, the solution provides the following advantages:

- The solution is readily accessible and user-friendly, as the tools offer an advanced graphical user interface (GUI) and are conveniently accessible within a unified portal, eliminating the need for complex installations.
- It facilitates the exchange and automatic verification of business information through familiar channels such as email, effectively concealing the technical intricacies associated with the internal format of exchanged documents.
- It aids in partner selection by leveraging the manufacturer's existing information and fosters an open collaborative environment for jointly planning and agreeing upon production plans with the selected partners.

The collaborative planning framework empowers each partner to directly propose new delivery dates, lead times, and costs through a shared web-based planning graphical tool accessible to all supply network partners. Whenever a partner suggests a change to a specific operation, it effectively requests the affected partner to accept the change and declare its associated cost or present a counterproposal.

Each negotiation round corresponds to a predefined time period dedicated to discussing and negotiating delivery times and costs, enabling partners to submit quotations for each request for quotation (RfQ) initiated by other partners.

Each proposed change "triggers" RfQs among all involved partners, prompting them to submit quotations that fully or partially address the requested RfQ or even propose further modifications. Once a proposal attains 100% agreement among all partners (i.e., no pending notifications), it is considered a plan. However, any supply network partner can still modify the plan within the negotiation time period.

In each negotiation iteration, the intelligent planning module suggests a revised stage framing, generating optimized responses through the multicriteria optimization module. This enhances the solutions offered throughout the collaborative planning process.

These collaborative plans are serialized on the basis of a predetermined set of criteria established by the broker and partners. For each criterion, the degree of importance can be defined using a percentage score as the final weighting factor, which determines the best partner proposal. This approach ensures that each criterion carries a distinct level of importance, expressed through a ranking system.

4. Application Case—Analysis and Results

The objective of the current section was to present and explain the approach through a simplified version of a practical case.

4.1. Application Case Description

In order to test and validate the intelligent collaborative planning framework proposal, an application case based on the footwear sector industry was constructed. This application case scenario considered a three-stage production process. For each one of the production stages, the partner search module identified four potential partners with the relevant KPIs presented in the Table 2. The list of KPIs presented in the Table 2 is indicative and defined according to the characteristics of the business opportunity, the potential customer requirements, and the agreement of the partners invited to enter the negotiation process. In reality, the negotiation platform has more than 100 assessment KPIs that cover aspects such as collaboration degree, technical expertise, product quality, delivery, cost, flexibility, and environmental practices.

Initially, the broker and the selected partners collaboratively define the criteria that will support subsequent decisions in the process, i.e., the multicriteria assessment of the plan proposals.

In the present application case, the collaboration degree presents the partners' historical assessment from other partners that were involved in previous projects. The quality certification is a binary assessment (1—yes; 0—no) that establishes if the partner has a quality certification desirable for that particular product. The third criterion chosen for the application case was cost. In this case, the cost is a function of the partner's capacity model (refer to Section 4.2) and the corresponding time period for the quotation request in the negotiation process. Table 3 presents the selected criteria and the corresponding weight.

Based on the weight values assigned to each evaluation criterion, the minimization process is carried out using the objective function defined in Equation (9), while ensuring the delivery deadline as a hard constraint. For each evaluation criteria, the normalized objective function is determined according to Equation (8).

However, interpreting the values derived from the normalized objective function for each optimal solution, during every iteration of the negotiation process, can pose understanding problems for the various partners involved.

Table 2. General information.

Information about Partners			
	Collaboration Degree	Quality Certification	Cost
Partner 1	90	1	$f\left(load_{partner1}, t\right)$
Partner 2	100	1	$f\left(load_{partner2}, t\right)$
Partner 3	95	0	$f\left(load_{partner3}, t\right)$
Partner 4	85	0	$f\left(load_{partner4}, t\right)$
Partner 5	75	1	$f\left(load_{partner5}, t\right)$
Partner 6	82	1	$f\left(load_{partner6}, t\right)$
Partner 7	85	0	$f\left(load_{partner7}, t\right)$
Partner 8	90	0	$f\left(load_{partner8}, t\right)$
Partner 9	100	1	$f\left(load_{partner9}, t\right)$
Partner 10	95	1	$f\left(load_{partner10}, t\right)$
Partner 11	90	0	$f\left(load_{partner11}, t\right)$
Partner 12	85	0	$f\left(load_{partner12}, t\right)$

Table 3. Selected evaluation criteria.

Parameter		Weight	Option Selected	Formula
Cost		0.7	Cost->Vector normalization	(1/value)/(1/minimum)
Partner	**Quality**	0.1	Benefit->Linear Normalization	value/maximum
	Collaboration	0.2	Benefit->Linear Normalization	value/maximum

To facilitate the multicriteria analysis and support decision making, a normalization criterion is utilized during the serialization process to assess all optimized alternative collaborative plans. In this case, linear normalization was chosen, utilizing the following transformations for cost $C(x)$ and benefit $B(x)$ to handle minimization and maximization criteria, respectively (see Equations (10) and (11)):

$$C(x) = \frac{\frac{1}{x}}{\frac{1}{m_{\text{ND}}}} = \frac{m_{\text{ND}}}{x}, \tag{10}$$

$$B(x) = \frac{x}{M_{\text{ND}}}, \tag{11}$$

where m_{ND} and M_{ND} are the minimum and maximum objective function values of non-dominated solutions found in the multi-objective optimization process. A weighted value function $V(x)$ is computed to score all nondominated solutions found in each iteration:

$$V(x) = W_1 C(f_1(x)) + W_2 B(f_2(x)) + W_3 B(f_3(x)), \tag{12}$$

where W_1, W_2, and W_3 are the weights established with the partners; values $f_1(x)$, $f_2(x)$, and $f_3(x)$ correspond to $f_s(x)$ in Equation (8). The assessment of solutions according to the value function results in values in the interval between 0% and 100%, which characterizes the score of each one of the alternative plans. The highest value corresponds to the best collaborative plan.

Table 4 presents an evaluation of five alternative plans, considering the agreed criteria, which consider the cost, collaboration degree, and quality certification. The data presented in Table 4 are based on a test case with the participation of partners from the project. In the presented application case, the scores for the alternative plan 1 involving 1, 5, and 10 partners were cost = 2400 (with best minimum = 2360), collaboration = 250 (with best minimum = 245), and quality = 2 ((with best maximum = 3). After normalization, the following values were obtained: cost = 0.9833 (2360/2400), collaboration = 0.8621 (250/290) and quality = 0.6667 (2/3). Finally, the plan score is obtained through the weighted average of these three normalized KPIs.

Table 4. Evaluation criteria for alternative plans.

Normalized Decision Matrix					
	Cost	**Collaboration**	**Quality**	**Partners**	**Plan Score**
Alternative Plan 1	0.983333333	0.862068966	0.666666667	1;5;10	92.741%
Alternative Plan 2	1.000000000	0.879310345	0.333333333	3;5;11	90.920%
Alternative Plan 3	0.973009447	0.862068966	0.666666667	3;5;10	92.019%
Alternative Plan 4	0.990070922	0.862068966	0.666666667	1;6;11	93.213%
Alternative Plan 5	0.993226899	0.862068966	0.666666667	1;5;12	93.434%

4.2. Capacity Models

In order to allow the effective testing of the intelligent collaborative planning framework in the application case scenario, the implementation of capacity models that could reflect each partner behavior during the negotiation was required. Since this capacity model information was considered confidential by the industrial partners in the project, an approximated static capacity model was developed for each one of the involved partners.

Using the experimental approach presented by Witte [33], each one of the capacity models followed the behavior presented in the load chart represented in the Figure 7. The author sustained that static capacity modeling can simplify the data collection and the validation effort necessary to respond to the market demand.

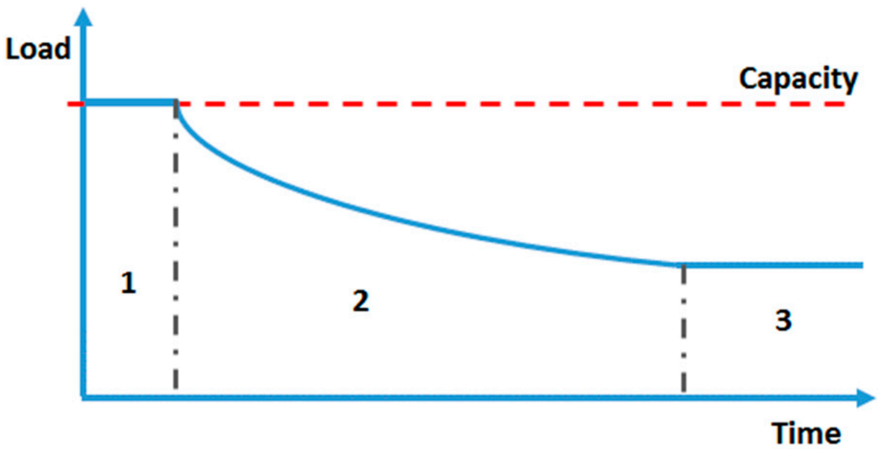

Figure 7. Static capacity model for partners.

In reality, the concept is very straightforward. In the time horizon considered, it is possible to establish a relationship between the demand load and the cost reply for quotations. By analyzing the planning time horizon, it is possible to identify three areas. The first area corresponds to the short-term period where the production capacity of the partner is totally committed and the cost of producing in this period is higher. In the second area, a medium-term period, the load usually decreases over time, and the corresponding cost reply for quotations from the partner follows the same trend. On the other hand, the third zone corresponds to a long-term period where the capacity load is minimal, and the cost reaches its structural minimum.

Based on the described approach, and using some individual replies provided by the project industrial partners, it was possible to define the necessary capacity models used in the application case.

4.3. Multicriteria Optimization

The multi-objective optimization module was implemented in MatLab version R2015a [MatLab]. The optimization problem was coded in MatLab language and solved using the intlinprog function provided in the Optimization Toolbox version 7.2. This function implements the branch-and-bound algorithm for linear integer programming problems. Different uniformly varied combinations of weights allow obtaining different nondominated solutions that approximate the Pareto-optimal set.

The nondominated solutions found during the multi-objective optimization process correspond to different tradeoffs of the objectives. Each one is an alternative plan that has to be chosen. The multicriteria analysis allows selecting one of these solutions by the computation of value function according to the weights established with partners. For illustration purposes, in Figure 8, the nondominated solutions obtained on the fifth iteration of the negotiation are plotted in terms of cost, collaboration level, and quality certification.

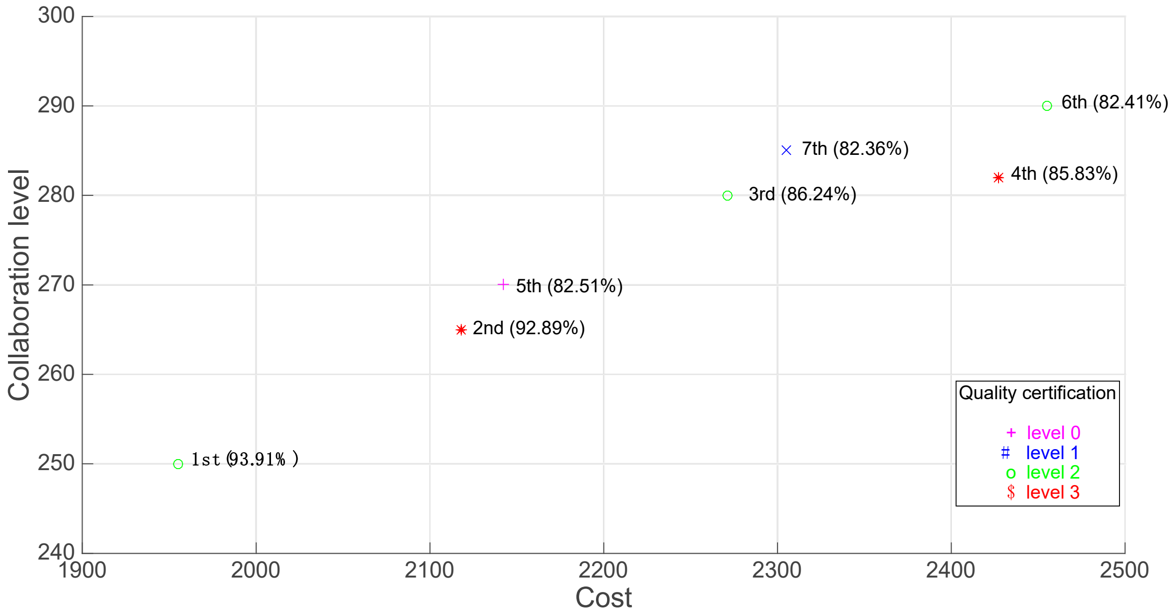

Figure 8. Multicriteria analysis of nondominated solutions.

It should be noted that the partner selection problem has a combinatorial nature, and there are a large number of different feasible solutions. The multi-objective optimization process allows finding the nondominated set. Since this is, in general, a small set, the decision-making process is simplified. Moreover, it is assured that the decision-making process is restricted to optimal solutions, and the tradeoffs among solutions can be inspected. It can be observed there are three solutions for the quality certification level 2, two solutions for level 3, one solution for level 1, and one solution for level 0.

It can also be seen that these solutions represent different compromises between cost and collaborative degree. For each solution, the score is indicated in terms of value function computed with the weights $W_1 = 0.7$, $W_2 = 0.2$, and $W_3 = 0.1$, as well as the corresponding order. The selected solution is that on the bottom left side of the graph with a score of 93.91%. The cost, collaboration level, and quality certification values are 1955, 250 and 2, respectively.

4.4. Intelligent Planning Approaches

As presented in the intelligent collaborative planning framework description, the intelligent planning module is intended as a facilitator in the iterative search for better collaborative planning solutions. This module works as feedback mechanism where the optimized outputted solutions of the multicriteria optimization module are analyzed, transformed, and routed back as inputs to the circuit of the collaborative planning negotiation in the next iteration as part of a cause-and-effect loop.

Since the negotiation process of creating the overall supply chain plan relies on the minimization of the number of requests for quotation (RfQ) for every potential partner, the approach of defining new framings is a critical step.

Using the four implemented strategies for the intelligent planning module (see Table 1) it was possible to assess the rate of improvement of the multicriteria evaluation of the optimized alternative collaborative plans on each iteration.

Table 5 presents the intelligent planning module results comparison for each strategy on each iteration using a uniform normalization procedure. The initial values for the temporal frames used in the RfQ were the same for all four approaches, which led to an initial set of results similar for all four strategies after the plan optimization. For the second and subsequent iterations, a new temporal frame was defined for every RfQ according to the applied strategy. Table 5 presents the normalized plan assessment score in each strategy approach through the five iterations.

Table 5. Intelligent planning strategy results comparison.

Intelligent Planning Strategy	Average	Weight Average	Best Proposal	Genetic Approach
Iteration 1	0.7984971	0.7984971	0.7984971	0.7984971
Iteration 2	0.8219750	0.8559725	0.8457682	0.8371205
Iteration 3	0.8430391	0.8651374	0.8799396	0.8753838
Iteration 4	0.8738795	0.8774835	0.9137538	0.9014386
Iteration 5	0.8886209	0.9038363	0.9390805	0.9258324

By analyzing the application case parameters for each strategy approach, it becomes evident that all four strategies examined in the intelligent planning module yielded noteworthy enhancements throughout the negotiation process. Particularly, in the fifth iteration, the results demonstrated a maximum deviation of less than 5.4% between the worst and best outcomes achieved.

The best strategy approaches were the "best proposal" and "genetic approach", where the results differences were less than 1.5% in the multicriteria evaluation score.

4.5. Overall Results

The initial analysis of the results in the application case revealed that the proposed framework yielded promising outcomes. Coincidently, the feedback from the project's industrial partners' assessment of the framework was very positive.

The analysis of Table 6 shows that, depending on the number of iterations in the negotiation of the collaborative plan, different strategies generate different outcomes. In the present application case for two iterations, the "weight average" strategy presented the best results.

For a higher number of iterations, the best performing strategy turned out to be the "best proposal". Nevertheless, all four of the empirical strategy proposals presented promising results.

Table 6. Iteration improvement of collaborative planning evaluation.

Intelligent Planning Strategy	Average	Weight Average	Best Proposal	Genetic Approach
Iteration 2	3.25%	7.28%	5.86%	4.80%
Iteration 3	5.69%	8.11%	10.14%	9.62%
Iteration 4	9.63%	9.68%	14.37%	12.90%
Iteration 5	11.51%	13.04%	17.54%	15.97%

A preliminary analysis, using the Delphi approach, based on a results discussion with the participants in the project, points to two explanations. First, since the supply chain studied has seasonal demand peaks and the load is shared among the competitors, the strategy approaches that seek to dynamically move away faster from the overload periods present better results (i.e., best proposal). Second, not every partner is really committed in competing for a business opportunity. This means that the strategic approaches that favor the best competitors tend to obtain best results faster (i.e., best proposal and genetic approach).

The final analysis of the results shows that, although the complexity of the multisite planning task of a collaborative network is very high, the present framework proposal has advantages compared to the traditional centralized and multi-hierarchical negotiation approach.

Using the feedback loop enabled the system to learn from previous responses and to generate better results in an intelligent way.

5. Conclusions and Further Developments

The case of collaborative networks involving independent SMEs needs to consider cross-sector interactions since some activities such as customer requirements analysis, product and process design, production planning, and product delivery need to be synchronized and collaboratively integrated.

The proposed intelligent collaborative planning framework aims to offer a practical and integrated set of methods, tools, and web-based technologies to assist independent SMEs to integrate and engage collaborative networks.

The already concluded European project called "customer-oriented and eco-friendly networks for healthy fashionable goods (CoReNet)" provided the initial momentum and valuable knowledge for the development of this framework.

One of the major outcomes of the CoReNet project was the development of a web-based platform where the actors involved in the collaborative network activities could find information, interact, and obtain support and easy access to the tools developed and configured within the collaborative community.

The collaborative platform evolved with further development work and subsequently included the designed methods and tools proposed in the intelligent collaborative planning framework. The current demonstration version of the web-based collaborative platform is now able to support the set of collaborative services comprised in this framework.

The novelty of the present framework solution derives from the implementation of an innovative non-hierarchical decentralized collaborative planning tool. This tool links a multicriteria optimization mathematical algorithm with an intelligent planning module, which feeds the optimal solution search engine with a feedback loop, enabling the system to learn from previous responses, and minimizing the number of negotiation iterations.

The authors of this research believe that the proposed framework can effectively address a real need met by decision makers in non-hierarchical collaborative networks. The prevailing circumstances have highlighted a pressing challenge faced by SMEs, particularly those operating within rapidly evolving industrial sectors like fashion and footwear. These enterprise networks struggle with the task of effectively using technical expertise and production capabilities to meet the demands of emerging business prospects. This aggregation is essential to enable these companies to compete with large proprietary supply chains. However, this need for collaboration is countered by the natural tendency of companies to be reluctant to share technical and operational data with other companies in the collaborative network. Therefore, what this framework offers to practitioners is a negotiated, modular, flexible, and tailored approach to the problem of forming and operating non-hierarchical collaborative networks.

The framework results were very promising for the tested application cases, and the industry partners that collaborated in the project outlined the merits of this approach. The system is currently available and accessible as a cloud service. The current version was subject to minor improvements over the years.

Regarding the limitations of the proposed tool, the authors believe that, because the study focused on networks of SMEs in the footwear sector, there is a need to validate the proposals of this work in other sectors. It is also important to acknowledge that, for the system function properly, it relies on the trust among partners participating in the collaborative network.

Through further developments, the research project team intends to additionally evaluate the current software prototype of the intelligent collaborative planning framework with more application cases based on other industrial sectors. Another research path includes the research and development of other intelligent planning strategies aimed at making the framework more flexible and effective.

Furthermore, it is the intention of the authors to explore new technological approaches to the non-hierarchical collaborative plan building phase. Among the promising approaches are the use of spherical fuzzy Dombi aggregation operators in decision support systems due to the fuzziness and unpredictability of the negotiation environment [34], as well as the combination of supervised machine learning techniques with discrete event simulation to address the delivery reliability improvement in the supply chain [35].

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