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Enhancing customer satisfaction through IIoT-Enabled coopetition: Strategic insights and impacts

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ABSTRACT

This research investigates the significant role of Industrial Internet of Things (IIoT) to enable Coopetition Network Practices (CNPs) in enhancing the performance of Small and Medium Enterprises (SMEs) within the context of global digital supply chains. Employing a quantitative approach, our study reveals that CNPs contribute to a noTable 51.0 % improvement in factors determining customer satisfaction. This underscores the strategic importance of blending competition with collaboration to refine production processes and align with consumer expectations. Additionally, the research presents a remarkable 69.1 % boost in operational consistency and reports substantial progress in manufacturing flexibility and the value-to-weight ratio, witnessing increases of 125.8 % and 33.2 %, respectively. These improvements are pivotal in optimizing production resources, which in turn, have led to a 29.3 % decrease in customer complaints and a 15.6 % rise in on-time delivery rates. Conversely, a slight decline in the consistency of the value-to-weight ratio was observed, pointing to potential areas for future research. The findings decisively show that CNPs offer concrete advantages by enhancing customer satisfaction determinants and operational efficiency in SMEs. The paper advocates for future studies to directly measure customer satisfaction and to formulate actionable guidelines for the effective implementation of coopetition strategies. This proposed research direction aims to provide solutions to the manufacturing sector's emerging challenges, thereby promoting competitive advantage and growth in the digital era.

1. Introduction

In the contemporary global marketplace, customer satisfaction has become a pivotal driver of success, particularly for manufacturing Small and Medium-sized Enterprises (SMEs) [62]. Unlike larger corporations, these SMEs increasingly engage directly with customers, making customer satisfaction an aspirational goal and a strategic imperative [15]. Achieving high levels of customer satisfaction impacts profitability, enhances market positioning, and ensures long-term business sustainability [14].

The correlation between customer satisfaction and repeat business is well-documented; satisfied customers are significantly more likely to return for additional purchases [52]. This repeat patronage is crucial as it reduces the costs of acquiring new customers and fosters enduring customer loyalty [14]. Loyal customers provide a steady revenue stream through frequent and larger purchases and represent a cost-effective source of long-term profitability for SMEs. Furthermore, satisfied customers often act as brand ambassadors,

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recommending products and services to their network, thus generating valuable word-of-mouth promotion [57]. For SMEs, which typically operate with limited advertising budgets compared to their larger counterparts, this organic advocacy can be instrumental in driving growth and expanding their customer base (M. [16]).

1.1. Problem statement

SMEs are often regarded as the backbone of Europe's economy, crucial in job creation, innovation, and wealth generation. These enterprises contribute over 20 % of the EU27′s total value-added and employ more than 35 million people, underscoring their significant economic impact [21]. Historically, SMEs distributed their products directly in local markets, where they could interact closely with customers or indirectly by supplying larger companies that handled distribution to broader markets. However, in the era of globalization, SMEs are compelled to compete on a global scale, facing stiff competition in local and distant markets [20].

Recent studies highlight a pressing challenge: manufacturing SMEs often need help to meet customer satisfaction demands in global markets [41]. This issue is exacerbated by their limited resources and smaller size, which traditionally posed barriers to scaling their operations [50]. To overcome these limitations, there has been growing advocacy for forming manufacturing alliances, enabling SMEs to collaborate and collectively satisfy customer needs [60].

A promising approach to this collaboration is "coopetition"—a strategic fusion of cooperation and competition [42]. This concept is gaining traction for its potential to balance businesses' competitive and collaborative dynamics [9]. Typically, successful coopetition networks revolve around a central, often larger, firm that anchors the collaborative efforts [32]. Leading companies such as Microsoft and Amazon exemplify this model; they dominate their respective networks and achieve significant financial gains, with profitability margins exceeding 29 % [44]. Conversely, smaller firms often rely on these giants to various extents, limiting their independence and strategic flexibility.

While large firms thrive in coopetition networks, the sustainability of such networks without a dominant "keystone" player is questionable, often leading to short-term failures. This dependency presents a unique challenge for manufacturing SMEs. Their inherently competitive nature can hinder the collaborative efforts required for digital growth and sustained customer satisfaction. The Economist Intelligence Unit [51] further emphasizes that European SMEs' reluctance to collaborate stifles their digital aspirations. It indicates a need for strategic frameworks that promote coopetition aligned with SMEs' distinct capabilities and market positions [51]. Given these challenges, how can coopetition be facilitated among manufacturing SMEs, and what are the potential gains in customer satisfaction can be achieved through such collaborations?

1.2. Underlying potential solutions

In addressing the core issue that unmet customer value expectations can lead to dissatisfaction and potential exclusion from the digital marketplace, the Service-Dominant (S-D) Logic literature offers invaluable insights [30]. According to S-D Logic, value does not inherently reside in products or services but is co-created through dynamic interactions between various actors, such as providers and customers [57]. Value materializes through the application of services, being uniquely tailored and perceived by the beneficiary. Thus, firms offer value propositions that customers actualize within their specific contexts through engagement and integration [29].

Understanding value from the S-D Logic perspective compels companies to focus on how they can facilitate value creation rather than merely supplying goods or services. In this vein, emergent and integrated technologies such as the Internet of Things (IoT) are seen as catalysts for a new era in which technology profoundly impacts ecosystems [55]. Empirical research highlights the transformative potential of IoT-based innovations in enabling new service offerings (M. [1]). Furthermore, the progression of the Industrial Internet of Things (IIoT) beyond conventional IoT frameworks signifies a significant leap in operational efficiency and intelligence, fostering global connectivity and facilitating direct device-to-device communication (Abbas [63]).

1.3. Research objective

This research explores how a coopetition network, enabled by IIoT, can enhance innovation outcomes tailored to customer satisfaction. To achieve this, the study is grounded in the S-D Logic and hypothesizes that such a coopetition network, facilitated by IIoT technologies, can significantly improve the ability of SMEs to innovate in ways that meet and exceed customer expectations.

The research will begin by contextualizing coopetition and technological innovation for value creation within the S-D Logic paradigm. The methodology for testing this hypothesis involves implementing an experimental IIoT-enabled coopetition network. It will include selecting empirical fields and companies, defining metrics and key performance indicators (KPIs) to assess innovation outcomes, and establishing data collection and performance analysis procedures.

A thorough quantitative analysis will follow, evaluating the impact of coopetition on customer satisfaction determinants before and after implementing an experimental IIoT-enabled coopetition network. The discussion section will focus on the findings, examining how coopetition practices influence innovation outcomes related to customer satisfaction determinants within participating SMEs. Finally, the Conclusion will summarize the key findings, clearly assessing whether the hypothesis— that an IIoT-enabled coopetition network significantly enhances customer satisfaction— is accepted or refused. The conclusion will also acknowledge the study's limitations and suggest future research directions for understanding and implementing coopetition networks.

2. Service-Dominant (S-D) logic perspective on coopetition

The S-D Logic, introduced by Vargo and Lusch [56], revolutionizes the traditional view of value creation [56]. It shifts the focus from goods to services, emphasizing that value is co-created through interactions between providers and customers rather than being embedded in products. This framework highlights that businesses offer value propositions that customers realise through contextual engagement [29].

Recent expansions of S-D Logic introduce the concept of service ecosystems, where value emerges from dynamic, systemic interactions among various actors [58]. In service ecosystems, technologies like the IoT play a dual role as both tools (operand resources) and active facilitators (operant resources) of value co-creation [25]. IoT and its industrial counterpart, the IIoT, enhance connectivity and operational efficiency [12], creating new service opportunities and fostering intricate networks (A. [63]).

The concept of "coopetition"—combining cooperation and competition—is essential in the S-D Logic framework, especially for SMEs. This approach enables firms to share knowledge and resources while competing, creating a collaborative environment that enhances innovation and value creation [9]. Successful coopetition often hinges on the presence of a central "keystone" player that anchors the network . However, in SME-centric networks, maintaining balance and sustainability without a dominant player presents a significant challenge [44].

S-D Logic advocates for SMEs to focus on their specialized competencies—like knowledge and skills—to facilitate service exchanges and create value collaboratively [37]. This perspective is crucial for SMEs to navigate competitive landscapes by integrating into broader service ecosystems and leveraging coopetition to enhance their offerings and market presence [34].

For SMEs, adopting a value co-creation perspective means recognizing the importance of participating in service ecosystems where coopetition can drive innovation and customer satisfaction. By blending competitive and collaborative strategies, SMEs can access new resources and markets, differentiating themselves through unique service propositions [46]. This integration facilitates their survival and growth in a rapidly evolving economic environment, underscoring the importance of cooperative strategies in sustaining competitive advantage [34].

The governance of service ecosystems through institutional arrangements ensures that despite competitive tensions, mutual value creation remains a focus. These shared norms, rules, and practices orchestrate the cooperative and competitive dynamics, promoting a sustainable and adaptable network [43]. Integrating S-D Logic into coopetition frameworks provides a strategic pathway for SMEs to innovate and enhance customer satisfaction. The theoretical underpinnings of S-D Logic offer a lens to understand how SMEs can leverage coopetition to co-create value and thrive in the digital marketplace. This literature review sets the stage for further exploration into the practical implementation and impact of IIoT-enabled coopetition networks on SMEs' innovation and customer satisfaction outcomes.

3. Value Co-creation through IIoT

Technological advancement, especially within intelligent technologies, has redefined the value creation landscape. Degani (2017) describes technology as "operant," meaning "something that works" or is "engaged in action," reflecting its autonomous capabilities to generate algorithms and undertake initiatives independently [19]. This concept aligns with the rapid evolution of technologies that perform actions without direct human intervention, marking a substantial leap in technological capabilities [10].

3.1. *Technological integration in S-D logic*

S- Logic places technology at the core of innovation, highlighting its transformative role in revolutionizing service delivery, innovation, and management [13]. S-D Logic explores how technology influences service innovation and value co-creation within ecosystems, serving as both enablers and drivers of innovation (Melissa [2]).

In coopetition, technology-based strategic networks are vital for fostering collaboration among diverse stakeholders [11]. This perspective aligns with S-D Logic's view of technology as both an operand (enabler) and operant (initiator) resource in value creation [8]. Integrating technology with human interactions, value propositions, and shared information paves the way for innovation and value creation [36].

3.2. *The role of IoT and IIoT*

S-D Logic recognizes emerging technologies like the IoT as ushering in a new era where technology profoundly impacts ecosystems [55]. IoT-based innovations foster new service offerings and enable companies to extend their service portfolios to include advanced options such as remote control and predictive maintenance [40]. This enhances operational efficiency and opens new avenues for value co-creation within coopetition frameworks [45].

The IIoT extends the capabilities of IoT, revolutionizing industrial operations with unprecedented efficiency and intelligence [33]. IIoT enhances global connectivity and enables direct device-to-device communications, significantly improving long-term operational efficiency and adaptability (Abbas [63]). For instance, IIoT frameworks for prognostic health management improve prediction accuracy and operational efficiency in industrial applications [26]. Additionally, the integration of edge computing in IIoT systems optimizes real-time processing and resource sharing, maximizing efficiency and social welfare [33].

4. Methodology

The hypothesis for this research posits that integrating the IIoT within coopetition frameworks empowers SMEs to innovate and co-create value more effectively, resulting in higher levels of customer satisfaction. This hypothesis explores the transformative potential of IIoT-enabled networks in reshaping competitive dynamics among SMEs. By fostering collaboration beyond traditional boundaries, these networks facilitate mutual value creation, allowing firms to leverage shared resources and capabilities to meet better and exceed customer expectations. The study seeks to demonstrate how IIoT technology can catalyze a synergistic environment where cooperation and competition coexist among SMEs, driving substantial enhancements in customer satisfaction determinants. The hypothesis suggests that such a network improves customer satisfaction through enhanced value co-creation determinants.

Given the multifaceted nature of customer satisfaction, which is influenced by production processes, logistics, and overall business activities, a comprehensive and structured case study approach is employed to test this hypothesis. A case study methodology includes the following steps:

1. Identify and establish quantitative metrics to evaluate the impact of the IIoT-enabled coopetition network on key manufacturing-side determinants of customer satisfaction. This involves selecting and developing specific KPIs that measure how the implementation of the IIoT-enabled coopetition network influences crucial aspects of customer satisfaction from a manufacturing perspective.
2. Select a suitable group of SMEs to participate in the experimental pilot IIoT-enabled coopetition network. The selection criteria include their readiness, willingness to engage in collaborative frameworks.
3. Establish the experimental pilot IIoT-enabled coopetition network among the selected SMEs. This process includes establishing the essential IIoT infrastructure to support secure and efficient data sharing, resource integration, and collaborative operations. Key steps involve implementing hardware and software components to ensure each SME can seamlessly connect to a common IIoT artefact. Ensuring robust security protocols are in place for safe and reliable data exchange among the network participants. They are facilitating the integration of shared resources, such as machinery, inventory, and expertise, to optimize collective operational efficiency and enable real-time communication and coordination through the IIoT artefact. It allows SMEs to work together more effectively and respond promptly to dynamic market demands. By connecting each company to this centralized IIoT platform, the pilot network will enhance its ability to coopetition.
4. Gathering data on the impact of the IIoT-enabled coopetition network on the defined customer satisfaction determinants. This step requires utilizing the developed metrics to collect data on KPIs.
5. Conduct a thorough quantitative analysis using the collected data to assess the hypothesis. It involves evaluating the changes in KPIs and exploring how integrating IIoT within the IIoT-enabled coopetition network enhances customer satisfaction determinants.
6. Analyze the results to understand how IIoT-enabled coopetition networks influence the manufacturing-side determinants of customer satisfaction. Examine the interplay between operational improvements and customer satisfaction, providing insights into how coopetition and IIoT technologies drive value co-creation.

Through this case study, the research aims to test the hypothesis and explore the effects of IIoT-enabled coopetition networks on the customer satisfaction determinants of SMEs. By focusing on quantitative metrics and empirical data collection, the study provides a robust framework for assessing the tangible impacts of these coopetition frameworks. This approach ensures that the findings are rooted in concrete, measurable outcomes, offering clear and actionable insights into the advantages of integrating IIoT technologies within coopetition networks.

5. Customer satisfaction determinants: Metrics, KPIs, and innovation outcomes

In the industrial sector, customer satisfaction stems from production processes, logistics, and overall business activities [59]. Under the S-D Logic, satisfaction is not just about delivering products but about how value is co-created through dynamic interactions within the service ecosystem [28]. S-D Logic focuses on how businesses facilitate value co-creation through efficient logistics, customization capabilities, and reliable delivery [5]. Key customer satisfaction drivers include streamlined logistics, ensuring timely, accurate deliveries, and enhancing customer satisfaction by providing seamless and reliable service [7]. Tailoring products to meet specific customer needs fosters engagement and satisfaction by delivering personalized solutions [27]. Consistently meeting deadlines builds trust and reinforces customer confidence in the business's dependability [57].

5.1. Streamlining logistics for better customer satisfaction

Optimizing logistics is essential for enhancing customer satisfaction, particularly by designing and delivering lighter products. Under the S-D Logic framework, customer satisfaction is co-created through the efficiency and effectiveness of service interactions, including how products are transported and delivered [57].

S-D Logic emphasizes value co-creation through seamless interactions within the service ecosystem. Logistics is not merely about moving goods but how these processes enhance the overall customer experience [31]. Lighter products simplify the supply chain, making handling more accessible and reducing logistical complexity. This results in faster, more reliable deliveries, directly contributing to a more satisfying customer experience [4].

For example, consider a machinery component redesigned to be lighter. This lighter component simplifies the loading and unloading process, reduces the handling time and effort required from logistics partners, and accelerates the delivery process. These improvements lead to quicker turnaround times and faster deliveries, which enhance customer satisfaction by ensuring that products reach them promptly and in good condition. Furthermore, reducing handling complexity minimizes the risk of damage during transportation, ensuring that products arrive intact and meet customer expectations.

Additionally, producing lighter products often leads to a smaller carbon footprint, as less energy is required for transportation. This environmental benefit aligns with the values of eco-conscious consumers who prioritize sustainability [7]. By offering lighter, eco-friendly products, companies can cater to this growing market segment, boosting customer satisfaction and fostering loyalty. This alignment with customer values is crucial to value co-creation in S-D Logic [23].

Companies can use the value-weight ratio (KPIVwR) to evaluate the effectiveness of logistics in contributing to customer satisfaction. This KPI (KPI_{VwR}) is assessed by dividing the product's value by weight, as shown in Eq. (1). This metric provides insights into a product's value relative to its weight [18]. It is particularly relevant in sectors where shipping costs significantly impact the total cost to the customer and the product's perceived value [35].

$$\mathrm{KPIVtW} = \sum_{1}^{54} \left(\frac{total\_transport\_costs_{(daily)}}{total\_value\_of\_goods_{(daily)}} \right) 100\% \tag{1}$$

Products with a higher KPI_{VwR} indicate a greater value per unit of weight, enhancing customer satisfaction by minimizing shipping costs and improving the overall value proposition. For instance, in the fitness industry, lightweight yet durable gym equipment reduces shipping costs while maintaining high functionality. It lowers customer expenses and enhances their experience by providing superior performance without high shipping fees.

5.2. Enhancing customer satisfaction through customization and flexibility

In today's competitive market, customer satisfaction is deeply influenced by a company's ability to offer customized products (Z. [17]). From the S-D Logic perspective, this customization fosters value co-creation by providing personalized solutions that resonate with individual customer needs [54]. Customization aligns closely with the S-D Logic view, where value is co-created through personalized interactions rather than standardized products. When businesses can tailor their offerings to meet specific customer preferences, they enhance the customer experience, making customers feel valued and understood (Z. [17]). For instance, a gym offering equipment customized to user specifications can deliver a more engaging and satisfying experience than generic, one-size-fits-all products [57]. Customization not only improves customer satisfaction but also streamlines operations. By producing items tailored to each customer's requirements, companies align production more closely with demand, reducing the need for extensive inventories and minimizing waste [24]. This efficiency simplifies logistics and reduces the complications and costs of managing excess stock. For example, a manufacturer that builds gym equipment to order avoids overproduction and the related costs of unsold inventory.

To succeed in customization, companies need high manufacturing flexibility. Manufacturing Flexibility (KPI_{Flex}) measures a company's ability to adapt its production processes to create various products without significant additional costs or delays, as shown in Eq. (2). High KPI_{Flex} allows businesses to quickly switch production lines to accommodate different product variations, which is crucial for responding to shifting customer demands.

$$\mathrm{KPIFLEX} = \sum_{1}^{54} \left(\frac{total\_parts\_customized_{(daily)}}{total\_parts\_produced_{(daily)}} \right) 100\% \tag{2}$$

Emphasizing customization and manufacturing flexibility enables businesses to align more closely with customer needs, streamline operations, and enhance value co-creation. This approach improves customer satisfaction and aligns with the S-D Logic view that value is created through interactive, personalized service experiences [38].

5.3. Enhancing customer satisfaction through on-time delivery

In today's fast-paced world, customers expect prompt and reliable delivery of their purchases. Consistently meeting or exceeding these expectations is crucial for enhancing customer satisfaction [47]. From the S-D Logic perspective, on-time delivery is vital to value co-creation, reflecting how well a company fulfils its promises and supports the customer's overall experience [5]. On-time delivery is more than just meeting a deadline; it represents a company's operational and supply chain effectiveness. Reliable delivery reduces customer anxiety and builds trust, making customers feel assured that they will receive their products as expected [24]. For instance, a gym equipment supplier known for punctual deliveries will satisfy existing customers and attract new ones through its reputation for reliability.

Delays can cause significant inconvenience, leading to customer frustration and dissatisfaction. Conversely, consistent on-time delivery reinforces the perception of a company's dependability. Efficient delivery processes indicate streamlined operations, which improve overall performance and reduce costs. This operational excellence becomes a competitive advantage, enhancing customer loyalty and encouraging repeat business.

Companies use the On-time Delivery (KPI_{OtD}) ratio to assess delivery performance, which measures the percentage of orders delivered on or before the promised date (Eq. (3)). A high KPI_{OtD} ratio reflects a company's strong performance in meeting delivery commitments, directly correlating with higher customer satisfaction. Customers value punctual delivery as it meets their expectations and enhances their overall experience with the company.

$$KPIOtD = \sum_{1}^{54} \left(\frac{total\_parts\_delivered\_on\_time_{(daily)}}{total\_parts\_delivered_{(daily)}} \right). \ 100\% \tag{3}$$

Achieving high KPI_{OtD} values consistently builds customer trust. Over time, customers rely on the company's ability to meet its delivery promises, fostering long-term relationships and loyalty. In competitive markets, this reliability becomes a key differentiator. Clear communication about delivery times, supported by a strong KPI_{OtD}, reinforces the company's reputation for dependability and enhances customer confidence.

On-time delivery is integral to the value co-creation [55], as it aligns with the customer's expectations and needs, contributing to a positive service experience. Reliable delivery enhances trust, a cornerstone of long-term customer relationships and loyalty, essential components of value co-creation in S-D Logic [40]. This focus on punctual delivery strengthens the customer experience, fortifies the company's market position, and promotes long-term success [23]. Emphasizing timely delivery through consistently monitoring KPI_{OtD} allows businesses to thrive in a competitive landscape and fosters enduring customer relationships.

5.4. Measuring customer satisfaction through the absence of product complaints

One effective way to gauge customer satisfaction is by monitoring the absence of product complaints [39]. This metric directly reflects how well products meet or exceed customer expectations [53]. Within the S-D Logic framework, a lack of complaints indicates successful value co-creation, showing that products reliably fulfil their intended purposes and satisfy customer needs [6].

The No Complaint Ratio (KPI_{NcR}) measures the percentage of products delivered without generating customer complaints (Eq. (4)). A high KPI_{NcR} signals that products consistently meet quality standards and align with customer expectations. High KPI_{NcR} values indicate that products perform as promised, minimizing customer issues and enhancing satisfaction. Delivering complaint-free products builds trust and fosters long-term customer loyalty, encouraging repeat purchases and positive recommendations.

$$KPINcR = \sum_{1}^{54} \left(\frac{1 \ - \ total\_complained\_parts_{(daily)}}{total\_parts\_delivered_{(daily)}} \right) 100\% \tag{4}$$

Monitoring the KPI_{NcR} provides valuable insights into customer satisfaction and product quality. High KPI_{NcR} values reflect products that meet customer needs without issues, aligning with the S-D Logic perspective of value co-creation. By minimizing complaints, companies can enhance customer trust, improve satisfaction, and strengthen their reputation for reliability and quality.

5.5. Innovation outcomes

According to Lusch & Nambisan [34], Innovation Outcomes (IO) evaluate the effects of innovations on KPIs, revealing how these changes enhance operational metrics [34]. This S-D Logic approach highlights the role of innovation in improving competitiveness and sustainability within the digital supply chain [49]. Incorporating the IO concept into this analysis is crucial for assessing how new practices, like joining coopetition networks or integrating new technologies, affect company performance (Eq. (5)).

$$IO = \frac{KPI_{CN.P} \ - \ KPI_{CB.P}}{KPI_{CN.P}}.100\% \tag{5}$$

By incorporating Innovation Outcomes into the analysis, this methodology provides a comprehensive framework to evaluate the impact of coopetition enabled by IIoT on customer satisfaction determinants [22]. These metrics shed light on innovative practices' stability, sustainability, and transformative potential. Embracing the S-D Logic view, this approach underscores how integrating IIoT can drive significant improvements in manufacturing efficiencies and customer satisfaction, ultimately fostering value co-creation in a digital and interconnected world.

6. Empirical context

This investigation is grounded in the systematic principles of quantitative research, focusing on Portugal's Ornamental Stone (OS) sector. The selection of this sector is strategic, aiming to provide a relevant and practical context for studying the dynamics and benefits of IIoT-enabled coopetition networks among SMEs. The OS sector's significant economic role and characteristics make it an exemplary case for understanding how digital technologies and collaborative frameworks can drive customer satisfaction and innovation.

Portugal's status as the second-largest exporter of ornamental stone on a per capita basis underscores its significant impact and competitive edge in the international market [48]. This prominence is a testament to the sector's capacity to compete globally and adapt to changing market demands. According to the Portuguese Association of the Mineral Resources Industry (Assimagra) for 2021, this sector is a significant contributor to the Portuguese economy, employing over 16,600 people and exporting to 116 countries, plays a vital role in generating private sector employment, particularly in Portugal's interior regions, which supports local economies and contributes to regional development, and despite facing various challenges, the sector has demonstrated resilience and steady growth, positioning Portugal as the eighth largest exporter of ornamental stone globally [3].

Focusing on the OS sector in Portugal, this study aims to provide valuable insights into the transformative potential of IIoT-enabled collaboration networks. The sector's significant economic role, global competitiveness, and adaptability make it an ideal context for

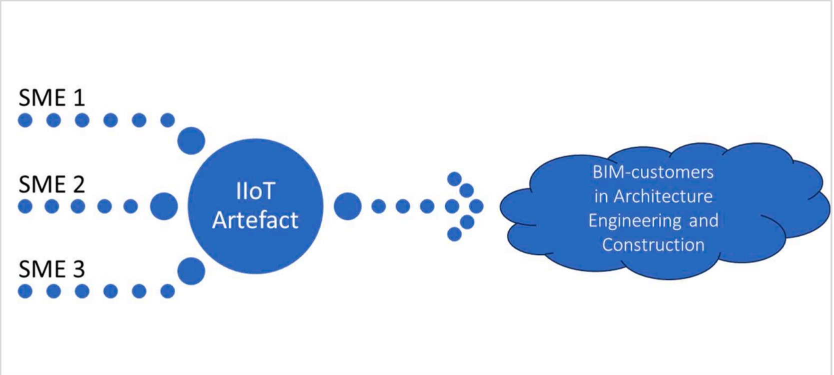

Fig. 1. The IIoT-Enabled coopetition network for ornamental stone SMEs.

exploring how digital and collaborative strategies can drive customer satisfaction and innovation within SMEs. The findings are expected to offer practical implications for SMEs leveraging advanced technologies and collaborative frameworks to enhance their market position and operational capabilities.

6.1. Implementation of an IIoT-enabled coopetition network

Implementing an IIoT-enabled coopetition network in the OS sector significantly advances value enhancement through digital innovation. This initiative, supported by substantial financial backing from the participating companies, has facilitated the development of a pilot IIoT-enabled coopetition network, pivotal for this research.

Building on the foundational work of Silva et al. [49], which demonstrated how IoT systems could connect OS SMEs to the cyber market, an advanced IIoT system has been developed [49]. This new artefact aligns with S-D Logic principles and emphasizes value co-creation within service ecosystems (Melissa [2]). It leverages cutting-edge technological capabilities to revolutionize stone processing, foster a collaborative environment, and ensure: (1) Flexible Network Participation - companies can join or leave the network freely, maintaining their autonomy while actively contributing to the ecosystem. This flexibility supports dynamic collaboration without long-term commitment constraints; (2) Resource Sharing - network members can access and offer resources such as stock and machinery, promoting reciprocal exchanges. This resource sharing optimizes utilization and enhances operational efficiency across the network; (3) Confidential Commercial Opportunities - each member's ongoing business opportunities are kept confidential, preserving competitive integrity and ensuring that sensitive commercial information remains private; (4) BIM Interoperability - the system guarantees compatibility with Building Information Modeling (BIM) systems used by architects, ensuring seamless integration and coordination with external stakeholders in construction and design processes; (5) Secure Communication - utilizes OPC-UA protocols to ensure secure and reliable data exchanges within the network. This secure communication framework protects proprietary information and maintains trust among network participants; and (6) Promoting Value Creation through Coopetition – the IIoT artefact enhances coopetition by integrating the shop floors of competing manufacturers into a unified network, fostering value creation for all stakeholders. By pooling resources and capabilities from rival firms, the system creates an environment where value co-creation is maximized. This collaborative approach ultimately delivers superior services to customers by combining the strengths of each participating company.

For this research, a prototype of the IIoT artefact was deployed with three ornamental stone producers. This pilot project aimed to test the hypothesis that an IIoT-enabled coopetition network enhances customer satisfaction through improved value co-creation determinants. The implementation allowed these SMEs to experience enhanced digital connectivity and collaboration within their operations, demonstrating how IIoT technologies can facilitate seamless integration and cooperative innovation. Fig. 1 illustrates this digital connectivity and the operational synergies achieved through the network.

The approach started with informal discussions with the managing directors of the selected companies, followed by formal invitations to participate in the study. A confidentiality agreement was established to protect the companies' proprietary data, client information, and competitive practices. With the consent of these leaders, the research team gained access to extensive data, including financial documents, order histories, and insights into management and production processes.

To ensure data integrity and confidentiality, the research team monitored operational activities daily, recording quantitative data from digital machinery and databases. This meticulous data collection process provided a solid foundation for analyzing the impact of the IIoT-enabled coopetition network on the participating companies, offering a comprehensive assessment of the network's effects on their operations.

6.2. Data collection

To assess the transition from Current Best Practices (CB.P) to Coopetition Networks Practices (CN.P), this study employs a structured data collection approach across two 54-day periods. This comparative framework enables a detailed analysis of KPIs before

Table 1
Summarized data collected in current best practices (CB.P).

Data ID	Description	Current Best Practices (CB.P)	Average (daily)
Data 1	Total transport costs (€)	total_transport_costs	1724
Data 2	Total value of goods sold €)	total_value_of_goods_sold	8463
Data 3	Total parts customized	total_parts_customized	52
Data 4	Parts produced	total_parts_produced	339
Data 5	Total complained parts	total_complained_parts	15
Data 6	Parts delivered	total_parts_delivered	339
Data 7	Parts delivered on time	total_parts_delivered_on_time	240
Data 8	Parts delivered	total_parts_delivered	339

Table 2
Summarized data collected in coopetition network practices (CN.P).

Data ID	Description	Coop. Network Practices (CN.P)	Average (daily)
Data 1	Total transport costs (€)	total_transport_costs	1376
Data 2	Total value of goods sold €)	total_value_of_goods_sold	10,395
Data 3	Total parts customized	total_parts_customized	157
Data 4	Parts produced	total_parts_produced	454
Data 5	Total complained parts	total_complained_parts	17
Data 6	Parts delivered	total_parts_delivered	454
Data 7	Parts delivered on time	total_parts_delivered_on_time	358
Data 8	Parts delivered	total_parts_delivered	454

Table 3
KPI and IO assessment.

KPIs	CB.P	CN.P	IOs
Value to Weight Ratio	$KPI_{VtW} = 20{,}1$ %	$KPI_{VtW} = 13{,}4$ %	$IO_{VtW} = 33{,}2$ %
Flexibility	$KPI_{Flex} = 15{,}4$ %	$KPI_{Flex} = 34{,}8$ %	$IO_{Flex} = 125{,}8$ %
On-Time Delivery	$KPI_{OtD} = 67{,}1$ %	$KPI_{OtD} = 77{,}5$ %	$IO_{OtD} = 15{,}6$ %
No Complains Ratio	$KPI_{NcR} = 93{,}7$ %	$KPI_{NcR} = 95{,}6$ %	$IO_{NcR} = 29{,}3$ %

and after implementing an IIoT-enabled coopetition network.

From April 17th, 2023, to June 10th, 2023, the first phase focused on documenting the operational metrics under CB.P. During this period, each company operated independently, managing their production and delivery processes without collaboration. This phase aimed to establish a baseline of traditional practices, providing a reference for later comparisons as detailed in Table 3.

The second phase, from September 9th, 2023, to November 14th, 2023, marked the transition to CN.P, where companies engaged in an IIoT-enabled coopetition network. The CN.P represents a strategic approach that blends competition and cooperation among companies. By sharing resources and leveraging IIoT technology, companies can enhance their operational efficiencies and innovate collaboratively. This phase encouraged coopetition, allowing companies to utilize each other's strengths and technological capabilities to co-create value within a secure and adaptable framework. The structured sharing and secure communication practices fostered an environment where companies could innovate and improve collectively, benefiting from the combined advantages of competition and cooperation. During this phase, the following practices were implemented:

1. Companies within the network confidentially shared and accessed each other's available resources, such as stock and machinery. This practice enabled more efficient resource use and fostered mutual support among network members.
2. Each company could join or leave the network anytime, providing flexibility and maintaining autonomy while participating in the collaborative ecosystem.
3. All interactions and data exchanges were conducted through secure OPC-UA protocols [26], ensuring confidentiality and protecting proprietary information.
4. Companies gave and gained access to resources based on a reciprocal model, enhancing cooperation while preserving competitive integrity.
5. The network was designed to integrate seamlessly with Building Information Modeling (BIM) systems used by architects [61], enhancing coordination across different stages of production and delivery.

Adhering to the confidentiality agreement, all data was meticulously stored and handled to ensure privacy and security. This rigorous data management process facilitated a comprehensive and secure analysis, enabling a robust evaluation of the impact of CN.P on operational efficiencies.

By contrasting operational metrics between CB.P and CN.P, from data collected, the study aimed to reveal the tangible benefits of

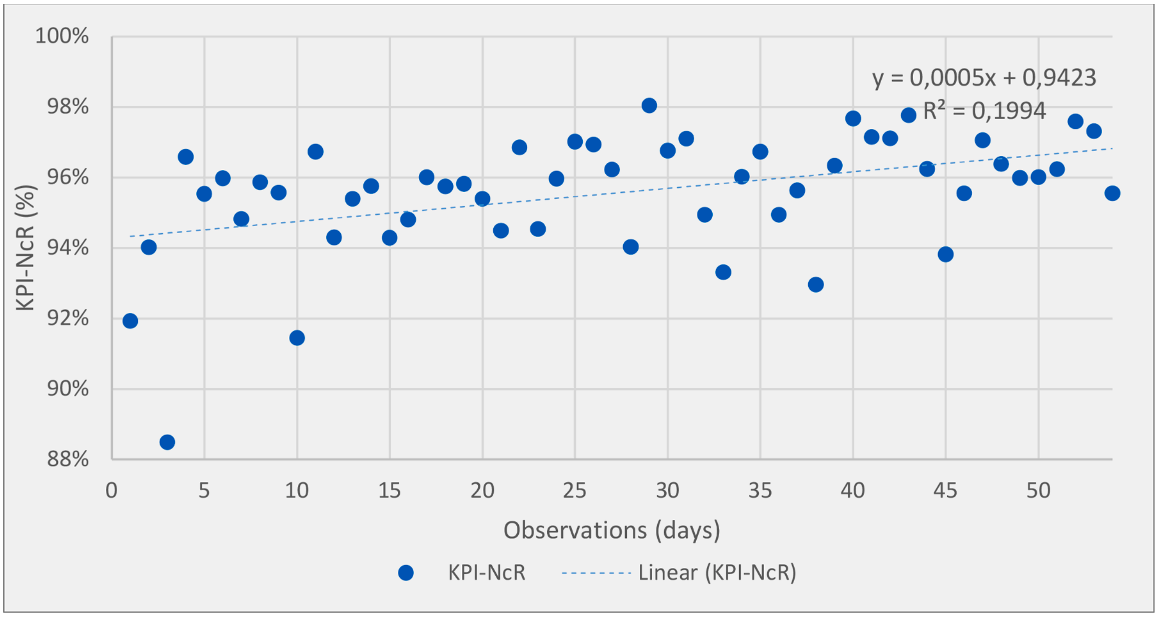

Fig. 2. Trend in KPI_{NcR} Under coopetition networks.

coopetition practices within SMEs.

7. Results and discussion

This section presents a detailed analysis of data collected from CB.P and CN.P. Table 1 captures the baseline metrics under state-of-the-art practices. In contrast, Table 2 outlines the metrics observed after implementing the IIoT-enabled coopetition network. Table 3 synthesizes these findings, offering a comparative analysis that illuminates the multifaceted effects of coopetition on customer satisfaction determinants.

7.1. KPI assessment

Value-to-Weight Ratio (KPI_{VtW}): Under CB.P, as detailed in Table 1, SMEs experienced an average daily transportation cost of €1724 while managing products valued at approximately €8463. This results in a KPI_{VwR} of 20.1 %, which reflects the cost efficiency of transporting these products relative to their value. This percentage indicates how effectively the transportation costs are balanced against the value of the goods being moved, showcasing the SMEs' ability to manage logistics costs efficiently under the CB.P framework. In contrast, Table 2 shows that after implementing the CN.P, the average daily transportation cost decreased to €1373, with the products' value rising to about €10,391. This results in a KPI_{VwR} of 13.4 %, reflecting a significant reduction in the cost per product transported. The decrease in KPI_{VwR} from 20.1 % to 13.4 % under CN.P signifies a marked improvement in transportation cost efficiency. This reduction is attributed to the coopetition strategies, where firms collaboratively optimized their logistics to meet market demands more competitively.

Flexibility (KPI_{FLEX}): Under the CB.P framework, data from SMEs indicated that, on average, 52 parts were customized daily out of a total production of 339 parts. This yields a KPI_{Flex} of 15.4 %, representing the portion of the production that could be customized each day (Table 1). This metric highlights the limited capacity of SMEs to tailor their production to specific customer requirements under traditional operational practices. Transitioning to CN.P brought substantial improvements. The daily average of customized parts increased dramatically to 157, with the total daily production rising to 454 parts. This significant boost in customization was achieved without changing existing work schedules, showcasing the distinct advantages of adopting CN.P practices. Through collaborative efforts on specific production processes, competitors enhanced their ability to effectively address diverse customer demands. As a result, the KPI_{Flex} surged to 38.8 % (Table 2), demonstrating a remarkable improvement in the capability to customize products. This increase underscores how coopetition allows firms to leverage shared resources and collective knowledge, enabling them to respond more agilely to market demands. The rise in KPI_{Flex} from 15.4 % to 38.8 % highlights the transformative impact of coopetition networks in enhancing operational flexibility and meeting customer expectations.

On-Time Delivery (KPI_{OtD}): Under the CB.P framework, data showed that an average of 240 parts out of 339 parts delivered daily were on time. This performance yields a KPI_{OtD} of 67.1 %, reflecting the proportion of timely deliveries under traditional practices (Table 1). Transitioning to the CN.P strategy resulted in a significant improvement in the On-Time Delivery Ratio. The average number of parts delivered on time increased to 358 parts per day. Despite maintaining the same overall production capacity, the KPI_{OtD} rose to 77.5 % (Table 2), demonstrating a marked enhancement in delivery reliability due to coopetition practices. The increase in KPI_{OtD} from

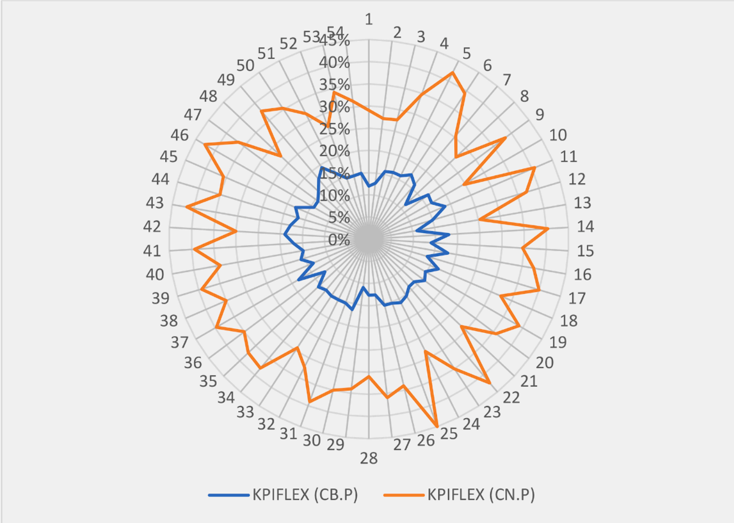

Fig. 3. Quantitative gains in flexibility achieved through coopetition networks.

67.1 % to 77.5 % under the CN.P strategy indicates a substantial improvement in the reliability of deliveries. This enhancement shows how coopetition enables firms to optimize their delivery processes and better meet customer expectations.

No Complaint Ratio (KPI_{NcR}): Data analysis within the CB.P framework, as presented in Table 1, indicates an average daily part without complaints of 324 out of 339 parts dispatched. It translates to a KPI_{NcR} of 73,7 %, as detailed in Table 1. The shift to the CN.P strategy, according to the information in Table 2, led to an increase in the daily average of manufactured parts to 454, with 17 still being rejected. This increase, linked to the heightened production volume, is a typical outcome of scaling up production. Notably, despite the surge in production volume, the KPI_{NcR} improved to 95,6 %, representing a positive shift of 1.9 % in customer complaints across the companies, as illustrated in Fig. 2.

The linear regression analysis of the KPI_{NcR} under the CN.P shows a positive trend, as indicated by the slope of the trend line. It implies that over time, there is a gradual increase in the proportion of products delivered without complaints, reflecting continuous improvement in product quality and customer satisfaction. The slope of 0.0005 suggests a very slight increase in the No Complaint Ratio over time. Specifically, for each unit increase in time or observation number, the KPI_{NcR} increases by 0.05 %. It indicates that, as time progresses, there is a minor but steady improvement in the proportion of products delivered without complaints. Though modest, the upward trend reflects a positive movement towards better quality and customer satisfaction over the studied period. The y-intercept of 0.9423 indicates that the estimated KPI_{NcR} is 94.23 % on the starting day. Moreover, An R^2 value of 0.1994 indicates that the time or observation number explains approximately 19.94 % of the variability in the KPI_{NcR}. In practical terms, this means that the slight upward trend over time is only partially explained by the time progression, implying that other operational or external factors may significantly impact the KPI_{NcR}.

7.2. IO assessment

Innovation Outcomes highlight significant improvements in customer satisfaction determinants and operational efficiencies. Table 3 offers a detailed summary of these enhancements, showcasing quantifiable advancements and reduced variability for each innovation outcome.

Innovation Gains in Flexibility: A notable finding from this study is the increase in Flexibility within the coopetition framework. As shown in Fig. 3, the flexibility in operations surged by 125.8 % after adopting coopetition practices.

This substantial and consistent improvement over the 54 days, denoted as IO_{Flex}, signifies the enhanced ability of firms to customize parts. Coopetition enables companies to delegate the production of components that fall outside their core expertise to other members within the network. This collaborative approach fosters increased production capacity and greater customization capabilities, as firms can leverage their peers' specialized skills and resources. By working together, companies can more effectively meet diverse customer needs and enhance operational flexibility through shared efforts.

Value-to-Weight Ratio Enhancement: Examining the IO_{VtW} among SMEs in coopetition networks, there is an improvement of 33.2 %, highlighting the competitive advantages of coopetition. This enhancement translates to significant reductions in transportation costs per part delivered. Companies can optimize transport and elevate overall delivery performance by aligning their production with other network members. This strategic adaptation helps firms mitigate costs amidst fluctuating market demands and evolving consumer expectations, demonstrating the transformative potential of coopetition within the manufacturing sector.

Improved On-Time Delivery: The KPI_{OtD} experienced an uplift of 15.6 %, reflecting enhanced utilization of existing production capacities under coopetition. This IO_{OtD} progress underscores how the synergy of collaboration and competition cultivates a highly predictable operational environment. Firms in a coopetition network benefit from a collective pool of expertise, capabilities, and

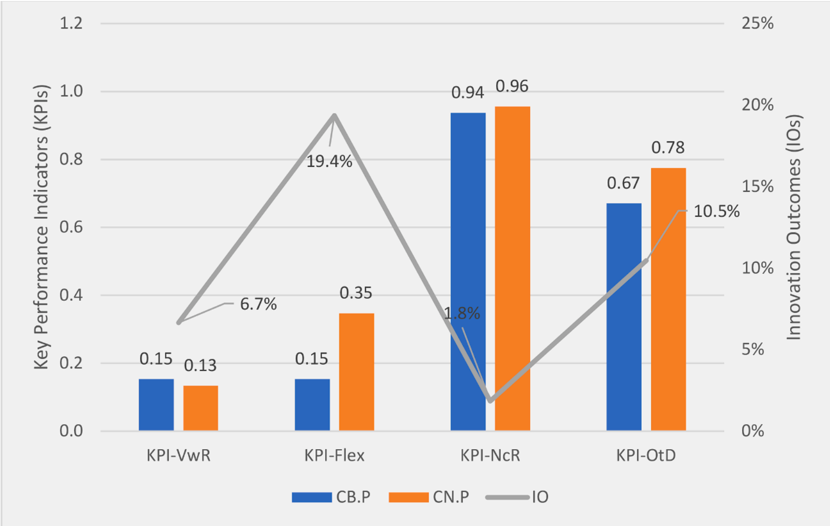

Fig. 4. Customer satisfaction determinants evaluation following the transition to CN.P.

technological innovations, boosting individual and collective market competitiveness. Coopetition practices thus represent a strategic approach to enhancing production output and achieving operational excellence.

Reduction in Customer Complaints: The IONcR analysis indicates a direct improvement in customer satisfaction, with a noTable 29.3 % decrease in the number of parts refused by customers. Such enhancements illustrate the streamlined practices and predictability introduced by coopetition networks, highlighting their strategic importance in fostering customer satisfaction and operational excellence.

Comprehensive Gains in Customer Satisfaction: The average assessment of innovation outcomes demonstrates a substantial impact on customer satisfaction determinants, with a **9.6 %** improvement following the adoption of coopetition network practices as illustrated in Fig. 4.

These results highlight the transformative impact of coopetition on customer satisfaction determinants, advocating for a strategic shift towards collaborative and competitive networks. Coopetition emerges as a powerful approach for SMEs, enabling them to harness collective strengths and navigate the complexities of today's market. By leveraging the combined strengths and resources within these networks, companies can significantly enhance critical determinants of customer satisfaction. The synergy created by blending collaboration with competition fosters an environment ripe for innovation and adaptability to market changes. This dynamic interaction accelerates operational improvements and enhances the ability of SMEs to meet and exceed customer expectations.

8. Conclusions

This research explored the impact of CN.P enabled by the IIoT on customer satisfaction determinants within SMEs in the ornamental stone sector. Grounded in S-D Logic, the study hypothesized that an IIoT-enabled coopetition network significantly enhances customer satisfaction by improving manufacturing flexibility, on-time delivery, and product quality KPIs.

To test this hypothesis, a detailed comparative analysis was conducted between **CB.P** and the innovative CN.P framework. The results confirmed that adopting an IIoT-enabled coopetition network leads to substantial improvements in customer satisfaction determinants. Specifically, the study found significant enhancements in operational flexibility, reduced delivery times, and higher product quality through collaborative efforts facilitated by the IIoT network. Additionally, the research addressed how coopetition can be facilitated among manufacturing SMEs and the potential gains in customer satisfaction achievable through such collaborations. The IIoT-enabled network provided a platform for these firms to integrate their resources effectively, allowing them to meet customer needs more efficiently and consistently. Overall, the study underscores the transformative potential of IIoT-enabled coopetition networks in fostering innovation and operational excellence, thereby significantly boosting customer satisfaction in SMEs.

The insights gained from this research underscore the transformative potential of IIoT-enabled coopetition networks for ornamental stone SMEs. The alignment with S-D Logic principles provides a robust framework for understanding how these networks can foster a more adaptive and resilient business environment.

While this study demonstrates the significant benefits of IIoT-enabled coopetition networks in the ornamental stone sector, several limitations must be acknowledged. The focus on a specific industry and the short-term analysis may limit the broader applicability of the findings. Additionally, the small sample size and some data variability suggest further validation and refinement.

For future research, exploring the long-term impacts of coopetition networks across diverse industries will provide deeper insights into their strategic value. Examining the role of digital transformation and advanced technologies can further enhance the efficacy of these networks. More extensive studies with more varied participants and extended timelines will help generalize the benefits and address the complexities of coopetition practices in dynamic markets.

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Nothing to declare.

CRediT authorship contribution statement

Agostinho da Silva: Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Antonio J. Marques Cardoso:** Writing – review & editing, Writing – original draft, Visualization, Visualization, Validation, Supervision.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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