Unleashing innovation and agility: Interaction between intellectual capital and supply chain analytics

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Abstract

Purpose – This study explores the impact of intellectual capital on the adoption of supply chain analysis by manufacturing companies. The authors also examine the potential role of supply chain analytics in supply chain innovation and agility.

Design/methodology/approach – Data were gathered from 268 managers and directors of Jordanian companies. The hypotheses were tested using the Smart PLS software.

Findings – The results reveal that human, structural and social capital significantly impact supply chain analytics. Moreover, the findings show that supply chain analytics significantly affect supply chain innovation and agility. In other words, cultivating intellectual capital is crucial for utilizing supply chain analysis to enhance performance in terms of innovation and agility.

Originality/value – This study adds to the literature on the determinants of the adoption of supply chain analytics and its function in establishing the dynamic capabilities of businesses, including supply chain innovation and agility.

Keywords Intellectual capital, Supply chain analytics, Supply chain agility, Supply chain innovation

Paper type Research paper

1. Introduction

Supply chains and production networks have become more dynamic, volatile, complex, and substantially more global, where new challenges and risks have proliferated (Hopkins, 2021; Peixoto et al., 2023). In this new business era characterized by a dynamic environment, accelerated advancement of industrial technologies, and a highly competitive business marketplace, supply chain collaboration and innovation among supply chain members become an urgent need for survival and prosperity (Ben-Daya et al., 2019; Alsmadi et al., 2023). Increasingly, scholars and practitioners realize that innovation cannot come only from internal sources, where collaboration with partners that have some common ground in the existing supply chains can also be a source of developing innovation capabilities (Herden, 2020; Bıyıközkan and Güler, 2021; Peixoto et al., 2023). Supply Chain Innovation (SCI) is an ongoing complex process developed to deal with environmental uncertainties and respond to the continuously changing needs of the market using new technologies to improve supply chain management (SCM) under such conditions (Malacina and Teplov, 2022).

Scholars have confirmed that the capabilities of emerging digital technologies have significantly leveraged SCI, leading to improved value creation across supply chains of industries (Kache and Seuring, 2017; Hopkins, 2021; Song, 2023). The highly dynamic external environment has motivated firms to develop integrative supply chain mechanisms in which advancements in information and communication technology (ICT) have substantially transformed the implementation, sharing, and coordination of operations, resources, competencies, and other capabilities to achieve objectives and collaborative value creation that are impossible to achieve individually, enhancing the performance of supply chains (Alzoubi and Yanamandra, 2020).
Companies aggressively pursue the acquisition of novel intelligent and analytical technologies to support their decisions to better match supply with production and market demand, reduce costs, and increase flexibility, productivity, and resource efficiency (Kache and Seuring, 2017; Heubeck and Meckl, 2022). The amount of data generated and shared over the ICT is substantially growing, which creates many challenges for businesses to analyze this flow of big data (Seyedan and Mafakheri, 2020; Wamba et al., 2020). Analyzing this huge amount of data can enable more targeted business decisions, providing unique insights into market trends and customer buying patterns, as well as identifying areas for cost reduction (Rathod and Kumar, 2021; Ogbuke et al., 2022). Supply chain analytics (SCA) have become more rooted in SCM, particularly with the birth of big data applications and their role in predictive analytics (Souza, 2014; Fosso Wamba and Akter, 2019).

Despite the literature emphasizing the great potential and real business value of SCA, the existing research has a notable gap in its limited consideration of the importance of intellectual capital in the context of SCA adoption. While many studies have extensively explored technology-related aspects of supply chain analytics, there is a clear shortage of scholarly research dedicated to the role of intellectual capital in its effective adoption and implementation in business intelligence technology. Although there is growing recognition of the importance of SCI and agility in a dynamic business environment, there remains a gap in understanding how SCA contributes to these critical dimensions. The current literature often stops short of examining the downstream effects of adopting supply chain analytics, specifically its impact on innovation and agility. To address these gaps in the literature, this study seeks to answer the following two main questions:

Q1. Does intellectual capital play a significant role in adopting SCA?

Q2. Does SCA significantly impact SCI and agility?

To answer these questions, this study empirically examines the impact of human, structural, and social capital, all of which are components of intellectual capital, on SCA adoption in manufacturing companies, building on dynamic capabilities theory as its foundation.

2. Theoretical framework

The literature confirms that innovative SCM data potentially leads to a competitive advantage for companies (Fosso Wamba and Akter, 2019; Bouncken et al., 2020; Ogbuke et al., 2022). SCA describes the use of data and analytical tools to enhance supply chain decision-making, planning, sourcing, production, and integration (Souza, 2014). It is considered an innovative solution to supply chain problems and a revolution that has transformed design and management (Fosso Wamba and Akter, 2019). According to Souza (2014), the SCA comprises three main functions: descriptive, prescriptive, and predictive. Practical applications of SCA include data utilization to understand and coordinate supply chain operations, employing data mining to support decision-making, using optimization modeling and simulations for risk analysis, and determining the best course of action (Sanders, 2016).

Driven by its high potential to collect, analyze, use, and interpret big supply chain data, SCA has enabled companies to derive actionable insights, generate new business value, and gain a competitive edge in rapidly changing contexts (Dubey et al., 2019). Nonetheless, most previous research has focused on tackling various challenges and opportunities connected to big data analytics and SCM, with a particular emphasis on technical aspects (Giannakis and Louis, 2016; Kache and Seuring, 2017; Seyedan and Mafakheri, 2020). Many scholars have examined how analytical capability impacts various dimensions of SCM (Kalaitzi and
Tsolakis, 2022; Shamout, 2023). Scholars have shown considerable interest in using big data analytics to enhance demand forecasting (Seyedan and Mafakheri, 2020; Rathod and Kumar, 2021). Although researchers have verified the link between analytical capabilities and improved SCM, theoretical and empirical studies addressing the causes and impact of SCA are lacking.

The KBV underscores the strategic value of knowledge assets and their influence on an organization’s competitive advantage, dynamic capabilities, and innovation (Inkinen, 2015; Herden, 2020). Intellectual capital intangible assets include explicit and tacit knowledge rooted in human resources, organizational structure, and relationships with stakeholders (Inkinen, 2015). However, there is general agreement that intellectual capital is an umbrella term for three types of intangible capital: human, structural, and social (Bontis et al., 1999; Namvar and Khalilzad, 2013; Inkinen, 2015). Human capital embodies the development and utilization of individuals’ knowledge in an organization (Bontis et al., 1999). It represents an organization’s thinking assets and its members’ combined knowledge, intelligence, and other capabilities, including education, skills, experience, and judgment (Han and Li, 2015). Structural capital describes the documented accumulated knowledge stored within structures, manuals, routines, procedures, organizational culture, trademarks, information systems, databases, and files (Hsu and Sabherwal, 2012; Pinto, 2020). Bontis et al. (1999) provided firms with the power to learn and innovate. Social capital refers to the knowledge transferred and incorporated through networks and relationships with organizations’ internal and external stakeholders (Chen and Chen, 2022; Alsmadi et al., 2022). Scholars have confirmed the significance of this social asset in pooling the expertise, competencies, and resources of business partners to facilitate collaborative knowledge creation (Han and Li, 2015; Tu, 2020; Alhawamdeh et al., 2023).

Business organizations face increasing challenges in integrating and streamlining supply chain operations. This prompts them to rethink and embrace strategies and capabilities that can quickly adapt to fluctuations in demand and supply by enhancing innovation across the supply chain members (Karaman Kabadurmus, 2020; Sarkis, 2020; Malacina and Teplov, 2022). SCI encompasses both incremental and radical changes in production, operations, marketing, technology, and resources. Scholes also considers SCI a strategic capability to enhance the adaptability of organizational processes that require collaboration between business partners and innovative SCM (Beltagui et al., 2020; Fan, 2022; Bouncken et al., 2023a). Scholars agree that SCI is manifested in various ways, including unique processes, goods, logistics, and support services (Bouncken et al., 2020; Sarkis, 2020; Kazemargi et al., 2022). However, recent studies indicate a lack of empirical research exploring whether business analytics capabilities impact SCI, necessitating further investigation (Jaouadi, 2022; Abourokbah et al., 2023). Despite the growing interest in investigating the relationship between SCI and big data capabilities in many contexts (e.g. Hahn, 2020; Fan, 2022; Abuzaid et al., 2023), there is relatively little empirical research on SCA in the context of manufacturing organizations.

Organizational agility reflects firms’ ability to foresee and react proactively to changes and exploit emerging opportunities in uncertain market volatility (Cegarra-Navarro and Martelo-Landroguez, 2020). The literature confirms that proactive behavior is a determinant of agile practices, especially in markets with unpredictable demand (Altschuller et al., 2010; Fosso Wamba and Akter, 2019). Scholars consider SC agility to be one of the critical dynamic capabilities that represent adaptive intelligence, which involves sensing and reacting to disruptions in a turbulent business environment (Gligor and Holcomb, 2014; Shamout, 2020). Scholars have studied the effects of information access, planning and control, operational capabilities, supply chain process integration, top management support, forecasting and replenishment, market sensitivity, and continuous learning on SC agility (Gligor and Holcomb, 2014; Patel et al., 2018). Moreover, substantial attention has been dedicated to
examining the contribution of digital solutions to supporting SC agility (Alzoubi and Yanamandra, 2020; Abourokbah et al., 2023).

Considering the existing research gap, the following section addresses the proposed potential impacts and connections between intellectual capital components, SCA, SCI, and SC agility. Subsequently, related hypotheses are presented.

3. Proposed potential impacts and hypotheses

3.1 Human capital and the adoption of SCA

Human capital encompasses the collective knowledge, experience, competencies, and skills of individuals involved in organizational decision-making processes and operations (Han and Li, 2015). It plays a central role in driving changes and shifts in management practices by providing education, awareness, and training and fostering an organizational culture that promotes the adoption of innovative practices (Ahmed et al., 2022; Bouncken et al., 2023a). Organizations must develop skilled human capital to implement business analytics initiatives effectively. Business analytics tools and applications require professionals and practitioners with diverse education, knowledge, and skills (Schiemann et al., 2018; Bonilla-Chaves and Palos-Sánchez, 2023). Scholars have affirmed that firms need to provide their employees with learning opportunities, encourage data-driven thinking, and invest in upskilling and training in new methodologies, techniques, and tools related to data analysis to build a strong foundation for business analytics capabilities (Hayajneh et al., 2022).

The availability of trained professionals who possess the necessary skills and expertise to effectively use innovative analytical tools is crucial for successfully adopting SCA and maximizing its benefits (Kalaitzi and Tsolakis, 2022). According to Jaouadi (2022), such professionals can implement analytical methodologies, decipher insights, and transform outcomes into actionable decisions, thereby creating innovative solutions to enhance SCM. Previous research has confirmed the vital role of human capital in data collection, cleansing, integration from various sources, appropriate data storage, management, and maintenance of data quality, improving SCM, and gaining a deeper view of the environment (Harlow, 2018; Muafi and Sulistio, 2022). Competent staff are crucial for determining data gaps and executing practical data governance rules, upon which SCA capabilities rely heavily (Jaouadi, 2022). Hence, we propose the following hypothesis:

\[ H1. \] Human capital significantly impacts the adoption of SCA.

3.2 Structural capital and the adoption of SCA

According to scholars, capital plays a pivotal role in driving and implementing business analytics initiatives (De Santis and Presti, 2018; Chen and Chen, 2022). It comprises frameworks, standards, procedures, and policies that govern and manage data integrity, security, and quality (Gravili et al., 2021). Studies show that leveraging structural capital empowers firms to improve their analytical capabilities, acquire new knowledge, gain practical insights, and drive operational excellence throughout their supply chain functions and operations (Inkinen, 2015; Chen and Chen, 2022; Nazir et al., 2023). Hardware, software, data warehouses, information systems, digital collaborative platforms, and networks are the necessary infrastructures for conducting SCA (Khan et al., 2023).

Fosso Wamba and Akter (2019) confirmed that a well-developed SCA infrastructure enables the handling of large volumes of data, performing complex data processing, analysis, and visualization, generating meaningful real-time insights, and making more informed supply chain decisions. These technological resources of structural capital allow an organization to gather, retrieve, store, and integrate data from suppliers, distribution channels, customers, and logistics partners, thereby enhancing the reliability and accuracy of
SCA. Additionally, knowledge-management systems facilitate the sharing of lessons learned, best practices, and SCM knowledge. Prior research has emphasized that these systems have enabled supply chain partners to disseminate analytical insights and foster a data-driven culture, accelerating the adoption of SCA (Herden, 2020; Shamout, 2020). Furthermore, the standardization and automation of repetitive supply chain processes have reduced errors and enabled faster data processing, thereby scaling the capabilities and effectiveness of SCA across the supply chain network (Büyüközkan and Güler, 2021). Therefore, we propose the following hypotheses:

\[ H2. \] Structural capital significantly impacts the adoption of SCA.

### 3.3 Social capital and the adoption of SCA

Social capital, including individual and organizational social networks, facilitates the exchange and sharing of information and expertise inside and across companies. It enhances communication channels, encourages collaboration, and facilitates the flow of data necessary for business analytics (Gravili et al., 2021; Chen and Chen, 2022). Social capital also enhances the transfer and exchange of analytics knowledge within and between organizations, enabling a collective understanding of analytics methodologies, tools, and techniques (De Santis and Presti, 2018). Information sharing and collaboration also accelerate the learning curve for new adopters of business analytics initiatives and foster a culture of continuous development (Prim et al., 2023). However, scholars have confirmed that relational networks play a pivotal role in diffusing and implementing analytical methodologies and tools across supply chain networks (Harlow, 2018; Khattab et al., 2022). At the organizational level, SCA implementation is influenced by factors such as trust, shared values, and communication networks (Kalaitzi and Tsolakis, 2022). Trust allows business partners to communicate critical data and information necessary to effectively implement analytics. Moreover, when shared values and norms emphasize the significance of analytics, they cultivate a supportive organizational culture that encourages the adoption of analytical practices (Ogbuke et al., 2022).

Social capital manifests at the broader industry level through industry associations, collaborations, and forums dedicated to knowledge sharing (Mubarik et al., 2022). These partnerships provide platforms for benchmarking, collective learning, and best practices (Meyer, 2023). By engaging in these interactions, organizations can acquire valuable insights into the advantages and obstacles of SCA implementation. This helps reduce uncertainty and promotes the widespread adoption of SCA throughout the industry. However, Kalaitzi and Tsolakis (2022) revealed that establishing trust and promoting information sharing among partners within the supply chain plays a pivotal role in achieving effective adoption and utilization of analytics tools. De Santis and Presti (2018) claim that social connections, trust, and cooperation are central determinants of adopting big data analytics among different participants in supply chain networks. Thus, it can propose:

\[ H3. \] Social capital significantly impacts the adoption of SCA.

### 3.4 SCA and SCI

SCI entails leveraging cutting-edge technologies and implementing creative strategies and innovative operations to enhance SCM (Shamout, 2019). Business analytics offer the ability to evaluate supply chain performance and empower organizations to recognize trends, patterns, and areas that can be improved (Büyüközkan and Güler, 2021). Businesses can foster ongoing improvements and innovation in their supply chain activities (Bouncken et al., 2023b). Scholars have revealed that advanced analytical tools and techniques have provided firms with deeper insights from complex and large supply chain datasets, enabling them to...
enhance their operational effectiveness, minimize risks, and maintain competitiveness in a rapidly evolving and intricate business landscape (Kalaitzi and Tsolakis, 2022; Shamout, 2023). SCA extracts critical information and provides important insights, contributing to a better understanding of supply chain operations and identifying areas where innovative solutions may be created and implemented.

Studies confirm that SCA enables business organizations to enhance their supply chain strategies and operations, focus on improving existing products or developing new ones, eliminate inefficiencies, and apply innovative strategies (Fosso Wamba and Akter, 2019; Kalaitzi and Tsolakis, 2022). Abuzaid et al. (2023) revealed that businesses can use SCA to analyze historical procurement data, industry costs, customer behavior, and market trends to accurately forecast demand, creating a conducive environment for innovation by providing an efficient allocation of resources and product development that aligns with market needs. Furthermore, studies have emphasized the crucial role of SCA in detecting supply chain inefficiencies and bottlenecks by analyzing data from different sources, including production, transportation, and inventory. This allows businesses to explore opportunities and areas for improvement and innovation (Shamout, 2023). Hence, this study hypothesized the following:

H4. SCA significantly impacts SCI.

3.5 SCA and SC agility

Business analytics involves analyzing data using statistical analysis and employing predictive modeling techniques to obtain valuable insights and make well-informed decisions (Shamout, 2020). Conversely, organizational agility implies the ability to swiftly adapt, respond, and prosper in fast-paced and ever-changing business environments (Giannakis and Louis, 2016). Recent studies have demonstrated that organizations can effectively and promptly address unexpected disruptions, evolving customer needs, and market dynamics by harnessing their analytical capabilities (Kähkönen et al., 2023; Shamout, 2023). This allows firms to efficiently coordinate their production, inventory, and distribution methods, enabling them to respond quickly to unforeseen changes in market demand. Improved demand planning leads to greater SC agility as organizations become more capable of responding swiftly to changes in demand (Seyedan and Mafakheri, 2020; Rathod and Kumar, 2021).

SCA delivers real-time information and insights into various supply chain activities such as procurement, inventory levels, demand patterns, production capacity, and transportation (Ogbuke et al., 2022). SCA also assists organizations in identifying areas of vulnerability and proactively deploying agile solutions to minimize relevant risks by evaluating data on supply chain environments (Khan et al., 2023). These solutions may involve identifying alternative suppliers, creating reserve inventory buffers, or developing contingency plans to successfully manage interruptions and ensure the supply chain’s flexibility and responsiveness. By analyzing inventory data, companies can recognize products that are experiencing slow sales or have lost popularity. They can employ dynamic inventory management strategies such as just-in-time inventory or predictive analytics to optimize stock levels based on customer demand patterns (Shokooheyar et al., 2022). Similarly, analytics can enhance the efficiency of logistics operations by analyzing transportation activities, opportunities for consolidating shipments, and data on carrier performance, thereby improving the agility of supply chains (Singh et al., 2023). Hence, it can propose:

H5. SCA significantly impacts SC agility.

Figure 1 depicts the research model and proposes links among the various dimensions of intellectual capital, SCA, SCI, and SC agility, as addressed and justified in the preceding subsections.
4. Research methodology

4.1 Measurement and development of research instrument

Items drawn from relevant literature were used to measure the research constructs, which included intellectual capital, SCA, SCI, and SC agility (See Table 1).

To confirm its validity, three experts in SCM, business innovation, and business analytics revised the questionnaire, which comprised 35 items (Table 2) for relevance, clarity, consistency and logical flow.

4.2 Sampling and data collection

The manufacturing sector is an appropriate domain to examine the factors and effectiveness of SCA for several reasons. In the manufacturing sector, supply chains are intricate and dynamic, involving multiple members such as suppliers, distributors, and retailers. Investigating the determinants and performance of SCA in this sector provides valuable insights into the unique challenges and opportunities related to managing and optimizing these complex networks. Manufacturing organizations generate large volumes of data throughout their operations, encompassing production processes, inventory management, and logistics. Furthermore, the manufacturing sector is at the forefront of adopting and harnessing cutting-edge technologies. These technologies generate vast amounts of data that can be effectively utilized through SCA to drive operational improvements, enable predictive maintenance, and facilitate real-time decision-making.

The sample was collected from the top 46 manufacturing companies in Jordan identified on the BestStartup.Asia website (https://beststartup.asia/46-top-jordanian-manufacturing-companies-and-startups/). Following the initial phone conversation, 24 companies consented to participate. The sample comprised a diverse group of managers, directors, and department managers.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Items</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intellectual capital</td>
<td>12</td>
<td>Hsu and Sabherwal (2012), Han and Li (2015), Al-Omoush et al. (2022)</td>
</tr>
<tr>
<td>SCI</td>
<td>5</td>
<td>Shamout (2019), Karaman Kabadurmus (2020)</td>
</tr>
<tr>
<td>SC agility</td>
<td>5</td>
<td>DeGroote and Marx (2013), Mandal and Saravana (2019)</td>
</tr>
</tbody>
</table>

Source(s): Created by the authors

Table 1. Measures sources
<table>
<thead>
<tr>
<th>Construct</th>
<th>Code</th>
<th>Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human capital</td>
<td>HC1</td>
<td>Our company invests in programs for training and development to enhance employee expertise</td>
</tr>
<tr>
<td></td>
<td>HC2</td>
<td>Within our company, there is a culture that promotes continuous learning and knowledge sharing</td>
</tr>
<tr>
<td></td>
<td>HC3</td>
<td>The expertise and competencies of employees contribute significantly to the success of our company</td>
</tr>
<tr>
<td></td>
<td>HC4</td>
<td>Our company is successful in attracting and retaining talented individuals with specialized skills</td>
</tr>
<tr>
<td>Structural capital</td>
<td>STC1</td>
<td>Our company has well-documented processes and procedures that facilitate efficient operations</td>
</tr>
<tr>
<td></td>
<td>STC2</td>
<td>Advanced technology infrastructure is in place within our company to support effective information sharing and collaboration</td>
</tr>
<tr>
<td></td>
<td>STC3</td>
<td>We possess a comprehensive knowledge management system that captures and shares organizational knowledge</td>
</tr>
<tr>
<td></td>
<td>STC4</td>
<td>The organizational structure of our company promotes effective communication and coordination among different departments</td>
</tr>
<tr>
<td>Social capital</td>
<td>SOC1</td>
<td>Trust and mutual respect are deeply ingrained in the relationships our company maintains with external partners</td>
</tr>
<tr>
<td></td>
<td>SOC2</td>
<td>Our company has a wide network of strong relationships and collaborations with other companies in our industry</td>
</tr>
<tr>
<td></td>
<td>SOC3</td>
<td>Employees within our company actively engage in knowledge exchange and collaboration with external stakeholders</td>
</tr>
<tr>
<td></td>
<td>SOC4</td>
<td>Our company nurtures a supportive and collaborative culture that encourages cooperation and the pursuit of shared goals</td>
</tr>
<tr>
<td>SCA</td>
<td>SCA1</td>
<td>The company effectively employs data analytics tools to analyze and optimize its supply chain operations</td>
</tr>
<tr>
<td></td>
<td>SCA2</td>
<td>Supply chain decisions are driven by data and supported by advanced analytics techniques</td>
</tr>
<tr>
<td></td>
<td>SCA3</td>
<td>The company gathers and examines real-time data to monitor its supply chain and identify areas for enhancement</td>
</tr>
<tr>
<td></td>
<td>SCA4</td>
<td>The company regularly utilizes predictive analytics to forecast demand and manage its inventory</td>
</tr>
<tr>
<td></td>
<td>SCA5</td>
<td>Our company has key performance indicators to assess the effectiveness of our initiatives in supply chain analytics</td>
</tr>
<tr>
<td>SCI</td>
<td>SCI1</td>
<td>Our company fosters and supports innovation within the supply chain to drive continuous improvement</td>
</tr>
<tr>
<td></td>
<td>SCI2</td>
<td>We actively explore new technologies and innovative solutions to enhance our supply chain processes and performance</td>
</tr>
<tr>
<td></td>
<td>SCI3</td>
<td>Our company cultivates a culture of creativity and openness to explore innovative ideas</td>
</tr>
<tr>
<td></td>
<td>SCI4</td>
<td>We allocate dedicated resources and investments to promote and implement initiatives focused on supply chain innovation</td>
</tr>
<tr>
<td></td>
<td>SCI5</td>
<td>The company actively collaborates with partners and suppliers to co-create innovative solutions</td>
</tr>
<tr>
<td>SC agility</td>
<td>SCAG1</td>
<td>Our company can quickly adapt to shifts in customer requirements and market dynamics</td>
</tr>
<tr>
<td></td>
<td>SCAG2</td>
<td>The company consistently evaluates and enhances its capabilities in supply chain agility to maintain competitiveness in a dynamic business environment</td>
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<tr>
<td></td>
<td>SCAG3</td>
<td>Our company has cross-functional teams and processes that facilitate agile decision-making within the supply chain</td>
</tr>
<tr>
<td></td>
<td>SCAG4</td>
<td>The company proactively monitors market trends and customer preferences to adjust our supply chain strategies promptly</td>
</tr>
<tr>
<td></td>
<td>SCAG5</td>
<td>Our supply chain processes are designed to be adaptable and responsive to any unexpected disruptions or events that may arise</td>
</tr>
</tbody>
</table>

**Table 2. Construct and measures**

**Source(s):** Created by the authors
heads representing various areas, including supply chain, operations, IT, logistics, procurement, research and development, and quality. These individuals were responsible for distributing the questionnaire to relevant individuals or teams within their respective areas of responsibility.

To collect the data, manufacturing companies sent a physical questionnaire along with a cover letter. An online version of the questionnaire was also emailed to the companies, allowing them to select their preferred response method. Companies that did not respond within three weeks received a follow-up email, and firms that did not provide their responses after four weeks were contacted via phone. After seven weeks, data collection yielded 268 valid responses (See Table 3).

5. Data analysis
Partial least squares (PLS) version 4 was used to assess the reliability and validity of the measurement instrument and hypothesized relationships. This structural equation modeling (SEM) method offers high flexibility and can effectively handle reflective and formative measurement models. In addition, it is less sensitive to distributional assumptions and sample size requirements than other SEM techniques.

5.1 Evaluation of the measurement model
The research model was evaluated by investigating its reliability and validity. The items’ dependability was determined by assessing their loadings on the underlying constructs. Factor loadings provide insights into the extent to which each measured variable is linked to a specific underlying construct. Items displaying a factor loading above 0.6 indicate a higher degree of shared variance with their respective latent constructs. Following Hair et al. (2014), the study eliminated items from the measurement scale and adjusted the research instrument by excluding those with factor loadings below 0.6. Consequently, one item from the SCA (SCA2) and one from SC agility (SCAG3) were removed. The internal consistency and

<table>
<thead>
<tr>
<th>Firms</th>
<th>No</th>
<th>%</th>
<th>Respondents</th>
<th>No</th>
<th>%</th>
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<td>Operations</td>
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<td>&lt;250</td>
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<tr>
<td>&gt;20</td>
<td>04</td>
<td>17</td>
<td>Total</td>
<td>268</td>
<td>100</td>
</tr>
<tr>
<td>Total</td>
<td>24</td>
<td>100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source(s): Created by the authors

Table 3. Respondents’ profile

Unleashing innovation and agility
reliability of the variables were assessed using Cronbach’s alpha and composite reliability (CR) tests, as presented in Table 4. Cronbach’s alpha assists in evaluating how well the items within a scale or construct correlate. CR plays a crucial role in verifying the internal consistency of the latent constructs and evaluating the overall quality of the measurement model, which is a pivotal stage in structural equation modeling. However, all constructs demonstrated high internal reliability, as evidenced by Cronbach’s Alpha and CR values surpassing 0.80 (Hair et al., 2014). This study also used the Average Variance Extracted (AVE) test with a threshold of 0.50 to determine the convergent validity of the constructs. The aim was to determine whether the underlying variables explained more than half the variation in their respective indicators.

Notably, the AVE values for all constructs above 0.50 support the convergent validity and suitability of the study scale (Fornell and Larcker, 1981). Fornell and Larcker’s (1981) discriminant validity criteria were used to measure discriminant validity. Table 5 shows that the square root of the AVE for each construct outperformed the correlations with other constructs, indicating that discriminant validity fulfilled Fornell-Lacker’s requirement.

5.2 Testing hypotheses

The results of path analysis (See Figure 2) indicate that intellectual capital explains 56.8% of the variation in SCA adoption. Furthermore, SCA adoption accounted for 50.1 and 18.3% of the variations in SCI and agility, respectively.

In empirical studies, crucial elements for testing hypotheses within SEM include the path coefficient, t-value, and level of significance. The path coefficient, commonly indicated as beta (β), indicates the direction and strength of the relationship between two variables in an SEM. Whereas the significance level, typically set at 5%, establishes a threshold for accepting or rejecting the null hypothesis, the t-value acts as a statistical measure for evaluating the significance of the estimated path coefficient. A t-value exceeding the 1.96 threshold indicates a more significant relationship (Hair et al., 2014). Table 6 shows the results of the hypothesis

<table>
<thead>
<tr>
<th>Construct</th>
<th>Cronbach’s alpha</th>
<th>CR</th>
<th>AVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human capital</td>
<td>0.806</td>
<td>0.875</td>
<td>0.641</td>
</tr>
<tr>
<td>Social capital</td>
<td>0.83</td>
<td>0.887</td>
<td>0.664</td>
</tr>
<tr>
<td>Structural capital</td>
<td>0.79</td>
<td>0.865</td>
<td>0.618</td>
</tr>
<tr>
<td>SCA</td>
<td>0.802</td>
<td>0.871</td>
<td>0.63</td>
</tr>
<tr>
<td>SCI</td>
<td>0.793</td>
<td>0.858</td>
<td>0.547</td>
</tr>
<tr>
<td>SC agility</td>
<td>0.817</td>
<td>0.882</td>
<td>0.657</td>
</tr>
</tbody>
</table>

Table 4. Measurement model criterion

<table>
<thead>
<tr>
<th>No.</th>
<th>Constructs</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Human capital</td>
<td>0.800</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Social capital</td>
<td>0.523</td>
<td>0.815</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Structural capital</td>
<td>0.430</td>
<td>0.453</td>
<td>0.786</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>SCA</td>
<td>0.626</td>
<td>0.648</td>
<td>0.529</td>
<td>0.794</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>SCI</td>
<td>0.507</td>
<td>0.707</td>
<td>0.365</td>
<td>0.708</td>
<td>0.740</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>SC agility</td>
<td>0.340</td>
<td>0.318</td>
<td>0.601</td>
<td>0.427</td>
<td>0.334</td>
<td>0.810</td>
</tr>
</tbody>
</table>

Table 5. Discriminant validity

Source(s): Created by the authors
testing. These findings indicate that each dimension of intellectual capital, namely human (H1), structural (H2), and social capital (H3), has a considerable impact on SCA adoption. The results also demonstrate that SCA significantly affects SCI (H4) and agility (H5).

6. Discussion
This study found that human capital significantly affects SCA adoption. These results align with previous research that emphasizes the need to provide employees with knowledge and skills, encourage data-driven thinking, and invest in upskilling and training in new methodologies, techniques, and tools to adopt and use business analytics tools and applications (De Santis and Presti, 2018; Chen and Chen, 2022). Prior research explains how human capital can contribute to attracting business analytics capabilities to companies (Kalaitzi and Tsolakis, 2022; Bonilla-Chaves and Palos-Sánchez, 2023). Many studies have confirmed the urgent need for skilled employees with the required knowledge and competencies to develop, apply, and exploit its benefits (Kalaitzi and Tsolakis, 2022; Jaouadi, 2022).

This study shows that structural capital significantly affects SCA adoption. This finding is consistent with earlier research, confirming the importance of structural capital in the decision to adopt and use business analytics (Verbano and Crema, 2016; Harlow, 2018). Furthermore, prior research has confirmed the importance of IT infrastructure in facilitating the successful implementation of SCA, which enables firms to handle large volumes of data; perform complex data processing, analysis, and visualization; generate meaningful real-time insights; and make informed supply chain decisions (Fosso Wamba and Akter, 2019; Khan et al., 2023).
The findings confirm that social capital significantly affects SCA adoption. These findings are consistent with earlier research, confirming the effects of firms' social networks on the transfer of knowledge between supply chain members, which facilitates the adoption of innovative digital solutions (Harlow, 2018; Shamout, 2019; Al-Shboul, 2023; Bouncken et al., 2023b). These results also align with those emphasizing the importance of social networks in promoting collaboration and exchanging data, experiences, and knowledge, enabling a collective understanding of analytics methodologies, tools, and techniques and accelerating the learning curve for new adopters of business analytics initiatives (De Santis and Presti, 2018; Kalaitzi and Tsolakis, 2022; Prim et al., 2023).

These findings confirm that SCA significantly impacts SCI, which agrees with prior research that demonstrates the significance of business analytics in SCI (Büyüközkan and Güler, 2021; Kalaitzi and Tsolakis, 2022). Moreover, these results align with prior research on the role of SCA in analyzing inbound and outbound data. This creates an innovative environment for enhancing SCM, eliminating inefficiencies, focusing on creating new products, improving current ones, and implementing innovative strategies (Fosso Wamba and Akter, 2019; Kalaitzi and Tsolakis, 2022).

These findings support previous research on the importance of SCA in enhancing SC agility, corroborating prior studies on the significance of data in enhancing organizational agility and its ability to enable companies to respond to sudden and unexpected supply chain disruptions (Wamba et al., 2020; Rathod and Kumar, 2021; Shamout, 2023). These results align with research that endorses the importance of strong business analytics in addressing unexpected disruptions and market dynamics, which empower companies to quickly adjust their production, inventory, and distribution strategies to meet unexpected shifts in market demand (Aamer et al., 2020; Seyedan and Mafakheri, 2020; Shamout, 2023).

7. Theoretical and practical implications
7.1 Theoretical implications
This study makes significant theoretical advances by broadening knowledge and providing fresh insights into the factors affecting SCA adoption and their implications for SCM and performance. By integrating the concepts of intellectual capital and SCA into a theoretical framework that highlights this relationship in manufacturing companies, this study improves our understanding of IC's role in intellectual capital and its relevance in driving or impeding SCA adoption. This integration helps bridge the gap between these two significant fields of inquiry. Furthermore, this study provides empirical data that suggests a substantial relationship between intellectual capital and SCA adoption. This evidence forms the basis for additional studies. Furthermore, it improves general knowledge of the mechanisms by which intellectual capital affects SCA adoption. This study’s research model adds to the advancement of SCM theory by emphasizing the function of analytics as a catalyst for innovation within the supply chain setting. This broadens our understanding of how analytics may improve supply chain operations, decision-making, and overall performance. Furthermore, this study contributes new insights into innovation theory by demonstrating how SCA may stimulate and assist innovation in SCM.

This study adds to the growing theoretical foundation of supply chain digital transformation by investigating the role of analytics in supporting SCI. These findings provide scholars with an empirical indication of the association between SCA and SCI. This knowledge can serve as the basis for further investigations in this field. This study also serves as a reference point for scholars interested in investigating the role of analytics applications in driving innovation across different organizational contexts beyond the scope of supply chains in various domains. By reviewing existing research, this study identifies and defines the key elements linking SCA with SC agility. This study provides empirical evidence
of the correlation between SCA and SC agility to support these theoretical claims. This validation strengthens the theoretical foundation and expands our understanding of how SCA enhances SC agility. These findings enhance our knowledge of SC agility by examining the role of SCA in its improvement. Furthermore, the potential challenges and barriers to implementing SCA to improve SC agility are identified through empirical research.

7.2 Practical implications

Exploring the association between intellectual capital dimensions and manufacturing companies’ adoption of SCA has practical implications. Recognizing the effects of human capital emphasizes the importance of hiring individuals with the necessary knowledge, skills, and expertise in analytics. Furthermore, by understanding the value of human capital, manufacturing businesses may develop strategies to attract and maintain skilled analytical experts and build a supportive work environment that recognizes and supports analytical skills.

Companies must invest in solid technical infrastructure and software solutions to facilitate SCA adoption. Effective data management practices are important for the successful implementation of analytics. Companies should focus on data governance, quality, and integration to provide accurate and trustworthy analytical findings. This includes developing data standards, implementing data cleansing procedures, and integrating data from various sources across the supply chain. Furthermore, the findings may assist businesses in rethinking their organizational structures to promote analytics use. This may involve forming specialist analytics teams, fostering cross-functional collaboration, and cultivating a data culture.

Collaborative communication channels among business partners facilitate the exchange of information, knowledge, insights, and feedback on SCA. Furthermore, building trust among stakeholders is essential to adopting and using SCA. Manufacturing companies should foster a culture of trust and collaboration by encouraging employees to share their data, ideas, and knowledge. Additionally, the results imply that trust among supply chain members is a vital factor in SCA adoption and use. Firms must consolidate and support a culture of trust and collaboration by encouraging employees and business partners to share data, knowledge, and innovative ideas.

On the other hand, rapid responsiveness to market changes, variances in client needs, and interruptions are critical for manufacturing organizations to achieve SC agility. Companies can explore analytical capabilities such as real-time visibility, predictive analytics for demand forecasting and risk management, and optimization algorithms for dynamic decision-making that contribute to agility by investigating the impact of adopting SCA on these capabilities. Understanding the relationship between SCA and SC agility allows firms to prioritize investments in analytic tools and capabilities that improve their capacity to adapt and respond quickly to changing situations.

Furthermore, examining the impact of analytics adoption on innovation and SC agility helps manufacturing companies identify areas within their supply chain processes where analytics can be effectively integrated. By understanding how analytics can support decision-making and process improvement in these areas, companies can develop implementation plans, effectively allocate resources, and ensure the seamless integration of analytics into their supply chain operations.

8. Conclusions

The capabilities of emerging digital technologies have played a pivotal role in improving SCM, resulting in enhanced value creation throughout the supply chain. The dynamic and
ever-changing external environment has compelled organizations to develop integrated supply chain mechanisms that rely on intelligent analytical tools to effectively address uncertainties and disruptions. However, the literature shows a dearth of studies investigating the relationship between intellectual capital, which includes human, structural, and social capital; business analytics in general; and SCA adoption in particular. Furthermore, empirical studies that examine how SCA promotes SCI and enhances SC agility are lacking. Therefore, this study examines the potential role of intellectual capital in SCA adoption. This empirical study also examines SCA’s role in shaping SCI and agility.

The findings reveal that the three dimensions of intellectual capital—human, structural, and social—significantly impact the adoption of SCA. Businesses with stronger intellectual capital are more likely to accept SCA technologies. These results indicate that organizations with well-established knowledge bases, effective information-sharing strategies and practices, and solid external networks are better positioned to use SCA to improve supply chain efficiency. This study also confirms that SCA significantly affects SCI. According to these studies, companies that exploit data-driven insights through analytics are better positioned to explore novel opportunities, enhance operations, and design innovative strategies. This enhances innovative capabilities and overall supply chain performance and promotes long-term sustainability.

Furthermore, this study reveals that SCA provides companies with opportunities to leverage the agility of their supply chains. These findings demonstrate that businesses can respond rapidly to disruptions, adapt to market changes, and confront difficulties proactively by integrating real-time data and predictive analytics. Integrating analytical technologies enables firms to promote supply chain agility, which can sustain high levels of efficiency, flexibility, and resilience.

This study emphasizes that companies need to develop their dynamic analytics capabilities and invest in intellectual capital and SCA to create and enhance SCI and agility. Organizations that successfully utilize these capabilities gain competitive advantages, improve their performance, and effectively navigate the complexities of today’s unpredictable supply chain environments. These insights provide valuable guidance to practitioners and decision-makers who strive to enhance their SCM capabilities and sustainably foster long-term success.

9. Limitations and future research
The applicability of the findings of this empirical study, conducted in Jordan, to other regions or countries is limited. Cultural, economic, and industry-specific factors in Jordan might influence the association between intellectual capital, SCA, SCI, and SC agility differently in other contexts. Conducting comparative studies across different countries or regions can provide insights into variations in these relationships. Such studies could help identify country-specific or regional factors that influence these relationships. Furthermore, this study’s reliance on a limited sample from the manufacturing sector may not fully capture the diverse and complex nature of the overall supply chain landscape. To strengthen the validity of these findings, researchers should employ larger and more diverse samples. Extending this research to different industry sectors would enable a deeper understanding of how intellectual capital, SCA, SCI, and SC agility interact in specific industries. This could reveal the sector-specific drivers, barriers, and mechanisms contributing to or hindering these relationships.

Gathering data at particular time points limits the ability to establish cause-and-effect relationships and to fully understand the dynamic nature of analytics, intellectual capital, SCI, and SC agility capabilities. Future research should explore longitudinal or experimental designs to better capture temporal relationships and causal effects. Conducting longitudinal
studies would allow the capture of the dynamics and changes in these capabilities over time, leading to a more comprehensive understanding of their interrelationships. Furthermore, investigating the mediating or moderating effects of factors such as company characteristics, organizational culture, top management support, and supply chain complexity could provide a more nuanced understanding of the relationships between intellectual capital, SCA, SCI, and SC agility. Exploring these factors could help to identify additional variables that influence or strengthen the observed relationships.

Several potential directions for future research can augment our understanding of the multifaceted relationships between intellectual capital, the adoption of supply chain analytics, supply chain innovation, and supply chain agility. Manufacturing firms often function as global supply chain networks. Subsequent research could explore how intellectual capital and supply chain analytics shape decision-making in a global context, considering factors such as international logistics, compliance with regulations, and cultural influences. Considering the rapid advancement of analytics technologies and artificial intelligence (AI), it is imperative to investigate the impact of these state-of-the-art tools on the correlation between intellectual capital and the adoption of supply chain analytics.

Exploring how manufacturing companies allocate resources for intellectual capital development and the adoption of supply chain analytics is vital. Understanding how decisions regarding resource allocation affect innovation and agility can offer insights into effective strategies for optimizing resource utilization. The manufacturing sector has increasingly embraced sustainability. Future research could investigate the intersection of intellectual capital, supply chain analytics, and sustainability practices to determine how these factors contribute to eco-conscious supply chain innovation and agility. Finally, incorporating case studies and exemplary practices from successful manufacturing companies can provide practical insights for organizations seeking to enhance their efforts in supply chain analytics and innovation. Analyzing real-world instances can yield more accurate recommendations.

References


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