Received: 2 March 2021 | Revised: 9 August 2021 | Accepted: 11 August 2021
IET Collaborative Intelligent Manufacturing
DOI: 10.1049/cim2.12040
The Institution of Engineering and Technology WILEY

ORIGINAL RESEARCH PAPER

Supply chain control towers: Technology push or market pull—An assessment tool

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Abstract

As digital technology and connectivity advance rapidly, the premise of bringing supply chain (SC) visibility across multiple tiers of supply, whilst facilitating the velocity to achieve strategic business objectives, is gaining interest. The feasibility and timing for successful adoption and implementation of such technology depend primarily on the readiness level and specific needs of each organisation, making it imperative to exercise insightful judgement as it can be expensive to acquire, develop and master. This research study examines the market pull versus technology push components of the functionalities enabled by digital SC control towers and buildings on the outcome of an extensive survey and expert interviews and proposes an assessment tool to aid decision making for the consideration of their adoption.

KEYWORDS

computer integrated manufacturing, decision making, manufacturing industries, manufacturing systems, supply chain control towers

1 | INTRODUCTION

The Fourth Industrial Revolution (4IR)—characterised by the promise of fusing the digital, biological, and physical worlds through the growing utilisation of digital technologies, such as artificial intelligence (AI), cloud computing, robotics, 3D printing, the Internet of things (IoT), and advanced wireless connectivity—has ushered in a new era of economic disruption. Industry 4.0 is a trending term for the ongoing transformation of manufacturing and supply chain networks (SCNs). As part of Industry 4.0, the IoT enables manufacturers to harness digitally connected, smart, and decentralised value chains so as to deliver greater competitiveness by acquiring the capability to respond and evolve as business conditions change over time [1].

In the dynamic world of global manufacturing, 4IR technologies could facilitate the implementation of cyber-physical integration across the borders of an organisation, deep into its supply chain (SC) [2]. To that end, digital inter-connectivity and data analytics capabilities can be used to provide real-time supply-demand scenario planning and dynamic exception management [3]. This has given rise to an increasing interest for 'Digital Twins', that is, computerised models that represent actual physical objects and processes in real time [4].

In contrast to the increasing hype around 4IR tools such as digital twins and SC control tower (SCCT), the on-the-ground end-to-end (E2E) use cases are still very few and in a nascent phase. There is a need for a richer understanding among investing organisations regarding which 4IR technology tools should be combined and adapted for different parts of their value chain. While there has recently been a lot of publicity around the possibilities digital transformation brings into SCs, the adoption of advanced digital technology is still low notwithstanding the blurred lines and overlapping features of many such digital tools. For adoption of any technology, organisations need to clearly understand the value proposition and innovation advantages as well as the deployment requirements and readiness for implementation, so they can ascertain credible benefits that translate to compelling return on investment (ROI) [5]. Therefore, some important questions that organisations should ask before investing or even considering digital SC technologies are as follows:

- What extra functionalities and advantages can the new technology unlock in supply chains?
- How and to what level does it optimise product, cash and information flows?
- How can we assess our maturity and readiness for this technology investment?
- What may be the best approach and timing for acquiring it?

These questions are fundamental when considering the 'Technology Push' versus 'Market Pull' trade-off concept. Technology push is a new technological invention that is actively promoted through persistent sales and marketing activities, pushing the market for its adoption frequently without considering whether or not it is fully mature, scalable, or able to satisfy users' needs [6].

'Market pull' is the scenario in which markets demand a specific product (or service) type or define an unmet need and producers respond by developing, producing, and delivering it. A pertinent example is the life-sciences industry's response in 2020–2021 to the need for an effective vaccine in combating the SARS-CoV-2 virus pandemic, which gave rise to the creation, testing, licencing, and manufacturing of a number of different vaccines in record time-to-market.

This research work aimed to provide a structured approach in assessing an organisation's state of readiness and requirements with regards to the utility of SCCT technology adoption and to offer a reflective approach on its implementation in order to enable better decision making by considering the technology push and a market pull factors.

The overall flow of the research work has been summarised in Table 1.

2 | SUPPLY CHAIN CONTROL TOWER–CONCEPT NOTE

Conceptually, a SCCT is a shared-service centre that, like the digital twin of a traffic control tower, offers real-time monitoring of the status and performance of E2E activities in SCs that extend beyond the boundaries of the nucleus organisation [7]. Supply chain control tower can therefore constitute a 4IR digital information hub serving as the 'single access point of truth' for all decision makers, planners, buying teams and cross-organisational SC partners. Such SCCT hubs aggregate, correlate and distribute information for early detection of risks and opportunities, providing so called '3M functionality': *Monitor, Measure and Manage.*

Supply chain control tower can bring together organisations (people), systems, and processes to power high product and process visibility through the value chain and easily connect the three types of goals of an organisation's SC, which are design, planning and management as shown in Figure 1.

End-to-end SC visibility is a need that SCCTs can practically fulfil, acting as an inter-organisational coordinating platform. Such visible coordination is a catalyst for collaboration between all the stakeholders of an SC, which is an inherently tricky concept fraught with the fears of asymmetry in relational power and 'leaks' of proprietary information. Whether suppliers cooperate with clients or not, depends to a great extent on the nature and appeal of the collaborative mechanism. Despite the challenges, the value of pursuing collaborative vendor-managed replenishment programs has stood the test of time. Supply chain collaboration can reduce bullwhip effect costs as well as overall inventory and administrative costs for the whole chain. Retailers can maintain operations without interruption, while upstream suppliers can build loyalty and reduce costs through information sharing. Over time, inventory and labour costs are reduced which means suppliers can retain customers while reducing costs. Thus, it is important to gain a deeper understanding of SCCT implementation issues, which could also be relevant to the research of how the benefits from collaboration may be shared among SC members [8].

At each SC goal level SCCT can bring different functionalities and benefits that can be grouped under the three broad categories of 'See-Plan-Act' as in Figure 2.

2.1 | See

- **B2B Integration**: Supply chain control tower can bring together all the trading partners of the nucleus organisation, making possible the smooth sharing of information in real time, thus minimising the potential of any bullwhip effects in the supply-demand flow.
- **End-to-End Mapping**: Supply chain control tower are rooted on accurate mapping of the entire SCN which aids

TABLE 1 Overall flow of research work

The structural flow of work	
Supply chain control towers	Concept note, functionalities, benefits and barriers in implementation
Literature review	Theoretical sensitivity around SC visibility, transparency, resilience, and agility to ascertain technology push and market pull influences
Assessment tool discussion	Detailed discussion on the proposed SCCT adoption assessment tool. This section delves into the evaluation of requirements, readiness, and SC maturity—that constitute the elements of assessment tool
Methodology	Detailed discussion on the methodology that was used to create the assessment tool. It focuses on the step by step approach used to develop every element of the proposed assessment tool

Abbreviations: SC, supply chain; SCCT, SC control tower.

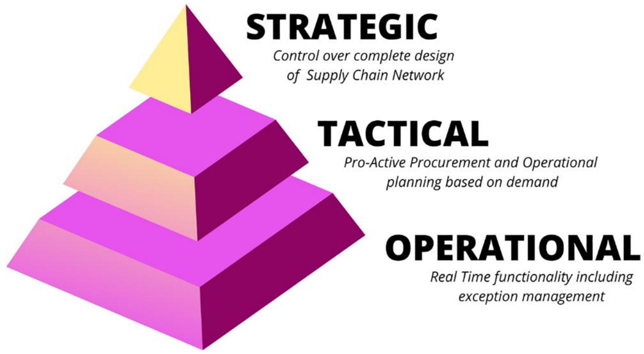

FIGURE 1 Management of supply chain at all levels

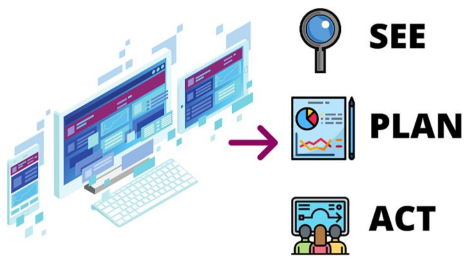

FIGURE 2 Functionalities powered by supply chain control tower

visibility and is the precursor of any attempt to develop autonomous decision making.

- **Real-Time Monitoring**: Improving customer service levels by tracking and recording data related to demand-supply performance in real time. This functionality increases the cost-effectiveness of planning for flexibility and responsiveness.
- **Granular Visibility**: Along with order status tracking and tracing, the granularity of visibility increases by pulling through high levels of detail for multiple parameters.
- **Data Management**: Control towers can help to store, append and structure SC data. This can ensure that visualisation is on-point and accurate, which is critical for optimum decision making, offering a stable baseline for further automation.
- **Alert Generation**: Supply chain control tower can send timely and relevant alerts to the right stakeholders about supply flow disruptions [9].

2.2 | Plan

Information analysis is required for sound commercial decisions. Therefore, data analytics can help improve the profitability of the business, increase market share and revenue, and provide a better returns to shareholders [10]. In order to improve their decision-making abilities, organisations increasingly rely on business analytics capabilities. Data analytics enable managers to make efficient and effective decisions that are relevant to business and its related operations by using tools, techniques, and processes, including algorithms and techniques that enable businesses to organise, visualise and curate data [11].

The five broad types of analytics powered by SCCT are as follows:

- Planning Analytics—What is our plan?
- Descriptive Analytics—What happened?
- Predictive Analytics—What will happen next?
- Diagnostic Analytics—Why did it happen?
- Prescriptive Analytics—What should be done about it?

2.3 | Act

- **Process automation**: Multiple standard business processes in SCCT can be organised in a 'landing' schedule, so they can run automatically without manual human intervention. Such scheduling routines give better visibility of which business processes are executed when and facilitate performance measurement transparency.
- **Human–machine collaboration**: Digital automation does not exclude human overseeing and interactivity. The business objective of this layer is to provide the means to collaborate across multiple functional areas both within and outside the organisation to effectively respond to an event. This is achieved by
  i. **Process management**: This allows various teams to leverage workflow capabilities to orchestrate an effective response to an event. For example, if a delivery is delayed then process management could trigger timely alerts to buyers, logistics managers, and transportation planners. These stakeholders can be empowered to provide feedback on a mobile-enabled workflow tool for immediate response and proactive mitigation of supply risks.
  ii. **Integration**: The SCCT tool can be integrated with enterprise systems to automate certain types of response mechanisms when initiated by the control tower team and/or its trusted algorithms.
- **Exception-based decision making**: Supply chain control tower can help in solving disruptions, cognitive risks and exception management even without human interventions.

The four key benefits of SCCT as shown in Figure 3 are as follows:

Cost savings: The SCCT uses natural language processing, machine learning, and statistics to identify issues from unstructured data resulting in accurate decision making which helps in saving a lot of costs associated with reactive trial-and-error actions.

Increased efficiency: Once the SCN is visible to every stakeholder, it presents a shared optimisation opportunity that can enable collaborative efficiency improvement projects and enhanced demand support.

Better customer experience: As all the SC partners can be connected in the SCCT dynamically, customers can get better, faster, and more effective responses.

Improved organisational models: Supply chain control tower helps connect all the silos of the SC into one big collaborative and compact network providing a 'single source of data truth' that can be used to target complex strategic and tactical goals of the organisation as a whole.

While there are multiple benefits of deploying an SCCT, there are certain challenges that are stopping companies from implementing them as shown in Figure 4 [12].

- **Lack of collaboration**: End-to-end visibility requires collaboration across trading partners. This collaboration gives birth to the challenge of transparency and data disclosure. A fully integrated SC provides the functionality of adjusting production plans in situations of erratic demand. Some organisations might not be comfortable in providing access to their partners to check their complete schedule modification history. Similar transparency issues can be anticipated in bill of material management, live inventory status along with other information that is shared by sales and operations planning teams with other stakeholders.
- **Accuracy and human intervention**: The basic framework needed for ensuring true agility must maintain consistent levels of accuracy throughout the SC. While the data collected digitally ensure a certain level of accuracy, the capability of the control towers to allow human intervention to update the data at multiple input points can have an impact on accuracy.
- **Integration challenges**: One of the most prominent challenges in implementation is the financial, time, and skills resource commitment needed to successfully launch an SCCT. Since integration must be done with all the trading partners at different levels of technological competency, delays and cost inflation risks may be high.
- **Budget and skillset constraint**: The one-time set-up costs of SCCT are very high. Therefore, few companies may be able to raise the funds to complete the entire E2E implementation.

FIGURE 3 Benefits of supply chain control tower

3 | LITERATURE REVIEW

3.1 | Supply chain visibility and transparency

The definition of SC visibility has been hitherto under refined. Even within the vast realm of SC literature, a consistent definition is elusive [13]. Supply chain visibility is often confused with information sharing whereas it is a broader capability that maps all the SC flows. Information sharing is one of the components of visibility that can be treated solely as an internal resource [14]. However, there is a need for seamless information integration between the linkages of the SC [15] across multiple echelons in a graphical way, depicting the flow of goods through trade lanes and partner facilities. This even entails the monitoring of thousands of data streams that can be outside the assumed boundaries of a SC per se, that is the weather forecasts, news feeds, social media trends, traffic reports, exchange rates, commodity, and stock market indices etc. to quickly and proactively surface alerts [16].

Prior research has conceptualised SC visibility as a capability [17] that may reduce the negative impacts of SC disruption [18].

Visibility is a key business enabler within the nucleus organisation and beyond its borders with affiliated stakeholders and partners. It can be a source of competitive advantage by facilitating the maximisation of key business metrics such as speed, flexibility, and cost [19].

Lack of SC visibility at the process level is the main concern for about 79% of the 150 large companies surveyed globally. This finding is in line with another recent survey of 400 SC executives worldwide [20].

There is a direct correlation between visibility powered by information sharing and operational performance. Furthermore, SC visibility improves decision making [21] particularly in situations of contingency, thus enhancing resilience [22]. In the last decade, it has become critical to develop inter and intra-organisation collaboration in order to identify and mitigate risks across whole SC systems. To achieve this, unfettered access and visibility of shared inter-company demand information are crucial [23]. Fashion retailer Zara's production scheduling and inventory control systems support this point. Zara has achieved sector leadership with its ability to adjust multi-plant and supplier production schedules daily on a real-time basis, enabled by information sharing between each store and its headquarters on a daily basis. This has reduced the probability of stockouts or excess inventory [24].

FIGURE 4 Barriers in supply chain control tower implementation

One of the major contributing factors for the lack of SC visibility is the challenge of identifying the specific areas of priority for further capability development. Visibility can positively affect manufacturing, transaction activities, planning, supplying, and evaluation [25] on both operational and strategic choice levels. On an operational level, it can impact forecasting, planning, and scheduling efficiency, along with execution accuracy and speed [26].

This is an important consideration for companies that find themselves increasingly under pressure by the hard-to-control complexities of the globalised nature of SCs. The enhanced visibility that enables global SC management to dynamically monitor, predict, sense, adapt, and optimise for supply-event exceptions, can provide a level of agility and resilience that can ensure the reliability of supply and improved responsiveness to market demand [27].

The increasing need to respond to complexity at speed and the realisation of the impact that increased visibility can have in achieving strategic, tactical, and operational benefits, elevates the functionality offered by digital 4IR tools such as SCCT to market pull rather than just a technology push trend. SCCT is a digital information hub serving as 'digital twins' of dynamic product and information flow, enabling SC management teams to reach higher levels of strategic, tactical, and operational control and visibility [28].

Transparency, which is roughly defined as disclosure of information, is a key concept of corporate sustainability [29]. Disclosure of information can be among other things about supplier names, sourcing details, procurement and labour practices, and volumes of activity [30].

The globalised complexity in SC with the increasing number of stakeholders being involved has rendered the transparency and authenticity of the information shared to be even more critical for effectively managing risks and recalls, to satisfy the rapidly changing consumer demand [31].

In addition, access to non-distorted, factual, [32] relevant, and timely SC information among all stakeholders including customers, helps promote trust and contributes significantly to brand building [33].

However, the fear of unfettered access to easily shareable digital information remains the dominant cause of collaboration inertia. Therefore, the adoption of technologies that could enable SC transparency is still being perceived by enlarging to be a technology push rather than a market pull phenomenon [33].

3.2 | Supply chain resilience and agility

Modern SCs operate in a world of volatility, uncertainty, complexity, and ambiguity and that makes them vulnerable to disruptions [34]. This makes the designing of SCNs a critical component for ensuring continuity of operations when exposed to risks [35] and gives rise to the increasingly popular concept of the resilience of supply. Supply chain resilience directly corresponds with a firm's dynamic capability to recover operational stability swiftly from unforeseen disruptions [36] and is increasingly seen as a source of competitive advantage. The most pertinent definition of resilience in this sense is given by Ponomarov and Holcomb (2009) [37] who describe it as

The adaptive capability of the supply chain to prepare for unexpected events, respond to disruptions, and recover from them by maintaining continuity of operations at the desired level of connectedness and control over structure and function. [37]

The biggest roadblock organisations face while building resilience is the huge amount of resources that they perceive they may need to invest in order to increase it. The challenge is not only associated with costs of risk mitigation but also with the way of establishing tangible ROI in disruption prevention. Some common approaches that are generally used to engineer resilience include building up redundancy in the supply network by having multiple alternative sources of supply, safety stocks, and overcapacity, all of which can be a burden on the cash flow [16].

Globalisation has made SC more prone to disruption. The coronavirus outbreaks are a testimony to how the resilience of SC was put to the test with 94% of the Fortune 1000 companies' SC being disrupted [38]. Only organisations with established countermeasures in place have been able to survive and eventually recover in this pandemic economy [39].

In the era of global pandemics and emerging SC chauvinism, markets are experiencing an increased amount of disruption [40]. An additional reason for this is the shortening life-cycle of mass-produced products. The overall demand for standardised consumer products has fragmented among the various competitors in the global markets. This situation imposes the challenge of adaptability and customisation while at the same time ensuring affordable pricing [41]. Such competitive forces in the global economy add further uncertainty to the overall business reality, making SC more vulnerable to shocks. The key to survival in such dynamic conditions is SC agility [42].

Agile SC respond flexibly and rapidly to changes in their environment, even if those changes are short-term and temporary [43].

Supply chain professionals are under constant pressure to ensure resilience in their networks of supply to keep up with the accelerating and unpredictable pace of change. Such needs for speedy responsiveness are supported by consulting companies and software providers that are constantly working on providing technology tools to enhance business trading agility [44].

The critical characteristics of an agile SC are [45]

a. Market Sensitivity
b. Network-Based flexibility
c. Process Integration
d. Virtual

These critical characteristics when combined together in a controlled way, can afford fast dynamic efficiency to organisations, making their SC resilient and agile as described in the following expression:

'Advanced Sensing + Flexibility + Co-ordination + Velocity = Agility' [45]

Companies and their major improvement initiatives tend to focus more on the factors of velocity and cost-effectiveness. What these organisations perhaps fail to realise is that cost-effectiveness and velocity alone do not provide substantial SC competitiveness as is normally expected [46]. While SC agility comes at a cost that is at times big enough to have a direct impact on profitability, it is a critical business prerogative to invest in, in order to ensure long-term resilience [47].

Therefore, SCCT functionalities that make SCs more resilient and agile can nowadays be considered a market pull factor rather than technology push forces.

4 | ASSESSMENT TOOL DISCUSSION

4.1 | Readiness score

Readiness Score for any organisation can be used to determine whether or not they are ready to introduce or even consider an E2E visibility technology like an SCCT. This score uses qualitative codes generated as a result of the analysis of interviews conducted during the research. The five constituting components of the score are

- **Transparency**: Nucleus organisation's willingness to provide open access to information without any barriers across trading partners.
- **Collaboration**: Willingness of suppliers and distributors in the value chain to come on board to implement this technology E2E.
- **Digitisation**: Prioritisation given to create a digital SC to make it more agile and resilient.
- **Autonomy**: Businesses focus to use cognitive intelligence to create a sustainable SC utilising the industrial IoT.
- **Financing**: Willingness to invest in technology to reap benefits in the future.

Responses from extensive interviews have been used to generate a prioritisation weights matrix.

Each organisation can self-evaluate itself on these five qualitative codes on a scale of 1 to 5 (1 being the lowest and 5 being the highest). A weighted average can be calculated to give the readiness score. The value of the readiness score will always be between 1 and 5 as shown and based on its actual value as shown in Figure 5 organisations can self-diagnose their state of readiness for SCCT adoption.

4.2 | Requirement score

The requirement score for any organisation can be used to determine whether or not they have the pressing needs for a high-end technology tool like control towers. This score uses the quantitative codes generated as a result of analysis of the survey conducted during the research. The five constituting components of the score are

- **Visibility**: Capability to see the E2E value chain in a 360° glance along with sensing and tracking abilities across all process levels, beyond the walls of the nucleus organisation.
- **Resilience**: Measure of organisation's potential to bounce back from a situation of contingency or market singularity without impacting the supply and production drastically.
- **Agility**: Measure of organisation's flexibility to changing business situations and capability to quickly adjust the supply and production accordingly.
- **Automation**: Organisation's emphasis on automating different segments of their value chain.
- **Velocity**: Importance of shorter lead time of moving apart from one end of the value chain to another.

Survey responses have been used to generate a prioritisation weights matrix.

Each organisation can self-evaluate themselves on these five quantitative codes on a scale of 1 to 5 (1 being the lowest and 5 being the highest) and a weighted average can be simulated to give the readiness score. The value of the requirement score will always be between 1 and 5 as shown in Figure 6. Based on the value of the requirement score, organisations can make further informed decisions on the merit of SCCT adoption.

$$\textbf{Readiness Score} = \frac{0.14 * T + 0.23 * C + 0.24 * D + 0.15 * AT + 0.23 * F}{100}$$

Readiness Score Range	Comment
Between 1 & 2	Low level of acceptance of the concept. Difficult to create a business case or a justified value proposition.
Between 2 & 3	Average acceptance level. A value proposition can be made with efforts.
Greater than 3	High level of acceptance. A very strong business case can be made and proposed for deployment.

FIGURE 5 Readiness score

FIGURE 6 Requirement score

$$Requirement\ Score = \frac{0.17 * VI + 0.19 * R + 0.22 * AG + 0.26 * AU + 0.17 * VE}{100}$$

Requirement Score Range	Comment
Between 1 & 2	Low level of requirement.
Between 2 & 3	Average requirement level.
Greater than 3	High level of requirement.

4.3 | Supply chain maturity

A SC can have different levels of maturity between the two extremes of simplicity and complexity. Most companies with established trading lanes and flows believe they have better than the average SC maturity.

However, when put to the test with a disruption—natural or man-made disaster—it becomes clear that not all SCs are created equal.

Best-in-class organisations' leverage real-time intelligence from their ecosystem of networked global trade partners to realise superior SC visibility and agility.

An SC can be a simple chain with one strand, a complex network, or any structure between these two extremes. SC needs to guarantee a steady flow of supply striving to reduce costs and the right chain structure can improve operating efficiency [48].

4.3.1 | Stages of SC management evolution

There is a four-stage model of SC management evolution

Stage 1: Multiple Dysfunction
This is a reactive SC that fulfils demand. It is perceived as a cost centre with a minimal focus on competitiveness, connectivity, and cost reduction.
Stage 2: Semi-functional Enterprise
This is a reactive efficient SC that supports competitive positioning by focussing on being efficient, low cost, and integrated. Greater importance is placed on connectivity technology, automation to improve capacity and throughput.
Stage 3: Integrated Enterprise
This is a proactive, efficient SC. It focusses on reducing cost and complexity. This can be done via changing product designs or sharing information across functions, using integrated information systems.
Stage 4: Extended Enterprise
This is a strategic driver SC. Demand generation and fulfilment are fully integrated. Supply chain contributes to the development of the organisation's overall strategy. Forecasting, planning, and replenishment are fully integrated and visible. Technological improvements, knowledge, and real-time information are shared with chain partners.

As shown in Figure 7, only organisations with both readiness score and requirement score greater than 3 and in either Stage 3/4 of the SC maturity level should proceed with considering investing in SCCT. It is tempting to attempt to solve all problems in one big digital transformation project. But it can be prone to failure and difficult to manage. Organisations should focus on incremental improvement once it is detected that their current level of readiness or maturity is low.

5 | METHODOLOGY

The grounded theory approach was used as a research methodology in this study because of its legacy of effectiveness on theoretical sensitivity and data synthesis, gathering, and analysis. The methodology encompasses a systematic literature review to understand the most prominent concepts around a topic which are then repeatedly probed and evaluated using surveys and interviews with stakeholders in the area of interest. The data gathered by this process is analysed to generate codes that can be either qualitative or quantitative depending on the nature of the data source. These codes can be used to generate their scores, models, frameworks, or theories [47].

From a holistic point of view, there are two major components of the grounded theory methodology that have been deployed in this study. The detailed step by step approach for the same is shown in Figure 8.

a. **Theoretical sensitivity**–A thorough literature review on the pertinent related concepts of visibility, resilience, agility, SCCT, 4IR technology enablers, benefits, and barriers to implementation was carried out. The key core concepts and parameters for the analysis were identified as a result.
b. **Coding**–Qualitative and quantitative codes were generated using surveys and interviews. For surveys, the repertory

#	Requirement Score	Readiness Score	Supply Chain Maturity	Comments
1	<3	<3	Stage 1/ Stage 2	No point of investing in Control Towers as the Supply Chain is not ready for it and neither there is a requirement.
2	>3	>3	Stage 1/ Stage 2	Recommended to switch it up to Stage 3/ Stage 4 before making huge investment in Control Towers.
3	>3	>3	Stage 3/ Stage 4	The supply chain is ready to upgrade to an end to end technology to provide tangible business benefits.

FIGURE 7 Decision making matrix

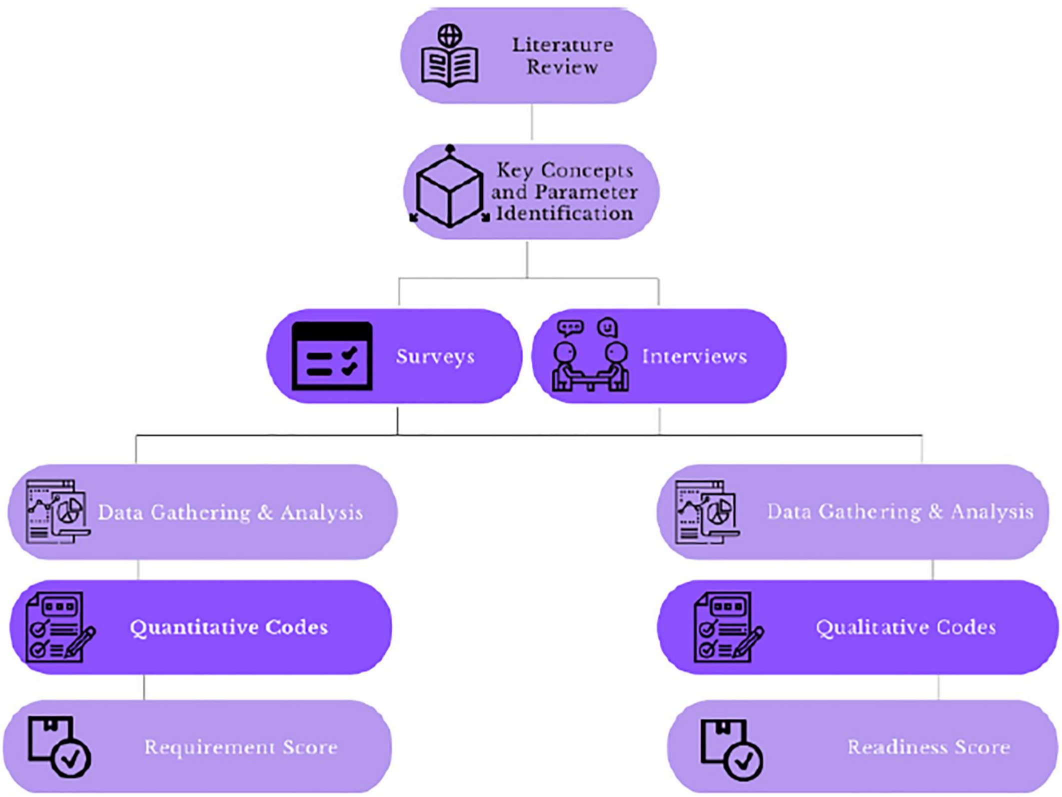

FIGURE 8 Step by step approach

grid approach was used with mostly structured closed-ended questions [47]. For interviews, a semi-structured approach was used to obtain a detailed perspective on the current research performed on a fixed set of parameters under the key concepts observation lens. By using these two contrasting approaches, converging concepts were evaluated to gauge the similarity of responses and reflect on their coherence. By studying the pattern of responses in both surveys and interviews, thematic codes were generated using open coding analysis. Open coding in the grounded theory method is the analytic process by which concepts to the observed data and phenomenon are attached during qualitative data analysis. It is one of the 'procedures' for working with text as characterised by Strauss and Strauss and Corbin [49]. Furthermore, this data was used to generate relative weights of the codes using the Analytical Hierarchy Process (AHP) which is a structured technique for organising and analysing complex decisions, based on mathematics and psychology [50]. These were further tested for their reliability and validation using Cronbach's alpha and triangulation approach. Cronbach's alpha is a measure of internal consistency, that is, how closely related a set of items are as a group. It is considered to be a measure of scale reliability. Triangulation is an important component of mixed-method designs which has its origins in attempts to validate research findings by generating and comparing different types of data and different respondents' perspectives, on the topic under investigation [51].

c. **Value Creation**–The codes generated were utilised to derive two scores that help in the assessment of the SC as a preparation step towards control tower technology implementation. A detailed implementation framework is proposed as an end deliverable.

As this research relied on creating qualitative and quantitative Codes, the industry's response to the concept and introduction was critical to the creation of codes. The quantitative codes were generated using the cross-industry survey, whereas the qualitative codes were generated using interviews with global SC Heads, business unit heads, and managing directors across India and Asia.

5.1 | Survey questionnaire design

The questionnaire was designed with mostly closed-ended questions distributed in three different sections.

The first section of the survey was created to put constraints on the kind of respondents. It ensured that the respondents were working professionals with relevant industry experience adding diversity to the sample set for analysis.

The second section, introduced the concept of SCCT along with a successful case study overview, to add context to the questions that followed. The questions revolved around gauging respondents' understanding and awareness of the concept and respective technology providers.

The third section aimed to capture the respondents' perceptions about the capabilities and challenges of the technology tool. It also included questions to get insights on the priorities and maturity level of their current SC.

5.2 | Survey results

In total 67 responses from across the industry were received. The diversity of the respondents is shown below in Figures 9 and 10.

A thorough analysis of responses was carried out using an open coding approach to shortlist the top five quantitative codes essential to evaluate the overall requirement of SCCT as a technology tool. The importance and reliability of these codes were verified by simulating the Cronbach's alpha value of these parameters with the responses received. Cronbach alpha for quantitative codes is 0.655, which means the inter-relation and reliability of these parameters is 65%. Furthermore, the data was used to determine the weights of importance of these codes to each other using the AHP approach [49]. Finally, a triangulation approach was used through member validation [51].

The final list of quantitative codes along with their weights ratios are shown in Figure 11.

5.3 | Selection of interviewees and interview questions

A semi-structured and standardised approach to interviews was used. The interviews were conducted virtually using technology bridges provided by Zoom and Microsoft Teams. Before the interview questions, an informational deck was presented to set the tone of the conversation with details on functionalities and features of SCCT. Examples of questions asked in the interview are shown in Figure 12.

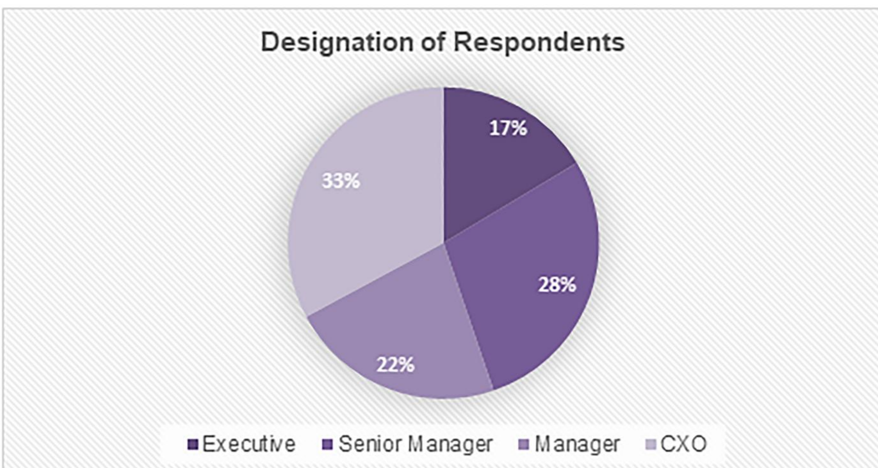

FIGURE 9 Designation of respondents

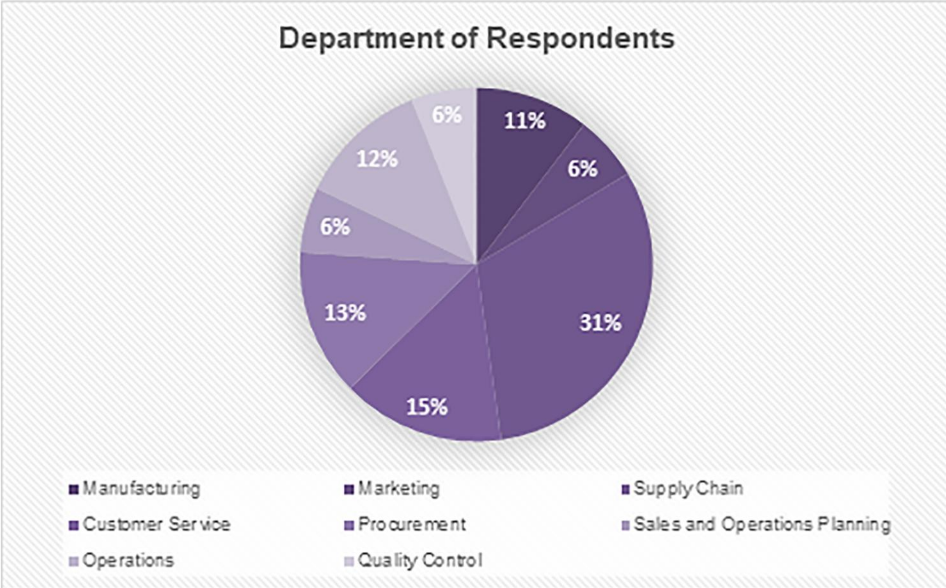

FIGURE 10 Department of respondents

#	Quantitative Code	Weights
1	Visibility	17%
2	Resilience	19%
3	Agility	22%
4	Automation	26%
5	Velocity	17%

FIGURE 11 Quantitative codes

The interviewees were selected keeping in mind

- Background relevance to the concept
- Work experience in the field
- Familiarity with the concept
- Industry and designation

In total 11 interviews were conducted with executives based in the UK and India primarily working in multinational organisations such as Siemens, Honda Cars, Nestle, Thoucentric, Saint-Gobain, and GSK among others.

5.4 | Interview results

The interviews were audio-taped with the explicit consent of the interviewees. Every transcript was checked and reviewed multiple times before using the data for analysis. Additionally, to ensure accuracy each transcript was cross-checked with the corresponding interviewees. Using an open coding approach initial coding was performed. The interviewee's views were divided into multiple categories of concepts and labelled to identify patterns. These patterns helped to develop common attributes from the raw data [52].

The semi-standardised answers obtained from interviews gave five concrete qualitative codes that show the readiness of an organisation to adopt CT for their SC. Furthermore, the data was used to determine the weights of importance of these codes to each other using the AHP followed by triangulation through member validation.

The codes shown in Figure 13 were used further to generate readiness scores—a self-assessment score that is indicative of the organisation's readiness to implement CT.

6 | CONCLUSION

Beyond the COVID-19 pandemic, organisations are focussing on the recovery of their SCs using traditional business process re-engineering (BPR) methods. There are two major steps involved in BPR, namely 'rebuild' and 'strengthen'. While rebuilding has usually a short-term focus on recovery, strengthening becomes the desired long-term goal of increased agile resilience which has emerged as a strong 'market pull' need. This long-term focus brings the need for SC visibility enhancements to the forefront. Leaner and more agile SC operations can be achieved only if there is dynamic visibility through the E2E system. Supply chain control towers is a technology tool that can be used for building this capability. The feasibility and timing for introducing such technology, however, depend on a thorough assessment of the current level of SC maturity, readiness, and specific requirements in order to

FIGURE 12 Interview questions

What according to you should be the capabilities of such a control tower?	What do you anticipate as core challenges in implementation of Control Towers in your Supply Chain?
Rank the following parameters in the proportion of relative importance to each other while considering implementation Transparency , Digitization, Collaboration , Financing , Autonomy	How would you rate relative importance of the following in your supply chains? Visibility, Resilience, Velocity, Agility, Transparency , Automation, Digitization, Automation and Autonomy
How difficult is getting collaboration from trading partners for such a technology tool?	Is digitization and automation of your Supply Chain a current priority
How important is financing in adoption of Control Towers for you?	Are autonomy and exception management something you are targeting in near future?
What do you understand of the trade of between visibility and transparency?	What are some apprehensions you have with regard to adoption of Control Towers?

#	Qualitative Code	Weights
1	Transparency	14%
2	Collaboration	23%
3	Digitization	24%
4	Autonomy	15%
5	Financing	23%

FIGURE 13 Qualitative codes

navigate the 'technology push–market pull' impact on technology adoption in the most optimum way.

This research provides a comprehensive self-assessment tool that will

- Calculate a readiness score on a scale of 1 to 5, which helps to determine whether or not the organisation is ready to consider or introduce an E2E centralising technology stack in their SC extending beyond tier 1 levels.
- Ascertain a required score on a scale of 1 to 5, to help determine if there is a pressing need for a powerful technology tool like SCCT in the SCN.
- The above two scores coupled with the current standardised mapping of an organisation's stage of the SC maturity stage can help to guide the evaluation of push-pull nuances in SCCT investment considerations irrespective of sector and size.

7 | FUTURE WORK

Supply chain digitisation is gathering pace and interest given the changing global business and environmental conditions. Supply chain control tower can bring together the complete stack of 4IR tools for deployment across the whole value chain and further opportunities that can be explored are

a. **Management of reverse flows of products**: Given the capabilities of SCCT in the management of information flows, the 'reverse flows' of products that include waste mapping, recycling, end-of-life take-back schemes and repairs, could be a future research strand given the emergence of the extended producer responsibility policy trends.
b. **Cyber security risk management**: Principally, SCCT makes the SCs more resilient by facilitating risk prevention and mitigation for the complete ecosystem. At the same time, such a high level of digitisation imposes the challenge of cyber security risks. This needs further contemplation and work by exploring the feasibility of complementary technologies such as the permissioned blockchain technology and AI integration with SCCT.
c. **Design of incentive schemes for effective collaboration**: Supply chain control tower can be successful in the truest sense only if all the trading partners come on board, collaborating for creating a sustainable ecosystem. Further work needs to be done to compute and design an incentive model that encourages small and medium enterprises to collaborate with global brands, taking SC relational power asymmetry into consideration.

ACKNOWLEDGEMENT

None.

CONFLICT OF INTEREST

The authors whose names are listed above certify that they have no affiliations with or involvement in any organisation or entity with any financial interest (such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licencing arrangements), or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

PERMISSION TO REPRODUCE MATERIALS FROM OTHER SOURCES

None.

DATA AVAILABILITY STATEMENT

Data available on request from the authors.

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How to cite this article: Patsavellas, J., Kaur, R., Salonitis, K.: Supply chain control towers: Technology push or market pull—An assessment tool. IET Collab. Intell. Manuf. 1–13 (2021). https://doi.org/10.1049/cim2.12040