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Analysis of supply chain sustainability with supply chain complexity, inter-relationship study using delphi and interpretive structural modeling for Indian mining and earthmoving machinery industry

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A B S T R A C T

The context of the sustainable supply chain (SSC) is progressively getting attention among supply chain (SC) managers due to its competitive advantage in firms' performance. Increasing supply chain complexity (SCC) is argued as one of the biggest risks in achieving the organisational goal with an adverse impact on operational efficiency, cost, profitability, on-time delivery, and customer satisfaction. Though drivers of SSC and SCC have seemingly demonstrated mutual relationship in a practical scenario, supply chain managers tend to address respective drivers independently for managing and controlling. Limited availability of literature investigating interactions among drivers of SSC and SCC with its overall impact on the supply chain motivates deeper research. To address the gap, current research aims to study the mutual relationship between SSC and SCC drivers. To achieve this, a combination of sequential exploratory two-phased research methodology is adopted. The Delphi technique is initially applied to identify the critical SSC and SCC drivers followed by using interpretive structural modeling (ISM) to decipher the mutual relationship among the SSC and SCC drivers. The interactions between SSC and SCC drivers explored in this work will provide supply chain managers a framework for informed decision making. The driving and dependence power of drivers can guide SC practitioners to prioritize and focus on key drivers with a high impact on the overall outcome. The organization can also be benefitted by managing SSC and SCC drivers in synergy against the silo approach. The research finding suggests that market uncertainty, institutional regulations, strategic supplier collaboration, customer pressure, and new technologies are key five drivers in decision-making.

1. Introduction

"Looking at the world through a sustainability lens not only helps us 'future proof' our supply chain, but it also fuels innovation and drives brand growth." The statement from a former CEO of Unilever and Chairman of the World Business Council for Sustainable Development (WBCSD) underscores the importance of adopting sustainability in the supply chain. The context of sustainable supply chain (SSC) is progressively getting attention among supply chain managers as an important topic for discussions due to incessant pressure from stakeholders; therefore, organisations are critically exploring opportunities to incorporate sustainable practices in their supply chain (Hsu et al., 2013; Flynn et al., 2016; Saeed and Kersten, 2019).

In the context of supply chain complexity (SCC), a former executive vice president of global supply chain operations for Open Energy Corporation commented, "complexity is destroying profitability in many companies and companies must reduce complexity if they are to survive and be profitable in a sustainable fashion" (Gilmore, 2008). In a 2016 survey conducted by Gartner involving supply chain leaders from different organisations, 63 percent of participants have informed "increasing supply chain complexity" as the highest risk to business continuity. A white paper released by a global logistics firm Geodis (2017) on supply chain worldwide survey, reported that '70% of respondent assessed their supply chain as very or extremely complex'. The survey findings signify the inherent complexity of the supply chain and the importance of managing supply chain complexities to improve delivery performance.

Researchers have enriched the literature of sustainable supply chain management (SSCM) by identification of various drivers, prioritization, their mutual relationship and managerial implication in decision making (Seuring and Muller, 2008; Dubey et al., 2017; Saeed et al., 2017; Varsei et al., 2014). SSC drivers are categorized as external and internal factors based on their source and influence the organization (Hassini et al., 2012; Varsei et al., 2014). Strategic supplier development (Kumar and Rahman, 2016), supply chain collaboration (Chen et al., 2017), government legislation, international regulations, customer pressure,

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corporate strategy (Saeed and Kersten, 2019), stakeholders' pressure (Meixell and Luoma, 2015) are some of the highlighted drivers for SSC.

Similarly, the available literature adequately studied SCC and its drivers due to its critical impact on overall supply chain management (Serdarasan, 2013; Bozarth et al., 2009; Mariotti, 2008). For effective and efficient management of complexity, firms' managers should identify, analyze, define, measure, reduce and control the SCC drivers (Isik, 2011). The multiplicity of factors, numerousness of decision variables, complicated mutual relationship, and different managerial approach to performance management has been reported in engendering SCC (Manuj and Sahin, 2011). Kavilal et al. (2017) analyzed the SCC through a case study of Indian mining equipment manufacturer and identified supplier unreliability, inaccuracy in forecasting, lack of visibility, number and variety of parts and processes are the dominant drivers.

Managing SCC drivers can have derived and extended benefits in implementing SSC. According to the review conducted by Ahi and Searcy (2015), among SSC performance metrics, greenhouse gas emissions, energy consumption and life-cycle assessment (LCA) are identified as critical to SSC. Upstream SCC is defined as a combination of horizontal, vertical and spatial SCC (Bode and Wagner, 2015). An increase in horizontal SCC (defined as the number of direct suppliers managed by a focal firm) results in a higher number of supplier interfaces to manage. Hence implementation of end-to-end sustainable practices through strategic supplier collaboration becomes a growing challenge, which is likely to prevent joint deployment of sustainable development. Spatial SCC, caused due to globalised distributed sourcing of supply chain, refers geographical distribution of suppliers. An extended spatial network of suppliers entails elongated transportation networks for physical movement of material resulting in higher vehicular emission and increased energy consumption (Geng et al., 2017).

Similarly, SSC also brings an overlapping impact on SCC. To implement sustainability in supply chain practices, firms often adopt strategic supplier collaboration and logistics optimization (Dubey et al., 2017) to gain the environmental and economic benefit of collaboration. These initiatives effectively result in a simpler supply chain network with diminished SCC. With increased regulation and customer's demand for sustainable products and services, firms' supply chains are continuously engaged on resourcing, recycling, life-cycle assessment, emission control which generates the varying level of impact on SCC in inventory management, lead time and demand planning (Katiyar et al., 2018).

Due to the impact of SSC and SCC on key supply chain processes involving planning, sourcing, executing, it is imperative for the focal firm to devise SC strategy considering both aspects simultaneously. Therefore, establishing the inter-relationship among the drivers of SSC and SCC will enable the supply chain managers to create a cohesive strategy for decision-making. According to the combined study of SSC and SCC drivers through ISM methodology, the obtained driving and dependence power of drivers will guide supply chain managers to focus on key drivers. Rather than addressing SSC and SCC individually, a combined evaluation of drivers is more appropriate to explain complex interaction among drivers. The relative scarcity of literature on this subject emanates the need for further study on the mutual relationship.

Serdarasan (2013) proved that managing and controlling SCC leads to increased performance and improved performance. Bode and Wagner (2015) established that a reduction in SCC would diminish the risk of disruption. In the quest towards building SSC, firms have adopted multiple SSC drivers like strategic supplier collaboration, continuous improvement, environment conservation, green product design (Dubey et al., 2017). Um and Kim (2018) argued that successful supply chain collaboration decreases transaction costs and improves firms' economic performance. An optimized logistics operation enables the firm in achieving the twin goal of reduced carbon footprint and lessened energy consumption, which results in lower operating costs and improved financial performance (Dey et al., 2011). Environment sustainability and green product design results in firms' higher resource efficiency, enhanced corporate image and increased sales (Dangelico and Pujari, 2010).

The context of SSC and SCC being critical for firms' overall supply chain performance is adequately discussed in literature. A considerable amount of research established that the subject of SSC and SCC should be included in firms' supply chain strategy and risk management. Seemingly, management of SSC and SCC improves delivery, reduces cost, increases supply chain collaboration, and creates competitive advantage. Having acknowledged the importance of SSC and SCC, supply chain practitioners are taking important initiatives in managing and controlling their respective drivers. But the relative scarcity of study combining SSC and SCC drivers for priority ranking, their interdependence, and managerial implications leaves enough scope for investigation. This research is motivated to answer the following research questions (RQ):

RQ1: What are the critical drivers for the integrated management of SSC and SCC?

RQ2: How is the mutual relationship and the level of interdependence among the SSC and SCC drivers?

RQ3: How supply chain managers should approach in controlling these drivers for achieving a positive result?

RQ4: How industry can be benefitted by the research outcome of this exploratory study?

1.1. A brief overview of Indian earthmoving and mining machinery

Construction and mining industry play a crucial role in economic growth and job creation due to its significant contribution towards infrastructure, steel, power, construction, housing development (Modak et al., 2017). Indian earthmoving and mining industry contribute about 10%–11% to the industrial sector and accounts for 2.2%–2.5% to economy's gross domestic product (Ministry of Mines, Annual report 2016–17). Mining and construction industry is considered as one of the key drivers in creating employment and economic development in many countries (Luthra et al., 2015). Earthmoving and mining machinery manufacturing industry plays a major role in driving the growth of the industry with a domino effect on the overall economy. The sector contributes significantly in execution of flagship infrastructural programs of Indian government for building highway and railway network, urban housing, rural road connectivity, development of smart cities, rural broadband connectivity, rural electrification, agricultural irrigation, port and airport development. This industry is experiencing steady demand due to increased government spending on infrastructure, growing economic activity, relaxation of FDI norms, favorable policy framework through de-licensing. This industry is estimated to attain the market revenue of Rs 35,000 crore by the financial year 2020 (Department of Heavy Industries, 2016–17) with increasing participation from global and local manufacturers like Tata-Hitachi, Kobelco, Terex, L&T, Case-New Holland, Komatsu, Caterpillar, John-Deere, JCB, Sany, Escorts, TIL, Metso, Atlas-Copco, Sandvik, Manitowoc, Volvo, Doosan, Tadano, Hyundai.

The Indian government reconstituted Development Council for construction, earthmoving and mining machinery. These Development Councils were formed to create an access forum for the participation of key stakeholders, machinery manufacturing organisations, customers, business leaders, and industry experts to deliberate on current industry trends and to contemplate on strategic planning and actions for implementation of the sustainable growth. Presently the Indian market has witnessed the presence of more than 40 large and global manufacturers of earthmoving & mining machinery with participation from around 200 small-size enterprises. The product range involves Hydraulic Excavator, Backhoe Loaders, Wheel Loaders, Vibratory Compactors, Crushing and Screening Plants, Truck Mounted Cranes, Batching Plants, Tower Cranes, Dump trucks, Dozers, Motor Graders, etc. Indian earthmoving and mining machinery industry has been growing consistently from last three years with the compounded annual growth rate of 16% during the financial year 2013-14 to 2016-17 and recorded turnover of Rs 24,945 crore (Ministry of Heavy Industries and Public Enterprises, 2017–18). Indian construction and infrastructure sector cumulatively have received FDI of USD 39 billion from April 2000 to December 2018 due to increased government spending towards infrastructure development coupled with favorable policy framework (FDI factsheet, DIPP, February 2019). Construction, earthmoving equipment, and mining machinery industry have benefitted from this growth. The sector has experienced sustained demand due to higher budget allocation in development of rail infrastructure, mass rapid transport and metro project, road, port, highways, irrigation, power, urban rejuvenation, sanitation, smart city, airports.

1.2. Sustainable supply chain initiatives by earthmoving and mining machinery

Existing literature has not adequately presented the actions initiated by firms' operating in earthmoving and mining machinery business. Therefore, to understand the subject better, supply chain experts with significant experience in the industry were consulted for insightful discussion; firms' homepages were also studied to explore recent industry trends. Experts have emphasized that firms are progressively taking sustainable drives in managing their supply chain to reduce environmental degradation and to become a responsible brand. JCB, a global earthmoving equipment manufacturing firm, headquartered at UK and serving Indian market from decades, is encouraging its supply chain partners for returnable stackable packaging solutions for better vehicle space utilisation resulting in lower carbon emission and use of transportation vehicles powered by dual-fuel compressed natural gas adhering to upgraded emission norms (https://www.jcb.com/en-in/company/sustainable-solutions/distribution). During our interaction, supply chain managers shared that firms have embarked upon the journey of sustainability audits with its extended supplier network to improve adherence on the environment through strategic supplier collaboration. A leading Japanese multinational company, manufacturer of construction & mining machinery, has reduced the environmental impact of carbon emission by shifting the mode of transportation from roadways to the usage of ports and waterways. A Niti Ayog report on 'Sustainable Development Goal', aimed with the purpose of mapping central sector schemes and ministries under government of India, recommended Ministry of Environment, Forest and Climate Change to encourage larger organisations to implement sustainable practices and include the sustainability reporting by year 2030 (Niti Ayog, Sustainable development goals, August 2018).

1.3. Supply chain complexity management practices in earthmoving and mining machinery industry

"In our industry, the competitor that's best at managing the supply chain is probably going be the most successful competitor over time. It's a condition of success." The comments from the former chairman and CEO of construction and mining equipment manufacturer, with a significant operating presence in India, underscores the importance of managing supply chains for global organisations in adapting growing uncertainty and complexity (McKinsey conversations with global leaders, November 2010). A leading European construction equipment manufacturer has developed a complimentary supply chain hub model for group's excavator attachment business to reduce SCC by simplifying the operating complexities. This has enabled the firm to improve customer satisfaction by reducing supply lead time, improving competitiveness through cost efficiency and driving future business growth for global operations. DHL, JCB's worldwide logistics partner, has aligned itself with JCB's vision and customized supply chain solutions to improve customer-centricity and competitive advantage. DHL, in its report, Building the World, surmised that the supply chain of construction equipment industry will experience challenges from changing need of a customers, growing regulations and compliances, the emergence of new technologies and skillful resource (DHL-Building the World, 2015). Caterpillar, one of the world's largest manufacturers of mining machinery, introduced big data analysis and incorporated digital tools to manage supply chain complexity with control the variability of demand and inventory management (Reiss, 2015). To overcome supply chain complexity, Komatsu, a Japan-based firm has adopted a mixed approach of global and local sourcing to improve supply chain efficiency by managing fluctuating demand.

1.4. A discussion on present status of SSC and SCC specific to earthmoving and mining machinery industry

To conduct our research work, we formally met with some of the industry practitioners at their respective manufacturing plants located in western India. Some SC managers discussed KPIs with us and 'action plan roadmap' to improve them consistently. We experienced that majority of the firms are concerned with growing supply chain complexity and its impact on performance. We are summarizing below the major initiatives adopted by firms to reduce SCC.

a) A leading mining machine manufacturer is systematically reducing the horizontal supply chain complexity (number of suppliers that a focal firm deals directly) by reducing supplier base by 22 percent in the next three years to reduce transactional cost and to improve resource efficiency through enhanced coordination.
b) To reduce inventory long-lead imported components, some of the firms are developing alternate sources in a drive termed as "Localization" and "Resourcing". This enables the firms to significantly reduce inventory carrying costs and uncertainty associated with multi-modal cross-country transportation. Two similar examples were cited where leading Japanese manufacturers of hydraulic pump, gearbox set-up their manufacturing plant in India to supply the Indian manufacturers.
c) The majority of the manufacturers are developing a wider dealership network to create a more geographically dispersed network with a minimum inventory of final product to reduce customer order cycle time.
d) Many of the surveyed manufacturing firms are implementing Total Quality Management (TQM), Total Productive Maintenance (TPM), Advanced Product Quality Planning (APQP), environmental certification as a part of strategic supplier collaboration.

We would like to highlight the following critical limitations observed in most of the mining machine manufacturing firms:

a) KPIs of SCC have negligible inclusion of SSC drivers; conversely, SSC KPIs do not carry any SCC drivers.
b) Typically, SCC and sustainability are managed by two distinct functions with a little overlap on drivers and respective functions.
c) Many of the sustainability drives are not reflective of SC performance and are not aligned to the business goal.

This research work is intended to identify the critical drivers in integrated management of sustainable supply chain and supply chain complexity for Indian mining machinery manufacturing industry. The mutual relationship and level of interdependence among SSC and SCC drivers is investigated with important industry insights from practitioners and academic experts. The research findings of this paper contribute towards managerial decision making for supply chain managers in strategizing their approach. Our research work enriches the existing literature on SSC, SCC and extends the understanding to benefit the practitioners and academicians.

Rest of the paper is organized as follows: In Section 2, a summary of the systematic literature review is outlined. We have explained the research methodology in Section 3. Results are tabulated and presented in Section 4. Section 5 presents results and managerial implication respectively. Section 6 concludes the research work limitations of the present work and opens direction for further investigation.

2. Literature review

The systematic literature review was performed as per the guidelines suggested by Tranfield et al. (2003) and Denyer and Tranfield (2009) for a deeper understanding on SSC and SCC drivers. The literature review was conducted to identify the SSC and SCC drivers captured in literature. The applied keywords were: “supply chain complexity”, “sustainable supply chain”, “drivers”, “enablers”, “supply chain management”, “mining machinery”, “earth-moving machinery”, “manufacturing”, “sustainability”. The published research papers and books were searched using the keywords from reputed peer-review journal databases in the areas of sustainability, sustainable supply chain management, production, and operations management. The resource database used for accessing the papers were: Wiley, Sage, Google Scholar, Science Direct, SCOPUS, Emerald, Springer. Following criterion were followed for selection of the paper:

- The papers must be peer-reviewed, written in the English language.
- The papers are published between 2000 and 2020.
- The research paper address subject of either SSC or SCC.

The search process resulted in shortlisting 117 papers for further study and evaluation. Based on the literature review, a list of five SSC drivers and 10 SCC drivers were identified as input for the Delphi study. The selected drivers of SSC and SCC are defined and presented in Table 1 and Table 2. The clustering of SCC drivers was primarily based on the published research work by Chand et al. (2018).

2.1. Sustainable supply chain (SSC) and drivers

“Sustainability is a worldwide concern that continues to gain momentum—especially in countries where growing populations are putting additional stress on the environment, and an increasing number of consumers in developed regions consider sustainability actions more of an imperative than a value-add.” This statement from the former senior vice president, Public Development & Sustainability, Nielsen highlighted the critical acknowledgment of sustainability as one of the pressing business needs (Nielsen Global Corporate Sustainability Report, 2015). “Sustainable supply chain management is the strategic, transparent integration and achievement of an organization’s social, environmental, and economic goals in the systemic coordination of key inter-organisational business processes for improving the long-term economic performance of the individual organization and its supply chains” (Carter and Rogers, 2008). Asefeso (2015) defined supply chain sustainability as “a holistic perspective of supply chain processes and technologies that go beyond the focus of delivery, inventory and traditional views of cost”. The HSBC Navigator survey, conducted on behalf of HSBC by Kantar TNS in 2018, covering 350 businesses in India, surmised that 26% of respondents considered ‘improving the sustainability of supply chain’ as one of the top 5 supply chain changes for next 3 years (HSBC Navigator Survey, 2018).

“Supply chain sustainability is the management of environmental, social and economic impacts and the encouragement of good governance practices throughout the life cycles of goods and services” (United Nations Global Compact, 2016). Sustainable supply chain management (SSCM) aims to analyze three critical dimensions (environmental, economic, and social) of sustainable development based on “Triple Bottom Line (TBL)" approach (Seuring and Muller, 2008). Supply chain management involves the processing of raw material and information flow from the initial stage to final product delivery to end-user; therefore,

Table 1
Sustainable supply chain drivers.

Serial No.	Sustainable supply chain drivers	Category	Description	Literature reference
1	Institutional pressures (Laws and regulations imposed by government, regional or international regulations)	Sustainability	Supply chains are progressively becoming global in scope of operation and exposed to vulnerability of changing regulations imposed by trade governing. Any sudden changes of these trade and environmental policies may potentially disrupt the supply chain.	Zhu and Sarkis (2007), Hsu et al. (2013),
2	Societal pressures (Social values and ethics)	Sustainability	Different societal groups, non-government organisations, public awareness programs, active social and mass media combinedly influence organisations to adopt sustainability objectives in their business strategy and improve on performance.	Ageron et al. (2012), Saeed et al. (2017), Walker et al. (2008), Alblas et al. (2014)
3	Strategic supplier collaboration	Sustainability	Aligning the suppliers with focal firms’ corporate strategy, engaging them towards meeting organisations’ business objective is critically important to achieving overall goal.	Freeman (2010), Giunipero et al. (2012), Kumar et al. (2016)
4	Market pressure	Sustainability	Growing customer awareness, competitive advantage in peer group, external pressure from various stakeholders in accepting sustainable environmental practices and effort to establish a corporate responsible brand are forcing organisations to orient itself towards	Gualandris and Kalchschmidt (2014), Govindan (2016)

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Table 1 (*continued*)

Serial No.	Sustainable supply chain drivers	Category	Description	Literature reference
			sustainable supply chain.	
5	Corporate strategy	Sustainability	Inclusion of sustainability in organisations' business strategy, commitment from top management towards achieving the same, improving operational and economic performance are crucial factors in implementing sustainable SC practices.	Walker et al. (2008), Schrettle et al. (2014),

adoption of sustainability practices in the supply chain is a critical step forward in the right direction (Ashby et al., 2012). Implementation of SSC management combining social and environmental drivers results positively on corporate financial performance (Wang and Sarkis, 2013). Giannakis and Papadopoulos (2016) established that SSC should be considered in firms' risk treatment strategies. Bai and Sarkis (2018) have developed a methodology for evaluating and mitigating SSC complexity, which can help supply chain managers in managerial decision making. Luzzini et al. (2015) argued that firms' sustainability commitment develops intra and inter-firm collaborative strength resulting into enhanced performance. Implementation of SSC initiatives result in benefitting the firms' through competitive advantage, value creation and reverse logistics (Hsu et al., 2016; Jayaraman and Luo, 2007).

The growing social awareness on sustainability, increasing adherence of laws and regulations imposed by governing bodies, rising preference of customers to accept sustainable products and services, are important drivers forcing organisations to incorporate sustainable practices in their supply chain operations (Mathiyazhagan and Haq, 2013; Diabat et al., 2014; Flynn et al., 2016). Researchers have adequately explored the motivation for adoption supply chain sustainability and synonymously applied enablers, drivers, pressures, triggers to highlight factors that encourage or/and facilitate the implementation of sustainable practices (Hsu et al., 2013; Koksal et al., 2017; Saeed and Kersten, 2019). Walker and Jones (2012) developed a typology for sustainable supply chain based on a variety of organisational approach and defined enablers as encouraging factors for adoption of sustainable SCM. Identification, prioritization, and mutual relationship of sustainable supply chain drivers are well-documented by researchers through literature reviews (Dubey et al., 2017; Koksal et al., 2017; Saeed and Kersten, 2019). A summary of the literature review on sustainable supply chain drivers are mentioned in Table 1 and categorized under 'sustainability' as suggested in the literature.

2.2. *Supply chain complexity (SCC) and drivers*

To emphasize the criticality of supply chain complexity, former vice president of a world's leading beverage company responsible for supply chain, commented, "If you are in supply chain management today, then complexity is cancer you have to fight" (Gilmore, 2008). It is argued by researchers and industry experts that SCC is considered as one of the most difficult problems that organisations are dealing in today's supply chain (Bode and Wagner, 2015; Bozarth et al., 2009). BSI and Business Continuity Institute Nielsen Global Corporate Sustainability Report

Table 2
Supply chain complexity drivers.

Serial No.	Supply chain complexity drivers	Category	Description	Literature reference
1	Number of suppliers	Upstream	Complexity and uncertainty in supply chain experienced by a firm for the number of direct suppliers is considered as horizontal complexity.	Choi and Krause (2006); Bode and Wagner (2015);
2	Spatial positioning suppliers	Upstream	Spatial distribution of suppliers generates complexity in managing the entire network of suppliers.	Bode and Wagner (2015);
3	Number and variety of customers	Downstream	In the globalised business scenario, firms have increasingly experienced the need to provide tailor -made products and solutions which suits to customer specific requirement. To fulfil the customer demand with emphasis on mass-customisation results in complexity.	Gerschberger and Hohensinn (2013), Serdarasan (2013), Kavilal et al. (2017)
4	Product Life Cycle	Downstream	Growing pace of technological innovation is forcing the organisations to develop new process and product suiting to customer requirement. This drives the organization to develop agile business strategies in inventory management, logistics planning, development of suppliers and cost management.	Krishnan and Gupta (2001), Bozarth et al. (2009)
5	Uncertainty in the market	External	Growing geo-political tension, increased globalised trade, economic sanctions, various market forces are reasons responsible for market uncertainty and increases the SCC in forecasting,	Gerschberger and Hohensinn (2013), Bode and Wagner (2015), Tarei et al. (2018)

(*continued on next page*)

Table 2 (*continued*)

Serial No.	Supply chain complexity drivers	Category	Description	Literature reference
			demand planning and supplier development;	
6	Laws and regulations imposed by the government	External	Supply chain operations spread at various geographies are often vulnerable to the specific regional/local business laws and regulations. It increases the complexity in supply chain as firm must devise region-specific strategies.	Kavilal et al. (2017)
7	Competition from peer firms	External	Market competition from peer firms forces the organization to actively look for differentiated offerings and thereby causes complexity.	Hashemi et al. (2013), Meixell and Luoma (2015), Saeed et al. (2017)
8	Forecast Inaccuracy	Operational	Inaccuracy in forecasting are caused due to multiplicity of factors like abrupt change in demand, lack of information flow, inaccurate market research.	McCarthy and Golicic (2002), Lu (2015),
9	Number of products	Operational	This complexity is generated due to continuous market pressure for new product development with mass-customisation objective.	Gerschberger and Hohensinn (2013), Hashemi et al. (2013), Kavilal et al. (2017)
10	Number of processes	Operational	Increase in number of processes creates complexity in supply chain.	Gerschberger and Hohensinn (2013)

(2015) highlighted that 77% of participating companies recognized SCC as 'the fastest growing risk to business continuity'. Additionally, supply chain performance and customer satisfaction can be improved by managing and controlling SCC (Serdarasan, 2013). Managing of SCC involves identification, prioritization, monitoring, and control of drivers of complexity (Isik, 2011).

SCC is considered as a growing potential risk for business continuity (BSI and Business Continuity Institute Nielsen Global Corporate Sustainability Report, 2015). Improved SCC management enhances firms' performance and increases customer satisfaction (Serdarasan, 2013). Firms, operating in the supply chain and experiencing complexity, can primarily restrict their resource orientation towards addressing critical drivers rather than all drivers (Subramanian et al., 2014). System-related weaknesses which are seemingly dormant in normal situations can be recognized and analyzed by addressing the SCC of the firm (Aitken et al., 2016). Fawcet et al. (2012) investigated the cause of supply chain complexity and attributed "heterogeneously dispersed resources and complementary competencies" as the major cause for generation of SCC. In recent times, supply chain is shaping increasingly complex due to multiple drivers such as uncertain market condition, technological innovation, shortening product life cycle, specific local regulations, cross-border trade relationships and customer demand (Gunasekaran et al., 2014; Bode and Wagner, 2015). This encourages industry practitioners and researchers to examine the supply chain complexity, which is posited as one of the major impediments in achieving the business goal (Bozarth et al., 2009; Choi and Krause, 2006).

Serdarasan (2013) defined supply chain complexity driver as 'any property of a supply chain which increases complexity' and classified as static, dynamic and decision-making based on the way it is been generated. Kavilal et al. (2017) applied an integrated fuzzy approach for prioritization, ranking of SCC drivers and established the inter-relationship among 14 identified drivers for Indian mining equipment manufacturing firms. Serdarasan (2013) explored and reviewed SCC drivers experienced by real-life situations and recommended complexity driver with solution strategy pairings for decision-makers of firms. Kavilal et al. (2018) clustered 18 identified SCC drivers considering the significant dimensions of complexity from the Indian automotive industry. Chand et al. (2018) analyzed the 23 SCC drivers for Indian mining and construction equipment machinery companies and categorized as upstream, operational, downstream and external drivers based on the source of their origination. Critical supply chain complexity drivers are mentioned in Table 2 and.

2.3. *Interpretive structural modeling (ISM) and its application in the supply chain*

ISM is a well-developed interactive methodology for identifying the mutual relationship among specific items in a complex system through the creation of a hierarchical model (Mathiyazhagan and Haq, 2013). Kavilal et al. (2018) established interdependencies among 18 identified SCC drivers applying ISM for the Indian automotive industry. Lim et al. (2017) applied ISM to find out driving and dependence power in SSCM within the context of knowledge management for textile industry in Vietnam. Analysis and identification of the dominant SSCM practices for adoption of SSCM in Indian mining and mineral industry were explored using ISM by Jia et al. (2015). Raut et al. (2017) presented the mutual relationship among critical success factor for the implementation of SSCM for Indian oil and gas sector. ISM technique was applied in modeling and analysis of SSC (Ghadimi et al., 2019), developing lean supply chain (Soni and Kodali., 2016), devising risk prioritization model for supply chain risks (Venkatesh et al., 2015), critical success factors of humanitarian supply chain (Yadav and Barve., 2015). Vasanthakumar et al. (2016) analyzed the of factors influencing lean remanufacturing practices using ISM for Indian automotive component remanufacturing organisations. ISM also finds its application in analyzing the barrier of green textile supply chain management (Majumdar and Sinha., 2018), barriers in implementing total productive maintenance (Poduval et al., 2015), barriers of reverse logistics in computer supply chain (Ali et al., 2017). Thirupathi and Vinodh (2016) developed a theoretical model to indicate the interrelationship among sustainable manufacturing factors for Indian automobile component sector. Govindan et al. (2013) identified important lean, green and resilient measures to improve supply chain performance using ISM. Application of ISM to address supply chain related issues are tabulated in Table 3.

2.4. *Research gap*

Acknowledging the criticality, the subject of SSC and SCC has drawn considerable attention in the existing literature. Researchers and industry practitioners have enriched the literature by exploring the subject of SSC and SCC contextual to various industry perspective. Academicians tend to approach the subject of SSC and SCC independently in proposing a framework for managerial decision-making. Industry

Table 3
Interpretive structural modeling (ISM) and its application in supply chain.

Sr No.	Researcher (Year)	Issues covered	Application Domain
1	Kavilal et al. (2018)	Finding out interdependence among SCC drivers;	Automotive industry, India
2	Lim et al. (2017)	Driving and dependence power in SSCM within the context of knowledge management	Textile industry, Vietnam
3	Jia et al (2015)	Identifying the dominant SSCM practices for adoption of the same	Mining and mineral industry, India
4	Ghadimi et al. (2019)	Literature review on SSC modeling and analysis	Multiple industry
5	Ali et al. (2017)	Barriers of reverse logistics in computer supply chain	Computer, Bangladesh
6	Dubey et al. (2017)	To analyze complex relationship among JIT, lean practices and TQM	Manufacturing industries
7	Govindan et al. (2013)	Influence of lean, green and resilient practices on supply chain performance	Automotive industry
8	Luthra et al. (2017)	Developing framework for sustainable supplier selection	An automobile company, India
9	Majumdar and Sinha (2018)	Analysing the barrier of green textile supply chain management	Textile industry, South-east Asia
10	Malviya and Kant (2017)	To develop the relationship among green supply chain management enablers and to understand mutual influences	Indian automobile industry
11	Poduval et al. (2015)	Analysing the barriers in implementing total productive maintenance (TPM)	Companies which implemented TPM
12	Raut et al. (2017)	To establish mutual relationship among critical success factor for implementation of SSCM	Oil and gas sector, India
13	Thirupathi and Vinodh (2016)	Application of sustainable manufacturing factors	Indian automobile component sector
14	Vasanthakumar et al. (2016)	Analysis of factors influencing lean remanufacturing practices	Indian automotive component remanufacturing organisations
15	Venkatesh et al. (2015)	Devised risk prioritization model for supply chain risks	Apparel industry, India
16	Yadav and Barve (2015)	Analysis of critical success factors of humanitarian supply chain	Humanitarian supply chain, India

practitioners often address the issue of SSC and SCC autonomously and devise important strategies to monitor and control respective drivers. The presence of separate functions to address SSC and SCC drives in most of the surveyed firms suggests the apparent disconnection in strategy and focus.

The context of managing SSC and SCC finds significant similar motivation for supply chain performance, firms' risk management, organisational cost efficiency, long-term supply chain resilience, corporate business strategy. Strategic supplier collaboration, being considered as an SSC driver in achieving environmental and economic goals enables the firms in reducing SCC by way of collaborative planning and forecasting. Likewise, reducing upstream SCC through a less complex supplier network augments in improved logistics networks with lesser energy consumption and lower cost (Dubey et al., 2017). Environment conservation and green product innovation not only augment firms' resource efficiency and corporate image (Dangelico and Pujari, 2010), but also influence downstream SCC in warehousing, managing product life cycle and meeting customer requirement.

The relative scarcity of existing literature combining SSC drivers and SCC drivers leaves considerable scope for further investigation by joint addressal drivers. This research work is intended to address the topic of SSC and SCC combining the respective drivers, their inter-relationship, driving and dependence power among the drivers. The study will guide industry practitioners in managerial decision-making keeping overall firms' perspective on SSC and SCC drivers.

3. Research methodology

A combination of sequential exploratory two-phased research methodology is applied. The qualitative Delphi technique is initially applied to identify the critical SSC and SCC drivers followed by using multi-criterion decision making (MCDM) tool ISM to establish a mutual relationship among the SSC and SCC drivers. The adopted research methodology for this paper is depicted in Fig. 1.

3.1. Delphi method

Delphi technique is defined as a method which is structured to facilitate a focussed group discussion on a complex problem to arrive at group consensus over a series of iterations and to achieve some future direction (Loo, 2002; Linstone and Turoff, 2002). As guided by Loo (2002), due attention was paid in designing, planning and executing the study with a detailed plan on defining the problem, selecting the members of the panel, defining panel size and conducting the Delphi rounds. The issue of SSC and SCC are two critical aspects to academicians, industry practitioners and decision-makers. Empirical evidence suggests the relative scarcity of research in approaching the SSC and SCC drivers combinedly.

Problem definition with required objective and scope is mentioned to ensure the right investigation of the problem with methodological appropriateness to arrive at intended outcomes. Drivers of SSC and SCC are explored from literature review. Applicability of the same for Indian earthmoving and mining equipment manufacturing industry is required to be ensured. In order to capture greater insights on the problem, the panel members (industry experts, academicians, and government representatives with more than 15 years of work experience in the areas of sustainability, supply chain operations, corporate strategy, health-safety-environment) were selected from three broad areas, as follows: 1) Earthmoving and mining industry, Indian or multinational firms with presence of manufacturing plant in India and operating in India for more than a decade, 2) Academia, including academic institutions with a presence of more than 20 years in operation and offering programs on supply chain, sustainability and environment for at least 10 years in India (Indian Institute of Management, Indian Institute of Technology), and 3) Government agencies for policy, involving in policy deployment authorities (Ministry of heavy industries and public enterprises, Department of Industrial Policy & Promotion).

As Delphi technique often involves several rounds of feedback collections, it is critical to have the commitment from prospective panel members in participation for several rounds of questionnaires and feedback spanning over months. Therefore, the participating panellists need to remain motivated during the period to ensure a stability of response throughout the study. Guided by research work of Delbari et al. (2016) for full-service airlines using Delphi, our research applied two types of non-random sampling, firstly purposive sampling followed by snowball sampling. Okoli and Pawlowski (2004) suggested taking the number of experts between 10 and 18 in the Delphi method who may not be required to meet face-to-face. We contacted at least 10 experts each from earthmoving and mining equipment manufacturing industry, academicians with subject matter expertise from premium Indian institutes, and government representatives responsible for driving and implementing initiatives. The Delphi method was conducted through two rounds of the questionnaire. We selected 36 experts with participation of 15, 12, and 9 experts from earthmoving and mining equipment

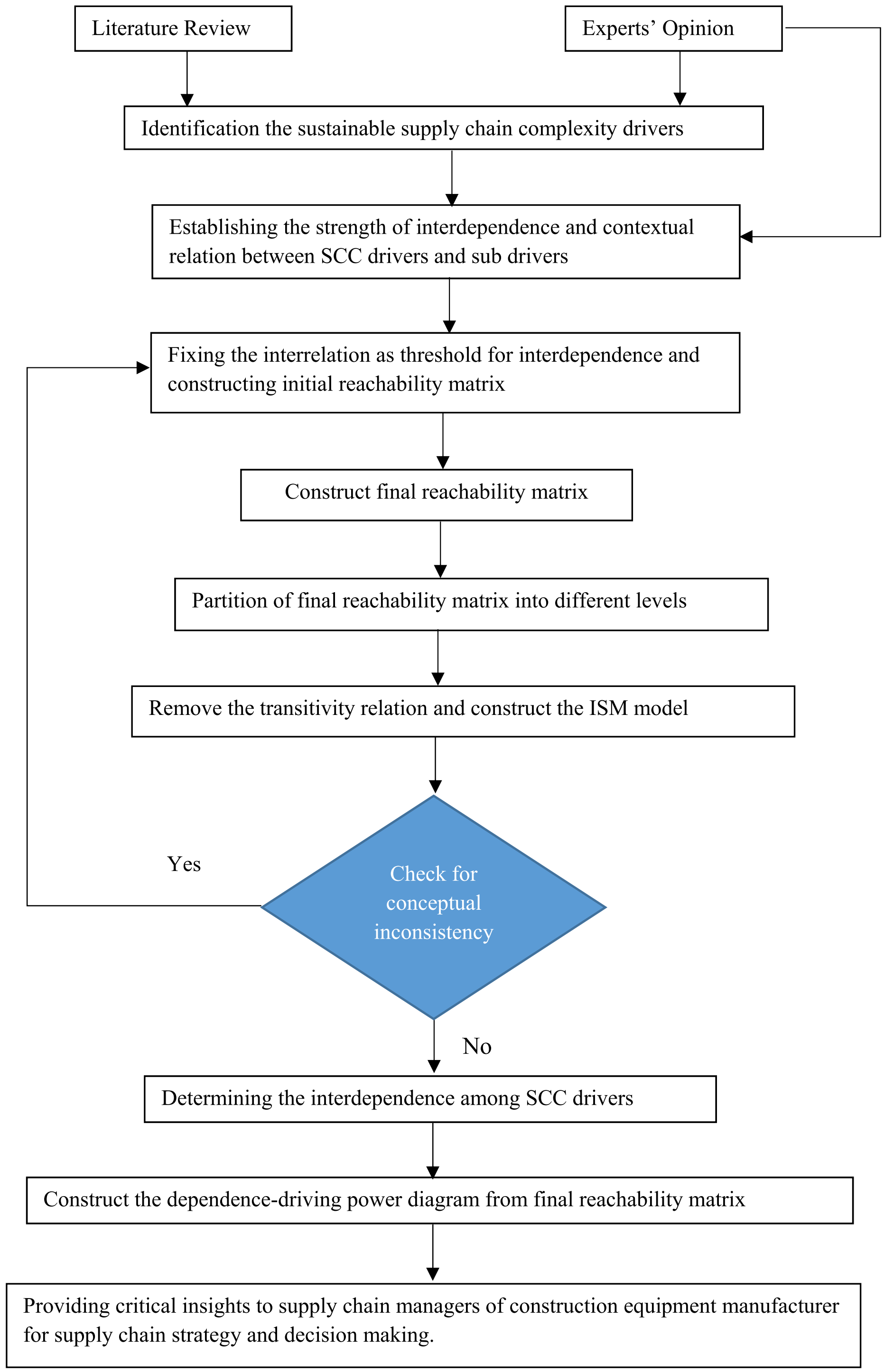

Fig. 1. Proposed research framework.

manufacturing industry, academia and government respectively. In the first round, we approached to 36 experts through semi-structured face-to-face interviews. We discussed the SSC drivers and SCC drivers for construction, earthmoving and mining machinery industry. The responses received from the panelists were reviewed. All the identified SSC and SCC drivers, derived from round 1 response and parallel literature review, were captured in forming the questionnaire for next round. The ideas and opinions presented in the first round were converged applying systematic content analysis (Neuman, 2011). The second round of questionnaire was structured based on the received responses of the first round. In round 2, panelists were requested to find out the level of importance of SSC and SCC drivers constructed on the five-point Likert scale ranging 1 to 5 (1 being not important to 5 being extremely important), to arrive at a consent on critical SSC and SCC drivers. Coding and indexing were used for analyzing the data of round 1, followed by examining the responses of round 2 applying the Content Validity Ratio (CVR).

3.2. Introduction to ISM methodology

ISM was developed in 1974 by John N. Warfield. Researchers are increasingly applying ISM methodology to characterize the mutual relationships among factors connecting to the issue (Attri et al., 2013). ISM is an interactive learning technique in which a set of related elements are organized into a comprehensive systematic model (Warfield, 1974; Sage, 1977). The interpretation in establishing the relationship among elements of a system are based on the organized and consistent thinking of a group of experts and therefore, this methodology is defined as 'interpretive'. It is a well-established modeling technique applied to analyze and identify interrelationships among the specific elements/variables of a system, which define the complex problem (Warfield, 1974). The influence of one variable on the other variables within the given system is analyzed in ISM by evaluating the individual driving and dependence power of respective variables. ISM methodology is structured with two important concepts, transitivity and reachability. Conceptual consistency is defined using transitivity, whereas reachability concept acts as a building block of ISM methodology (Malviya and Kant, 2017). Application of transitivity consents to use inferential opinion to fill the cells of the reachability matrix (Watson, 1973).

The complex problem of finding mutual relationships among SCC and SCC drivers is investigated by ISM. The relative importance of SSC and SCC drivers concerning supply chain strategy was established constructed on driving and dependence power. Steps involved in the ISM technique are as follows (Kannan et al., 2009):

Step 1: Identification of SSC drivers and SCC drivers relevant to Indian earthmoving and mining machinery industry by literature review and group problem-solving Delphi method.
Step 2: Examining the contextual relationship between selected drivers for pairwise comparison and establishing the relationship among the concerning pairs of drivers at a time
Step 3: Preparing a structural self–interaction matrix (SSIM) based on pairwise comparison of drivers.
Step 4: Developing an initial reachability matrix from the SSIM and examining the matrix for transitivity. This transitivity is developed based on the assumption of ISM technique. It proposes that if a driver 'X' is related to 'Y' and 'Y' is related to 'Z', then 'X' is related to 'Z'.
Step 5: Partitioning of the obtained reachability matrix and arranging the drivers into their different levels.
Step 6: Creating a directed graph to represent the relationships obtained from reachability matrix.
Step 7: Creating an ISM-based model by converting the resultant digraph, by replacing driver nodes with the statements; and
Step 8: Checking the conceptual inconsistency of the model and incorporating the required changes.

For ISM, we approached the same identified experts participated in the Delphi technique with the final list of SSC and SCC drivers obtained after round 2 of Delphi. The mutual relationship among the identified SSC and SCC drivers are modelled through brain-storming technique. The inter-relationship between any pair two drivers are investigated with "Yes" and "No" questions (Dubey et al., 2017). For n identified SSC and SCC drivers, the total number of paired comparisons will be $^{n}C2$. The questionnaire was sent to the same 36 participants who responded in Delphi. We could able to receive the response from only 32 experts resulting in a response rate of 88.9%.

4. Results and findings

4.1. Finding from the Delphi method

During the first round of the Delphi, we approached 42 experts to check their availability for interview participation. But only 36 contacted experts (15, 12, and 9 experts from earthmoving and mining equipment manufacturing industry, academia and government respectively) confirmed to participate in semi-structured face-to-face interviews. We apprised all the participated panel experts about the objective of this research and detailed them about drivers of both sustainable supply chain and supply chain complexity. The panelists were also updated about the earthmoving, construction and mining machinery industry, its participants, business outlook, future trends based on the available reports from industry journals, corporate bodies, government concerned departments, company webpages and special issues on industry-specific exhibitions in the operating sector. The duration of the conducted interview is kept as 30 min on average. The discussion points during the interview were covered through notes and audio-recording to ensure capturing of opinions and feedbacks. Based on the interview, opinions shared by the panelists were converted to meaningful information about our research using coding and indexing. The obtained information on drivers of SSC and SCC from experts is then compared with the available drivers in the existing literature. The results of round 1 suggested that a new set of drivers of SSC and SCC were identified by the experts besides confirmation of the identified drivers through literature. Three new SSC drivers (organisational culture, organisational characteristics and organisational resources) and six new SCC drivers (supplier's regional strategies, numbers of layers of suppliers for focal firm, level of service expectation, spatial positioning of customers, focus on mass-customisation and technological disruption) were identified. Frequency of interviewees reporting the new SSC and SCC drivers are mentioned in Tables 4 and 6. Tables 5 and 7 summarizes the definitions of these newly identified drivers respectively.

The identified drivers of SSC and SCC a) by the panel experts in first round, and b) mentioned in the literature (Table 1 and 2) were included in a questionnaire for round 2. In second round, we requested experts to evaluate the level of importance of SSC and SCC drivers on the five-point Likert scale ranging 1 to 5 (1 = not important to 5 = extremely important), to reach at an agreement in selecting key drivers of SSC and SCC respectively. Drivers, which attained a CVR of at least 0.31 (number of responded experts was 36; Lawshe, 1975) were finally selected as the responsible drivers of SSC and SCC for this research context. The following formula was applied in calculating CVR for each driver.

$$\text{Content Validity Ratio(CVR)} = \frac{ne - N/2}{N/2}$$

where n_e is the number of experts in the panel indicating "essential" and N is the total number of panelists. Lawshe (1975) categorized three options for every response which includes 'essential', 'useful but not essential', and 'not necessary'. As all the received responses were scaled in the five-point Likert scale, the two scales were comparatively matched. Consequently, 'extremely important (=5)' and 'very important (=4)' of Likert scale were matched equal to 'essential' option, 'moderately important (=3)' considered as equal to 'useful but not essential' option, and 'slightly important(=2)' and 'not important (=1)' were equated to 'not necessary' option of Lawshe (Delbari et al., 2016).

Based on the round 2 responses, drivers of SSC and SCC with corresponding CVR value and acceptance/rejection status were shown in Table 8 and Table 9. Drivers which obtained CVR higher 0.31 in round 2 were accepted and others were rejected. Table 8 suggests that out of 8 considered SSC drivers, only 4 is included for the next phase of data collection, whereas Table 9 indicates that only 8 SCC drivers are selected from the list of 16.

From the outcome of the two-round Delphi technique, it is evident that institutional pressures, strategic supplier collaboration, market pressure, and corporate strategy are the four top-most SSC drivers for Indian mining and manufacturing context. Besides, 8 SCC drivers (number of suppliers, number and variety of customers, product life cycle, uncertainty in the market, competitive rivalry, forecast inaccuracy, spatial positioning of customers, New technologies/technological disruption) are identified. A total of 12 identified SSC drivers and SCC drivers are represented in Table 10 and ascribed with reference code for ISM.

Table: 4
New sustainable supply chain drivers as identified by Delphi panel members.

Sr No.	New Drivers	Frequency of responses: Industry experts (n = 15)	Academicians (n = 12)	Government representatives (n = 9)	Total
1	Organisational culture	7	4	3	14
2	Organisational characteristics	5	6	5	16
3	Organisational resources and focus	3	2	1	6

Table: 5
The definitions of new sustainable supply chain drivers (SSC) identified by Delphi panel members.

Serial No.	Sustainable supply chain drivers	Category	Description	Literature reference
1	Organisational culture	Sustainability	Organization's preference towards accepting sustainable practices through health and safety of its employees, willingness to improve sustainability performance, applying sustainable tools drive supply chain to adopt sustainability practices.	Hsu et al. (2013), Govindan et al. (2016), Alzawawi (2014), Paulraj et al. (2015)
2	Organisational characteristics	Sustainability	Firm's operating sector and category of industry, its positioning in the supply chain network, geographical location of functioning, degree of internationalisation collaboratively influences the firm's supply chain.	Tate et al. (2010), Ayuso et al. (2013)
3	Organisational resources and focus	Sustainability	Organisations are increasingly developing resources and focussing on implementation by adoption of sustainable supply chain tools and techniques (i.e. logistics optimization, green product design, green warehousing, training and development, continuous improvement etc)	Schrettle et al. (2014), Havercamp et al. (2010), Giunipero et al. (2012), Dubey et al (2017)

4.2. Research finding from the ISM

For ISM, we approached the same identified 36 experts participated in the Delphi technique with the final list of SSC and SCC drivers, as obtained after round 2 of Delphi. The mutual relationship among the 12 identified SSC and SCC drivers (as referred in Table 10) are estimated by determining the contextual relationship between any pair of two drivers with "Yes" and "No" questions. For 12 identified SSC and SCC drivers, the total number of paired comparisons will be 66 (=12C2).

Table: 6
New supply chain complexity (SCC) drivers identified by Delphi panel members.

Sr No.	New Drivers	Frequency of responses: Industry experts (n = 15)	Academicians (n = 12)	Government representatives (n = 9)	Total
1	Supplier's regional strategies	1	1	0	2
2	Numbers of layers/tiers	2	1	2	5
3	Level of service expectation	2	0	1	3
4	Spatial positioning of Customers	3	3	0	6
5	Mass-customisation	1	3	1	5
6	New Technologies/ Technological disruption	6	4	5	15

4.2.1. Developing the structural self-interaction matrix (SSIM)

To develop SSIM for Table 10, symbols (V, A, X, O) were used to represent the contextual relationships between drivers i and j and illustrated in Table 11 (Darbari et al., 2017) (see Table 12).

4.2.2. Developing reachability matrix

The obtained SSIM is thereby transformed to a reachability matrix (Table 13) by replacing V, A, X and O with 1 and 0 as mentioned in Table 11.

4.2.3. Transitivity principle

We have applied the transitivity principle to fill some of the cells of the initial reachability matrix by inference. Transitivity can be illustrated as: if element 'A' relates to element 'B' and element 'B' relates to element 'C', then transitivity implies element 'A' relates to element 'C' (Sharma et al., 1995). Transitivity provides conceptual consistency in ISM and helps in removing the gaps between drivers. In Table 13, some cells with "0″ values are replaced with "1″ applying transitivity rule. The replacing value is represented by "*'' besides the value 1. We arrive at final reachability matrix as obtained in Table 14 after applying transitivity principle.

4.2.4. Level partitioning

The hierarchical structure of level partitioning is achieved by finding the reachability set and interaction set at each level (Khalid et al., 2016). This process is continued till the assigning of each element is completed. The outcome of the level partitioning process resulted in 7 levels for considered drivers and shown in Table 15. The entire process of level partitioning is illustrated in Appendix A1 (Table A1 to Table A7).

4.2.5. Developing digraph

Based on the final reachability matrix (Table 14) and level partitioning (Table 15), a directed graph with a hierarchical level of drivers (or nodes) connected with lines is developed to denote the structural model. The nature of the relationship between any two drivers 'i' and 'j'

Table: 7
The definitions of new supply chain complexity (SCC) drivers identified by Delphi panel members.

Serial No.	SCC drivers	Category	Description	Literature reference
1	Regional strategies of suppliers	Upstream	Different region-specific strategy followed by suppliers and focal firm cause complexity in business and supply chain alignment.	Chand et al. (2018)
2	Numbers of layers of suppliers	Upstream	It is referred as SCC caused due to number of layers of suppliers	Bode and Wagner (2015); Chand et al. (2018)
3	Level of service expectation	Downstream	To meet customer's growing expectation on product and service, robust network for spare part and service supply chain is required;	Chand et al. (2018)
4	Spatial positioning of Customers	Downstream	Dynamic market condition, firms' adaptability to meet customer expectation on quality requirements complying to specific regional acceptance standards, reduction in customer delivery lead time spread at different geographical location are drivers responsible for complexity in supply chain operations.	Geodis (2017), Chand et al. (2018)
5	Mass-customisation	Downstream	Customer's insistence on products and services tailored to their specific requirement increases SCC in inventory management with a greater number of parts to be developed and handled.	da Silviera (2005)
6	New Technologies/ Technological disruption	External	Advent of digital supply chain, adoption of new technologies, rapid pace of technological innovation pose challenge on conventional supply chain practices and expose them to the vulnerability of disruption.	Kavilal et al. (2017)

Table 8
Results of acceptance or rejection of sustainable supply chain drivers.

Sr. no.	Sustainable supply chain drivers	n_e	CVR	Result
1	Institutional pressures (Laws and regulations imposed by government, regional or international regulations)	33	0.83	Accepted
2	Societal pressures (Social values and ethics)	23	0.28	Rejected
3	Strategic supplier collaboration	29	0.61	Accepted
4	Market pressure	26	0.44	Accepted
5	Corporate strategy	31	0.72	Accepted
6	Organisational culture	22	0.22	Rejected
7	Organisational characteristics	19	0.06	Rejected
8	Organisational resources and focus	15	−0.17	Rejected

Table 9
Results of acceptance or rejection of supply chain complexity drivers.

Sr. no.	Supply chain complexity drivers	n_e	CVR	Result
1	Number of suppliers (Horizontal Complexity)	32	0.78	Accepted
2	Spatial Positioning of suppliers	22	0.22	Rejected
3	Number and variety of customers	28	0.56	Accepted
4	Product Life Cycle	27	0.50	Accepted
5	Uncertainty in the market	33	0.83	Accepted
6	Laws and regulations imposed by the government	22	0.22	Rejected
7	Competitive rivalry	31	0.72	Accepted
8	Forecast Inaccuracy	29	0.61	Accepted
9	Number of products	20	0.11	Rejected
10	Number of processes	21	0.17	Rejected
11	Supplier's regional strategies	19	0.06	Rejected
12	Numbers of layers/tiers of suppliers	22	0.22	Rejected
13	Level of service expectation	21	0.17	Rejected
14	Spatial positioning of Customers	28	0.56	Accepted
15	Mass-customisation	23	0.28	Rejected
16	New Technologies/Technological disruption	34	0.89	Accepted

Table: 10
List of SSC and SCC drivers with corresponding reference code.

Serial No.	SSC/SCC drivers	SSC/SCC drivers reference code
1	Number and variety of customers	D1
2	Product Life Cycle	D2
3	Spatial positioning of Customers	D3
4	Uncertainty in the market	E1
5	New Technologies/Technological disruption	E2
6	Competitive rivalry	E3
7	Forecast Inaccuracy	O1
8	Institutional pressures (Laws and regulations)	S1
9	Strategic supplier collaboration	S2
10	Market pressure	S3
11	Corporate Strategy	S4
12	Number of suppliers (Horizontal Complexity)	U1

Table: 11

Representative symbols	i → j	j → i	(i,j) th entry	(j,i) th entry
V	✓	×	1	0
A	×	✓	0	1
X	✓	✓	1	1
O	×	×	0	0

is represented by the type of line used. If driver 'i' leads to driver 'j', a unidirectional line starting from 'i' is directed to driver 'j'. If a driver 'i' and driver 'j' leads to each other, a bidirectional line is applied to denote the mutual relationship. ISM model involving 12 identified SSC and SCC

Table: 12
Structural self-interaction matrix (SSIM).

	U1	S4	S3	S2	S1	O1	E3	E2	E1	D3	D2	D1
D1	V	O	O	O	O	A	A	A	O	A	O	
D2	V	O	O	O	O	V	O	O	O	O		
D3	V	O	A	A	A	X	A	A	O			
E1	V	V	V	O	V	V	V	O				
E2	V	O	X	A	A	V	O					
E3	O	O	O	O	A	O						
O1	V	A	A	A	A							
S1	V	V	O	O								
S2	V	O	V									
S3	V	V										
S4	V											
U1												

Table 13
Initial reachability matrix.

	D1	D2	D3	E1	E2	E3	O1	S1	S2	S3	S4	U1	Driving Power
D1	1	0	0	0	0	0	0	0	0	0	0	1	**2**
D2	0	1	0	0	0	0	1	0	0	0	0	1	**3**
D3	1	0	1	0	0	0	1	0	0	0	0	1	**4**
E1	0	0	0	1	0	1	1	1	0	1	1	1	**7**
E2	1	0	1	0	1	0	1	0	0	1	0	1	**6**
E3	1	0	1	0	0	1	0	0	0	0	0	0	**3**
O1	1	0	1	0	0	0	1	0	0	0	0	1	**4**
S1	0	0	1	0	1	1	1	1	0	0	1	1	**7**
S2	0	0	1	0	1	0	1	0	1	1	0	1	**6**
S3	0	0	1	0	1	0	1	0	0	1	1	1	**6**
S4	0	0	0	0	0	0	1	0	0	0	1	1	**3**
U1	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Dep Power	**5**	**1**	**7**	**1**	**4**	**3**	**9**	**2**	**1**	**4**	**4**	**11**	

Table 14
Final reachability matrix.

	D1	D2	D3	E1	E2	E3	O1	S1	S2	S3	S4	U1	Driver Power
D1	1	0	0	0	0	0	0	0	0	0	0	1	**2**
D2	1*	1	1*	0	0	0	1	0	0	0	0	1	**5**
D3	1	0	1	0	0	0	1	0	0	0	0	1	**4**
E1	1*	0	1*	1	1*	1	1	1	0	1	1	1	**10**
E2	1	0	1	0	1	0	1	0	0	1	1*	1	**7**
E3	1	0	1	0	0	1	1*	0	0	0	0	1*	**5**
O1	1	0	1	0	0	0	1	0	0	0	0	1	**4**
S1	1*	0	1	0	1	1	1	1	0	1*	1	1	**9**
S2	1*	0	1	0	1	0	1	0	1	1	1*	1	**8**
S3	1*	0	1	0	1	0	1	0	0	1	1	1	**7**
S4	1*	0	1*	0	0	0	1	0	0	0	1	1	**5**
U1	0	0	0	0	0	0	0	0	0	0	0	1	**1**
Dependency Power	**11**	**1**	**10**	**1**	**5**	**3**	**10**	**2**	**1**	**5**	**6**	**12**	

Table 15

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection set	Level
D1	1	1,12	1	2
D2	2	1,2,3,7,12	2	4
D3	3	1,3,7,12	3,7	3
E1	4	1,3,4,5,6,7,8,10,11,12	4	7
E2	5	1,3,5,7,10,11,12	5,10	5
E3	6	1,3,6,7,12	6	4
O1	7	1,3,7,12	3,7	3
S1	8	1,3,5,6,7,8,10,11,12	8	6
S2	9	1,3,5,7,9,10,11,12	9	6
S3	10	1,3,5,7,10,11,12	5,10	5
S4	11	1,3,7,11,12	11	4
U1	12	12	12	1

drivers is shown in Fig. 2.

4.2.6. *MICMAC analysis*

MICMAC analysis Matrice d' Impacts croises multiplication appliqué and classment (cross-impact matrix multiplication applied to classification) is abbreviated as MICMAC. MICMAC analysis is conducted to analyze the driving power and dependence power of SSC and SCC drivers. Dependence power and driving power is plotted against X and Y axis, respectively. Based on the driving power and dependence power (ref: Table 16), the drivers have been classified into four categories: autonomous, driving, linkage and dependent as presented in Fig. 3.

4.2.6.1. *Findings from MICMAC analysis.*

Cluster 1: Autonomous SSC and SCC drivers- These drivers exhibit weak drive power and weak dependence power. Product Life Cycle (D2), competitive rivalry (E3) and corporate strategy (S4) are positioned in this cluster.

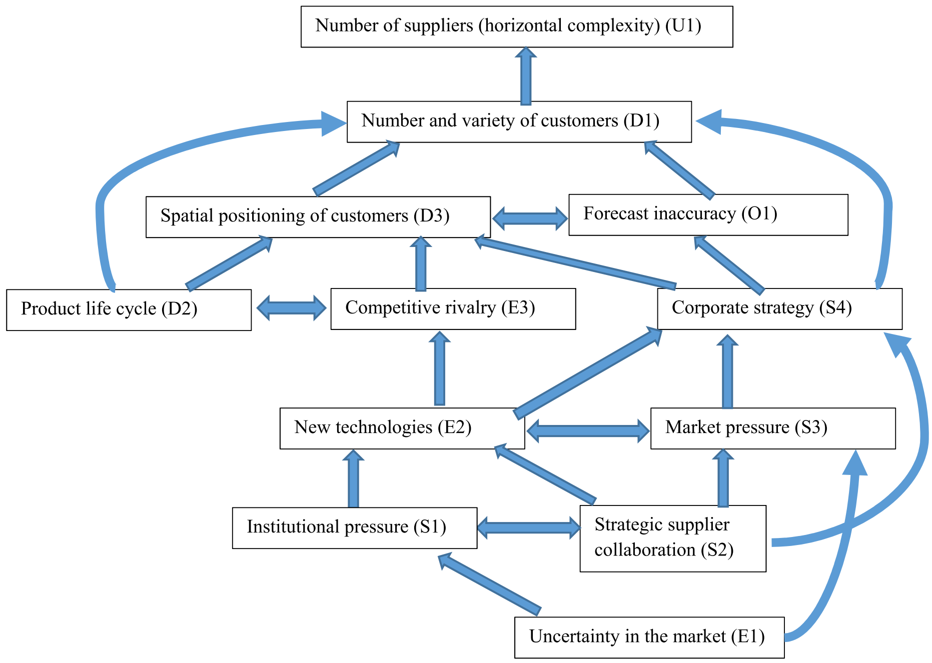

Fig. 2. ISM model.

Table 16
Position coordinates of identified SSC and SCC drivers.

Drivers	Dependency Power (X)	Driving Power (Y)
D1	11	2
D2	1	5
D3	10	4
E1	1	10
E2	5	7
E3	3	5
O1	10	4
S1	2	9
S2	1	8
S3	5	7
S4	6	5
U1	12	1

Cluster 2: Dependence SSC and SCC drivers- These drivers are characterised with strong dependence power and weak drive power. Number and variety of customers (D1), spatial positioning of customers (D3), number of suppliers (U1) and Forecast inaccuracy (O1) are within this cluster.

Cluster 3: Linkage SSC and SCC drivers- We do not find any driver falling in this cluster.

Cluster 4: Driving SSC and SCC drivers- These drivers have strong drive power but weak dependence power. We have five drivers, i.e., institutional pressures (S1), strategic supplier collaboration (S2), market pressure (S3), uncertainty in the market (E1), new technologies (E2) in this cluster.

5. Discussion and managerial implication

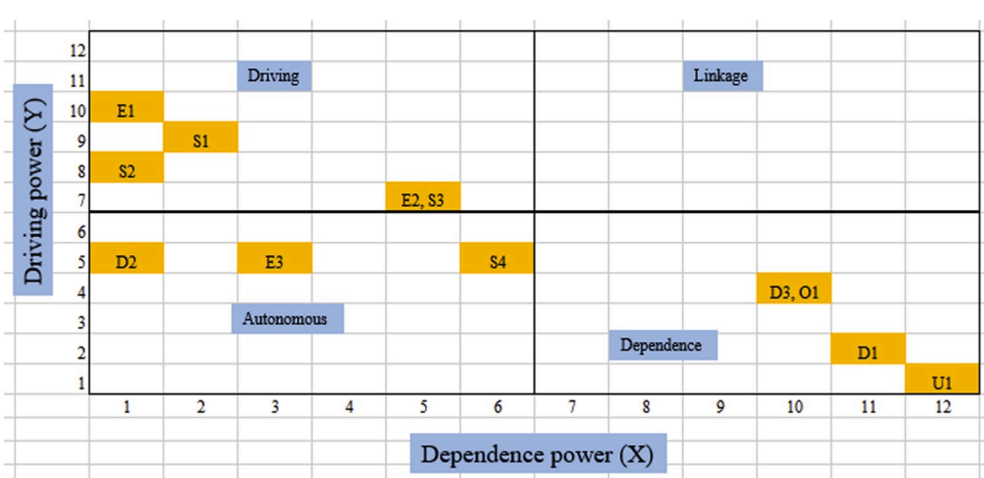

Fig. 3. Plotting of position coordinates of identified SSC and SCC drivers.

Knowing the interrelationship among SSC and SCC drivers will enable the supply chain managers in well-aligned sustainable supply chain planning. This study has been conducted in mining and earth-moving machinery manufacturing firms operating in India to analyze the industry dynamics of construction equipment, material handling, and off-road vehicle manufacturing industries. Limited availability of literature in analyzing interactions among SCC drivers with SSC drivers and its impact on overall supply chain management is addressed in this study. This research attempts to bridge the gap between studies exploring SSC and SCC drivers independently. Our research established seven-levelled model involving twelve identified critical drivers combining SSC and SCC. Based on driving and dependence power derived in ISM and MICMAC analysis, the relative importance is structured. Following critical managerial insights can be inferred to frame policy recommendations:

a) It is evident (ref: Fig. 3, MICMAC analysis), that uncertainty in the market (E1), institutional pressures (S1), strategic supplier collaboration (S2), market pressure (S3), new technologies (E2) are key drivers which require urgent attention from decision-makers. Uncertainty in the market influentially drives sustainable drivers like institutional pressures (S1), strategic supplier collaboration (S2), market pressure (S3). Uncertainty in the market is caused due to the multiplicity of factors like globalised economic risk, geo-political events, cyclicity of markets. To highlight the criticality of market uncertainty, Managing Director of automobile sector of DHL once commented "Global economy has demonstrated one clear fact: with complexity comes uncertainty; uncertainty in global supply chain cause traditional supply chain models to break down" (CIPS, 2014). To corroborate the fact with case, Indian construction machinery industry experienced significant supply chain uncertainty due to disruptive increase in tax rates from 18% to 28% by the implementation of Goods and Services Tax (GST). This resulted in significant demand slowdown with excess inventory (Chand et al., 2018). The mining and earth-moving machinery industry experienced degrowth in the financial year 2017 as the impact of the same. The industry underwent similar uncertain time in March' 2017 due to sudden change in legislation by Indian apex court asking the industry to comply with BS-IV vehicle emission norms. This temporarily disrupted the supply chain operations in manufacturing plants and entire supply chain network for the sector in general.
b) SSC drivers like institutional pressures (S1), strategic supplier collaboration (S2), market pressure (S3) with relatively higher driving power (ref: Table 16) have major impact in forming the overall structure of ISM digraph. This emphasizes the fact that supply chain managers should focus on said drivers to control the supply chain performance. Geodis (2017) survey on companies with worldwide supply chain presence, argued that specific local regulations and the varying levels of maturity exhibited by suppliers have resulted in increased operational complexities. Institutional pressure and obligations are often driven by societal, environmental and economic needs as highlighted in sustainable development model mentioned in TBL.
c) Our research finding highlights the importance of strategic supplier collaboration (S2) in controlling critical sustainable drivers like institutional pressure (S1), market pressure (S3), new technologies (E2), corporate strategy (S4). This strengthens the research finding of Kumar et al. (2016), who proves buyer-supplier relationship as a crucial factor in implementing sustainable supply chain for the Indian automobile sector. In a research, jointly conducted by Michigan State University's Eli Broad College of Business and APICS Supply Chain Council titled "Supply Chain Management: Beyond the Horizon, MANAGING THE COMPLEXITY PARADIGM (2017)", interviewed more than fifty firms around the world. The research outcome suggested that institutional regulation and supplier collaboration are important drivers in managing complexity. One of the leading Indian industrial group, as a part of the sustainable journey, has developed programs to share knowledge with suppliers and to enable them in equipping responsibly sustainable partners (United Nation Global Compact Office and Business for Social Responsibility, 2010).
d) The outcome of this study suggests that adoption of new technologies (E2) plays important role in implementing sustainable supply chain. It influences drivers such as competitive rivalry (E3) and shapes corporate strategy (S4) of a focal firm. Increasing awareness among customers for sustainable, environmentally acceptable and smart products is motivating the manufacturers to develop and innovate products and solutions built with intelligent features. JCB, leading construction equipment (CE) manufacturer, is using internet-of-things (IoT) and big data using telematics technology to improve the product performance and customer experience. Another Indian CE manufacturer has incorporated the adoption of newer technologies in the firm's vision statement to enhance the customer experience. In a research report by Gartner (2019) titled 'The Future of Supply Chain Operations', vice president analyst of Gartner emphasized on adoption of 'new business models and technologies to excel in an increasingly complex and volatile world' and suggested supply chain leaders 'to innovate and invest in new processes and technologies to help their companies remain relevant in their markets'. This statement underscores the importance of new technologies as a key driver towards the firm's SC strategy and corroborates our research finding.

5. Conclusion and future scope

This research work is endeavored to build a novel theoretical framework by integrating the SSC and SCC drivers in a complex dynamic business scenario. The study, aimed at investigating the interactions among drivers of SSC and SCC simultaneously, enables in developing an effective supply chain strategy. Developed interrelationship models among SSC and SCC drivers will enable supply chain managers in adopting a unified approach for informed decision-making. This work is aimed to open-up further research for studying the impact of combined drivers of SSC and SCC on various areas of the supply chain like SC agility, SC strategy, SC responsiveness, SC performance. This research framework can act as a guide in building theory about the impact of the mutual relationship among SSC and SCC drivers on a firm's financial, operational, sustainable performance.

The supply chain managers are increasingly emphasizing on sustainable supply chain and supply chain complexity for enhancing the overall supply chain performance. Often researchers conducted the study of SSC and SCC independently by exploring respective drivers. Our research outcome will bring a new dimension to approach the subject with an integrated outlook. This study enriches the existing literature with its critical contribution in signifying sustainable drivers corroborated by practical insights from industry experts.

This study has been conducted in mining and earthmoving machinery manufacturing firms operating in India. The research framework of this paper can be extended to analyze construction equipment, material handling, and off-road vehicle manufacturing industries due to similar sectoral dynamics. In the future, research may also be extended to other manufacturing sectors applying a different set of identified drivers. Research can also be applied in other countries to construct a more generic model.

The hybrid decision-making two-phased research methodology is adopted in this research. The Delphi technique followed by interpretive structural modeling (ISM) was applied to determine the mutual relationship among important 12 identified drivers based on the study. The mentioned methodology provides flexibility to structure research problems integrating rich industry-academia outlook with a different set of drivers. There can be drivers, not included in this study, that may affect the research findings. In the future, the research outcomes of this paper can be validated by applying a different set of MCDM tools. In future authors intend to integrate ISM with structural equation modeling (SEM) for statistical validation of result.

Declaration of competing interest

No conflict of interest for the following paper.

CRediT authorship contribution statement

Pushpendu Chand: Writing - original draft, Writing - review & editing, Conceptualization, Methodology, Formal analysis. **Jitesh J. Thakkar:** Writing - original draft, Writing - review & editing, Conceptualization, Methodology, Formal analysis, Supervision, Writing - original draft, Writing - review & editing, Conceptualization, Methodology, Formal analysis, Supervision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.resourpol.2020.101726.

Appendix A

Level partitioning intermediate steps

Table A1
Intersection of reachability and antecedent sets and representation of level group 1.

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection set	Level
D1	1	1,12	1	
D2	2	1,2,3,7,12	2	
D3	3	1,3,7,12	3,7	
E1	4	1,3,4,5,6,7,8,10,11,12	4	
E2	5	1,3,5,7,10,11,12	5,10	
E3	6	1,3,6,7,12	6	
O1	7	1,3,7,12	3,7	
S1	8	1,3,5,6,7,8,10,11,12	8	
S2	9	1,3,5,7,9,10,11,12	9	
S3	10	1,3,5,7,10,11,12	5,10	
S4	11	1,3,7,11,12	11	
U1	**12**	**12**	**12**	**1**

Table A2
Intersection of reachability and antecedent sets and representation of level group 2.

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection set	Level
D1	**1**	**1,**	**1**	**2**
D2	2	1,2,3,7	2	
D3	3	1,3,7	3,7	
E1	4	1,3,4,5,6,7,8,10,11	4	
E2	5	1,3,5,7,10,11	5,10	
E3	6	1,3,6,7	6	
O1	7	1,3,7	3,7	
S1	8	1,3,5,6,7,8,10,11	8	
S2	9	1,3,5,7,9,10,11	9	
S3	10	1,3,5,7,10,11	5,10	
S4	11	1,3,7,11	11	

Table A3
Intersection of reachability and antecedent sets and representation of level group 3.

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection set	Level
D2	2	2,3,7	2	
D3	**3**	**3,7**	**3,7**	**3**
E1	4	3,4,5,6,7,8,10,11	4	
E2	5	3,5,7,10,11	5,10	
E3	6	3,6,7	6	
O1	**7**	**3,7**	**3,7**	**3**
S1	8	3,5,6,7,8,10,11	8	
S2	9	3,5,7,9,10,11	9	
S3	10	3,5,7,10,11	5,10	
S4	11	3,7,11	11	

Table A4
Intersection of reachability and antecedent sets and representation of level group 4.

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection Set	Level
D2	**2**	**2**	**2**	**4**
E1	4	4,5,6,8,10,11	4	
E2	5	5,10,11	5,10	
E3	**6**	**6**	**6**	**4**
S1	8	5,6,8,10,11	8	
S2	9	5,9,10,11	9	
S3	10	5,10,11	5,10	
S4	**11**	**11**	**11**	**4**

Table A5
Intersection of reachability and antecedent sets and representation of level group 5.

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection Set	Level
E1	4	4,5,8,10	4	
E2	**5**	**5,10**	**5,10**	**5**
S1	8	5,8,10	8	
S2	9	5,9,10	9	
S3	**10**	**5,10**	**5,10**	**5**

Table A6
Intersection of reachability and antecedent sets and representation of level group 6.

SCC/SSC drivers reference number	Corresponding serial number	Reachability	Intersection Set	Level
E1	4	4,8	4	
S1	**8**	8	8	**6**
S2	**9**	9	9	**6**

Table A7
Intersection of reachability and antecedent sets and representation of level group 7.

Supply chain complexity drivers reference number	Corresponding serial number	Reachability	Intersection Set	Level
E1	**4**	**4**	**4**	**7**

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Further reading

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