ORIGINAL RESEARCH

Assessment of Supply Chain Flexibility Using System Dynamics Modeling

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Abstract *Although personal care sector within fast-moving consumer goods industry has been known as a key contributor toward the growth of the economy, barely any study has been conducted to assess the flexibilities in the personal care supply chain. Further, being competitive and challenging environment of the industry, domestic personal care firms are stressed for their supply chain performance. The state of affairs is predominantly critical in the soap manufacturing firms, which have simple, but yet long, supply chain with ample amount of uncertainty due to intense competition, and therefore increase the challenges for firms such as "how much to produce" and "how much should be the production lead time." Using expert views along with academicians and literature support, this paper investigates the flexibilities associated with soap manufacturing supply chain. The paper utilizes a distinctive approach of assessing the supply chain flexibility through system dynamics (SD) model and endorses the model in a soap manufacturing setting in India. The setting has been examined by changing the level of order rate and production lead time. The model along with the overall supply chain performance of a soap producing unit evaluated indicates the degree of flexibility achievable by the firm. Flexibility dimensions having considerable and outranked influence on enlightening the supply chain performance are recognized. The findings of study indicate demand pattern of packed and unpacked soaps shows seasonal fluctuations;*

interesting thing is that when one category soap demand increases, the other category's demand shows slowdown. If case firm takes measures to improve the backlog or production gap through varying lead times, the performance of flexible supply chain can be enhanced. Finding also suggests that improved results may be obtained by varying the order rate. Simulation results show improvement in inventory of packed and unpacked soaps, shipment gap and hiring rate of the firm. The study is exclusive in reviewing the common man's sector of personal care industry, which has received the least consideration in the literature and practice. The study claims to be unique by applying SD modeling to respond to research questions raised up along with inferences for practice and theory.

Keywords Soap manufacturing · Supply chain flexibility · Supply chain performance · System dynamics

Introduction

FMCG sector in India is a fourth-largest sector having a size of US$ 13.1 billion. The common products of the industry are toilet soaps, shampoos, toothpaste, packaged foodstuff and household accessories (CII 2018). Indian FMCG industry will grow 15% in the next 2–3 years (The Times of India 2017). Market was at US$ 29.4 billion in 2016 and is expected to grow up to US$ 220 billion by 2025 (IBEF 2018). Rural consumption is going to drive the FMCG market (ETRetail.com 2017). 70% of the population lives in rural areas (Business Standard 2013). Toilet soaps have highest penetration among other products at 88.6% (Fig. 1). These soaps are easily available in 5 million retail shops in India. Around 75% of the retail shops exist in rural areas (Equitmaster 2016). The Indian Ministry of Health and Family

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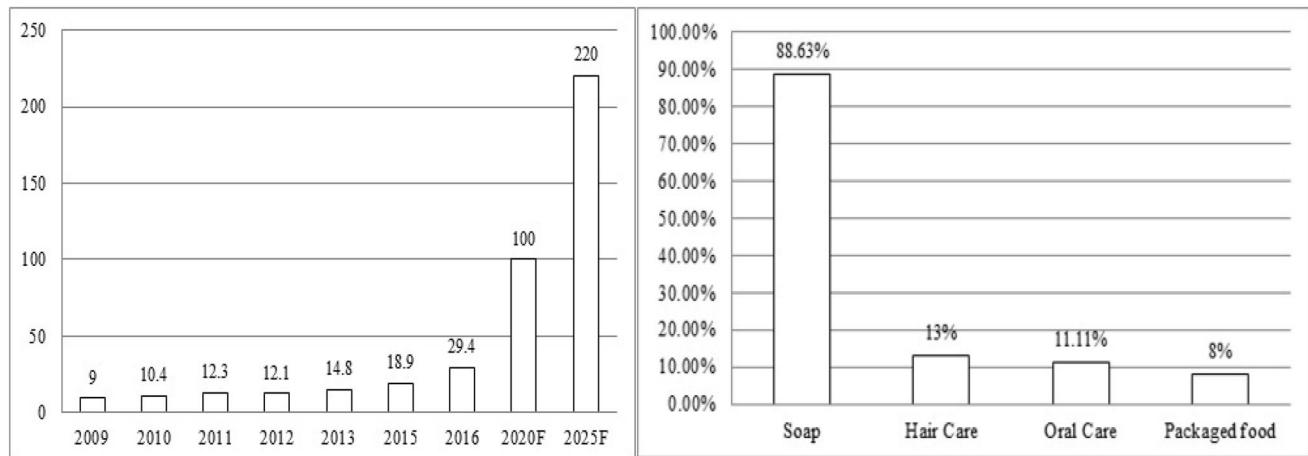
Fig. 1 Rural FMCG market in India (US $ billion) and rural FMCG penetration. *Notes*: F—forecast

Welfare has few schemes to promote the personal hygiene. On December 29, 2016, Government of India (GOI) has launched a program named as "Swachh Swasth Sarvatra" which means "clean and healthy everywhere" (NDTV 2016). The objective of this program is to improve the health outcomes through improved sanitation practices and lifestyle (Business Standard 2016). Over a period of time, the level of awareness about hygiene has grown in rural areas. This growth is due to easier access, changing lifestyle and penetration of e-commerce sector (ETRetail.com 2017; IHPCIA 2017). The increased disposable income in rural and urban sectors opens the doors for FMCG growth (IBEF 2017). It is clear that soap is most commonly used for basic personal hygiene in urban and rural areas. The Indian FMCG market (personal care) is dominated by multi-national companies (MNCs) (Business Standard 2017). Due to the options available and choices made by consumers, it is difficult for the firms to track the exact demand (McKinsey & Company 2000). Additionally, today's digital era has created the disruption which requires firms to change their approach about the design of their supply chain activities (Waller and Fawcett 2013; Müller and Voigt 2018; Schniederjans et al. 2019). At the same time, customer expectations are growing due to exposure to online access and other types of information available (Boone et al. 2018; Vakulenko et al. 2019). A trend toward customization and individualization forces the firms to do changes frequently (Bhardwaj and Fairhurst 2010; Fornasiero et al. 2015; Schniederjans et al. 2019). Today with the number of platforms and wide range of information availability, it is easy to buy and sell the products on one hand, while it drives a tough competition among supply chains on the other hand (Ai et al. 2012; Kumar et al. 2018). Real-time planning will let firms respond flexibly to variations in demand and supply (Schachter et al. 2016). Performance of a firm and supply chain depends upon a large number of indicators in uncertain environment (Fischer et al.

2014; Kaur and Singh 2019). It is also necessary to analyze and classify the type of flexibilities required for your supply chain and measure the degree of flexibility of a supply chain to improve further if required (Liu et al. 2019). Additional factors like order rate and lead time in supply and production can further hamper the flexibility in value chain (Hohenstein et al. 2015). Hence, planning will be a nonstop process in flexible supply chains that can respond dynamically to changing requirements of market (McKinsey & Company 2017). This planning will include all the areas of supply chain right from raw material purchase to last mile delivery of the product to consumer (Baldi et al. 2019; Le and Ukkusuri 2019; Zhang et al. 2019). Thus, it is rational to develop a system for flexible supply chain that can help firms to achieve their targets of sales and optimum cost in running the operations in uncertain time. The flexible system will help firms to turn out to be more viable and competent. Hence, firms need to have flexible orientation of supply chain in uncertain environment (McKinsey & Company 2009). In the present study, the author(s) have made an attempt to access the supply chain flexibility (SCF) implementation in soap manufacturing firm and examined how flexibility implementation can improve the supply chain performance.

Personal care industry needs to have sufficient degree of flexibility to cater the demands in today's dynamic environment (Nemtajela and Mbohwa 2017). The flexibility in supply chain will help firms to optimize and become sustainable. With the help of this study, the author(s) attempt to answer the succeeding research questions:

RQ1: Which indicators of supply chain flexibility have impact on performance of a firm in dynamic environment?

RQ2: What are the main types of flexibilities and how does a firm assess the degree of flexibility that are predominant in supply chain activities?

RQ3: What is the order of flexibilities that impact supply chain activities?

RQ4: How did the supply chain flexibility get impacted by the level of production lead time and order rate?

In the present study, the author(s) conducted a systematic literature review along with expert discussion for the identification of the areas of uncertainty in supply chain of a soap manufacturing firm. These areas of uncertainty in the entire supply chain have been carefully evaluated and converted into the flexibility dimensions. The typical value chain of soap manufacturing is from raw material procurement to delivery to customer. The industry's supply chain is changing not in terms of channel of flow, but in terms of volume to ship and time of the demand. The soap industry has taken a new shape due to industry disruptions. There are various other channels of distribution other than traditional one along with changing retail trends (Singh and Acharya 2013, 2014). The customer landscape has changed along with their consumption patterns. Innovation has emerged as a growth driver in last few years (Malaviya and Wadhwa 2005; Mladenow et al. 2014). The global competition is also contributing toward the disruption and uncertainty (Govindan et al. 2017). Therefore, an approach like SD modeling in accessing the flexibilities has been considered in the present study specifically in soap manufacturing setting. Being a complex manufacturing and supply chain of soap industry, the SD modeling is a suitable tool to evaluate and assess the logical control of flexibility indicators. Our study can be viewed as an additional contribution toward this direction of strengthening the supply chain. The rest of the paper is organized as follows: "Literature Review" section evaluates the supply chain performance of personal care industry through flexibility with the relevant literature along with fit of SD modeling-related literature. "Soap Manufacturing: Case Firm" section provides the brief description about case firm. "System Dynamics Modeling" section explains the SD modeling for the simulation of soap manufacturing supply chain. Results and discussion are described in "Results and Discussion" section. "Concluding Remarks" section summarizes the paper with model findings followed by limitations and scope for future research in "Limitations and Scope for Future Research" section.

Literature Review

Supply Chain Performance Through Flexibility

Supply chain is a complex network consisting nodes and links. Supply chain activities involve many departments of the firm right from operations, information systems, purchasing, and logistics to name a few (Chen and Paulraj 2004). SCM is an art of managing activities to achieve competitive advantage and maximizing the value (SCRC 2017). Firms need to adopt agility, speed and flexibility in their supply chain to compete and secure target margins (Brain & Company 2017; Chirra and Kumar 2018; Khorasani 2018). Today's business environment is turbulent and creates uncertainty and dynamics of high order (Sushil 2012). The firms in personal care industry compete strategically (Euromonitor International 2017). The firms compete to have better supply chain visibility, lower supply chain risk and enhanced supply chain flexibility (Stevenson and Spring 2007). Therefore, flexibility is not only a philosophy, but a cultural requirement that firms need now a days. Flexibility can be classified into internal and external elements (Das 2001; Olhager and West 2002; Shukla et al. 2019). The supply chain design is affected by the flexibility and strategy adopted by a firm. For instance, a low-volume producing plant's flexibility is dependent on subcontracting firm, while the other plant with high volume flexibility might grip the demand fluctuations (Olhager and West 2002; Sánchez and Pérez 2005). Supply chain flexibility can also be viewed as "elasticity" among buyer–supplier relationships (Das and Abdel-Malek 2003). The flexibility in supply chain can be classified from hierarchical view. The classification includes operational flexibilities (shop floor and resource level), strategic flexibilities (firm level), tactical flexibilities (plant level) and supply chain flexibilities (network level) (Stevenson and Spring 2007). Supply chain flexibility has been studied by earlier researchers (Kazemian and Aref 2016; Shibin et al. 2016; Obayi et al. 2017; Um 2017; Dubey et al. 2018; Ivanov et al. 2018). However, flexible supply chain in personal care industry-related studies has not been reported. In addition, supply chain management practices are very much prevalent in personal care industry. The lean practices and flexible supply chain enhance faster decision making, which help to have the increased agility in personal care industry. The greatest supply chains are not just cost-effective and fast, but they are agile and adaptable and also ensure that their firm's objectives are aligned in their supply chains. Therefore, the identification of flexibility dimensions and their modeling can serve as a prospective resolution for superior supply chain performance in dynamic environment (Um 2017 and Song et al. 2018).

Flexibility Addresses the Uncertainty

Uncertainty is a sign of system that indicates the incomplete information in which a system develops certain conditions. Uncertainty in any system can be due to intelligence, human or natural factors. Intelligence uncertainty is due to the knowledge power of decision support

system, and human uncertainty is due to human knowledge, whereas natural uncertainty is due to environmental changes (Ivanov and Sokolov 2010). Uncertainty factors can be classified as risk, uncertainty, disturbance, and disruption. A risk originates from uncertainty, whereas the disturbance is the magnitude of the risks. On the other hand, disruption is the product of discomposure influence and uncertainty is general property of the system. Klibi et al. (2010) have classified uncertainty in supply chain as hazard uncertainty (risk of uncommon events with significant impact), deep uncertainty (severe disruption risks), and random uncertainty (demand fluctuation risks). Random uncertainty is much more prevalent in business like personal care industry (Kleindorfer and Saad 2005; Chopra et al. 2007; Aqlan and Lam 2015; Bierwirth and Meisel 2015). The random uncertainty generally considered in bullwhip effect (Ouyang and Li 2010). The past research has covered the relationship of flexibility, uncertainty, and supply chain performance (Stevenson and Spring 2007). The interaction between flexibility, uncertainty, ambiguity, and supply chain is given in Table 1 (Appendix). (For an in-depth review of former studies on this topic, refer to Stevenson and Spring 2007; Kumar et al. 2008; Angkiriwang et al. 2014; Ivanov et al. 2018.) A considerable amount of papers in the latest past indicates the importance and rise of the area along with the need for research in this field. For instance, in 2017 a special issue of *International Journal of Production Economics* titled "*Emerging Issues in Multi-Channel Operations Management in the O2O Era*" was dedicated to the construction of a flexible supply chain for consumer products to address the online and offline issues of supply and demand operations (Sreedevi and Saranga 2017). Moreover, very recently *International Journal of Operations and Production Management* has called for papers under the theme of "*Dealing with the Unpredictable: Supply Chain Resilience*" which will be published in 2019–2020. The scope of the papers includes the linkage of supply chain resilience and supply chain flexibility.

Appropriateness of SD Modeling

SD is a technique based on the principles of response control scheme to tackle multifaceted complications present in different organizational operations. SD helps in analyzing and offers inferences to a wide range of operative and tactical resolutions. This technique is centered on the design of qualitative and quantitative models in multifarious but realistic scenarios. Through this, a simulated and lively environment can be developed to spot the system behavior. Ghadge et al. (2013) have developed a model using SD for measuring and quantifying the risk assessment process to understand overall risk behavior. SD is

used to simulate the multi-level supply chain (Campuzano and Mula 2011). Aggregate production planning (APP) policies are important part of any supply and can be modeled using SD to enhance the trade-off (Mendoza et al. 2014). Computer-centered simulations and models have potential of achieving the objectives of entire system behavior (Hettinger et al. 2015). Sensitivity and past data help in developing a realistic model through computer characteristics. SD can be helpful to multifaceted supply chains, where a large number of interconnected variables are present. The technique of SD deals with causative interrelationship of these variables (Bakoa and Božek 2016; Frazzon et al. 2017). SD unveils a graphical summary of a system in the form of causal loop vision. SD model is capable of tracking the behavior of supply chain system and identifying the risks involved at various nodes. This aids apprehending the inclusive dynamics and helps in analyzing the performance of entire supply chain activities (Baradaran and Keshavarz 2015). Earlier studies indicate that SD has seen its applications in management of manufacturing and supply chain to enhance the performance and reduce the uncertainty (Croson and Donohue 2005; Tako and Robinson 2012). The methodology also has been used to develop and implement the programs and policies in health care (Royston et al. 1999; Faezipour and Ferreira 2013). SD approach has been applied to investigate the probability for dealing with bullwhip effect with the adoption of vendor-managed inventory style (Disney et al. 2003; Wilson 2007). SD methodology has been applied to software project management (Acharya and Mahanty 2008), airport terminal analysis (Manataki and Zografos 2010; Suryani et al. 2010), pollution at toll plazas (He et al. 2011), transport systems (Wilson 2007; Pfaffenbichler et al. 2011), highway maintenance and construction areas (Chasey et al. 2002 and Fallah-Fini et al. 2010). The existing studies indicate the role of flexibility in supply chain to sustain in dynamic environments (Obayi et al. 2017).

After observing the entire supply chain operations of personal care industry, interrelations among different operations and associated flexibilities were clearly identified and recognized. The author(s) consider that the present study will address this research gap and integrate the interrelationships with the help of SD methodology. Since personal care industry's supply chain processes and other variables make it complex and have a great impact on supply chain performance, SD modeling seems to be a fitting instrument to recognize and evaluate the flexibility of a soap manufacturing firm's supply chain. In-built dynamism is supply chain activities that can be captured with the help of SD modeling. The main challenge at present for Indian personal care industry is to increase the supply chain profit by tackling the uncertainty through emphasis on appropriate

flexibilities. In personal care industry, the supply chain cost is approximately 50–60%, which includes distribution and retailer side of the system (Argus 2017). High degrees of uncertainty present in today's supply chain push the system to adopt an appropriate approach to have targeted performance. In addition, the case firm's supply chain operates with traditional method of distribution and logistics, which is the key reason for uncertainty. To apprehend the causal relationship between these variables and performance pointers such as levels of packed and single-unit soaps, order backlog, shipment gap, production gap, and availability of manpower are being integrated in the recommended SD model.

The review conducted shows that not several studies were dedicated for the identification of flexibilities relevant to especially personal care industry, where competition is high and uncertainty is humongous. Our study claims to be distinctive in relations of developing an assessment approach to estimate the flexibility types dominant in a soap manufacturing firm with the help of interrelations within the flexibilities and other dynamics. The present study highlights on evaluating performance of a soap manufacturing firm's supply chain in changing market circumstances based on strategic and operational signs. Case study approach has been utilized, and supply chain flexibilities with respect to an Indian soap manufacturing firm have been considered. Primary data were collected with the help of professional interviews followed by far-reaching field study at a soap manufacturing firm in India. Collected data lead us to develop the SD model. The developed SD model can work as a tactical tool to supply chain advancement in the case firm and other similar setups. The present study also claims to be first addressing supply chain flexibility of personal care industry in Indian context.

Soap Manufacturing: Case Firm

The current study has been conducted in a reputed and considerably large soap manufacturing firm named as Aromatic Soap Ltd. (The real name of the firm is hidden due to confidentiality reasons.) Aromatic Soap Ltd is one among the leading firms in personal care industry in India. The firm is one of the biggest sellers of toilet soaps in the country. The firm deals in the products like toiletries, hair care, cosmetics, and fabric care products with other products. The firm has a range of its operations in Asia, Europe, North and Latin America, Africa, and Gulf countries. In India, their head office is in Mumbai. The firm's three brands are in 100 most trusted brands in India. The firm's manufacturing plant is the one integrated with modern technology. In plant, they process raw oils into soaps through fatty acid rough. Aromatic Soap Ltd is committed

to quality and driven by quality management system (QMS) since 1995. It is ISO 9001:2015 certified along with other certifications like OHSAS 18001 (Occupational Health and Safety Assessment Series) and ISO 14001. Firm has a strong presence in emerging markets outside India also. To strengthen a global portfolio, firm acquired 51% stake in an African firm and 60% stake in a Chilean company which is into hair color segment. The main product of the firm is toilet soap. The firm has installed capacity of more than 55,000 tones/annum. The revenue of the firm is Rs. 89,678.1 million (March 2016) (Annual report of the company 2016).

Flexibility Areas Related to Aromatic Soap Ltd

Eleven major flexibilities have been identified with respect to the case firm and are explained as follows:

(i) *Product flexibility* It is the ability of the firm to produce the products categorized by different sizes, colors, options and features as per market demand (Kumar et al. 2006; Stevenson and Spring 2007).

(ii) *Volume flexibility* This defines the ability of a firm to produce the products above and below the installed capacity as per market fluctuations (Sánchez and Pérez 2005; Stevenson and Spring 2007).

(iii) *Launch/new product development flexibility* This is the ability of a firm to timely launch new products to remain competitive in market (Ndubisi et al. 2005; Kumar et al. 2006, 2007).

(iv) *Sourcing flexibility* This ability helps the firm to outsource one product from multiple suppliers in case of the increase in demand (Sánchez and Pérez 2005; Kumar et al. 2006; Yi et al. 2011).

(v) *Physical distribution flexibility* This is the ability of a firm to change the distribution process to meet the quick demand of market (Zhang et al. 2002, 2005; Yu et al. 2012).

(vi) *Demand management flexibility* This flexibility is about enhancing the responsiveness by improving service levels, delivery time, and price (Lee 2001; Zhang et al. 2002; Yu et al. 2012).

(vii) *Coordination flexibility* This is about how a firm uses its integrative capabilities to develop relationship between partners (Sezen and Yilmaz 2007; Wilson and Platts 2010; Yu et al. 2012; Bag and Gupta 2017).

(viii) *Manufacturing flexibility* This is the capacity of a firm which defines the rate at which a firm can change the gears to produce the required production rate. This involves reduction in time of die exchange (Oke 2005; Yazici 2005; Dubey and Ali 2014; Solke and Singh 2018).

(ix) *Response to market flexibility* This is the aptitude of a firm which helps a firm to respond to dynamic situations (Sánchez and Pérez 2005; Kumar et al. 2006).

(x) *Process flexibility* This is the talent of a firm to produce different kinds of products using the same amenities in production system with smooth flow (Sánchez and Pérez 2005; Stevenson and Spring 2007; Dutt and Chauhan 2019).

(xi) *Expansion flexibility* This is the skill of a firm to expand the capacity of a system in challenging scenarios (Parker and Wirth 1999; Stevenson and Spring 2007).

These 11 dimensions were extracted through extensive literature survey and interaction with experts. After DEMATEL (decision making trial and evaluation laboratory) analysis, it was clear that three flexibilities are majorly influencing the entire supply chain of Aromatic Soap Ltd. (DEMATEL analysis is done by the authors; see Singh et al. 2019) Figure 2 indicates the nine steps followed in the conduct of this study.

System Dynamics Modeling

Main areas of flexibility in the soap manufacturing supply chain were recognized using DEMATEL. The three flexibilities that have significant impact on soap supply chain comes out are product flexibility, demand management flexibility, and physical distribution flexibility. The supply chain performance dimensions are impacted by the influence of market demand rate, availability of resources, and production lead time among others. These magnitudes were assessed with the support of SD model to examine the flexibility of the supply chain. The initial inputs for the model were considered on the basis of standards obtainable from the firm in December 2014. Demand in the supply chain was projected for the next 104 weeks after running the model.

Overview Diagram

The sequence of supply chain and associated flexibilities in a soap manufacturing firm starting from inbound supply chain to outbound supply chain till consumer is shown in Fig. 3 (Singh and Acharya 2013). In the inbound phase of supply chain, firm sources the raw material from a network of vendors. In this phase of supply chain, information exchange between focal firm and supplier influences the coordination. The identified related flexibilities to this phase are sourcing, demand management, and coordination which impact the focal firm supply chain performance. The

next stage in the supply chain belongs to in-house, where all the internal processes and transformation of the product takes place. The related flexibilities include product, volume, manufacturing, response to market, processes, expansion, and launch/new product development. The last phase of supply chain is outbound. In outbound supply chain, the finished goods are transported via a designed network of warehouses, dealers, distributors, and retailers. Finally, the product reaches to the consumer. Physical distribution and coordination are major influencers of flexibility in this phase of supply chain.

Causal Loop Diagram

Figure 4 demonstrates the underlying association among soap manufacturing supply chain processes. The firm may not be in a position to meet the entire market demand all the time. The market consumption rate here refers to the actual amount of soap units' dispatched to the market and is influenced by the demand. This implies that if the market demand at a particular time is high and there are goods available in the warehouse, then more goods can be shipped which indicates the higher consumption in the market. Market consumption rate being highly fluctuating in nature, there is a need to average it out. Thus, the average consumption rate dictates the desired inventory on the basis of number of weeks of consumption the firm decides to hold in its warehouse. Thus, the gap between the desired inventory and the actual inventory along with average consumption rate and backlogs is ordered to the shop floor for production. It has been seen that a higher demand usually involves high degree of product variety which increases the equipment changeover time. Hence, there is an increase in the overall production lead time which in turn increases backlog and slows down the shipment rate. Frequent equipment changeover increases the cost which adds to product price. A higher unit price of product (soap) adversely (or negatively) influences its demand. Similarly a very high demand results in a greater delivery delay because of the issues such as outsourcing and higher supplier's lead time. A greater delivery delay again reduces the demand.

Product demand is the crucial component for any organization. It has been observed that higher demand will lead to the increase in product variety. The reason belongs to different categories of consumers in terms of geographical region, varied income levels and living standard. India is a country of socially diversified people, and this leads to the variation and demand which increases product variety in the organization. Higher product variety leads to higher equipment changeover time. It is not feasible for the organization to build a separate manufacturing setup for each category of product since product variety is usually

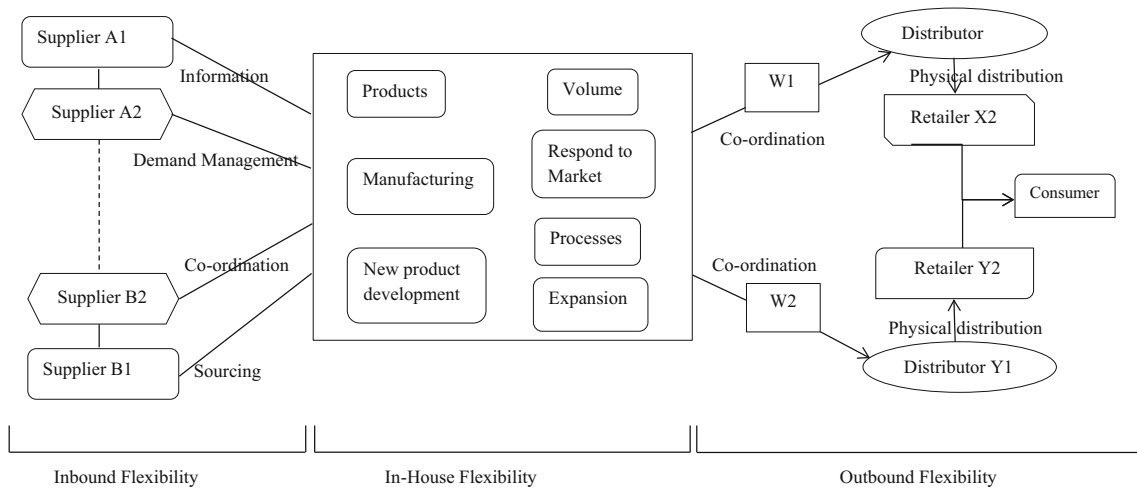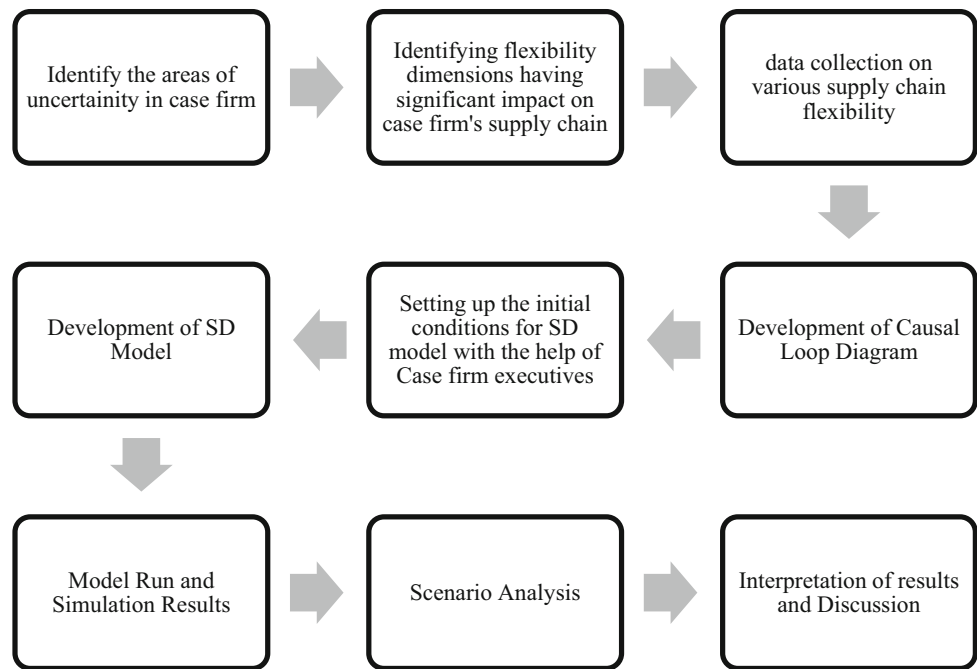**Fig. 2** Methodology adopted in conducting the study

Fig. 3 Supply chain process and associated flexibility areas

high in personal care product category. So as per the production plan of the day, once the production of "A" category of soap is finished, same machines and other resources are utilized for production of "B" category of soap. It takes some time to switch from one category to another, which is called equipment changeover time. Changeover time leads to changeover cost, and higher changeover time will lead to higher changeover cost. If the cost is higher, product appeal will reduce automatically for consumers. Soap is a kind of product where slight increase in price will lead to the decrease in demand drastically.

Similarly, if the demand is high, capacity required to manufacture the product will also be high. When demand is less or at par with the available capacity of other firm's

installed capacity, manufacturing within the firm is possible. But when demand exceeds from installed capacity of manufacturing firm, outsourcing comes into picture. So, higher capacity requirement will lead to higher outsourcing to any third-party or contract manufacturer. Same supplier who supplies material to focal firm does supply material for third-party manufacturer. For this, suppliers also need to reschedule their plan, which takes time greater than the normal processing time and hence increases overall supplier lead time. The increase in supplier lead time increases the delay in delivery of the final product to consumer. The late delivery of product affects the customer satisfaction negatively. Drop in customer satisfaction will lead to decline in demand. Higher demand will lead to an increase

Fig. 4 Causal relationships among components of supply chain flexibility dimension

in the order processing time due to higher equipment changeover, recruiting, training of new employees and increase in supplier lead time. Higher order processing time will raise the overall pick to ship cycle time which will result in the decrease in timely delivery. The increase in delivery time results in delivery delay of product to consumer and also increases the planned warehouse inventory. To deliver the product on promised date and time to consumer, the case firm relies on third-party logistics. When demand is much higher, firm needs to contact different logistic providers who are not easily available in the area where the case firm manufacturing plant is installed. It takes considerable amount of time to get third-party logistic services. Higher time to get 3PL services will lead to the increase in planned warehouse (PWH) inventory. The increase in PWH inventory results in problem of finding additional space or warehouse where additional products can be stored. The increase in time to find additional space will again increase the overall supply chain inventory. To deliver the increased inventory, additional logistic services are needed which results in the increase in additional delivery cost. Additional delivery cost results in the reduction of cash in hand and which again increases the time to get the services of third-party logistics.

Primary Settings and Equations

Field visits helped us to generate sufficient primary data to set up the primary conditions (assumptions) for the model. The data collected for a month for soap production, inventory (for both packed soap and single-unit soap) backlog order data, etc. were collected from January 2015 to November 2015. The base era of the study is considered as January 2015. Most of the parameters are mentioned in metric tonnes (MT) so that we can balance the other units. This way one can convert the production of soap to MT of quantity as the soap sizes are standardized.

Figure 5 shows the detailed system dynamics model established in this study and reflects the supply chain of soap manufacturing. Here, several events included are displayed in the form of flow diagram along with stock. Stock represents the level variable and is presented through rectangular boxes. Some of the level variables (which are physical accumulations) shown in the diagram include RMI (raw material inventory), UPS (unpacked soap), PS (packed soap), backlog, etc. This particular stock flow diagram tries to combine the three aspects of supply chain flexibility, i.e., product, demand and physical distribution flexibility in the soap manufacturing unit. We have

Fig. 5 Flow diagram of soap manufacturing process

considered here one set of product variation in the form of packed soap (where three or four soaps come out as a single pack) and unpacked soap that refers to as single unit of soap. After the production, there is an accumulation of packed and unpacked soaps in the levels of PS and UPS, respectively. Market consumption rate is given as consumption rate (CR), where CR1 presents the unpacked and CR2 indicate the packed soap consumption. A standard order rate known is referred to as demand here for the moment. Backlog accumulates with the increasing gap between order rate and the actual shipment characterized by CR1 and CR2. The real demand gets revised upward and downward from the order rate by the features of shipment rate and price factor.

The discrepancy between order rate and production rate decides the additional people required to make up the shortfall. This information prompts a hiring process and causes a delay in production due to hiring (3 months) and training the people (6 months). New people emerged fully trained to join the existing workforce that will produce the desired amount of goods.

The collected data on monthly basis were utilized to generate and design the model, after setting the primary conditions (initial).

The following initial values are considered in the model.

Initial inflow of raw material = 1500 MT/week

Warehouse stock of unpacked soap carried over from previous week = 4500 MT/week (company intends to maintain a monthly inventory of 18000 MT–20000 MT of unpacked soap which totals to approximately 12 days of market consumption)

Warehouse stock of packed soap carried over
  from previous week $= 600$ MT/week

Initial backlog $= 200$ MT

Initially trained people $= 300$

System Dynamics Equations

Raw Material Supply to the Firm The firm gets its raw material (for soap) from the suppliers. The order rate to the supplier firm is based on the gap between the actual raw material inventory consumed and the one firm that wishes to maintain.

Customer orders give the thrust to any supply chain to work upon. To avoid any discrepancy, firms maintain their optimum level of inventory. In terms of fluctuating demand rate, the raw material inventory level gets affected. Focal firm sends the orders to their suppliers to get additional raw material inventory in the time of high demand. Existing orders that are supposed to dispatch in near future are termed as backlog orders.

Here, customer order backlog at supplier end is given by:

$$CBL(t) = CBL(t - dt) + (COR - SR) * dt \qquad (1)$$

$$COR = DRMI - RMI \qquad (2)$$

$$INIT\ CBL = 15000$$

$$DRMI = 2000$$

$$SR = SMTH1(COR, ST)$$

where CBL = customer backlog in MT (here firm is the customer for its raw material suppliers); COR = customer order rate (MT/Week); SR = supply rate (MT/Week); DRMI = desired raw material inventory; and RMI = raw material inventory.

Inventory of Packed and Unpacked Soaps The inventory of the packed and unpacked soaps depends on two rates, namely *production rate and the consumption rate of soap*. Consumption rate (actual amount shipped to the market) is exogenous.

$$UPS(t) = UPS(t - dt) + (PR1 - CR1) * dt \qquad (3)$$

$$INIT\ UPS = 4500$$

$$PS(t) = PS(t - dt) + (PR2 - CR2) * dt \qquad (4)$$

$$INIT\ PS = 600$$

$$PR1 = DELAY1(PORU, PD1)$$

$$PR2 = DELAY1(PORP, PD2)$$

$$CR1 = GRAPH(TIME)$$

$(0.00, 1164), (10.0, 598), (20.0, 805), (30.0, 704),$
  $(40.0, 792), (50.0, 850), (60.0, 1062), (70.0, 871),$
  $(80.0, 770), (90.0, 1425), (100, 1306)$

$$CR2 = GRAPH(TIME)$$

$(0.00, 61.0), (10.4, 52.0), (20.8, 70.0), (31.2, 96.0),$
  $(41.6, 108), (52.0, 150), (62.4, 188), (72.8, 154),$
  $(83.2, 105), (93.6, 75.0), (104, 75.0)$

where UPS = inventory of unpacked soap; PS = inventory of packed soap; PR1 = production rate of unpacked soap; CR1 = consumption rate of unpacked soap; PR2 = production rate of packed soap; CR2 = consumption rate of packed soap; PD1 = production delay of unpacked soap; PD2 = production delay of packed soap; PORU = production order rate of unpacked soap; and PORP = production order rate of packed soap.

Production Order to the Shop Floor The firm wishes to maintain a certain inventory level, which is between 18,000 and 20,000 MT per month or about 12 days of consumption. The amount ordered to the shop floor for production is sum of average consumption rate (actual amount shipped to the market per unit time) and the gap between the desired and the actual inventory levels.

$$PORU = ACR1 + (GAP1/TAI1) \qquad (5)$$

$$PORP = ACR2 + (GAP2/TAI2) \qquad (6)$$

$$ACR1 = SMTH1(CR1, CAT1)$$

$$ACR2 = SMTH1(CR2, CAT2)$$

$$GAP1 = DINV1 - UPS - (0.9 * BACKLOG) \qquad (7)$$

$$GAP2 = DINV2 - PS - (0.1 * BACKLOG) \qquad (8)$$

where PORU = production order rate of unpacked soap; PORP = production order rate of packed soap; ACR1 = average consumption rate of unpacked soap; ACR2 = average consumption rate of packed soap; GAP1 = gap between the desired and the actual values of inventory in unpacked soap; GAP2 = gap between the desired and the actual values of inventory in packed soap; TAI1 = time to adjust inventory of unpacked soap; and TAI2 = time to adjust inventory of packed soap.

Demand As already mentioned, the actual demand is different from a fixed order rate according to firm assumptions. The demand rate is revised by different multipliers. Product variability influences the equipment changeover rate (ECR) which in turn influences the product price and hence the demand. Similarly, shipment gap is the

difference between the desired shipment and the actual shipment (the latter is sum of CR1 and CR2).

$$\text{Demand} = \text{order\_rate} * \text{shmultiplier} * \text{Demand\_mult} \quad (9)$$

Demand_mult = GRAPH (Price_multiplier)
(0.9, 1.10), (1.00, 1.00), (1.10, 0.8), (1.20, 0.6)

ECT = GRAPH (PrVa)
(0.08, 0.22), (0.09, 0.44), (0.1, 0.44), (0.11, 0.44),
   (0.12, 0.66), (0.13, 0.66), (0.14, 0.66), (0.15, 0.66),
   (0.16, 0.66), (0.17, 0.66), (0.18, 0.66)

Price_multiplier = GRAPH (ECT)
(0.00, 0.9), (0.25, 0.9), (0.5, 1.10), (0.75, 1.20),
   (1.00, 1.20)

shmultiplier = GRAPH(shipment_gap)
(0.00, 1.10), (100, 0.98), (200, 0.95), (300, 0.9),
   (400, 0.85), (500, 0.8)

$$\text{shipment\_gap} = \text{des\_shipment\_rate} - \text{CR1} - \text{CR2} \quad (10)$$

where ECT = equipment changeover time and PrVa = product variability.

Workforce required In soap manufacturing firm, particularly in which the demand is highly unpredictable and volatile, the firm needs to be flexible enough in labor recruitment to cope up with all kinds of situations. Since the numbers of operations-level employees are very higher than those who take part in real production process, it leads to high attrition rate. The reason behind it is that most of the employees work on daily basis wage plan, so hiring and training process is an all-time job for the case firm.

When there is a larger demand, if the firm has adequate equipment availability then it would like to produce the desired amount by inducting more people into the system. New people hired undergo training before being sent to production system.

$$\text{People\_in\_Trg}(t) = \text{People\_in\_Trg}(t - dt) \\ + (\text{Hiring\_rate} - \text{TrComp\_rate}) * dt \quad (11)$$

INIT People_in_Trg = 0

$$\text{Hiring\_rate} = \text{AddPeop\_reqd}/\text{HR\_delay} \quad (12)$$

$$\text{AddPeop\_reqd} = \text{Disc}/\text{productivity} \quad (13)$$

Validation of Model

SD model displays the reality, and we wanted it to be verified with real data. The simulation runs can be conducted for policy experimentations. The SD model developed here is verified in the following mode. First, it was run with the historical data and varying the key parameters. We have considered per month total inventory as one of the key parameters here. The inventory in MT values is equated with the actual data for the case firm. Figure 6 presents the assessment among the simulated and the actual data for the monthly total inventory formed up in firm. Figure 6 indicates an extreme closeness between the actual and the simulated results.

Results and Discussion

SD model described in the earlier section was run, and behavior for one hundred and four weeks was studied. The behavior of key performance of the firm with regard to soap manufacturing such as inventory and order backlog of packed and single-unit soaps, customer order backlog at supplier's end and people in training which is obtained through SD modeling gives sufficient indication about the supply chain flexibility of the firm. The model also helps to generate a variety of flexibility measures. The basic exploration of the model has been indicated in the form of graphs. The packed soap demand is at peak in the summer season and goes down during winter season. In winter season, there is a greater demand for unpacked soap. The demand in summer is high for packed one, because of promotion offers and discount offered by the firm for packed soap. Therefore, the firm tries to manage its inventory level as per the demand in the market.

Figure 7 shows the desired inventory level of packed and unpacked soaps, inventory of soaps in both packed and unpacked categories, the desired and the actual levels of inventory for unpacked soap, and the desired and the actual levels of inventory for packed soap (clockwise).

Figure 8 shows the production gap, shipment gap and product variability. The time when the firm maintains acceptable level of inventory at its warehouse to cater the market requirement shipment gap diminishes. Product variability refers to the frequency with which different products are ordered (and hence produced). It also shows the simulation result of hiring rate and training the people. Firm makes recruitment from time to time that is necessitated by higher capacity requirement and human resource issues such as attrition and superannuation. The trend shows when the hiring rate is high and after a certain fixed time, it increases the number of trained people in the firm. The hiring and the training delay defer the actual induction of productive people. The figure shows that the hiring process is intermittent and reduces gradually as the desired manpower level is attained.

Figure 8 further indicates the average market consumption rate of packed and unpacked soaps. These are the smoothed values of market consumption rate. It has been
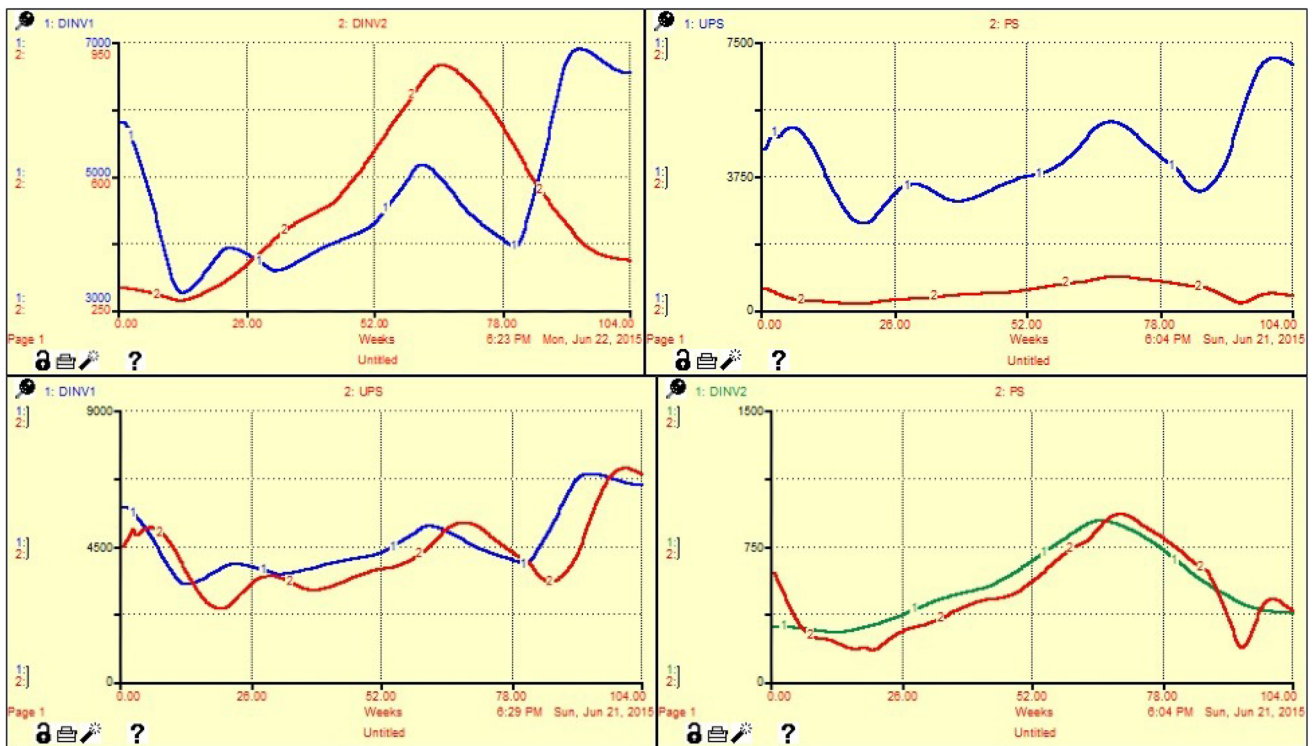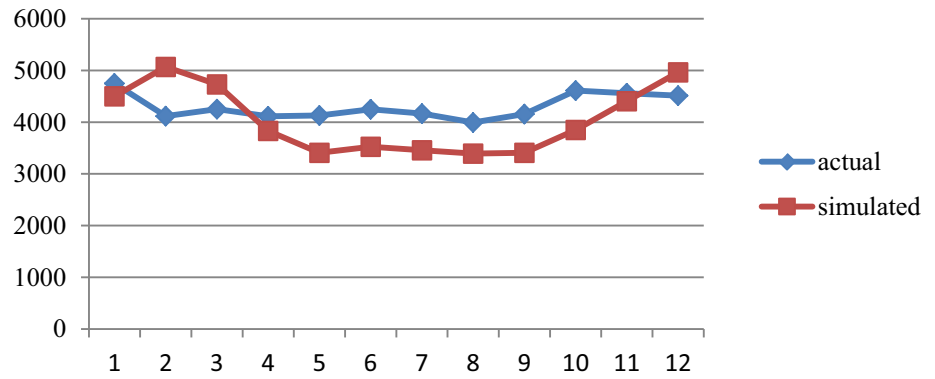
Fig. 6 Inventory (MT)

Fig. 7 Desired inventory level, actual level of inventory in warehouse, desired and actual level of inventory of unpacked soap, desired and actual level of inventory of packed soap (clockwise)

seen that when market consumption of unpacked soap has attained a peak, packed soap demand falls down, and when packed soap market consumption is at its peak, unpacked soap shows downward demand pattern. But more or less, market consumption of unpacked soap is greater than the packed soap. It is because of a larger market base in rural area compared to urban locality, where people generally buy single soap rather than buying a pack of 3 or 4 soaps (as found so often in the organized retail units in urban area). Figure 8 also explains the variation in demand pattern. Demand here refers to the actual demand for soaps. However, the firm is able to dispatch only as per availability in the warehouse. The demand fluctuates throughout

the year. The demand also varies based on the price fluctuations and the delivery delay.

Figure 9 shows the behavior of backlog. As seen here, firm has been able to control the backlog.

Linking Flexibility to Reduce Uncertainty

Flexibilities can be openly associated with uncertainty areas, and the increase in flexibility helps in reducing the uncertainty. This section demonstrates this relationship by identifying the uncertainty areas in different parts of the value chain of soap manufacturing firm. Figure 8 (demand pattern) shows that there is a significant amount of
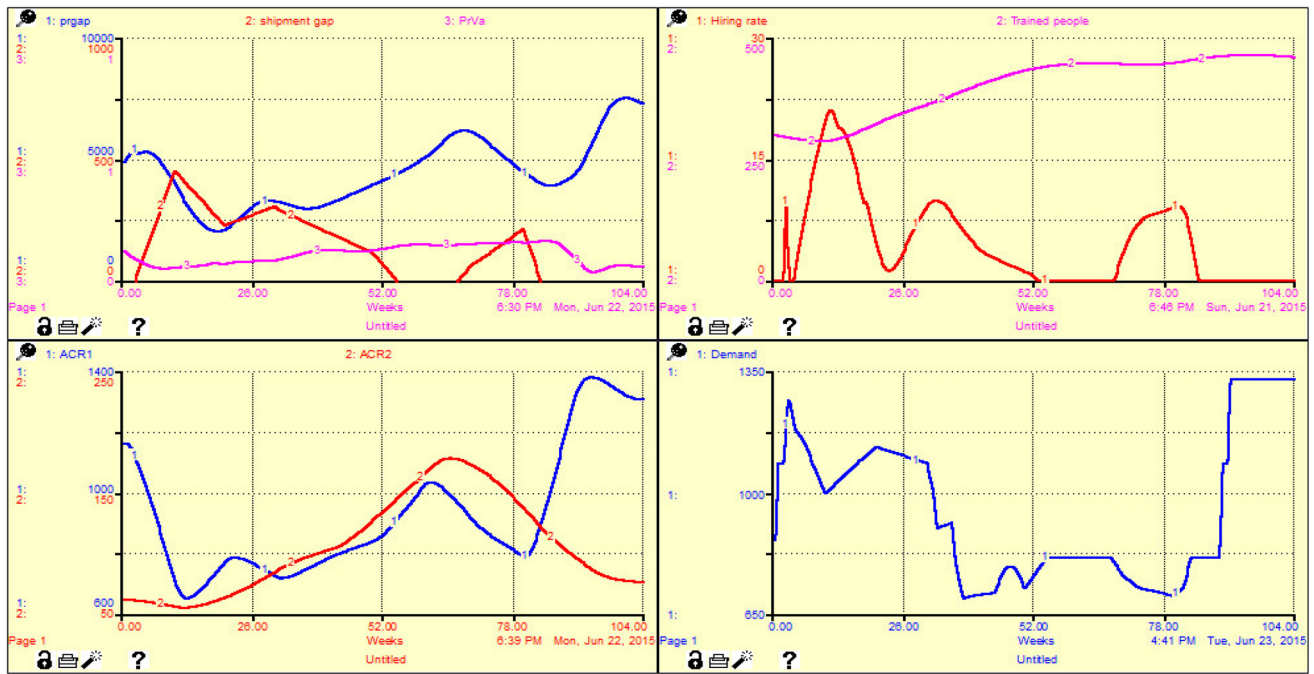
Fig. 8 Product variability and gaps in production and shipment, hiring rate and trained manpower, market consumption rate of unpacked soap (ACR1) and packed soap (ACR2), demand pattern (clockwise)

Fig. 9 Order backlog
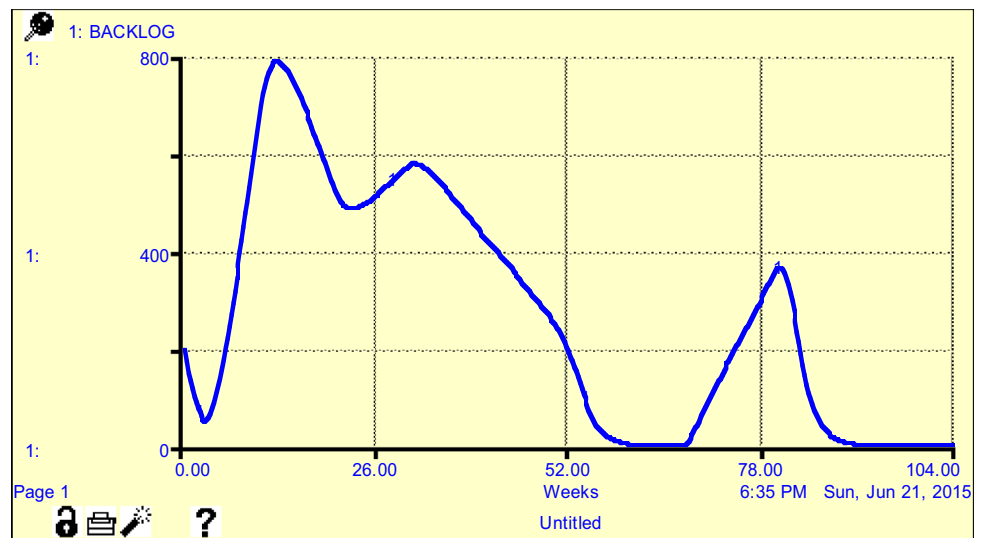
variability that exists in demand pattern and creates uncertainty in customer requirements. Uncertainty causes the variation in inventory levels and other performance parameters. Highly flexible supply chains are considered the latest mechanism for gaining a competitive edge, offering quicker and more cost-efficient response to varying customer requirements (Seebacher and Winkler 2013). A certain variety of the soap of the case firm has a huge rural market base. The product demand in such areas is appreciably influenced by the price fluctuations. It has been observed that a 20% increase in price of the soap in past has

resulted in approximately 40% drop in the existing customer in these regions. A greater demand for soap compared to firm's capacity results in outsourcing of the surplus (access) demand which more often results in delivery delay. Delay becomes more prominent because of greater supplier lead time to the outsourced firm as the raw material are supplied by the same supplier which supplies material to the parent firm. Therefore, this duo role of supplier is critical for the supply chain performance. The supply chain performance can be improved through flexibility indicators which will encounter the present uncertainty. The soap
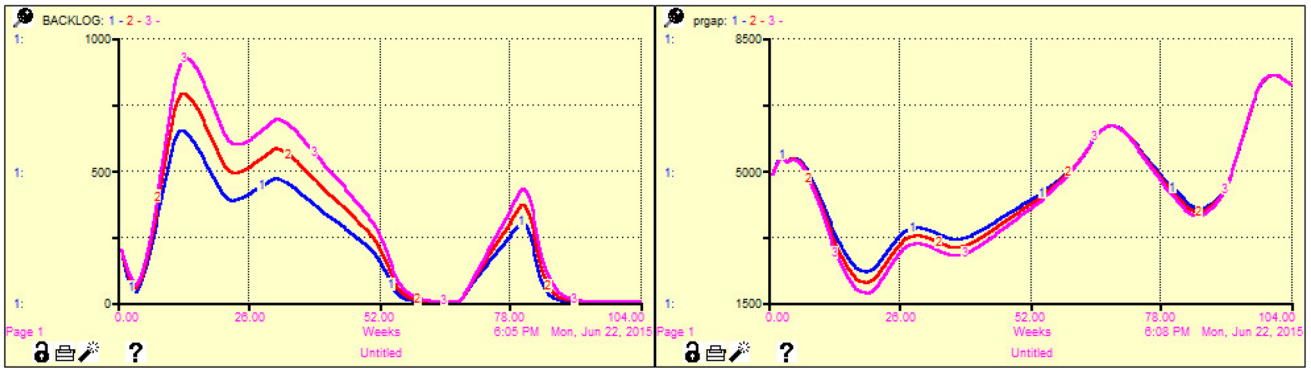
Fig. 10 Order backlog versus production lead time and production gap versus production lead time
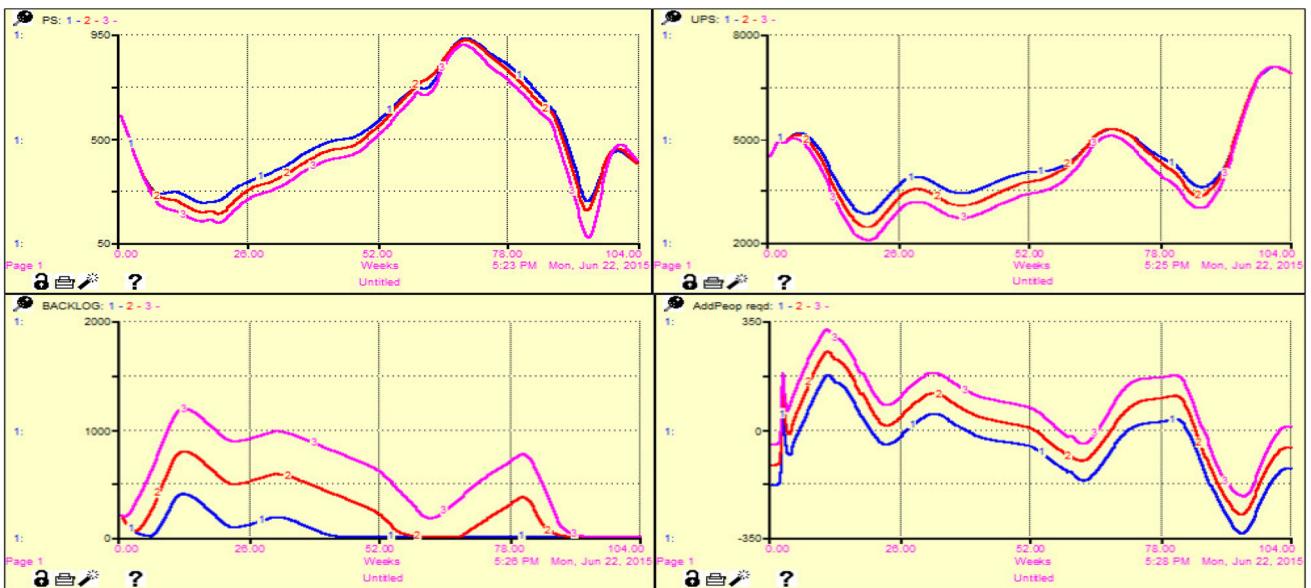

Fig. 11 Inventory variation of packed versus unpacked soap

manufacturing firm in our case does not have the exact information about the requirements and demand from customer. The primary reason behind it may be the overambitiousness of firm as discussed with experts in terms of targeting all market segments. Soap manufacturing firm wants to grab all categories of customers throughout the country, but did not meet requirement of each segment.

Interpretation and Scenario Analysis

The SD model developed assists in generating two scenarios: First is the production lead time effect and second is about the variable order rate effect.

Effect of Varying Production Lead Times

Here we have taken: Pr lead time = 1.6 weeks (1), 2 weeks (2) and 2.4 weeks (3), respectively

As presented in Fig. 10, backlog increases with an increase in production lead time, but the difference reduces with time. As the backlog in general gets tapered off gradually, the firm seems to have better management with minimal variation in response to a varying lead time. A higher inventory cushion sometimes helps in reducing the backlog. Similarly, the variation in production gap also minimizes gradually as shown in figure.

Varying Levels of Order Rate

Effect of Varying Order Rates   Here we have taken: order rate = 900 (1), 1100 (2) and 1300 (3), respectively.

Figure 11 shows the variation in the actual inventory of packed and unpacked soaps, respectively. It is interesting to note that while variation is minimal in early stages for packed soap, it is minimal in later stages for unpacked soap. The inventory levels in both the categories have
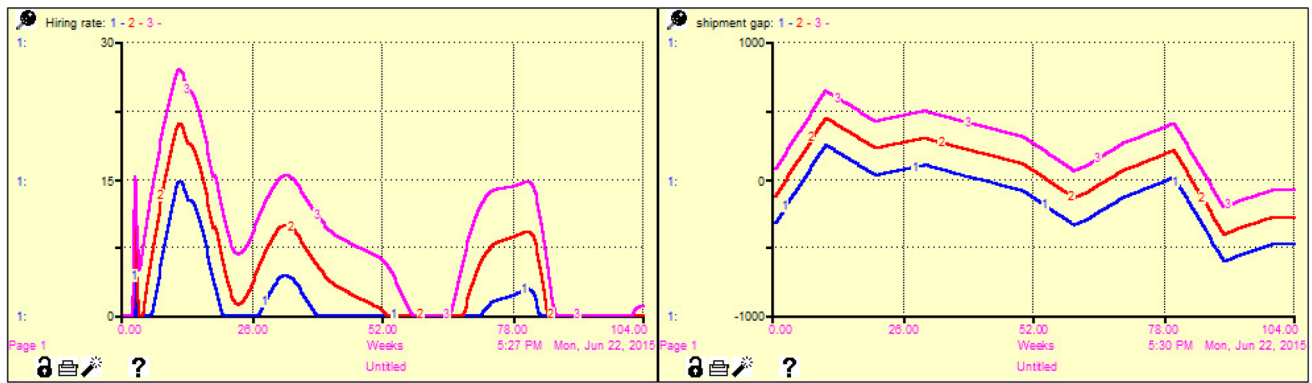
Fig. 12 Hiring rate and shipment gap versus order rate

shown drop with higher order rate. It is also indicated that the variations in backlog with increasing order rate. So while backlog becomes negligible in lower level of ordering, it increases gradually with greater ordering. Similarly, the additional people required become more with greater order rate as shown in figure. This would trigger more hiring to meet the manpower requirement as evident in Fig. 12.

Figure 12 also indicate the packed soap inventory versus order rate, unpacked soap inventory versus order rate, order backlog versus order rate and additional manpower required versus order rate (clockwise).

Figure 12 shows that the shipment gap is increasing with the increased ordering. Shipment gap is the difference between the desired shipment and the actual shipment. With large orders, the desired shipment goes up and the firm finds it difficult to meet the market requirement and would have to resort the measures such as outsourcing to a third party. This would result in delivery delay and the shipment gap and it becomes even more prominent.

Prioritization of Supply Chain Flexibilities

On the basis of data collected from soap manufacturing firm utilizing SD approach of modeling, we prioritized three flexibility dimensions that have significant influence toward supply chain performance (see Fig. 13). The simulation was conducted by aggregating dimensions of flexibility while keeping else constant in the model. The behavior change in the performance of supply chain was noted, and further it has been compared across the flexibility dimensions. Overall results indicate the highest priority for product flexibility.

Market dynamics is causing rapid product changes and increase in the uncertainties that poses problem for product management (McKee and Konell 1993). A firm supplies its manufactured products across the country and globe in different regions, where customer requirements are entirely different from each other. This complexity triggers the case

firm to have variety and wide range of products to satisfy the consumers across the regions. With the growing customer demand for product, a variety of products have led manufacturing firms to introduce a wide range of products by accommodating flexibility (Asadi et al. 2017). Following the product flexibility, demand management stood second in the priority. Physical distribution flexibility received the least priority. Firms may have to adapt different distribution strategies to cater demand of huge consumer base. Given different circumstances, firms might choose an appropriate distribution flexibility strategy that fits in their distribution environment requirements (Yu et al. 2012). Most detrimental dimensions in the soap supply chain context also have been identified. These dimensions can significantly flatten the supply chain performance. Meanwhile, these interpretations are being derived from the know-how of a single firm; it may not be considered for generalization through the production for other firms.

Concluding Remarks

Soap supply chain is a complicated process and has a high amount of uncertainty. This leads to a pressing requisite of evolving supply chain scenarios where uncertainty can be coped up and supply chain performance can be enhanced in multiple ways. The soap manufacturing firm encounters a significant amount of variability in its demand, mostly triggered by seasonal variation of whether conditions and supply infrastructure. To make this point clear, there is a greater demand for soap in summer season in comparison with winter season. To cope up with these variations, appropriate usage of resources is required. Appropriate use of capacity is the crucial to avoid idle time in any supply chain and bring appropriate flexibility (Mendoza et al. 2014) and to cater the ever changing demand of consumers. There are different types of products that need different setup changes. These changes can be in terms of either size,

Fig. 13 Prioritization of flexibilities
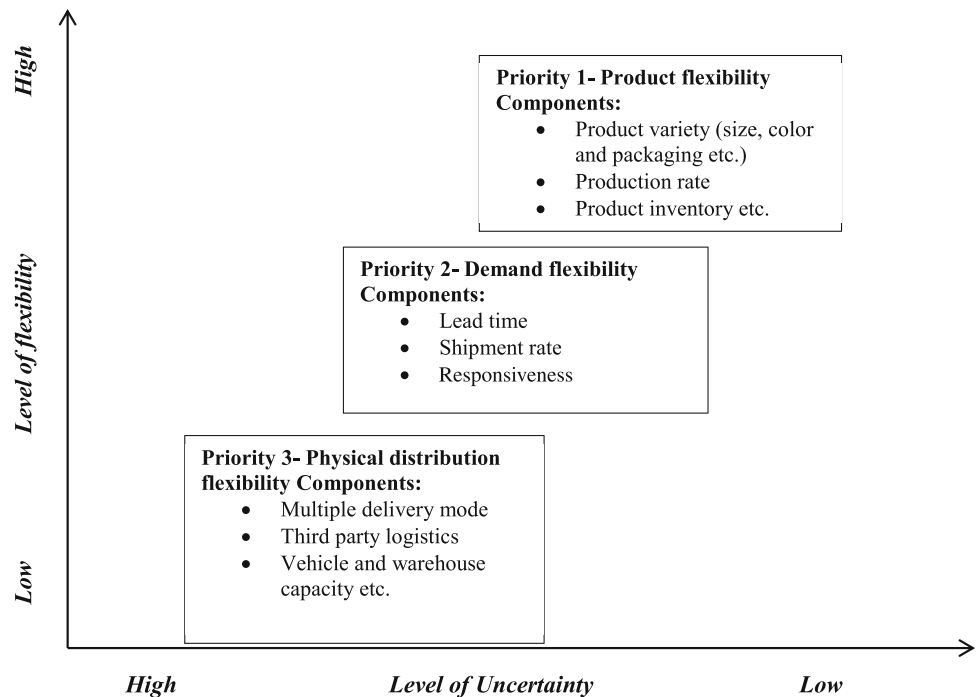
color or flavor. There are also packaging-related product variations. A three in one or four in one pack becomes more attractive in comparison with single-unit soap particularly in summer season where there is a greater demand of soap in general. Moreover, such packed soaps become more eye-catching because of the cost savings due to promotions offered. The product variations explained so far either in terms of size, color, flavor and packaging requires equipment changeover for a new batch of production. The time spent due to equipment changeover increases the production lead time and reduces the shipment rate that adversely influences the demand. Lengthy lead time increases the bullwhip effect due to the fact that the longer the lead time, the higher the safety stock needed for replenishment and the greater the variations (Poornikoo and Qureshi 2019). We have made an attempt to propose the assessment framework for flexible supply chain to the case firm so as to reduce and address the uncertainty and improve the operating performance. To start flexible supply chain execution, the first task was to classify the areas of uncertainty that exist in soap supply chain process and dimensions. The present study deals with the recognition and identification of supply chain flexibility dimensions that have significant amount of impact on its performance. An exclusive approach of SD model is deployed for mimicking the soap supply chain course and to examine and evaluate the supply chain performance. This framework serves as both operational and strategic tools for flexibility assessment to businesses.

Supply chain flexibility dimensions that have substantial impact on influencing supply chain were recognized and ranked. Four research questions were posed and had delineated the clear intentions of the study. The author(s) carried out an extensive literature survey on existing approaches and way to deliberate the supply chain flexibility and its impact on firm's performance. Through literature review, the author(s) concluded that hardly any prevailing studies have made an effort to comprehend the concept of supply chain flexibility in soap manufacturing industry; especially in Indian context. Hence, the author(s) tried to tackle this gap through the longitudinal study in an Indian soap manufacturing firm. With considerable plant visits and interviews, the author(s) generated the data on various supply chain flexibility indicators in soap manufacturing such as production lead time, backlog, demand variability, warehouse inventory, and goods shipment rate. These are influenced by a variety of factors such as factory production rate, equipment changeover time, backlog adjustment rate, hiring rate, and manpower productivity. The vibrant dealings of these factors can be effectively captured by SD modeling. This answers the first research question. The author(s) have mined different dimensions of flexibility through extensive review and interaction executives from the firm under consideration. After interaction and interview, only those dimensions that have significant impact on soap supply chain of the case firm are used in the study.

Once the sufficient data were collected, the approach of SD modeling was utilized to understand the grounded

relationship among various indicators. A detailed SD model analysis helped in understanding degree of supply chain flexibility of the case firm. Also SD analysis helped in determining areas of improvement, as the study revealed that the firm is performing poorly in managing shipment and inventory. This helps in answering the second research question posed in "Introduction" section. The degree of impact was considered as basis to prioritize the dimensions of flexibility and helped us to answer the third research question. At last, a comprehensive scenario analysis was conducted through varying order rates and production lead times to answer the fourth research question.

Implications

The present study utilized SD model approach due to its property of staying closer to reality in supply chain setting. Distinct phases for graphic and uniformity examination of supply chain processes for recognition and refinement of uncertainty, order backlog, inventory of both packed and unpacked soaps, production gap, manpower required, and hiring rate factors are considered in the model.

The primary conditions for the model are set up by the initial data composed through field study. Most of the parameters are expressed in metric tonnes. This demanding and actuality grounded modeling of the soap supply chain process helped in scheming a SD model that has structurally validity. Therefore, the author(s) consider that the practical implications accomplished from the effects of study are astute and genuine. The suggested supply chain flexibility estimation methodology on the basis of SD modeling is an extremely advantageous tool for the senior management and executives for forecasting the longitudinal scenarios and takes preemptive remedial actions with data to keep the state of affairs in compliance. For illustration, the developed model anticipated that there is always a significant gap in the desired and the actual levels of inventory; also, a significant amount of shipment gap and order backlog exists that costs a huge revenue loss for the firm. Such comprehensions can specify and assist executives in optimally leveling their means and assets for accomplishing wide-ranging commercial targets (Mato-poulos et al. 2015; Teece 2018; Mosca et al. 2019). Therefore, the author(s) rely that established framework in the present study can assist as an outline for creating and developing long-term policies to persist practical and profitable dimensions. The suggested evaluation model also includes the interrelationships between supply chain flexibility dimensions and the total flexibility level. Scenario analysis helped in finding out that inventory levels of soap, order backlog, production, and shipment gap are the major determinants of supply chain flexibility and played an important role in improving overall flexibility and

supply chain performance. Further, it helped the firm's supply chain in two ways. Firstly, scenario analysis on the production lead time clearly indicates that backlog increases with an increase in production lead time and backlog becomes negligible in lower level of ordering; it increases gradually with high ordering. Secondly, increasing order rate reduces the inventory. Also it is important to note that while variation in inventory levels is minimal in early stages for packed soap, it is minimal in later stages for unpacked soap. The study also reveals that the firm is not able to meet the shipment requirement as shipment gap increases with an increase in order rate. By adapting an adequate degree of flexibility, management can improve the supply chain performance.

Limitations and Scope for Future Research

The present study has few limitations. The study was conducted at a specific firm in personal care industry, and the model may not be generalized to other industries. The future studies can adopt an empirical approach to take a broad view of flexibility indicators for the industry as a whole. The present study offers one way mechanism to analyze the impact different dimensions of flexible supply chain. The upcoming studies may consider the different supply chain scenarios. The future study could also include the second- and third-tier suppliers along with distributor and retailer for the complete assessment of the supply chain. One can also include the indicators of sustainable supply chain management in the future study to assess the flexibility of supply chain (Ortas et al. 2014; Beske-Janssen et al. 2015; Sauer and Seuring 2017; Das 2018). The future author(s) can generalize the implications found in the present study by considering flexibilities such as delivery, supplier–supplier coordination, material handling, and transshipment. Service supply chains can be considered for the study in future with reference to the model established in the present study to check the role of different flexibility dimensions such as service promise time, underutilization of resources, and number of transactions took place to complete the service.

Compliance with Ethical Standards

Conflict of interest The authors hereby declare that there are no potential conflicts of interest in terms of authorship, research and/or publication of this article.

Appendix

See Table 1.

Table 1 Literature review on relationship between supply chain flexibility and firm performance

S. No.	References	Research intentions	Unit of analysis	Tool of analysis	Approach adopted	Setting	Major findings
1	Dubey et al. (2018)	To study how and when firm requires big data analytics capability to enhance supply chain capability and get competitive benefit	Firm	Partial least square structural equation modeling	Survey	Auto component firms from India	Big data analytics capability has an encouraging and major impact on supply chain agility. Further firm's flexibility has a positive moderation impact on big data analytics and supply chain agility
2	Ivanov et al. (2018)	To identify the major flexibility drivers in manufacturing, supply chain and service operations	Supply chain	Meta-analysis	Literate review	–	After a careful review, four major flexibility drivers are identified as: digital and smart operations; disruption risks, ripple effect on supply chain; behavioral flexibility and supplier integration; and sustainable and closed-loop supply chains
3	Song et al. (2018)	Supply chain operations design for emergency operations. Minimize the lateness when delivering the critical products to the survivors. Prediction of customer demand in disaster-like situations	Supply chain	Structural equation modeling	Survey	Manufacturing firms from China	Optimum model for production and distribution is developed. A policy for inventory replenishment for manufacturers and distribution centers is designed which helps in minimizing the total tardiness. When demand increases, a supply chain flexibility approach can be adopted to manage uncertainty
4	Sreedevi and Saranga (2017)	The identification of antecedents supplies chain operation risk encountered by organizations. To study the conditions under which these risks can be diminished. To recognize the contribution of supply risk, delivery risk and manufacturing process risk in overall supply chain risk	Individual Plant	Structural equation modeling	Survey	Manufacturing companies from India	Uncertainty in the value chain point toward great supply chain risk. Supply and manufacturing flexibility help firms to cope with supply and manufacturing risks in uncertain environments, respectively. In emerging market, the internal capabilities of the firm may not be sufficient in reducing the supply chain delivery risk

Table 1 continued

S. No.	References	Research intentions	Unit of analysis	Tool of analysis	Approach adopted	Setting	Major findings
5	Um (2017)	Investigate how variety management activities containing variety management strategy, close customer relationship and supplier partnerships impact the supply chain flexibility and swiftness at various stages of customization	Firm	Structural equation modeling and cluster analysis	Survey	Manufacturing firms from the UK and South Korea	Internal variety management strategy and external supply chain integration have optimistic effect on supply chain flexibility and agility. Variety management strategies and customer relationships impact supply chain flexibility more than supplier partnerships, whereas strategies in variety management and supplier partnerships have more influence on agility than customer relationships
6	Obayi et al. (2017)	Aims to develop and validate measurement model for testing the mediating role of relational capabilities (absorptive capacity, firm's interoperability and trans active memory systems) on supply chain flexibility (configuration flexibility and planning and control flexibility) and performance of retail firm	Firm	Structural equation modeling	Survey	Retail stores in the UK	All three relational capabilities mediated partially positive influence on planning and control flexibility and configuration flexibility in niche and middle-level retailers. The flexibility has a positive interaction impact on firm's interoperability and trans active memory systems as compared to absorptive capacity
7	Singh et al. (2017)	To recognize the attributes and develop main attributes appropriate for supply chain flexibility	Supply chain	Interpretive structural modeling	Interview	Factors adopted from previous studies in manufacturing and service industries	Top management pledge is a main driver for cultivating the strategies which helps in improving the flexibility in supply chain. Supplier development and capability of logistic management help in the improvement of supplier's flexibility of distribution and manufacturing
8	Han et al. (2017)	To theorize a research model that integrates varied processes for supply chain management. The identification of factors where IT flexibility influences firm performance in supply chain context	Firm	Partial least square structural equation modeling	Survey	Manufacturing and retail firms from the UK	Transactional IT flexibility influences operational IT flexibility, whereas strategic IT flexibility is impacted by operational IT flexibility. Operational and transactional flexibilities affect organizational performance indirectly

Table 1 continued

S. No.	References	Research intentions	Unit of analysis	Tool of analysis	Approach adopted	Setting	Major findings
9	Asad et al. (2016)	Identification and prioritization of IT-based supply chain flexibilities. Measurement of IT-based supply chain flexibility dimensions	Supply chain	Gray-based DEMATEL	Interview	Expert and academician opinion	Sourcing and information technology integration are the causal factors, whereas distribution flexibility and operating system flexibility are effect factors. Sourcing flexibility has major impact on supply chain flexibility. Use of ERP in supply chain activities, capability to hand over the delivery schedules, capacity to change yield volumes along with proficiency to change supply time of vendor's order are major contributors in flexibility of supply chain
10	Luo and Yu (2016)	To equate the two types of fits (high–high fit vs low–low fit) and two type of misfits (underfit vs overfit) between supply chain flexibility and environmental uncertainty	Firm	Regression	Survey	Manufacturing firms form China	For similar degree of misfit, underfit fades performance other than overfit. Highly uncertain environment requires high flexibility in supply chain and results in higher performance (high–high fit) in comparison with low uncertainty in environment requires lower-flexibility supply chain
11	Manders et al. (2016)	To decode the pattern of supply chain flexibility experience by supply chain members. To understand the reasons being flexible. Prioritization of supply chain flexibility dimensions for the sustainability of the firms. To identify which flexibility dimensions are important for different members in supply chain	Supply chain	Coding and Identifying the Pattern	Case study	Dutch manufacturing companies in FMCG-food supply chain	Volume flexibility is most important being flexible. Certain dimensions are prioritized by different members depending upon the time frame for which aims are expressed. Prioritization of flexibilities depends on three time horizons: (1) short-term or daily operations, (2) medium-term or weekly/fortnightly targets and (3) long-term or yearly targets
12	Rojo et al. (2016)	To examine whether supply chain ambidexterity increases supply chain flexibility and its impact of supply chain competence and firm performance	Firm	Structural equation modeling	Survey	Manufacturing firms from Spain	Supply chain ambidexterity supports to attain the best level of supply chain flexibility and supply chain management is required to organizational performance

Table 1 continued

S. No.	References	Research intentions	Unit of analysis	Tool of analysis	Approach adopted	Setting	Major findings
13	Fayezi and Zomorrodi (2015)	Decoding the perception of role of relationship in the development of supply chain flexibility and agility. The relationship integration with partners. The identification of importance of relationship integration for supply chain flexibility and agility	Firm	Cross-interview analysis	Interview	Practitioners and operations professional from Australian manufacturing firms	Supply chain flexibility and agility can be developed by allocating resources to relationship-intensive actions and reserves. Relationship integration is instrumental in strategic planning to develop flexible and agile supply chain among their Australian partners
14	Seebacher and Winkler (2015)	Practical and appropriate secondary metrics to assess a supply chain's flexibility. Modifying process capability analysis to an appropriate evaluation of supply chain flexibility in practice. Application of methodology to have flexibility in whole supply chain	Supply chain	Bivariate unilateral process performance and capability analysis	Mathematical modeling	Three supply chain configurations	Supply chain flexibility defines the ability of a supply chain to meet its delivery dates and cost of operations in varying circumstances. Supply chains should be able to respond to changes without any loss in terms of time and cost. If the supply chain shows the low capability value, one needs to analyze the value adding activities and sub processes. A flexible supply will require endless or periodical data feed for flexibility assessment

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Key Questions

1. What is the role of flexible supply chain indicators in dynamic environment?
2. Is there any pattern of flexibilities that influence supply chain?
3. How do the regular operations of a company affect the performance of flexible supply chain?

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