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Responsive supply chain: A competitive strategy in a networked economy☆

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Abstract

Supply chain management (SCM) has been considered as the most popular operations strategy for improving organizational competitiveness in the twenty-first century. In the early 1990s, agile manufacturing (AM) gained momentum and received due attention from both researchers and practitioners. In the mid-1990s, SCM began to attract interest. Both AM and SCM appear to differ in philosophical emphasis, but each complements the other in objectives for improving organizational competitiveness. For example, AM relies more on strategic alliances/partnerships (virtual enterprise environment) to achieve speed and flexibility. But the issues of cost and the integration of suppliers and customers have not been given due consideration in AM. By contrast, cost is given a great deal of attention in SCM, which focuses on the integration of suppliers and customers to achieve an integrated value chain with the help of information technologies and systems. Considering the significance of both AM and SCM for firms to improve their performance, an attempt has been made in this paper to analyze both AM and SCM with the objective of developing a framework for responsive supply chain (RSC). We compare their characteristics and objectives, review the selected literature, and analyze some case experiences on AM and SCM, and develop an integrated framework for a RSC. The proposed framework can be employed as a competitive strategy in a networked economy in which customized products/services are produced with virtual organizations and exchanged using e-commerce.
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1. Introduction

Companies are undergoing a revolution in terms of implementing new operations strategies and technologies in response to the challenges and demands of the twenty-first century. Businesses in the twenty-first century have to overcome the challenges of satisfying the demand of customers for products of a high quality, but low price. To this end, firms need to be responsive to customers' unique and rapidly changing needs. Companies are now seriously exploring the potential of the concept of supply chain management (SCM) to improve their revenue growth. In particular, they are attempting to develop agile supply chains to get their product to market faster at a minimum total cost. Effective SCM is an essential strategy for success in the global and e-markets. SCM incorporates the entire

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exchange of information and movement of goods between suppliers and end customers, including manufacturers, distributors, retailers, and any other enterprises within the extended supply chain. The responsive supply chain (RSC) addresses new ways of running companies to meet these challenges. RSC represents a global industrial paradigm for manufacturing in the twenty-first century. In a changing and competitive environment, there is a need to develop in a cost effective solutions to organizations and facilities that are highly flexible and responsive to changing market/customer requirements. The objective here is to describe a framework for building a supply chain that is flexible and responsive.

Youssef, Burgess, and Gunasekaran [1–5] have concurred about the need for manufacturers to be flexible and to cater to changing market conditions through "agile manufacturing." Youssef [1] described agile manufacturing as, " A Manufacturing system with extraordinary capability to meet the rapidly changing needs of the marketplace. A System that can shift rapidly amongst product models or between product lines, ideally in real-time response to customer demands." AM requires firms to adapt to the strategic requirements of the supply chain. Strategic agility planning requires a strong partnership between suppliers and customers, and information systems for effective supply chain management [6]. Agile supply chain requires the capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services [3,7].

Agile manufacturing is a natural development from the original concept of "*lean manufacturing*." In lean manufacturing, the emphasis is on the elimination of waste, where the philosophical emphasis is similar to that of SCM. The requirement for organizations and facilities to become more flexible and responsive to customers led to the concept of "agile" manufacturing as differentiated from the "lean" organization. This requirement for manufacturing to be able to respond to unique demands moves the balance back to the situation prior to the introduction of lean production, where manufacturing had to respond to whatever pressures were imposed upon it, at the risk of compromising on cost, speed, and quality. Therefore, agility should not only be based on responsiveness and flexibility, but also on the cost and quality of goods and services. This requires the integration of AM and SCM to develop a RSC with the objective of achieving agility in a supply chain environment.

Gunasekaran and Yusuf [8] have defined Agility in manufacturing as, " The capability of an organization, by proactively establishing a virtual manufacturing with an efficient product development system to (i) meet the changing market requirements, (ii) maximize customer service level, and (iii) minimize the cost of goods, with an objective of being competitive in a global market and for increased chance of long-term survival and profit potential. This must be supported by flexible people, processes and technologies".

Considering the implications of AM and SCM, it is essential to develop a strategy that combines the positive features of both of them. This strategy could be called "the responsive supply chain (RSC)." The main objective of this paper is to define what RSC is, and then develop a framework for a RSC based on the review of strategies, methods, and techniques of AM and SCM. For this purpose, the literature available on AM and SCM has been reviewed with the view of identifying the major factors for developing a RSC.

The organization of the paper is as follows: Section 1 presents the introduction to the research subject and its scope and relevance. The concepts and definitions of RSC are presented in Section 2. Section 3 reviews selected literature available on AM and SCM. Some case examples on RSC are presented in Section 4. In Section 5, a framework is offered for developing an RSC. Section 6 concludes the paper.

2. Definition of responsive supply chain (RSC)

Agility is interpreted as using market knowledge and a virtual corporation to exploit profitable opportunities in a volatile market place. This requires the slashing of process lead times and costs throughout the chain. It is not simply enough to enable agility; similar steps must also be taken to reduce information lead times and costs, resulting in the concept of the "information enriched" competitive and responsive supply chain [9]. The five necessary basic functional activities in a value stream include: (1) procurement (maximum purchasing discounts), (2) inbound logistics (low transportation costs), (3) operations (low production costs), (4) marketing and sales (wide product range/high availability), and (5) outbound logistics (low transportation costs).

SCM is defined as the coordination of resources and the optimization of activities across the value chain to obtain competitive advantages. SCM facilitates organizational coordination required in an agile/virtual enterprise. These include: (i) the development of an interconnected information network involving a selected group of trained suppliers, (ii) a successful balance

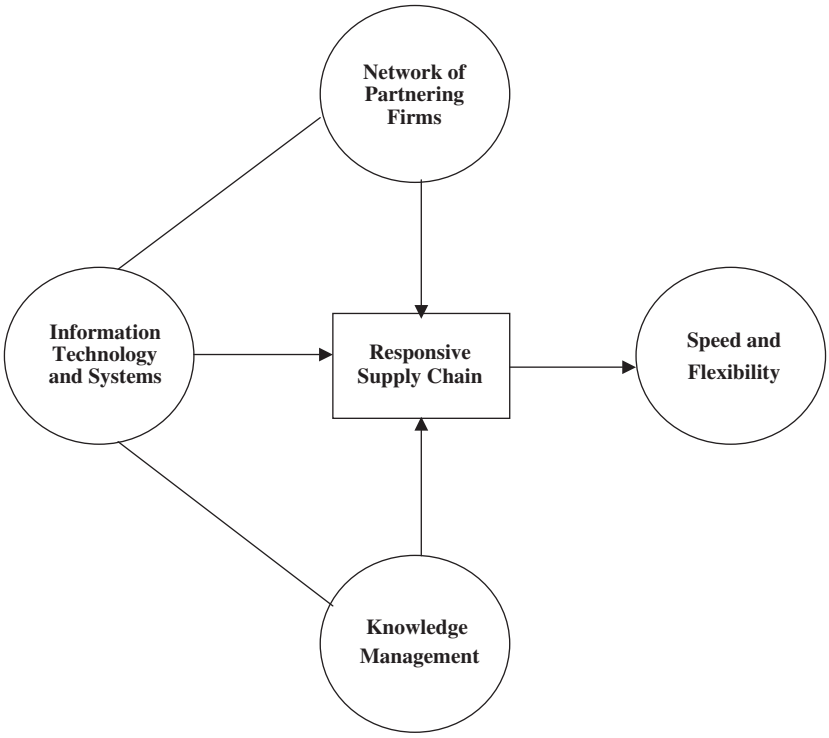

Fig. 1. Responsive supply chain (RSC).

between a low level of stocks with high-quality delivery service, (iii) the designing of innovative products with the active collaboration of suppliers, and (iv) cost-effective delivery of the right products to the right customer at the right time [10,11]. As discussed earlier, AM only focuses on speed and flexibility and not on cost. Therefore, an effective supply chain is required to achieve all of these competitive performance objectives.

An RSC can be defined as, "A network of firms that is capable of creating wealth to its stakeholders in a competitive environment by reacting quickly and cost effectively to changing market requirements." There is a need to meet the changing market requirements by developing a suitable network of collaborative firms based on the core-competencies and on leveraging people and information as quickly as possible and in the most cost-effective manner.

The concept or definition of RSC is illustrated in Fig. 1. There are three major enablers of RSC, namely, value chain or a collaborative network of partners, Information Technology (IT) and systems, and knowledge management. The interaction between these will lead to a supply chain that is responsive and flexible. A supply chain is the basic component of an RSC, wherein suppliers play a major role in performing value-adding activities. Since a supply chain is primarily developed for lean production with the aim of achieving reductions in cost by eliminating non-value adding activities, it lacks speed and flexibility. Hence, there is a need to devise strategies, methods, and technologies for improving the speed and flexibility of the supply chain. The objective of this paper is to address this issue of RSC.

Considering the overall characteristics of the strategies and technologies of AM and SCM, the enablers of RSC can be identified as (i) strategic planning, (ii) virtual enterprise, and (iii) knowledge and IT management. An RSC system requires a level of compatibility and interactivity that will allow the company to cope with the changes and increasingly complex settings of organizations and markets, particularly in a networked economy.

3. Review of selected literature on SCM and AM

In this section, selected works on agile manufacturing and SCM are reviewed. Having reviewed the literature on AM and SCM [3–5], the three factors have been identified as the major components of developing a RSC. Hence, this review is based on three major determinants of an RSC: (i) strategic planning, (ii) virtual enterprise,

Table 1
Review of selected literature on RSC and AM

Classification criteria	References	RSC/AM-strategies, techniques, and technologies
Strategic planning	[3–5,12–30] Pellew (1996), Kusiak and He (1997), Yusuf (1999)	Multidisciplinary teams, network of partnering firms, IT and KM systems, self-directed teams, top management support, logistics chain, collaborative relationship with suppliers, flexible software for agility, development of contract manufacturers, concurrent engineering, enterprise information systems, customer–supplier relationship strategies, postponement strategy, distributed enterprise, employee empowerment, TRIZ, TOC, BTO-SCM
Virtual enterprise/organization	[3–5,31–41]	Network of suppliers, core competencies, strategic alliances, education and training, communication, IT such as ERP, communication for global supply chain, managing processes, partnership development, streamlined logistics network, empowered teams, legal protection, virtual logistics, virtual manufacturing, computer and communication technologies, organizational structure and relationship
Knowledge and Information Technology management	[13,31,42–51] Wilding (1998)	Intelligent sensing and decision-making systems, CAD/CAM, MRPII, EDI, internet, WWW, e-commerce, RFID, data management framework, ECR, human resource management, IT/IS on reverse logistics, choice of IT/IS, CRM and ERP, AGVS, and Robots

and (iii) knowledge and IT management. The objective of this review is to determine suitable strategies, methods, and technologies that will enable the development of a responsive supply chain. Achieving agility may require focusing on strategic planning, virtual enterprise and knowledge, and IT management. A summary of the strategies, techniques, and technologies for SCM and AM are presented in Table 1 based on a review of selected literature.

3.1. Strategic planning

Strategic planning for improved performance is gaining attention in all areas of an organization. The reason for this is that such a strategy takes into account the long-term interests of a company in determining suitable business and operational policies. Agility in manufacturing can be achieved through customer-integrated multidisciplinary teams, supply chain partners, a network of collaborative enterprises/partners, and knowledge and information systems [12].

Achieving agility in a supply chain requires radical changes in line with a productive reengineering business process. This level of change in any organization demands the total support of top management in terms of providing the necessary technical and financial support together with employee empowerment. As part of multidisciplinary empowered and self-directed teams, a human factors' practitioner can be asked to assume leadership of the communications team with the task of developing an information infrastructure to support a product development project structure and the facilitation of information flow in a large, geographically dispersed, project team. This responsibility should reflect recognition of the importance of human interactions in an information-driven product development process [13]. Also, the involvement of top management is vital to the effective re-engineering of the supply chain and logistics processes. Williams et al. [14] studied the impact of an electronic supply chain on the current and future structure of strategic alliances, partnerships, and logistics leadership.

The adoption of time-based competitive strategies also recognizes the long-term advantages that can be derived from supplier integration. This collaborative relationship is from supplier integration and is a means of achieving the advantages of vertical integration without owning the means of production and facing the inherent risks of advances in technology or changes in the law. The sub-contracting of manufacturing technologies that are not considered to be areas of core competence increases the motivation to gain efficiencies from external resources [15,30].

AM has different requirements/conditions for a workforce as compared to those of traditional systems. These requirements/conditions include: (i) closer interdependence among activities, (ii) different skill requirements, usually higher than average levels of skill, (iii) where

any malfunction will lead more immediate and costly consequences than in a traditional system, (iv) where the output is more sensitive to variations in human skill, knowledge and attitudes, and mental effort rather than physical effort, (v) where there is continual change and development, and (vi) a higher capital investment per employee, which favors employees responsible for a particular product, part, or process. These, to some extent, define the characteristics of an agile workforce. These characteristics also include: workers skilled in IT, knowledge in team working and negotiation, advanced manufacturing strategies and technologies, empowered employees, a multifunctional workforce, a multilingual workforce, and self-directed teams [13,31].

In order to reduce time to market, concurrent engineering (CE) principles can be employed in the product development process in AM. Noonan and Wallace [16] discussed the design and verification issues of an optimal response development system for contract manufacturers through value-focused strategies with the help of an industrial survey conducted in Ireland. The response system has four layers starting from the top, including a signals card (external developments, customer profile, competitor profile, and complementor profile), a manufacturing card (operation profile, industry-specific profile), an actor card (people profile), and a response and timing card (response profile).

Holweg and Miemczyk [19,20] discussed the implications of inbound, outbound, and sea transportation logistics, leading to the development of a strategic framework for future automotive logistics operations based on a 3 daycar (the order-to-delivery cycle is 3 days for a car) research program (a three-year study of the UK automotive supply chain). Ritchie and Brindley [21] evaluated the management of a global supply chain in terms of three levels of economic activity: (a) a strategic global and national competitive environment, (b) industry structures and supply chains, and (c) business level strategies, processes, and skills.

Organizational culture has a significant influence on the management of a global supply chain for improved flexibility and responsiveness. McAfee et al. [47] discussed the effects of culture and human resource management policies on SCM strategies. The culture is defined by various human resource policy areas such as the staffing, training, compensation, and evaluation of employees [47]. Companies need tools to measure both ongoing business processes and to evaluate strategies across their supply chains. A supply chain information system can be used to connect all tiers of a supply chain network. Regardless of the organizations' size, location, or IT operating environment, people within the networked supply chain can collaborate simply and quickly. A Web-based system will help a manufacturer establish closer ties with customers.

Gunasekaran [3–5] and Youssef (1999) highlighted the role of employee empowerment in improving cooperative supported work in a physically distributed virtual enterprise (VE). Frayret et al. [22] proposed a strategic framework for designing and operating agile networked manufacturing systems. This framework allows for the collaborative planning, controlling, and managing of day-to-day operations and contingencies in a dynamic environment. Stratton and Warburton [23] explored the role of inventory and capacity in accommodating variations in demand uncertainty and variety, and identified how the right solution at the right time (TRIZ) separation principles and theory of constraints (TOC) tools may be combined in the integrated development of responsive and efficient supply chains. Waller [24] discussed the profile of market responsive manufacturing for automotive supply chains. He argued that an automotive build-to-order supply chain must be able to meet seasonality within markets, and understand the detailed demand volatility for certain elements of a complex product-mix, from which much of an automotive company's profitability is derived. The combination of late capacity setting and revenue management can enable the whole extended enterprise to operate as a single entity. Wisner [25] highlighted the importance of the relationship between the customer relationship strategy and supply chain strategy, and the implications of inbound and outbound logistics using structural modeling with the objective of enhancing the flexibility and responsiveness of supply chains. Chiou et al. [26] investigated the adoption of a form postponement strategy in a global logistics system in the IT industry in Taiwan, and discussed the concepts of postponement; the influence of product and demand characteristics, and types of form postponement.

Both postponement and the decoupling of information have been considered relevant initiatives in making the agile supply chain a reality. Postponement centers around delaying activities in the supply chain until customer orders are received, rather than performing them in anticipation of future customer orders, and performing them with a focus on customization as well as cost efficiency. The elements of a supply chain include: customer sensitive, vertical integration, process integration, and network integration [27]. Hoffman and Mehra [28] discussed efficient consumer response (ECR) as a supply chain strategy in grocery businesses by analyzing

the adoption of an ECR strategy by five major grocery operations in US markets.

For example, Sheu [52] presented a multilayer demand-responsive logistics control strategy for alleviating the bullwhip effect of a supply chain effectively and efficiently. The proposed method estimates the time-varying demand-oriented states of the logistics system, which originate directly and indirectly downstream from the targeted members of a supply chain, and associates these estimated demands with estimates of different time-varying weights under the goal of systematically optimizing the logistics performance of members of the chain [29].

The articles reviewed under strategic planning for AM and SCM deal with issues such as VE and strategic alliances (partnership formation) based on core-competencies, responsive logistics, rapid product design, and knowledge and IT. The major issues in developing AM are how the resources can be reconfigured/reused to meet the challenges of market dynamism, technological advancements, infrastructure, government policies, and legislation. In AM, strategies can be formulated based on a top-down approach, but they can be implemented using a bottom-up approach. Therefore, the determination of issues such as market types, strategic alliances, and capital investment decisions should rely on the top management, while their implementation should rest on functional-level managers and employees [3–5].

3.2. Virtual enterprise/organization (VE/VO)

The virtual manufacturing/enterprise (VM/VE) has been considered an important enabler of agility in a supply chain environment. A VE is different from VM. A VE is based on developing partnerships based on core competencies for achieving agility in a supply chain environment. VM is the use of IT and computer simulation to model real world manufacturing processes for the purpose of analyzing and understanding them. Globalization has opened up more markets to manufacturers and generated a great deal of pressure on them to provide high-quality products quickly, economically, and with a high level of adaptability [36].

In a VE, manufacturers no longer produce complete products in isolated facilities. They operate as nodes in a network of suppliers, customers, engineers, and other specialized service functions. The main objective of a VE is to allow a number of organizations to rapidly develop a common working environment; hence, to manage a collection of resources provided by the participating organizations toward the attainment of some common goals. Because each partner brings a strength or core competence to the consortium, the success of the project depends on all of the organizations cooperating as a single unit [38]. Virtual enterprises are characterized by several strategic objectives: (1) maximizing flexibility and adaptability to environmental changes, (2) developing a pool of competencies and resources, (3) reaching a critical size to be in accordance with market constraints, and (4) optimizing the global supply chain. VE structures are highly dynamic. Their life cycles can be very short. Reactivity and flexibility, which are the major benefits of VE, are a source of problems to solve. There is an opposition between this structural dynamism and the time needed to complete some aspects of the firms' activities.

A virtual organization emphasizes the integration of complementary core competencies distributed among a number carefully chosen, but real organizations all with a similar supply chain and tending to focus on market responsiveness, cost reduction, and quality [31,40]. Generally, a single organization often may not be able to respond quickly to changing market requirements. Strategic alliances or partnerships based on the core competencies of firms will help to improve the flexibility and responsiveness of organizations. However, coordination and integration can prove to be complicated to achieve. Appropriate strategies and methodologies, which will involve communication, training and education, and goal deployment, must be adopted for the effective coordination and integration of participating firms at different levels of cooperation [3–5,39].

As noted earlier, partnership for developing a network of firms is based on core-competencies, and strategic alliances to facilitate agility in manufacturing. In partnership development, there is a need for information on three functions of AM, namely, prequalifying partners, evaluating a product design with respect to the capabilities of potential partners, and selecting the optimal set of partners for the manufacture of a given product [32,41]. Enterprise resource planning (ERP) can be used to analyze and optimize an entire supply chain from purchasing/suppliers using a streamlined logistics network, and to overcome cultural, communications, and cross-functional obstacles [33]. The cultural, communication, and cross-functional obstacles can be overcome in a VE by providing training and education, setting up strategic alliances, and adopting advanced information technologies to improve communication and teamwork by empowered employees.

In a VE, training and education should have a different focus compared to that of traditional organizations.

For example, an international team of empowered employees and self-directed teams should be developed with a view to improving the effectiveness of a globally distributed manufacturing enterprise. This requires that each member of the team understand the culture and language of the other members of the team, and be sufficiently literate in the analysis and synthesis of computerized information. Groupware has been used as a group decision-making environment to help teams evaluate a quality function deployment framework for risk management and AM designs [34]. The virtual design environment is information architecture to support design-manufacturing-supplier-planning decisions in a distributed heterogeneous environment. The approach utilizes evolutionary, intelligent agents as program entities that generate and execute queries among distributed computing applications and databases. The evolutionary agents support a global evolutionary optimization process in which successive populations systematically select planning alternatives that reduce costs and increase throughput.

Clarke [35] introduced the concept of virtual logistics. With virtual logistics, the physical and information aspects of logistics operations are treated independently from each other. In such operations, the ownership and control of resources is effected through Internet (or Intranet) applications rather than through direct physical control. This removes numerous operating constraints, and allows for the more efficient design of logistics networks. Logistics systems could then be constructed by purchasing an appropriate portfolio of resources. Such a portfolio could be easily and quickly adjusted to reflect changes in demand, changes in markets, or changes in products. The author discussed virtual stockholding, virtual warehouses, virtual supply chains, virtual stock control, virtual trading, virtual production, virtual logistics services, virtual markets, virtual growth, and virtual organizations.

As more companies are adopting the concept of the virtual enterprise, inter-organizational interactions (customer–supplier relations) are in the process of emerging. The growing importance and convergence of computer and communication technologies are leading to a new vista for businesses in the form of e-commerce [37]. Companies are using Internet-based logistics systems to speed up the flow of information along the value chain. A number of issues are faced in the development of partnerships, including establishing criteria for the establishment of the relationship, evaluating and selecting suppliers (and customers), developing the relationship, and maintaining and promoting the relationship. Each of these steps in the process is important independent of the level of involvement and maturity of the organizational relationship. Sarkis and Sundarraj [37] discussed how the role and practice of brokering needs to evolve with emerging organizational forms. They have highlighted the supporting tools, technologies, and mechanisms needed to implement e-commerce based brokering.

A VE/VO highlights the role of strategic alliances/partnerships based on core-competencies in achieving flexibility and responsiveness. This obviously becomes an important enabler for an RSC.

3.3. Knowledge and IT management

AM needs intelligent sensing and decision-making systems capable of automatically performing many tasks traditionally executed by human beings. As pointed out earlier, physically distributed manufacturing environments/VEs demand high-level communication systems such as Internet, EDI, and e-commerce to exchange information at various levels of manufacturing organizations .

A data management framework (DMF) to support AM is needed [42]. A DMF has been defined as the ability of an enterprise to manage distributed data, information, and knowledge as the decisive enabler for core enterprise business processes. The purpose of a DMF is to provide a seamless enterprise data management solution in support of an RSC. Rahman [43] has studied the impact of the Internet in customer services, purchasing, the handling of materials, and stock control. The application of the Internet in a supply chain will result in a reduction in service costs and response times to customer requirements through the use of a shared information platform such as WWW and e-mail and such technologies as EDI and RFID to improve the communication among partners along the supply chain to make it easier to trace materials flows.

Subba Rao [44] discussed the future of e-business in process industries with the aim of improving the agility of companies to meet changing market requirements. E-business will streamline the business processes, provide windows into operations, integrate the supply chain and plant systems in place, increase customer services, and streamline distribution. Kurnia and Johnston [45] discussed an e-commerce enabled grocery industry supply chain management strategy, viz. the ECR which is designed to make industry more efficient and responsive. They explored the experiences of the Australian grocery industry with ECR adoption. Based on an analysis of the survey, the following six deductions were made: lack of understanding of ECR, retailers lead

Table 2
Comparison of lean, supply chain, agility, and RSC

Objectives and major determinants	Lean/supply chain	Agility	RSC
Objectives/goals	Reduced costs, moderate speed, and flexibility	Increased speed and flexibility. Cost is not a major criteria	Reduced costs, increased speed and flexibility
Strategic planning	Fewer suppliers, outsourcing, IT	Core competencies, global outsourcing, virtual enterprises	Supply management, strategic alliances, virtual enterprises, global outsourcing, and IT
Organizational structure	Supplier development	Virtual enterprise, partnership formation based on core competencies	Virtual enterprise, supply chain integration, and IT
Knowledge and Information Technology	Supply chain integration, knowledge workers	Agile and knowledgeable workforce, enterprise resource planning systems	Training and education to operate in a global environment, ERP systems

manufacturers in the adoption of ECR, retailers and manufacturers have different interests and perceptions, retailers experience more benefits than manufacturers, retailers are more powerful than manufacturers, and their lack of cooperation and trust.

One of the factors contributing to the ability to become an agile manufacturer has been the development of manufacturing support technology that allows marketers, designers, and production personnel to share a common database of parts and products, to share data on production capacities and problems—particularly where small initial problems may have larger, "downstream," effects [46].

Weston [17] described the important role that software-based integration infrastructures and integration structures can play respectively in supporting and organizing system behavior in a way that facilitates system extension and change. Such a software-based system is likely to become common building blocks of AM. IT is providing the means for companies to better integrate their internal and external activities. This level of integration is achieved through "Enterprise-wide systems" that reflect the current operations and processes of the business and allow decision-makers to digest information more rapidly and accurately, and with more flexibility in manufacturing [18]. Al-Mashari and Zairi [48] highlighted the development of ERP, which creates an opportunity to reengineer supply chains within and beyond the scope of an organization. Most notably, SAP R/3 has been widely implemented to create value-oriented supply chains that enable a high level of integration, improve communication within internal and external business networks, and enhance the decision-making process.

The systems for AM should include mostly software/decision support systems for various planning and control operations including materials requirements planning, design, manufacturing resource planning, scheduling, and production planning and control. Several system's solutions are available that can be used for an RSC, some of which are as follows: (i) MRPII, (ii) Internet, CAD/CAE, (iii) ERP, (iv) EDI, (v) multimedia, and (vi) e-commerce.

Future operations in manufacturing organizations will require the integration of IS through scattered manufacturing plants. The utilization of technologies such as the Internet will bring together applications related to resource planning (MRP, ERP, and cost-accounting systems), manufacturing execution (factory-level coordinating and tracking systems), and distributed control (floor devices and process control systems) [49]. Sanders and Premus [50] explained the role of IT applications in supply chain organizations as a link between competitive priorities and organizational benefits. They discussed three key dimensions of IT in supply chain environments: (1) organizational competitive priorities, (2) choice of specific IT applications, and (3) performance measures achieved. Stefansson [51] highlighted the flow of information between parties in a supply chain for carrying out the effective and efficient transition of goods. Although the electronic data interchange (EDI) technology has existed for more than 30 years, it has not been adopted by small- and medium-sized enterprises to any significant extent.

An attempt has been made to analyze the characteristics of a lean/supply chain, an agile enterprise, and a responsive supply chain. The attempt started with a comparison of the features of these operations strategies so that a framework for a responsive supply chain can be developed. Table 2 presents a summary of the differences and characteristics of a lean/supply chain,

an agile enterprise, and a responsive supply chain, together with their objectives and goals. These aspects have been studied with reference to major dimensions of emerging enterprise environments that include strategic planning, a virtual enterprise, and knowledge and IT management. For example, strategic planning for a lean/supply chain focuses on fewer suppliers, global outsourcing, IT, and outsourcing. On the other hand, the strategic planning of an agile enterprise is comprised of strategic alliances with partners, global outsourcing, and virtual enterprises. The strategic planning of an RSC should include global outsourcing, SCM, strategic alliances, and IT. ERP and application integration systems are of paramount importance for an RSC. Organizational structure is another important component of RSC. Looking at the structure of a lean/supply chain and agile enterprise, RSC requires a virtual organizational structure with partners for different services and goods, and the integration of a network of partners with IT. Knowledge and IT is important in all of these three operations strategies. However, an RSC demands training and education in IT, including the Internet, WWW, and ERP.

4. Case examples of flexible and RSC

In this section, some reported case experiences in the literature and WWW are analyzed with the objective of identifying critical success factors for RSC. Table 3 summarizes each company's background, goals, strategies, and technologies for achieving flexible and responsive supply chain. The data for these cases have been collected from secondary sources such as annual reports, news reports, and information available on company websites. The reliability of the data has been studied with the help of information collected through multiple sources and comparisons.

The supply chain may be broken down into three basic segments: (i) sourcing, (ii) manufacturing, and (iii) delivery. The flexibility and speed of these supply chain segments lead to the definition of supply chain agility. Flexibility and complexity determine the external vulnerability of the supply chain. The factors affecting supply chain exposure include: the extent of the geographic areas covered by the supply chain, the political areas and borders crossed, the number of transportation modes and their speed, the technical infrastructure and its degree of use, and random occurrences [53].

CEMEX : CEMEX is one of the largest producers of cement in the US. Their operational focus has been on better customer service and reduced costs. They realized the importance of Internet-powered enterprise resource planning solutions. In order to succeed with B2B and B2C, CEMEX implemented EDI, MRP, ERP, and CRM. CEMEX was able to reduce the costs and improve their levels of customer service. They outsourced their non-core materials and service requirements in order to achieve lean production. Their main focus was on the accurate forecasting of customer demand/requirements. Using the Internet as a starting point, they made use of the applications and systems developed by numerous venders designed to help companies manage some or all of their supply chain processes. With these changes, CEMEX was able to achieve greater responsiveness, improve profitability, and obtain a higher market share.

The critical success factors identified for achieving RSC from CEMEX are an extensive distribution channel (logistics), global suppliers, accurate demand forecasts, just-in-time deliveries, and applications of various technologies such as the Internet-based solutions (B2B, B2C, ERP, CRM, EDI, and MRP) and transport systems.

AT&T (*electronic consumer products*): AT&T (electronic consumer products) produces consumer electronic products. It is the number one in market share for its core product lines. Their products are a highly positive consumer brand. The company's core strength lies in manufacturing innovations. AT&T aimed to focus on its areas of core competency to be competitive in a global market. Also, AT&T decided to improve the reliability of its supply chain by consolidating the supplier base, co-locating manufacturing and distribution operations, and reducing the number of distribution centers. The major strategy which the company employed was an IT strategy with the objective of encouraging the sharing of information and knowledge at various levels of decision making, i.e., the operations, tactical, and strategic levels.

The company focused on the reliability of supply chain. Here, they developed performance measures and metrics for how to measure the reliability of their supply chain. The reliability of the supply chain is directly related to its responsiveness. The company has implemented the electronic transactions, the electronic exchanging/sharing of information, and electronic collaboration at all levels.

Libbey, *Inc.*: Libbey, Inc. is a leading supplier of glass tableware in North America and a leading provider of tabletop products to the food service industry. Libbey, Inc. employed the big-bang approach towards business process reengineering, using an integrated information system. They also focused on ERP incorporating APS, and supply chain/logistics to improve the responsiveness and flexibility of their value chain. The company

Table 3
Summary of case experiences and findings on RSCs

Company	Background information	RSC	
		Strategies	Technologies
CEMEX (www.cemex.com)	Largest cement producer, better customer service and reduced costs, improved profitability, higher marker share, greater responsiveness	Global supply chain, customer-focused, extensive distribution channels, low-cost production, customer demand forecast, JIT, ERM	Internet-based solutions, B2B, B2C, ERP, CRM, EDI, MRP, transport systems
AT&T Electronic Consumer Products (www.att.com)	Produces consumer electronics, number one in market share for its core product lines, highly positive consumer brand, core competence in manufacturing	Supply chain reliability, flexibility/responsiveness, costs and assets utilization, consolidated supplier base and reduced number of distribution centers, co-located manufacturing and distribution operations, strategic sourcing, team up with accenture, customer-focused lifecycle approach facing supply chain functions	Electronic execution of transactions, electronic sharing or exchange of information, electronic collaboration on strategic tactical and operational planning
Libbey, Inc. (www.libbey.com)	Leading supplier of glass tableware in North America and a leading provider of tabletop products to the food service industry	Joint venture, new innovative products, extensive sales and distribution network, business process reengineering, big-bang approach using integrated systems, leveraging customer relationships with partners, teamwork, preparing for changes, benchmarking, and innovation	Enterprise resource planning (ERP), advanced planning and scheduling (APS), and supply chain/logistics (SCE), 5S Program (sort, simplify, systematic cleaning, standardizing, and sustaining)
Nissan (North America) (www.nissan-na.com)	Producer of cars (Nissan and Infiniti), plans to enhance the ability of its Web customers, guaranteed delivery	Focus on corporate governance, innovation in products and technology solutions, transforming suppliers, eliminating non-core assets, cross-functional teams, modularization, enhancing quality, value-up program, web-based solutions, customer-centric business model, resulting in higher sales, greater customer satisfaction, automotive demand chain, collaborative network linking production facilities with dealerships	ERP, Web-based solutions, enterprise profit optimization (EPO) solutions, integrated application suites
Wedgwood (www.wedgwood.com)	Porcelain maker, luxury ceramics	Reduce inventory, cut supply cycle time, improve customer relations, and cut costs, pull model, structural change, benchmarking, best people on the team, multidisciplinary teams, new performance indicators	Information Technology/ systems

has used the following strategies to enhance the responsiveness of their supply chain: setting up joint ventures, designing new and innovative products, setting up an extensive sales and distribution network, forming strategic alliances with suppliers, and engaging in business process reengineering.

Nissan: Nissan (North America) produces cars (Nissan Infiniti). The company plans to enhance their ability to guarantee deliveries to their Web customers. Nissan has employed similar strategies to enhance its agility of their supply chain. They have implemented a Web-based solution, for which they have a customer-centric business model resulting in higher sales and customer satisfaction. They developed an automotive demand chain with the help of a collaborative network of firms linking production facilities with dealerships. The IT used

include ERP, Web-based solutions, profit optimization solutions, and integrated application suits.

Nissan has focused on corporate governance with a suitably formulated vision, mission, and strategies to achieve excellence in customer service. The company has primarily relied on innovative products and technological solutions to improve the responsiveness of their supply chain. Moreover, they have developed a supplier base, together with their resources, to assure that their supply chain has the required agility. The other associated strategies that they have employed include cross-functional teams, modularization, and quality enhancements.

Wedgwood: This company produces porcelain and luxury ceramics in the US. With the objective of improving customer service, their strategies are primarily aimed at reducing inventories, cutting supply cycle times and improving customer relations and costs. Wedgwood implemented a pull model and made structural changes using benchmarking, by making use of the best people on its team (multidisciplinary team). Also, it employed new performance measures and metrics for monitoring the process of change and its outcome over the designated time period. Based on the above reported case experiences, the critical success factors can be summarized as follows: a global supply chain, B2B, and B2C, ERP and CRM, JIT, Internet-based (WWW) logistics, Pull, BPR, and a collaborative network of firms.

The major strategies and technologies used by the case companies in strategic planning, the setting up of a virtual enterprise/organization, and in managing knowledge and IT to develop a RSC are summarized in Table 4.

5. A framework for developing a RSC

In this section, a framework for developing RSC is presented based on the literature survey and some reported case experiences on RSC. The model is based on three major factors: (i) strategic planning, (ii) virtual enterprise/organization, and (iii) knowledge and IT. The framework focuses only on strategies and tactics, not on operational issues. Generally, a major portion of the manufacturing cycle time is shared by the product development time. Reduction in product development cycle time is important in RSC to meet changing market requirements by suitably reconfiguring the available resources and developing suppliers.

An agile supply chain has to be engineered to cope with uncertainty, yet still profitably satisfy customer demand. This indicates the importance of achieving an integrated supply chain to reduce the total cycle time and, hence, of being flexible and responsive [54,55]. The following are key to the success of a responsive supply chain: timely information sharing, shortening the total cycle time, coordinating the workflow at different tiers of the supply chain, good decision support systems, reducing lead times for information and materials flows, integrating information about operations, reducing redundant echelons, and flexible capacity.

Christopher [56] and Power et al. [57] identified a number of characteristics that a supply chain must have in order to be "truly agile." These include being market sensitive (through the capturing and transmission of point-of-sale data), creating virtual supply chains (based on information rather than inventories), process integration (collaboration between buyers and suppliers, joint product development, etc., and networks (confederations of partners linked together as against "stand alone" organizations). An underlying assumption in this model is the transparency of information and the use of technology to create "connectivity" (i.e., the ability of organizations to share information in "real time"). The level of complexity in terms of brands, products, structures, and management processes can significantly hinder agility in individual organizations.

A framework for the development of an RSC is presented in Fig. 2. This framework focuses on three major areas: strategic planning, virtual enterprise, and knowledge and IT management. An integrated system for these will result in an RSC and, hence, in improved responsiveness and flexibility. For example, strategic planning includes the decentralization of operations to achieve flexibility and speed. Global outsourcing and strategic alliances with partners help reduce the time to market. Also, the system should be proactive.

5.1. Strategic planning

Strategic alliances and the integration of complementary core competencies are necessary in developing a virtual enterprise for RSC. Therefore, based on the given level of demand along the supply chain, there is a need to select partners based on their involvement in the value-adding chains. The development of a VE requires the following: (i) a framework for the process of formulating corporate and business strategies based on global competitiveness for manufactured goods and services, (ii) a decision support system for selecting suitable partners based on the required core competencies, (iii) an ERP system for controlling operations in a VE, and (iv) a performance measurement system for continuous improvement in RSC. Existing methods and

Table 4
Strategies/technologies along the line of a conceptual model for RSC

Company	Strategic planning	Virtual enterprise/ organization	Knowledge and IT management
CEMEX	Global supply chain, Customer-focused, enterprise resource management (ERM)	Strategic alliances, extensive distribution channels, low-cost production, JIT, customer demand forecast, transport systems	Internet-based solutions, e-commerce models, including CRM, EDI, and RFID
AT&T Electronic Consumer Products	Supply chain reliability, cost and asset utilization, reduced number of distribution centers, co-located manufacturing and distribution operations, customer-focused life-cycle approach facing supply chain functions	Consolidated supplier base, strategic sourcing and alliances	EDI, Internet, WWW, RFID, and ERP
Libbey, Inc.	Joint venture, new innovative products, extensive sales and distribution network, business process reengineering, benchmarking, and innovation.	Big-bang approach using integrated systems, leveraging customer relationship with partners, teamwork, preparing for changes	ERP, APS, 5Ss
Nissan (North America)	Corporate governance, product and technological innovation, supplier development, eliminating non-core assets, modularization, customer-centric business model, Better customer service	Cross-functional team, enhancing quality, value-up program, web-based solutions, developing partners	ERP, WWW, EPO, and Integrated application suites
Wedgwood	Reduce inventory, improve customer relations, cut costs, pull model, benchmarking, best people	Multidisciplinary teams, new performance measures and metrics	Information technology/ systems such as EDI, Internet, EDI, ERP, and RFID

tools can be used to formulate strategies and select partners to develop RSC enterprise. To achieve RSC, several sub-strategies are needed, including the establishment of a virtual enterprise, the rapid formation of partnerships, the management of knowledge and IT, and the establishment of temporary alliances based on core competencies. Without suitable business and operations strategies, technologies and systems alone are not sufficient to achieve responsiveness in supply chain.

Also, RSC can be achieved by forming suitable strategic alliances based on mergers and acquisitions with the objective of obtaining the required services. Other external factors such as the type of market and products, location, government policies, and environmental regulations need to be considered in the strategic planning for the suitability of RSC and its development. Fawcett and Magnan [58] discussed the views of managers on the supply chain, leading to many useful insights such as an increased understanding of SCM and the enabling conditions for the development of SCM in practice.

With regard to an agile supply chain, the involvement of top management is vital in the effective reengineering of the supply chain and logistics. In agile supply chain environments, relationships with suppliers and interactions between suppliers should be flexible in terms of the delivery of products/services and responsiveness.

5.2. Virtual enterprise

Companies are seeking to become more responsive to changing market conditions by streamlining and restructuring their organizations, and making use of virtual enterprises and knowledge work teams. To achieve this responsiveness, a customer-oriented supply chain is required to manage the flow of information within the network of enterprises. To be truly responsive, supply chain partners should be able to move even more quickly with the efficient utilization of existing equipment, existing facilities, and even existing designs [59]. VE is an important concept in manufacturing. The concept

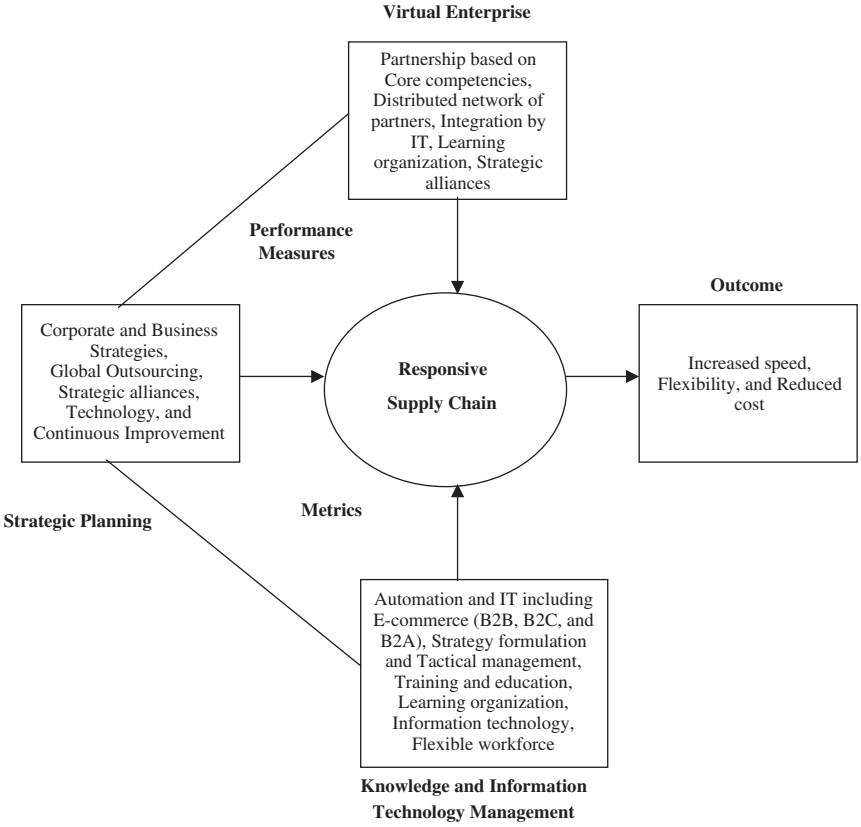

Fig. 2. A framework for the development of RSC.

of VE is defined somewhat differently from virtual manufacturing, and a VE needs more advanced inter-organizational IT. Furthermore, it also has the same constraints as concurrent engineering. This concept has been used to characterize the global supply chain of a single product in an environment of dynamic networks between companies engaged in many different complex relationships. It is supported by the extensive use of information and communication technology [61].

Considering the role of VE in an RSC, a systemic framework is required for its development. The following steps can be employed for developing a VE: (a) identify the corporate objectives, (b) based on multiple competitive performance objectives, identify the product/service requirements from suppliers, (c) select partners based on the core competencies using a suitable supplier ranking system, (d) use the time scale, which should be rather short, linking all partners as a VE with the help of automation and IT.

5.3. Knowledge and IT management

Automation and IT play a dominant role in the development of a physically distributed enterprise or VE. The role of automation and IT can be identified in several areas of the development process. The most important elements for them are (i) strategy formulation, (ii) tactical management, (iii) operations control, and (iv) systems. From the review of RSC-enabling technologies, it can be noted that the selection of technologies for RSC depends upon strategies that are selected to meet changing market requirements. For example, JIT may require EDI, FMS may need AGVs, Robots, and NC machine tools, while responsiveness relies heavily on a virtual enterprise or physically distributed manufacturing environments. A good amount of cooperative supported work for prototyping is required to help an engineering team design RSC. The prototype systems should support the following: autonomous inputs, the parallel processing of information, group memory, electronic brainstorming, and consensus building. Suitable algorithms should be developed and tested for the computer supported cooperative work.

An RSC organization should possess the capability of a learning organization. For this purpose, IT can be used along with a suitable organizational structure that

promotes innovation, training and education. In a global operations environment, the communication should be standardized to improve the cooperative supported work in a VE. This requires standard computer-aided communication systems with suitable changes to suit the local environment such as translation into a different language.

Certain challenges from human factors posed by the RSC can be overcome by a series of team meetings during which the team will jointly develop the project plan. Such a plan would involve objectives; strategies for meeting objectives; a detailed task network, schedule, and resources; and funding projections. Information technologies alone are not sufficient to achieve the desired efficiency in communications. If anything, the unfamiliarity of the technologies could impede efficiency in communications [5,8,60].

Global competition forces companies to opt for an extended enterprise within the framework of supply chain management. ERP systems such as SAP, Oracle, Peoplesoft, BAAN, and JD Edwards can be used to achieve effective integration in RSC. The extended enterprise demands commercially available tools for the integration of applications in a supply chain. This poses a challenge to IT. Hence, the communication industry is to play a major role in achieving responsiveness in a supply chain [8]. In an RSC, information is transmitted via multiple channels depending on its urgency, content, and distribution through phone, voice-mail, fax, e-mail, and http. The workforce should be capable of meeting increasing technological challenges, designing their work places, solving quality-related problems, engaging in team-to-team learning, improving the availability of equipment, using mistake-proofing processes, dealing with increased complexity of the system and, finally, helping labor unions achieve harmony between their members and the company [62].

6. Conclusions

In this paper, an attempt has been made to study the literature on RSC with the aim of developing a framework for responsive supply chain. Also, a framework has been offered in the paper to develop an RSC system.

The main objectives of this paper are to highlight the importance of both SCM and agile enterprise. It has been believed that agility be achieved with the supply chain alone. This is, of course, true. But an agile supply chain can be developed with advanced IT and investment in knowledge and IT. An agile supply chain relies on the development of global suppliers/partnerships and enterprise resource planning systems. A conceptual framework has been proposed to develop an RSC with the objective of achieving speed, flexibility, and cost reduction. However, performance measures and metrics need to be developed for the RSC. This should be based on productivity of IT/IS, speed, and responsiveness of a supply chain.

In order to achieve an RSC, a suitable information system integrating ERP, EDI, and the Internet is important for improving communication and ensuring a smooth flow of materials along the value chain. The effective implementation of IT/IS is highly desirable if a supply chain is to be responsive and flexible. This requires that business processes be reengineered prior to the implementation of IT/IS. Investment in knowledge and IT is essential for achieving agility in the supply chain. Also, appropriate benchmarking, performance measures, and metrics are required to encourage
agility in the supply chain [63]. A flexible information architecture that supports decentralized collaborative processes is essential. Visibility and collaboration are key to advances in the development of a responsive supply chain. The following are some future research directions to assist the development of RSCs:

- The optimal architecture of a supply chain taking into account the integration of the supply chain for speed and flexibility as well as cost reductions.
- The integration of a virtual supply chain (network of partners) using ERP.
- Criteria for selecting partners for global supply chain management.
- Performance measures and metrics in RSCs.
- Cost management in RSCs.
- Quality management in RSCs.

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