Evolution of operations management: past, present and future

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Abstract

Purpose – This paper seeks to analyze the evolution of shift in the area of operations management (OM) and attempts to anticipate potential developments in the relevant areas of OM.

Design/methodology/approach – A hybrid approach is adopted to understand how the field of OM has evolved over time relying on the perspectives of both academics and business practitioners. This evolution of shift in the area of OM is examined based on a thorough literature review and the authors' industrial experience.

Findings – From the days of functional point solutions relying on concepts like reorder point to finite capacity planning, OM research at present deals with a set of important problems facing both private and public sectors at the organizational level. Most prominent of these include e-business, supply chain management, production planning and scheduling, product development, decision support systems, information-based strategy, systems development and implementation, risk and environmental management. OM has also embraced several organization-wide philosophies including lean production, mass customization and agile manufacturing.

Practical implications – With the advent of Internet and burgeoning of the new economy, this paper provides important insights regarding the evolution of OM in the past, recent developments at present and what the future holds for this field. It is envisaged that a focus on the issues central to OM will soon propel both researchers and industry practitioners beyond existing technologies and also provide the catalyst for developing new ones.

Originality/value – This paper provides useful insights to both researchers and practitioners who are interested in the field of OM.

Keywords Operations management, Lean production, Resource management

Paper type General review

1. Introduction

Operations Management (OM) is a function that enables organizations to achieve their goals through efficient acquisition and utilization of resources (Krajewski *et al.*, 2007; Chase *et al.*, 2006). In earlier decades, the term "Operations Management" referred primarily to manufacturing production. However, over the period of time the field has expanded to include service systems as well, since operations permeate every functional area of the organization ranging from marketing, accounting, purchasing/logistics, information management to engineering and human resources. Emphasizing this shift, Chopra *et al.* (2004) define the area of OM as the design and management of

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transformation processes that create value for society. In fact, this shift makes the limits of OM field blurred (Hayes, 2000; Pilkington and Liston-Heyes, 1999). However, OM is crucial to any organization because only through successful management of people, capital and materials that an organization can meet its goals.

As Figure 1 illustrates, OM is management of a systemic transformation process to convert a set of inputs into outputs (Knod and Schonberger, 2001; Chase *et al.*, 2006; Russell and Taylor, 2006). These inputs include labor, equipment, raw material, information and other capital resources, while the outputs are goods and services. Customers could participate to define the requirements of the final goods and services in terms of cost, quality and variability. Feedback on the products and services can be received from the marketplace and the service centers. In this environment, OM serves as a continuous improvement process to enhance quality, productivity and customer satisfaction.

Based on a time scale, Figure 2 presents significant innovations that have had an impact on OM. Henry Ford and Charles Sorenson developed a comprehensive

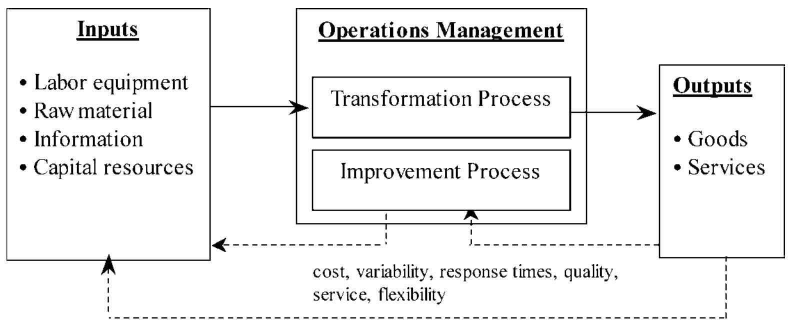
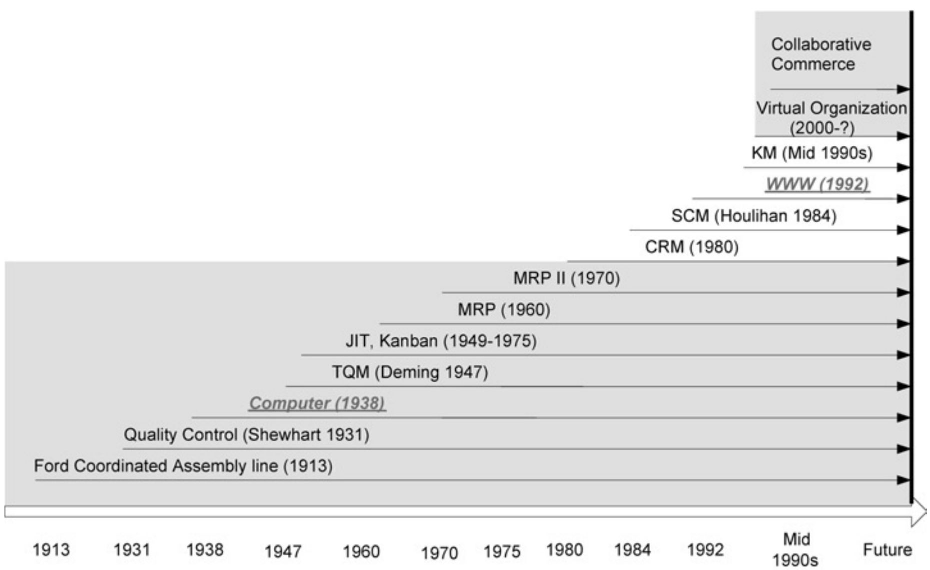


Figure 1.
Operations management



Source: Adapted from Nankervis *et al.* (2005)

Figure 2.
Innovations in operations management

manufacturing strategy by combining standardized parts with an assembly line in 1913. In 1924, Walter Shewhart established the foundation for statistical sampling and quality control. The first digital computer was described and built in 1938, while information science emerged and became an essential component of OM. The use of computer information has enhanced capabilities of OM tremendously to handle problems that previously could not be tackled. Starting from the early seventies, tactical tools such as Total Quality Management (TQM), Material Requirement Planning (MRP), Kanban, Manufacturing Resource Planning (MRP II) began to emerge. Unfortunately, such tools became insufficient in a relatively short period of time as we moved away from stand-alone functional applications to the applications which attempt to integrate all organization and which directly support the final goods and services. Over the past decade, the developments in communications, primarily based on Internet/www-based technologies, have created a new platform for OM to connect enterprises and customers in a seamless information network. New management tools or concepts like Customer Relationship Management (CRM), Supplier Relationship Management (SRM), Supply Chain Management (SCM) and Knowledge Management (KM) have become key models for the success of an enterprise.

The primary purpose of this review paper is to analyze the evolution of shift in the area of OM and attempts to anticipate potential developments in the relevant areas of OM. The remainder of the paper is organized as follows. The next section presents the methodology adopted for this paper. Based on extensive review of relevant literature, sections 3-5 provide an analysis of the past, present and future development of OM field, respectively. The conclusion is the final section.

2. Methodology

The OM-based literature has provided several approaches to analyze the evolution of OM and to identify the main trends in each era. One widely used approach is to examine the recent publications and identify the main interests in the relevant period and compare the findings with those of the past studies. This approach has been adopted by several researchers (e.g. Amoako-Gyampah and Meredith, 1989; Filippini, 1997; Scudder and Hill, 1998; Pannirselvam *et al.*, 1999; Pilkington and Liston-Heyes, 1999; Johnston, 1999). As Filippini (1997) points out, OM is very much of an applied discipline responding to issues emerging within industry. Pilkington and Liston-Heyes (1999) even extend this view further that theoretical developments tend to lag well behind innovations made by practitioners. Therefore, it is somewhat difficult to envisage the research fields and future of OM drawing solely on existing publications.

The second approach focuses on the periodic survey of firms with regard to their problems and strategies (e.g. Ward *et al.*, 1998). The use of case studies and panel of experts to identify the benefit of a specific OM topic is among the other approaches to elicit the feedback of practitioners.

This paper will focus on the evolution of OM from an organizational domain perspective by considering main challenges in both organization's task and general environment in each era. General environment includes the technological, economic, global and socio-cultural forces which may affect organizations' success in the market place. The task environment constitutes an organization's competitive environment that the organization directly interacts with its stakeholders in order to conduct its daily business. This paper addresses the OM evolution through three specific areas of focus: structure, concepts/tools and philosophies/approaches. Structure is a means of organizational response to the environment to enable effective use of organizational resources. Concepts, tools and philosophies are the representatives of the work practices, potential problems and culture of the organization. Such organizational-based analysis may be informative to understand "reason-whys" of the research themes evolving, help foresee the future of OM and thus contribute to the practice of OM significantly.

The forthcoming sections will discuss the past, present and future of OM based on the organizational domain analysis. Following a brief history of OM, the past refers to the period from the early 1970s to the mid-1990s. It was during this period when computers found their way into organizations (Chase and Prentis, 1987). It is the same period when quality management practices were introduced by Japanese auto producers. The present covers the era from the early 1990s to date. The widespread use of Internet in business applications is the prevalent characteristics of this period. Intensive communication media along with fast growing globalization has enhanced all sources of information flows among business partners, while making possible to integrate businesses in a virtual environment. The future of OM field will be speculated based on the analysis performed in the earlier periods and the industry experience of the authors.

3. Operations management – past: shift of focus from cost to quality

According to Skinner (1985), the functions of OM first came into being during the period of 1890-1920 with the works of Frederick W. Taylor, Frank and Lillian Gilbreth and Henry L. Gantt. This era was later defined as "scientific management". However, notwithstanding the great depression in 1930s, in many ways the period from 1920 to 1960 can be considered as the golden age for the development of industry in the USA (Hopp and Spearman, 2001). During this era, the main focus of OM was on the labor productivity improvements where time and motion studies, layout, production control, queuing theory were among the popular techniques to improve labor productivity. Operations Research and Management Science applications dominated the OM field starting from the post World War II until the 1960s. Most of the research during this period focused on developing algorithms and methodologies to solve optimization problems in several functional areas (Chopra *et al.*, 2004). While the techniques such as aggregate capacity planning, quality control and inventory control were studied extensively, they were mostly abstract applications of techniques and were rarely empirical (Filippini, 1997). According to Chase and Prentis (1987), the 1960s were an era where specific text books on OM were written and the term "operations" was introduced to extend the scope of OM into service settings.

The use of computers to perform routine accounting tasks starting from the early 1960s has led J. Orlicky and O. Wright to use computers in the solution of operational problems such as production control. Following the development of MRP systems in 1970s, databases and information systems have emerged as indispensable tools to manage large data sets and heavy number crunching in OM field.

The period of the 1980s was recognized as an era where OM has been widely accepted as one of the functional fields of an organization. Increasing competition spurred by the success of Japanese products in the global markets led OM to focus heavily on improving manufacturing strategies, service operations, new product development and developing better performance metrics to produce for less. At the same time, TQM, just in time (JIT) and MRP were considered as new areas of research, while engineering techniques, work measurement and facility location lost ground (Filippini, 1997). At the strategic level, OM was involved in product and service plans, positioning strategy and process management, while at the tactical view OM was involved in job design, capacity, location, logistics, materials management, production and staffing plans, master production scheduling, inventory and operations scheduling.

Although efforts in OM mainly focused on cost reduction during early 1980s, the focus shifted to quality through collaboration of information systems and leanness, within the next decade (Heizer and Render, 2006). Great attention to JIT by academicians has also tightened the link of OM field to the practitioners, which will be a driver of the field growth later in the 1990s (Chopra *et al.*, 2004).

3.1 Environment

While the early 20th century is associated with wider implementation of mass production principles to achieve economies of scale in order to lower costs, heavy use of computers for decision-making has encouraged the developments in information systems during the 1970s. Introduction of computers as business tool to enhance the productivity shifted the attention to development of new computer integrated systems. The periods of 1970s and 1980s were largely dominated by computerized production planning and control systems, including MRP and MRP II. While computers have been incredibly changing the way tasks were performed, human beings were still the key decision-makers even for operational issues because of the limited computational power and storage capacities of the computers. Main characteristics of the applications developed in this era had data that were fragmented, so maintaining its integrality and accuracy was a big problem. Without the integrated databases, data sharing among different functions of an enterprise was a big issue. With integration of the scientific management principles, "divide and conquer" solutions were considered as a "good enough" solution for the available technology. Stand-alone applications initiated tremendous productivity improvements and increased the efficiency in scheduling, forecasting, planning and management. OM gained considerable benefits from the Statistical and Operations Research methodologies during this time.

On the other hand, stiff competition initiated by Japanese companies in global markets, especially in the USA, and the increasing economic power of Japan, created a great interest in Japanese production systems. The striking features of Japanese-based competition in terms of cost, quality and speed have shifted the attention of the companies to JIT practices such as Kaizen, Kanban and TQM. The simplicity of JIT surprised and also puzzled many organizations using complex computer-based systems introduced in the early 1980s.

3.2 Task environment: stakeholders

In the early days of OM, shareholders were considered as only stakeholders of an enterprise. Many mathematical models developed for OM problems also reflected this view in their objective functions with cost minimization and profit maximization of shareholders. Cost was considered as the widely used measure to satisfy the customers with limited choice of goods. After the late 1970s with the advancement of the quality concept and quality management applications, customers became the main focus of OM as a major stakeholder group. This initiated a shift from "sell what you produce" to "sell what customers want". Quality under TQM was considered as a new competitive weapon and a main driving force for effective management of operations.

3.3 Organizations

3.3.1 Structure. Organizations of the past were mostly functional and generally organized around four management responsibilities as shown in Figure 3: money, demand, design and OM (Knod and Schonberger, 2001). In functional organizations, communication and collaboration among the departments were potentially weak, so fully integrated organization-wide efforts were hard to practice.

With the collaboration of JIT, employee involvement has become a prerequisite of many other efforts. This characteristic has also influenced organizational structures creating new positions and hierarchies in the work environment, though real movement toward flatter organizations are geared by reengineering introduced in the early 1990s.

3.3.2 Concepts/tools. Re-Order Point (ROP) systems were one of the early methodologies for the replenishment of stocks. With the advancement of computers, MRP was introduced to production planning for dependent demand items. In the late 1970s, the scope of MRP was expanded to include resources planning modules such as capacity requirements planning, shop activity control, purchasing and customer service. This evolution enabled integration of several sub-functions within MRP II. The core of MRP was a computer program that prepares all the plans and schedules based on the available data and helps decide which one would produce what, when and how many in a push-type environment. Flexible Manufacturing Systems and Computer Integrated Manufacturing were other technologies that OM specialists were heavily involved in the early 1980s (Chase and Prentis, 1987; Sarkis, 1991).

In contrast, Kanban as an inventory control technique within the JIT philosophy supported the pull-type production environment where the continuous improvement process and employee involvement were the critical factors for success. It was one of the techniques of JIT which supports simple and visual manufacturing environment.

3.3.3 Philosophies/approaches. Most of the 1970s and 1980s were dominated by MRP and MRP II applications that helped to establish a push system. By nature, push systems enforce centralized decision-making through computers. Human beings were considered as one of the inputs (e.g. in deciding the capacities of machinery and equipment) to obey to the central plans and are not expected to involve in decision.

Rather than viewing quality as a distinct concept, TQM as a management philosophy addressed the notion of quality as part of a production process. TQM stressed the principles of customer satisfaction, employee involvement and continuous improvements (Kaizen) in quality. It also involves benchmarking, product and service design, process design, purchasing and problem-solving tools (Krajewski and Ritzman, 2002; Choi and Eboch, 1998).

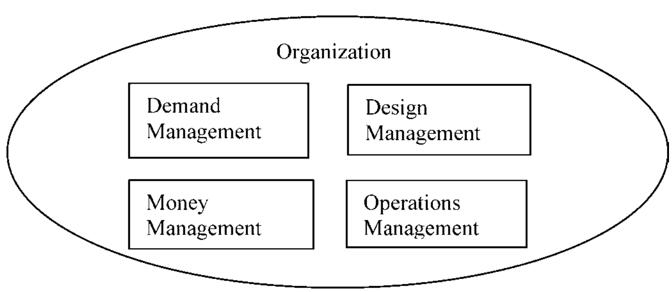


Figure 3.
Typical organization – the past

The rationale of JIT is to deliver the right product to the right people at the right time and right quantity thereby eliminating the need for maintaining huge inventories. In principle, JIT questions everything in the system including labor forces, processes and the entire organization. While seeking excellence in the details, JIT attempts to create a self-disciplined simplicity in the work environment. Operators know exactly what to do under each circumstance. As a pull system, JIT philosophy places human-centric and employees are the main drivers of the manufacturing system.

Figure 4 summarizes the evolution of OM in the past. The concepts and tools are shown in oblong squares, while philosophies are denoted by circles.

3.4 Research themes

Since OM was considered a field of production and inventory management research themes were largely dominated by manufacturing applications. The functional structure of organizations, a dominant role of shareholders, and limited capabilities of computers led the researchers to deal with stand-alone isolated systems.

During the 1950s, OM was often defined as industrial management or factory management. The scope of OM was later expanded by advancements in management science and operations research (OR). In addition to the techniques shown in Figure 4 applied to industrial operations, some scientific methods started finding their way into OM. More advanced methods including simulation, mathematical models such as linear programming (LP), game theory, break-even-analysis, all emerged during this period, though models on design robustness and maintenance were not prevalent.

Miller and Graham (1981) suggested operations policy (strategic decisions, manufacturing strategy and operating policies), operations control (aggregate planning, control system design, MRP), service operations (service delivery, productivity and positioning) and productivity and technology (introduction and adoption of new technologies, quality of work life) as research areas for the 1980s. Amoako-Gyampah and Meredith (1989) noted that classical research areas such as inventory control, MRP, JIT, aggregate planning and forecasting were dominant, in which mathematical, statistical, graphical and heuristic OR techniques as well as simulation were commonly used.

William Skinner's seminal work (Skinner, 1969), introduced operations strategy and this topic gained popularity amongst researchers. Over 80 articles and several books were written on the subject by the late 1980s (Anderson *et al.*, 1989). Service sector applications were rare and only 6 per cent of the total number of papers reviewed focused on services. The concept of JIT as a manufacturing philosophy gained widespread acceptance. Compared to pre-1980s, the areas of work measurement and process design received relatively less attention.

Cost and shareholder focus of the field in the early phases led researchers to find more productive ways of manufacturing. With increased interest in topics related to

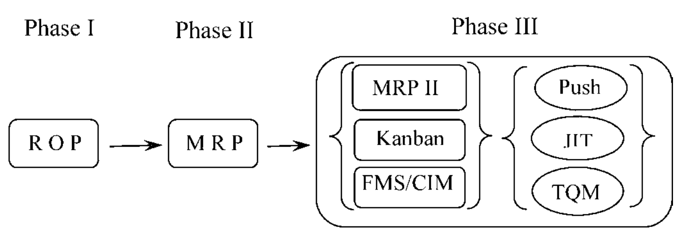


Figure 4.
Phases of OM – past

quality and customers as stakeholders, OM practitioners started to understand the complex nature of customer needs and interaction among many other functions of organizations. This trend initiated inter-disciplinary studies and service operations within OM. Similarly, researchers began to examine OM issues using non-OR perspectives seeking to explain phenomena that could not be explained by the existing theory (Chopra *et al.*, 2004).

Amoako-Gyampah and Meredith (1989) used 17 categories to investigate the research issues as summarized in Table I along with the relevant concepts, philosophies and the most prominent studies undertaken in the 1980s.

4. Operations management – present: era of mass customization through Internet and integration

After focusing on cost and quality of goods and services, OM practitioners have found mass customization as a way to satisfy the growing variety of customer needs in a customer-oriented market (Heizer and Render, 2006). In their empirical study on manufacturing plants within the USA, Ward *et al.* (1998) have developed four reliable

Topics	Concepts/ philosophies	References
Inventory control	MRP JIT ROP	Fisk (1978), Liberatore (1979), Lau (1982), Afentakis *et al.* (1984), Blackburn *et al.* (1986), Monden (1981), Huang *et al.* (1982)
Aggregating planning	Mathematical model Simulation Heuristic methods	Holt *et al.* (1955, 1956), Manne (1958), Akinc and Roodman (1986)
Forecasting	MRP Mathematical model	Puckett and Kamat (1982), Weitman and West (1980), Makridakis *et al.* (1982)
Scheduling	MRP Simulation OPT	Greenshields (1976), Graves (1981), Fox (1982)
Capacity planning	MRP/MRPII	Schmitt *et al.* (1984)
Purchasing	Mathematical model JIT	Derijcke *et al.* (1985) Hahn *et al.* (1983)
Facility location	Mathematical model	Plastria (1984), Ballou (1984)
Facility layout	Mathematical model	Smith and Pelosi (1984)
Process design/technology	Simulation model	Spur *et al.* (1984), Baybars (1985)
Maintenance	Mathematical model	Feichtinger (1982)
Quality	TQM	Greene (1984), Ebrahimpour (1985)
Work measurement	Mathematical model	Greene (1984)
Strategy	MRP Mathematical model	Twiss (1974), Skinner (1985), Wheelwright and Hayes (1985), Anderson *et al.* (1989)
Quality of working life	Human management	Sorensen *et al.* (1985)
Project management	Mathematical model TQM	Booker and Bryson (1985)
Services	Survey	Mabert (1982)
Distribution	None	None

Table I.
Major research areas of OM – past (1980s)

and valid scales for commonly accepted competitive priorities: cost, quality, delivery time and flexibility. Along with the development of these competitive priorities, many other developments including globalization have all led to the rise of mass customization. In addition to reengineering, the Internet has radically changed the landscape of business. Increasing involvement of businesses in global markets has led to a remarkable shift in traditional business models and their target audiences. In contrast to dispersed functional operations of the past, the present business environment necessitates intra-organizational and inter-organizational integration in order to respond to the new market conditions. As a result, current OM practices attempt to integrate many classical functions of the enterprise under the label of business processes initiated by a reengineering approach pioneered by Hammer and Champy (1993). This approach gave rise to the emergence of forecasting and marketing through Enterprise Resource Planning (ERP), CRM, accounting, sales, marketing and production through activity based costing. Defining OM as a transformation process which focuses on processes has enhanced the scope of OM. Along such a process, a technique, Six Sigma was introduced to focus on the processes that create or eliminate defects for quality control (Harry and Schroeder, 2000). Compared to TQM, Six Sigma provides a measurable approach to reduce variability in a process in order to fulfill better the needs of industrial environment. On the other hand, seamless integration of the chain members from suppliers to customers is a need to fulfill customer demands properly. SCM emerged as a tool for inter-organizational integration, and become a very popular area shaping our present era. Through SCM, organizations may consolidate their financial flows, purchasing and logistic activities.

4.1 Environment

The cost- and quality-based competition of the past has shifted to time-based mass customization. Timeliness and quick response are prerequisites of the present business world where mass customization of goods and services produced constitutes a real challenge.

Compared to the past, time horizons of long- and medium-term decisions have been significantly shortened. Operations managers find themselves in constant need of reconsidering their plant layouts due to frequent changes in product mixes and volume. Research and development and marketing have to come up with different product development ideas to be able to satisfy rapidly changing customer needs and preferences. Business strategies have to be renewed faster, while manufacturing facilities are to be managed even more efficiently in order to cope with the shrinking product life cycles. Through available technologies within SCM, an efficient and timely movement of material and information back and forth between suppliers and customers is established.

Instead of closed, one-to-one electronic data interchange markets, the Internet provides infrastructure for a many-buyers to many-sellers marketplace allowing access to open and global markets. Essentially any enterprise can join the marketplace 24 h a day and seven days a week, regardless of its geographical location. The Internet economy has empowered the customer through comparison-shopping. More organizations are now undertaking their business practices on a Web platform, thereby capitalizing on the efficiencies and effectiveness of streamlining business processes and increasing worker productivity. Tasks once performed by human beings can now be automated, allowing business users to spend more time in analyzing data rather than performing rote tasks. One theme underlying this increasing shift to the Internet is the desire to have mission-critical information available throughout an organization on a real-time basis.

4.2 Task environment: stakeholders

Customers with a strong emphasis on their needs are the main drivers of the recent shifts in current business practices. They are the most powerful stakeholders of organizations. In addition, society and community as a whole constitutes one of the powerful stakeholder groups for organizations. This shifting stakeholder focus obviously leads OM to carefully consider the broader affect of operational decisions on environment and society at large. Organizations need to increasingly communicate their environmentally friendly policies to nurture good public relations with society. In the design of supply chains, the views of political and environmental groups should also be considered. For example, manufacturers should design their facilities in line with the policies about how to manage industrial waste and reverse logistics flows as well as recycling. As a natural consequence of the JIT philosophy, employees have become another emerging stakeholder group of the present era. The higher customer satisfaction is more likely with better satisfied employees. The policy shift from customers to employees brings employee involvement to the work environment, which is the key idea behind lean production (Knod and Schonberger, 2001).

4.3 Organizations

4.3.1 Structure. In order to respond to environmental changes and better fulfill stakeholder expectations, organizations need to enhance their internal integration by restructuring to cross-functional teams, blurring the task definition of classical functional departments. Employee empowerment emerges due to vertical integration of many tasks. As suggested by Hammer and Champy (1993), integration of many cross-functional tasks is the key for redesigning enterprises. Since processes may cross several functional borders, general OM models and principles would be relevant in many business functions where the design of a process, simply the identification of how and what to do in order to achieve outputs, is required. As shown in Figure 5, this perspective places OM's role at the center of the organization and extends the scope of OM applicability across finance, accounting, R&D, marketing and sales. This integral approach to the organization has already produced significant productivity improvements within organization-wide activities. A good example would be the integrated product teams, commonly used in manufacturing where employees work together as a team from the design stage to the delivery of the product to the final customer and even the provision of after-sale services.

Adoption of a cross-functional structure along with the emergence of process-oriented organizations attempts to reduce the gap among the functions of an enterprise. A

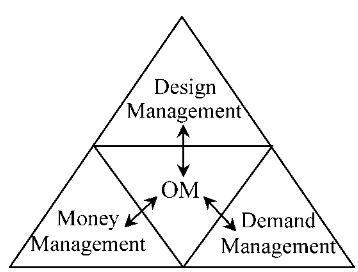


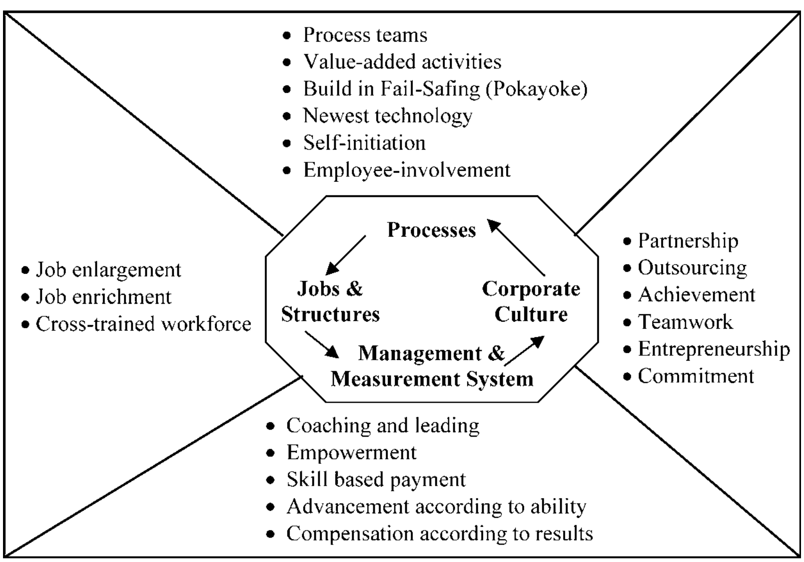
Figure 5.
Typical organization – present

process-oriented approach necessitates substantial changes in the enterprise model. According to Hammer and Champy (1993), a process redesign triggers the changes in other components of the business system including jobs and structures, management and measurement systems, and corporate culture. Largely drawing on the business system diamond framework developed by Hammer and Champy (1993), Figure 6 illustrates new features of the work system elements in OM. Since the processes are essential parts of OM, possible changes in the work system elements in Figure 6 are also essential for every successful OM application. For instance, operator involvement is key for maintenance, fail-safing (Poka-Yoke) and process teams reshape how quality should be maintained while inspection and quality control are replaced by quality assurance systems, partnership and outsourcing programs for procurement.

4.3.2 Concepts/tools. The latest technologies and philosophies have enabled OM to come out with new models for effective management of the organization. The most prominent of these models mainly attempting to integrate the functions of the organization are ERP, CRM, SCM, SRM and KM.

ERP aims to seamlessly integrate the functions of an organization under unified software and a centralized database where various departments can more easily share information and communicate with each other. ERP comprises modular solutions that enable performance improvements in most transaction processing activities of a company (Scott, 1998).

With the contribution of technological innovations and popular process-oriented foundations for the enterprises, relationships among the participants of a supply chain need to be restructured. SCM reduces inefficiencies in supply chains through better materials, information and cash flows management between suppliers and customers. It involves effective anticipation of customer demand, optimal positioning of resources commensurate with this demand and its efficient fulfillment. While enterprises get leaner, benefits through possible enterprise-wide productivity improvements have become marginal. However, better coordination of activities among the participants of



Source: Adapted from Hammer and Champy (1993)

Figure 6. New features of the work system characteristics in OM

supply chain still offers incredible opportunities for improvement for all the parties involved.

CRM is a strategy that is used to learn more about customers' needs and behaviors in order to develop stronger relationships. It becomes much more cost-effective to retain an existing customer than to attract a new one. CRM applications can be used to provide customized product offerings, marketing campaigns and an additional communication channel via the Internet. Richer marketing strategies and sales tactics predicated on better data, along with superior customer service may lead to increases in top-line growth and profitability.

SRM is a recent complementary tool to improve the integration of the organization and to better manage its interactions with the suppliers by building valuable relationships. A well-managed supplier relationship provides organizations with strategic competitive advantage in terms of cost, productivity, quality and competitiveness through closer, stronger and more dependable supplier relationships. Traditional short-term, cost-driven buyer-supplier relationships have been superseded by long-term, co-operative strategic partnerships through advanced information sharing systems. This movement compels organizations to monitor and gather information about the financial position, profit and loss sharing strategies and joint decision-making plans of their suppliers. The suppliers which have a dominant position in product development costs, stock levels, production schedules and the timely delivery of the materials and services are critical for financial position and profitability of the organizations.

KM provides the solution to access and collect data for decision-making. Data mining (DM) and knowledge discovery (KD), which has been defined as "the nontrivial extraction of implicit, previously unknown, and potential useful information from data" (Frawley *et al.*, 1992) is applied to discover and present knowledge in a comprehensive form.

4.3.3 Philosophies/approaches. Severe competition and fast changing customer needs require enterprises to become leaner and more agile in order to better respond to the fast changing market conditions. Lean production, agile manufacturing and mass customization, as illustrated in Figure 7, emerge as some of the main philosophies and approaches discussed during the present period.

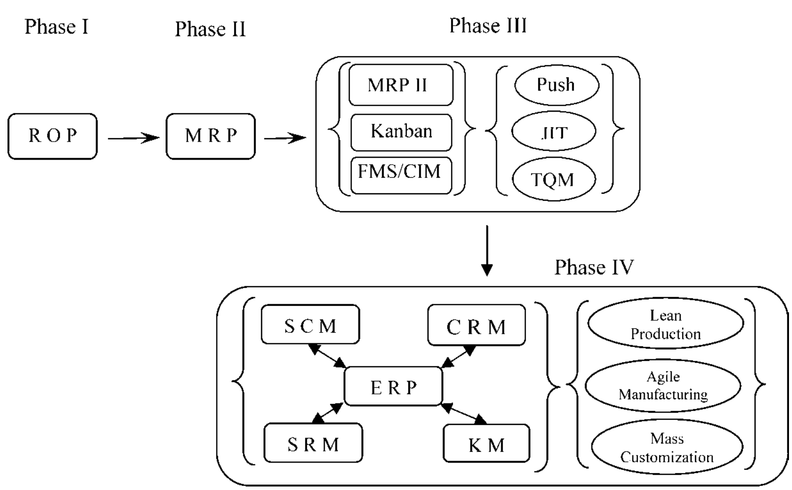


Figure 7. Evolution of OM – present

Lean production is an approach that eliminates waste by reducing costs in the overall production process, and in the utilization of production labor through continuous improvement process (Womack *et al.*, 1990). It focuses on the value stream a product follows through manufacturing, eliminating non-value added operations such as storage, transportation and inspection.

Agility is the ability to thrive and prosper in an environment of constant and unpredictable change (Gunasekaran, 1999; Sarkis, 2001). The swift trend toward a multiplicity of finished products with short development and production lead times has led many enterprises into problems with inventories, overheads and efficiencies. Agile manufacturing implementation requires that the company already be a world class manufacturer that uses lean manufacturing methods. Some important aspects of agile manufacturing are: customer relationship, management of people and information, cooperation within and between firms, and adaptability for change (Sharifi and Zhang, 1999).

Initiated by the idea of combining the best parts of craft and mass production, mass customization involves the production and delivery of a wide variety of customized goods or services on small quantities with perfect quality at low cost and on-time (Simchi-Levi *et al.*, 2003). Since the mid-1990s, it has been successfully implemented by organizations such as Dell Computers, Motorola, IBM, Proctor and Gamble, General Motors, Ford and Hewlett-Packard (Selladurai, 2004).

Postponement is one of the main approaches to realize mass customization along with part, process, product and procurement standardization. Postponement or delayed differentiation is a concept to finalize the production or delivery of the products/ services until the customer order occurs. Strategic partnership and supplier integration, modularity in products and processes, effective and rapid integration are essential organizational strategies for the successful implementation of mass customization (Selladurai, 2004). As Van Hoek (2001) states, postponement needs to focus on whole supply chain rather than only on production or delivery channels. Global supply chains and service chains as well as customization in these settings warrant some interesting areas for future research.

4.4 Research themes

OM permeates the lifecycle of a product from inception to retirement of a product. OM models for Product Life Cycle Management include cross-functional areas of product innovation management, product family design, design repositories, lean principles, extended enterprise product change management and virtual factory simulation models.

Recent OM models have also expanded considerably into services (Johnston, 1999). Chen *et al.* (2000) and Beamon (1998) state that there is a considerable interdependence between areas of operations and logistical requirements, and the complexity of future logistics will require innovative arrangements. They also point out to the significant trade-off that exists between manufacturing economies and marketing requirements. These can be reconciled only by a soundly designed logistical capability.

Integration issues in SCM, operations strategy, quality and global offshore projects are some popular topics of research. Along with time, issues related to growth of the service sector, productivity changes, global competitiveness, quality, time, technological changes, and continuous improvements are also addressed in today's OM models (Nof, 1999; Krajewski and Ritzman, 2002).

Several OR concepts traditionally known for OM have also found their way into many other functional areas such as marketing, accounting and finance in the earlier decades. For mathematical models, LP still remains an effective technique to solve a variety of planning problems. Constraint programming also evolved from problems in which the availability of resources is constrained and real-time scheduling decisions are required. These practices of the past along with growing pressure for integration during the present decade gave rise to the inter-disciplinary research and helped explicit recognition of decentralized locus of control and local incentives (Chopra *et al.*, 2004).

In updating the study of Amoako-Gyampah and Graham (1989), Pannirselvam *et al.* (1999) first defined a way to include the new topics under the original ones (see Table I). They considered new product development under the captions of scheduling, quality and strategy based on its orientation. Similarly, SCM was included under the captions of strategy, purchasing and distribution. Their findings show significant changes in research undertaken throughout the 1980s and 1990s. In contrast to the 1980s, strategy and quality issues gained popularity, while research on OM has become more integrative (Filippini, 1997). In their factor analysis of citation/co-citation of the extant literature, Pilkington and Liston-Heyes (1999) noted following concentration areas for OM over the mid-1990s: manufacturing strategy, Japanese systems, performance measures and best practices. Researchers have highlighted the distinctions between North American and European researchers in terms of their research priorities (e.g. Filippini, 1997; Pilkington and Liston-Heyes, 1999). North American researchers focused more on modeling and simulation of the systems, while European counterparts focused heavily on survey- based research for theoretical concepts. Empirical studies in OM have also increased (Scudder and Hill, 1998). Table II provides a summary of highly cited studies on 17 research topics along with the present concepts/philosophies.

5. Operations management – future: the post-information era

At present, globalization has had great influenced on the business world. Over the decades since its formation, the field of OM has been undergoing a continuous change and has included subject areas extending the frontiers of operations functions. The challenge of defining OM boundaries OM still remains an issue. Efforts to integrate organizational business functions and supply chain organizations over the last decade may be expanded into integrated e-business applications through implementation of new technologies. It is envisaged that OM models will play a major role in manufacturing and service industries along with e-business applications. Enabling technologies, new customer requirements arising from new advancements, new performance measures in addition to speed, timeliness and responsiveness of the past, may have all their own contribution to the expansion of the OM field. According to Hayes (2000), the best way to have an idea about the limits of OM is to look at the real problems of operations managers and study what they do everyday. This observation leads to the need for tighter integration among different functions and well-developed inter-disciplinary system solutions. Although there are many good local solutions developed for many functional domains, we still strive to come up with a "good enough" global system solutions.

5.1 Environment

Rapid technological advancements provide operations managers with tremendous opportunities for improvement. Pressure of intense competition requires organizations

Topics	Concepts/philosophies	References
Inventory control	ERP, SCM	Lee and Billington (1993), Inderfurth and Minner (1998), Glasserman and Tayur (1995)
Aggregating planning	Mathematical model	Nahmias (2005)
Forecasting	Mathematical model, SCM	Aviv (2001), Lee *et al.* (1997)
Scheduling	Mathematical model	Pinedo (2002)
Capacity planning	Mathematical model, agile manufacturing	De Matta *et al.* (2001), Bretthauer and Shetty (2002)
Purchasing	SCM	Tan *et al.*, (2002)
Facility location	Mathematical model	Syarif *et al.* (2002)
Facility layout	Mathematical model, SCM	Syarif *et al.* (2002)
Process design/technology	KM	Ali and Chen (1999)
Maintenance	KM, CRM	Skormin *et al.* (2002)
Quality	TQM, KM, CRM, Six Sigma	Saxena (1993), Ahire *et al.* (1995), Harry and Schroeder (2000)
Work measurement	Lean manufacturing	Kroll (1996), Neely *et al.* (2005), Neely (2005)
Strategy	SCM, Green SCM, E-Business, New product development	Ward *et al.* (1998), Sarkis (1999), Narasimhan and Kim (2002), Cagliano *et al.* (2003), Sarkis (2003), Krishnan and Loch (2005), Gunasekaran and Ngai (2005)
Distribution	ERP, SCM	Fustar (2001)
Quality of working life	Human management, SCM	Lau (2000)
Project management	TQM, SCM	Kerzner (2006)
Services	JIT	Duclos *et al.* (1995), Johnston (2005), Machuca *et al.* (2007)

Table II.
Major research areas of OM – present

to seek out new tools for handling their current processes and also gaining access to new markets. Globalization opens up new horizons for businesses through new business models (e.g. e-commerce-based B2B and B2C relationships). A rapidly changing business environment requires close and swift interactions among an organization's stakeholders to better understand the market. Different communication means and standards to enhance mutual benefits of stakeholders will be the underlying characteristics of the future environment.

Similar advancements are also likely to occur in manufacturing facilities. More functional machineries with smart features such as self-scheduling and self-maintenance may characterize manufacturing cells of the future. With shorter product life cycles and growing need for mass customization, better project management skills are likely to be essential asset for human resources of the future.

5.2 Organizational structure

A possible future organizational structure and its work environment are delineated in Figure 8. A future organization will focus more on their core competencies. Outsourcing and partnership will be a common practice for many traditional in-house activities. Most likely, an organization of the future needs to focus on a few of the processes as shown in Figure 8. Many of the processes will be performed by specialized "supply network" members. While this trend has already been widely observed in some

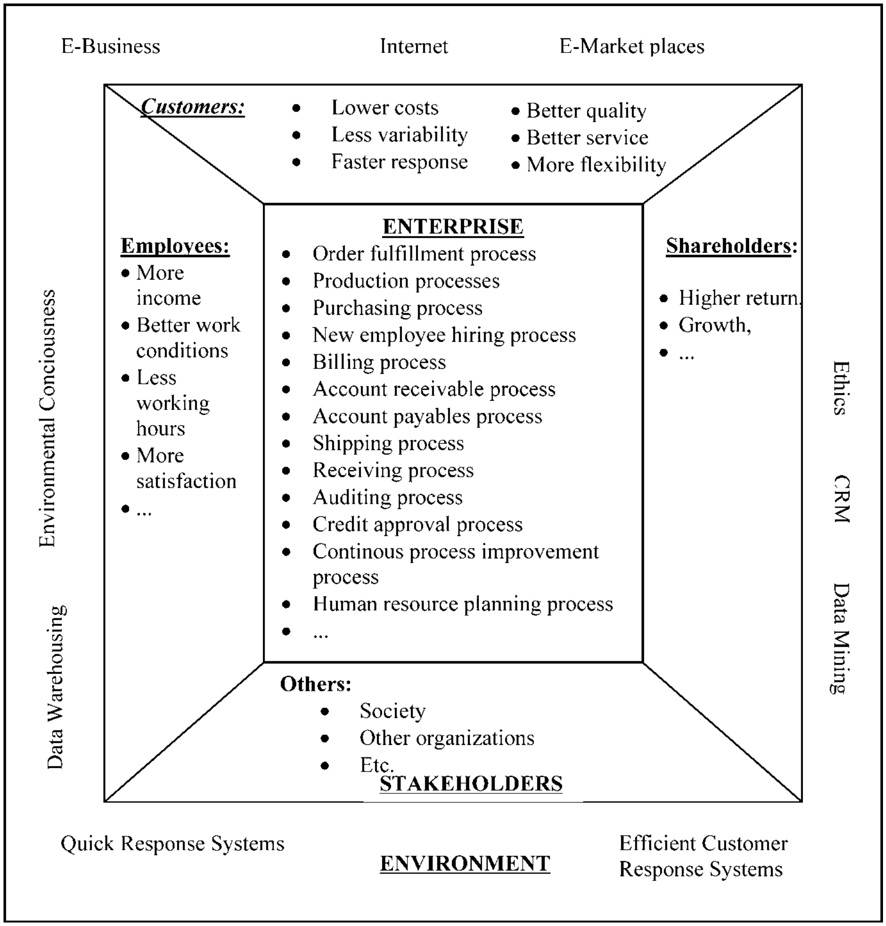


Figure 8.
Organizations in the future

areas such as human resources, auditing, accounting and logistics, it may also be extended to non-traditional areas including marketing, sales and R&D.

5.3 Challenges

According to Russell and Taylor (2006), the challenges that organizations are facing at present are wide ranging and include: intense competition, global markets, global sourcing, global financing, global strategy, enhanced product variety, mass customization, service businesses, quality improvement, flexibility, advances in technology, employee involvement, environment and ethical issues. Therefore, an organization should make use of strategies and technologies to form a virtual organization, in which participants collaboratively respond to the unexpected changes in customer demand in a more agile manner. Agile organizations require faster and leaner processes. As virtual organizations are considered to be a dominant form of future organizations, the following research themes may be proposed related to its formation:

- developing flexible knowledge supply chain to enable mass customization of products and services;
- forming cross-border alliances with enterprises to broaden product-line or fill product-line gaps;
- developing benchmarking for entrepreneurial smaller business to join supply network;
- enabling seamless integration of multiple, distinct business entities by using modern information technology;
- integration of 3-D human models to simulate the workplace safety, agility will also play a role in factory layouts, product design, production and maintenance.

To achieve these objectives, OM should address these topics as the field.

5.4 Agility and built-to-order supply chains

Within the evolving economy, a burgeoning of e-organizations and agility, have become a new competitive strategy (Dove, 1999). It is not an easy task to cope with the speed and depth of change in every aspect of an organization. As seen in Figure 8, KM is one of the enabling technologies for agility, but not the only one. Organizations need to be lean enough and capable of adapting to the changes quickly. Along with the competitive priorities of today such as cost, quality, delivery time and flexibility (Ward *et al.*, 1998), agility with some solid measures appears to be a new addition to the list.

The built-to-order supply chain (BOSC) concept is introduced for increased degree of flexibility and responsiveness to changing market/customer requirements (Gunasekaran, 2005). In a built-to-order environment, parts and components are ready to be assembled for order and there is no finished goods inventory (Gunasekaran and Ngai, 2005). Information technologies through the Internet and close supplier partnerships are essential for quick and flexible response to the customers by real- time information sharing. Implementation of BOSC requires significant investment in the areas of the redesign of organizational and technical processes, the distribution channels and customer service procedures, and training of the staff (Gunasekaran and Ngai, 2005).

5.5 Extensions to ERP and SCM: ERP II

Blackburn (1991) has argued that time-based competitors should focus on the bigger picture, i.e. the entire value delivery system, in order to transform the entire value chain into a single organization emphasizing the total time required to deliver a product or service. Other than intra-organizational integration through ERP packages, inter-organizational integration by using the SCM models has also been implemented. This integration may improve enterprises to act on information in a timely manner. Development of distributed simulation models will be highly useful in the analysis of global supply chains, which include factories and warehouses linked each other through alternative transportation and planning methods. As bigger enterprises will evolve to adapt to the global changes, medium and smaller size enterprises will continue to push to become a part of this global enterprise.

Under the imperatives of the "new economy", the Internet as a business medium will require extension of ERP into ERP II in order to integrate the organization's internal business processes with those of its customers and suppliers (Beheshti, 2006). The fundamental benefits of ERP systems stem from their efficient transaction processing abilities through organized record keeping structures other than their planning capabilities (Jacobs and Bendoly, 2003). Current ERP systems provide an information infrastructure as a backbone for businesses to apply many new techniques, concepts and strategies. Through E-business systems and business intelligence techniques such as DM, how to extend the functionality of ERPs in order to increase the competitive advantage of the future organizations represents a true challenge for researchers.

A properly implemented ERP system also facilitates to attain the level of effectiveness expected from "new economies" such as B2B e-procurement (Bendoly and Schoenherr, 2005). As shown in Figure 8, ERP will have a major role for any organization in the future, but these new work and organizational-based approaches need to be researched extensively (Dery *et al.*, 2006).

5.6 Globalization

The vision of the future for many organizations involves designing production lines that can seamlessly change over to new product models anywhere in the world, while meeting changing consumer tastes. Organizations with a well-structured global supply chain will have a competitive edge over their rivals. Designing, producing and manufacturing in different countries, while distributing and serving worldwide create a new dimension for OM models. Sound logistics models that are interconnected with the ERP and SCM systems will become new tools to address the imperatives of globalization. The global distribution of manufacturing resources and expanded supply networks will challenge information systems to maintain operations under control. Under the globalization phenomenon, the virtual presence instead of the physical one should be seriously considered when designing supply chains. Several organizations or individuals will form virtual organizations by combining their area of particular expertise with the complementary expertise of other partner companies, to co-operate for a particular mission that no single enterprise or individual alone could handle. As a matter of fact, retail markets and many services are already becoming virtually available around the world.

5.7 New product/service development

Shortening of product life cycles and proliferation of customer needs and preferences make new product and service development (NPD-NSD) a current key success factor for most companies. Traditionally known as a creative and very innovative process, NPD-NSD can be defined as a set of activities that start with responding to a market opportunity and end with the delivery of a differentiated product or service (Krishnan and Loch, 2005). Despite its significance, there is a paucity of research in the area. The following areas deserve the attention of researchers: developing research frameworks of what technology and NPD-NSD strategies are; connection between technology strategy and NPD-NSD operations; idea generation process and alternative NPD-NSD processes (Krishnan and Loch, 2005).

5.8 Outsourcing and extended leanness

Outsourcing has been called one of the most important management ideas and practices of the last 75 years (Sibbet *et al.*, 1997). More companies are now relying on outsourcing their non-core business processes and several back office operations to third-parties in order to focus on their core businesses. For example, third-party logistics (3PL) companies provide services on purchasing, logistics and the more mundane aspects of product design and repair. In effect, they want to become operations-for-hire for technology industry leaders. It is no longer about making inexpensive products. Instead, it is about creating more and more high-value functions for the organization. Furthermore, fourth party logistic (4PL) companies acting as coordinators are able to provide supply chain wide solution by incorporating the resources and expertise of many 3PL contractors (Rushton *et al.*, 2006). Even though there is a dearth of applications of 4PL currently, it may be envisaged that 4PL applications will play an important role in future organizations. Emergence of new OM models and the extended lean models will also address uncertainties related to supply interruptions through political, economical and natural disaster scenarios.

5.9 Open vs closed loop

OM has primarily dealt with open systems where information and material was assumed to have a one-way flow. However, the functions of an enterprise integrated with ERP systems are connected to several enterprises by SCM systems, and the whole information system has now become a closed loop. Future OM models should address the closed loop models. Vast amounts of data are being collected at every stage of the process including the final point-of-sale. This information has to be analyzed and fed back into the system. KD and DM are the research tools that will help us model the complete dynamics of this closed loop system. These approaches will be used for forecasting, planning, scheduling, production and very complex large-scale combinatorial problems. With the interconnection of several enterprises, the intention is not to solve these combinatorial models but to develop a system equilibrium based on pre-specified policies. Instead of developing individual optimization models, future OM models should focus on taking large-scale average of system equilibrium at the macro-economic level.

5.10 Real options analysis

Real options analysis (*Business Week*, 1999) is an emergent tool from finance. OM can utilize the concepts of real options in future models to predict various organizational dynamics. The earliest applications of real options have been in oil, gas, copper and gold, where companies in these commodity businesses are also among the largest users. The extension of real options into the rapidly changing industries of biotechnology, pharmaceuticals, software and computer chips are important areas for research.

5.11 Green supply chain management: environmentally conscious policies and ethical issues

Environmental issues are becoming more and more restrictive for producers. Some of the challenges facing companies at present are using recyclable materials, recycling the final products, disposal of industrial waste, managing reverse logistics flows, green consumerism and green product development. From marketing and manufacturing to human resources and information technologies, almost all functions of an organization are under pressure to become environmentally sound (Sarkis, 1999; Zhu and Sarkis, 2004). Managing reverse flows with recycling effectively using reverse engineering principles will have a clear impact not only on logistics but also on sales and marketing, and new product development. New product designs should take into consideration the new concepts such as design for the environment and design for disassembly. While products become more globally focused, there is an increasing need to implement environmentally friendly policies along with the supply chain models. Management of green supply chains may be influenced by product life cycles, organizational value chains (including green purchasing/procurement, production, distribution, reverse logistics and packaging), environmentally conscious business practices (such as leanness, re-usage, re-manufacturing, recycling and disposal) and organizational performance measures (Sarkis, 2003). While standards like ISO 14000 may lead to more strict measures on environmental policies, total quality environmental management needs to be improved as an organizational goal (Sarkis, 1999). Thus, political and ethical concerns in terms of production and sales of goods and services become an inevitable part of marketing strategies.

5.12 Contemporary performance measurement systems

Performance measurement is a process of quantifying the efficiency and effectiveness of action (Neely *et al.*, 2005). From the viewpoint of systems thinking, a performance measurement system defines a set of metrics used for performance measurement, which is the essence of OM, provide an excellent survey of the studies on performance measurement by the mid-1990s. Performance measures traditionally used by the manufacturers are inappropriate, as these measures encourage short-termism, local optimization and variance reduction rather than improvement, and they also lack strategic focus and fail to provide information on customer needs (Neely *et al.*, 2005). Over the last decade the field of performance measurement is dominated by the balanced scorecard (Kaplan and Norton, 1992). Thus, there is a need to extend the framework with a "predictive performance measure". Identifying and developing such measures and further incorporating the measure to existing framework can be one important future research direction (Neely *et al.*, 2005). Developing dynamic measurement systems rather than static ones focusing on enterprise and/or supply networks performance management is necessary. The supply-chain operations-reference model has been suggested by Supply Chain Council to measure supply chain performance with extensions in this direction recommended (Lambert and Pohlen, 2001).

There is no unified and well-accepted set of measures to assess every facet of processes. For service industries at present, classical waiting line theory is far from being satisfactory, since the technology has changed the way how the things are done. For example, Internet and electronic-auctions are already used in the design of marketing channels and pricing strategies. Instead of pre-arranged prices, future organizations should use real-time decision tools (e.g. dynamic pricing engine) to offer the customers more competitive quote for the service or product. These new means of negotiations enforce OM to develop more composite models to measure the performance of processes.

Classical areas of OM, such as location and layout theories, have been affected by off-shore contracting. Technological innovations diminish the relative importance of distance. Performance measures through call-centers, web sites and home-delivery systems will spur new models of OM in service industries. Traditional make or buy models will have to be extended or modified to examine the advantages and disadvantages of off-shore projects.

The diminishing role of functional departments and increasing popularity of process-oriented philosophies would introduce new missions to facilities planning performance criteria. Also, commensurate with increasing emphasis on human resources and implementation of ergonomic norms along with industrial psychology is likely to be new focus of layout studies.

Traditional performance measures developed for human resource productivity may prove inadequate in future processes. Assessment of the people's capabilities, measuring and managing the intellectual capacity and overall compensation of human resources are potential avenues for future research.

5.13 Collaborative commerce and advanced information technology

Collaborative commerce specifies a set of techniques allowing companies to better manage their extended organization. The strategies in collaborative commerce involve not only coordination of multi-disciplinary personnel but also information management across every phase of a process. Over the last two decades, computer-based information management tools have been introduced to facilitate the communication among extended organizations. As the Internet and distributed computing technology progress, novel distributed platforms including remote repository, remote web services and agent technologies have evolved to enable globally distributed collaboration.

As a business process, e-business applications rely heavily on the Internet to complete business transactions. Internet influences the usage of supply chains by facilitating the implementation of ERP and advanced planning tools, being able to reach the real-time information, and integrating the information across functional business units (Swaminathan and Tayur, 2003). In order to gain these capabilities, many organizations attempt to involve with e-business applications. Adaptation of Internet technologies into supply chain processes may take the forms of e-commerce, e-procurement and e-operations. There is a close link between the use of Internet tools and the level of integration with customers and suppliers (Cagliano *et al.*, 2003). Four different types of Internet adoption can be identified: traditionals (no relevant use of Internet-based technologies within the supply chain), e-sellers (adopting Internet mostly for sales and customer care), e-purchasers (adopting Internet only for one upstream process, namely purchasing) and e-integrators (full fledge adoption of Internet). This is an indication of incremental adaptation of Internet technologies, and shows the progress level on e-business implementations. Real-time supply chain models on product life-cycle management, dynamic pricing and production coordination, integrated models of marketplaces, coordination of Internet and traditional channels are likely to be the significant areas for future applications.

5.14 Forecasting

Demand forecasting is critical for the order fulfillment process which requires implementation of proper inventory policies, adequate planning systems and right facility capacity. In such a world where a lean philosophy is an emergent business practice while technology leads the competition, there is a growing need to reconsider basic assumptions of forecasting. Since costly resources and reduced product life cycles make "holding inventory" unfavorable, prediction of future demand becomes more important. On the other hand, new technological capabilities such as the Internet and DM enable to better predict customer behaviors, which eventually lead to more accurate forecasts. All these changes will shift the focus of forecasting from short-term operational policies to foreseeing the future business areas and opportunities. A number of new techniques like *N*-dimensional market visualization techniques, innovation modeling and early technology impact forecasting methods will find their way in forecasting.

5.15 Operations strategies

Historical development in the area of operations strategies moves mainly from "how to produce" through "how to sell" to "how to be demanded". Under the process-oriented approaches associated with technological innovations, it is not surprising for future operations strategies to focus more on "how to design creatively from concept to sales in an integrated fashion". In the case of online software sales, some of the value chain activities such as packaging operation, holding inventory and classical distribution channels are eliminated. In addition, since the product can be updated more frequently, the risk of shorter product life cycle is reduced.

Another challenge for operations strategies is to find a resolution among the different set of processes with conflicting objectives in the realization of organizational targets. Traditional OM models addressed this conflict through zero-sum game theory models associated with profit levels, stakeholders' value and few other entities. The models of future will include additional composite measures based on environmental policies, agility and sustainability of the company in the future and efficient use of scarce resources.

5.16 Service operations management

A service is a time-perishable, intangible experience or activity performed for a customer acting in the role of co-producer (Fitzsimmons and Fitzsimmons, 2006). Services (SOM) represent the majority of economic output but they have seen relatively little OM research (Machuca *et al.*, 2007). Service operations management (SOM) has been cited as one of the popular research topics of the future since the 1980s. The empirical studies show some progress but with ample room for significantly more emphasis. "New economy" applications may help SOM research to gain some ground. In addition to B2B services, non-profit organizations place an incredible opportunity for SOM and OM (Johnston, 2005). Main research areas include: linking operations performance to business drivers; performance measurement and operations improvement; guarantees, complaints and service recovery – tools for improvement; people management; service design; service technology; the design of internal networks; the service encounter; managing service capacity (Johnston, 1999).

5.17 Supply chain risk management

Managing risk has become a critical component of SCM due to severe crises. In addition, the risks can be costly and lead to significant delays in supply chain. Due to the complex and dynamic nature of supply chain and uncertainties inherent in such systems, supply chain risk management may serve to be a challenging task. Uncertainty exists in demand requirements, capacity, delivery time, manufacturing time and cost (Taylor and Brunt, 2001). The detrimental effects of uncertainties may be compounded by inefficient operations in manufacturing systems, production policies and inflexible process changes. There are a number of tools for managing such uncertainties such as Theory of Constraints for improving production efficiencies Goldratt and Cox (1992), accurate response (Fisher *et al.*, 1994) for improving forecasting accuracy and multi-channel manufacturing (Kulonda, 2002) for managing demand fluctuations. Though promising, most of the tools offer only point-based solutions that deals with a limited set of risks. Therefore, there is a need to develop a comprehensive risk classification system, which lists risks based on an extensive review of the literature and interviews with industry practitioners. A rigorous methodology is then required to evaluate the risk factors provided by the risk classification system.

6. Conclusion

The field of OM needs to continually monitor its research base against evolving industrial realities. The core of OM, however, will continue to remain with the design and management of the transformation processes that create value for organizations and society. Operations will still be a human organization which converts ideas for products into reality from raw and recycled materials. However, organizational functions will be decentralized and yet so highly integrated that they will function concurrently as virtually one entity which links customers to innovators of new products and functions. The form and identity of companies will be radically changed to encompass virtual structures that will coalesce and vanish in response to a dynamic marketplace. OM models to be developed for future organizations are expected to address each one of the following issues, which include synthesis and architecture for converting information into knowledge; unified communication methods and protocols for the exchange of information; adaptable and reconfigurable manufacturing processes and systems. It is envisaged that a focus on the issues central to OM will soon propel both researchers and industry practitioners beyond existing technologies and provide the catalyst for developing new ones.

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