

THE GLOBAL IMPACT OF INFORMATION TECHNOLOGY ON MANUFACTURING SYSTEMS

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This paper explores the recent trends of research and development in modern manufacturing systems. Those trends happen to direct the business activities of this sector towards the globalisation of the usual markets and the creation of a new virtual, agile, and extended production environment whose purpose is to ensure fast, responsive, and adaptable reaction to the new market conditions. This paper also attempts to investigate the implications and consequences of the new trends on emerging and developing economies.

1. INTRODUCTION

It is clear that the last decade of this century has been witnessing the emergence of economic globalisation, a phenomenon where different economies are merging into a unified global market. This matter has been of vital importance to the advanced industries whose objectives are to expand their markets and to sustain growth by looking for new opportunities worldwide. On the other hand, it created a new challenging environment for developing and emerging economies as well as their industries, which have become obligated to face such immediate changes in the new environment. Hence, getting to know those global trends in all their aspects, especially in the sector of manufacturing, becomes of paramount importance for local producers in those economies to cope with these changes and to build the necessary infrastructure that ensures their progress and sustained growth within this new atmosphere of globalisation.

This inevitable process of transformation into globalisation, put on a fast track, can be thought of as the combination of the following three main factors:

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- The wide proliferation of information technology,
- The development of international standards for product quality and performance, and
- The emergence of regional and worldwide trade agreements that yield larger markets with consumer-dominated characteristics.

This paper intends to describe how these factors are exerting significant pressures on international manufacturers to cooperate for the development of new strategies for global competition. It describes as well how these cooperative efforts are making effective use of the strategic tools of information technologies and knowledge-based systems to form multinational enterprises. Such an initiative has been provoked by leading international industries and is focusing on the efficient use of computer and telecommunication technologies such as the Internet, world-wide web and teleconferencing in order to enable the realisation of a virtual work environment. The main theme for these cooperative ventures is based on seizing new market opportunities fast, at lowest cost and with minimum organisational complexity. This has led to the new concept of “agility”, which is the characterisation of a virtual work environment being highly responsive, rapidly adaptive, and significantly intelligent, using a very advanced wealth of innovative technologies. This new environment has been realised in what is called the Agile Virtual Enterprise (AVE).

The next section presents a partial look at the various sources of data and the literature about AVEs and their characteristics. Section 3 elaborates further on the drives of change towards globalisation, and definitions for AVEs, agility, and their characteristics are given in section 4 and a brief description of the prerequisites for the agile environment is presented in section 5. The information infrastructure necessary for AVEs and the new concept of “smart agents” and their role in the corresponding virtual system are exposed in section 6. Section 7 addresses the implications of the new era on developing countries as well as some necessary measures they can take to follow the new trends. The paper concludes with section 8.

2. SOURCES OF DATA AND LITERATURE

Most of the sources of data and information about the topic of agility and AVE have been identified by surfing over the Internet for various

sites on relevant interest. This search showed that the topic of agility has been a hot area for research and investigation over the last few years due to its significant benefits to global businesses. It also showed how those benefits have been pushing major international manufacturers from different parts of the advanced world to join their efforts in this investigation and what implications agility can have on their activities.

An important such effort was realised in the grouping of several international industrialists in what is called the Intelligent Manufacturing Systems programme (IMS). This was established in 1995 by leading producers from many international industrialists whose main objective was the preparation “for the next generation of manufacturing technologies and systems through cooperative research and development, by encouraging projects into all aspects of manufacturing”[3]. A report of one such project was about the “next generation manufacturing systems” that proposed a new paradigm on how manufacturing would benefit from the leveraging impact of information technologies as well as other key technological developments [11].

Several web sites on the Internet have been continuously presenting relevant reports, discussions, papers and presentations about agility and agile virtual enterprises. A partial list of those sites from which valuable data were derived and incorporated in this work is given in the references. These sites belong to organisations, forums, journal publishers, electronic libraries and others, where search engines are used efficiently to identify objective information.

Finally, divers literature about agility and related topics is referred to in the body of the paper. The main observation in this literature inspection is the explosive flourishing of academically refereed journals in the area of agility, which is a clear indication of the vast interest in doing research in this area and investigating further the characteristics and benefits of this new era of agile manufacturing.

3. GLOBAL DRIVERS OF CHANGE

The new business environment that major manufacturers and industrialists faced over the last decade was the era of globalisation. It has been established through several dimensions, among which were [13]:

- The open markets and regional economic coalitions that result from regional and worldwide economic cooperation agreements, especially those of GATT and its inheritor the World Trade Organisation (WTO). This spurred growing and serious competition worldwide and contributed to the fragmentation of the classical mass production markets.
- The mass customisation of the product as a result of constantly evolving customer's expectations and requirements. This changed the product into something more sophisticated which could be viewed as a solution rather than just a commodity for consumption [14].
- The universal access to information and widespread know-how through the Internet provided manufacturers easier access than ever to new markets and enabled customers to look for alternatives to the products they needed using high speed search engines.
- The expansion of available new technologies worldwide that is accelerating the pace of global competition. This has been forcing international producers to heavily invest in research and development and to look for means and solutions that maintain their survival among the fresh, burden-free new manufacturers in the world.
- The vast proliferation of telecommunications that tied different societies together and forced the emergence of new consumer attitudes and consumption habits.

Such new trends towards economic globalisation forced manufacturers to strive for survival and search for opportunities for growth through keen self-adaptation to the changes. The strategy that global manufacturers came to agree upon as a solution to the new challenges was "cooperate to compete" in coordination with partners scattered all over the world. This has led to the formation of think-tank consortiums of researchers as well as academics in giant producers who joined their efforts for the objective of accommodating new technologies into the business environments, namely information and knowledge based technologies.

On the other hand, this evolution towards globalisation exerted pressure on producers to set objectives concerning their global business activities such as:

- Cutting costs of production and operations while improving the quality of the globally-marketed product.
- Responding fast to the continuously changing customer needs and providing immediate support to new and emerging markets, where prompt delivery and shorter lead times are important factors to win new customers.
- Reducing risks in a world of fierce competition in continuously changing, highly segmented, customer-dominated markets full of unexpected and unpredictable courses, and aiming to benefit from these trends and to seize further opportunities.
- Accessing crucial information and extending the knowledge base using the recent advances in information technologies and artificial intelligence systems.
- Accelerating the pace of developing and deploying new products with highly flexible and easily reconfiguring manufacturing systems.

To help in adapting to these pressures, producers sought integration of efforts with global partners. Such partners could be members of a vertical integration through the supply chain of the products where suppliers, distributors, and customers cooperate in the product design and production processes. Partners could as well be competitors who would like to broaden their global share through profound horizontal cooperation for the common cause of survival and growth (mergers, take-overs). Expansion could be even as simple as penetrating new markets through the establishment of franchise partners worldwide.

This drive towards globalisation necessitated the existence of a solid infrastructure of telecommunication network and especially the extensive use of the Internet due to its capability in facilitating the fast flow of shared information among partners and with customers in a more collaborative environment than ever [2]. On the other hand, speed, flexibility, openness, adaptability, responsiveness and scalability became key factors for success for such collaborating infrastructure. This has led to the emergence of the agile virtual enterprise.

4. DEFINITION AND CHARACTERISTICS OF AN AGILE VIRTUAL ENTERPRISE

This is a new form of global manufacturing ventures that seeks collaboration and cooperation between partner companies in order to

integrate their capabilities and resources in an international business context. This coalition is viewed as “an opportunistic aggregation of entities working toward a common goal” [9]. It appears as a single entity, but in fact it consists of many, legally separate partners bound together by occasional contractual agreements. The partners in such an enterprise communicate in a virtual work environment based on “collaborative computing” [15], which is the integration of strategic technologies permitting communication to any place, at any time, on a totally shared information and knowledge-based infrastructure.

Agility, on the other hand, provides the unprecedented flexibility of adding, substituting or deleting services of partners at any time. This also means the possibility of either dissolving or reconfiguring the enterprise in accordance with changes in the business environment, only for the purpose of increasing its capacity in the market.

Agility is ideally obtainable in dynamic, highly customised markets where a manufacturer cannot just rely on long-time suppliers and neglect other resource providers competing worldwide with better quality, lower price, and faster delivery. Establishing relationships the usual way with new suppliers can take forever compared to the rapid and swift customer behaviour. With the use of the Internet, worldwide electronic commerce has increased the potential for finding highly efficient suppliers, as well as looking for new customers, while contracting is becoming smoothly rapid with the use of electronic mail technologies. Desktop conferencing and multimedia tools have been providing real-time conferencing where participants including producers, suppliers, and customers are getting involved in designing and developing new products. Monitoring the production process on-line has also become highly accessible to clients who wish to check the whereabouts of their orders with the use of information navigators. Third party brokers are having their jobs of matching customers with producers and producers with support service-providers amply simplified through the world-wide web. All of this favoured the perception of agility as “a strategy for profiting from rapidly changing, continuously fragmenting global markets for (consumer) ‘individualisable’ relationship based on products and services”[1].

Agile virtual enterprises are therefore manufacturing alliances that pay little attention to legal bonds, but rather focus on “integrating many businesses and processes with mechanisms that are capable of rapidly changing to unpredictable and unexpected directions” [4]. This new

paradigm of collaborative environment provides each member in the coalition with more readiness to contingencies and brings together their core competencies and associated resources to address new business opportunities [9].

Synonyms for agility in characterising the new form of global enterprises have been widely used in many parts of the world. They include “fractal”, “distributed”, “holonic”¹, “lean”, and “extended”. Extended enterprises, however, are meant to represent the integration of partners in the same supply chain of the product.

Among the characteristics of AVE as recently shared by many researchers and practitioners are the following:

- The objective of an agile enterprise is to gather partner companies to team up in mastering all parts of the value chain of a given product in global markets.
- Agility is maximised when production systems are built based on a distributed, virtual infrastructure relying entirely on electronic communication and computing capabilities. This ensures maximum coordination with the use of special protocols for information exchange, contracting, and job delegation among partners.
- AVEs are coalitions that have the capability of evolving with changes in their markets and have the ability to reconfigure or to dissolve at the end of their common ventures.
- Agile systems should be quickly responsive to unexpected and unpredicted changes in consumer-dominated markets that are full of uncertainties but of opportunities as well. Such markets are further manifested into a new “era of virtual customer” that succeeded the “quality era,” fuelled by globalisation factors, new technologies, zero lead time delivery and influencing prices [8].

5. REQUIREMENTS FOR AGILITY

To achieve an agile environment, several requirements need to be fulfilled in terms of selecting and coordinating with partners, providing the

¹ Holonic is a name that was introduced by Koestler [5] to represent autonomous elements called holons in manufacturing systems that are capable of cooperating with other holons, and possess a high degree of self-reliance, stability, and ability to survive disturbances. A holon can be a machine, a schedule, or a production process.

enabling technologies, developing the standards of interactive procedures and securing the internal infrastructure of each member company.

With regard to the selection of partners in an AVE, research was conducted to test two alternative criteria. The first engaged information about the manufacturing processes that were available at the partner plant, and the other was based on using data about similar products in terms of design and manufacturing processes in what is intended to be fabricated, as well as the plant's own capabilities and performance. It was found [10] that selecting a partner based on its ability to manufacture the product, and validated capability regarding the intended design using feedback information at early stages is more beneficial in determining the right partner.

Following their selection, collaborating with agile partners should provide the necessary ground to share and gain expertise and knowledge rather than simple access to new markets. Those partners should respond collectively and quickly to seize opportunities from unexpected changes, and must facilitate information feedback that should help reduce turn-around life cycles and costs [15]. For this purpose, partner certification becomes of paramount importance to new candidates available worldwide.

The second important requirement for agility is the functional requirements for the enabling technology that should be used in coordinating activities among partners. Such technologies are mainly characterised by [12]:

- Openness to allow any approved partner to provide services.
- Scalability that is needed to link numerous agile partners of different sizes, from multiple companies, and at different levels of the production process. In this sense, even a particular machine at the shop floor could become a partner when properly introduced to the system.
- Extensibility and graceful degradation that allow services to be added, substituted, or removed at any time but with incremental impact on capacity and performance.
- Compatibility that is needed to link partners having different platforms in the same system.

Some enabling technologies for agility already exist through the use of concurrent design of the product and its production processes in what is called “concurrent engineering.” This makes use of available Computer Aided Design (CAD) and Computer Assisted Manufacturing (CAM) systems. To provide fast design and rapid development, prototyping and deployment of new or improved products, rapid virtual prototyping and simulated manufacturing processes are used with agile enabling technologies that look for optimising designs and intelligent closed-loop control systems for performance and productivity.

A third type of requirement for an agile environment is the need for standardisation of the metrics that will be commonly used across the enterprise in setting directions, experiments, measurements, and shared information [15]. The international Standards for Exchange of Product Data (STEP) code listed under ISO 10303 international standards provide the necessary ground to support the free exchange of product design data between the firm and its partner companies [10].

Last but not least, an agile partner needs to develop its own internal agile environment and to match its information infrastructure with those of other partners in the agile enterprise. The use of an Enterprise Requirement Planning (ERP) system is eventually for this purpose. This is due to ERP’s capabilities in integrating the firm activities into a comprehensive system with “more flexibility to configure business processes at much more reasonable cost and risk, but more importantly, creating the opportunity for a competitive advantage” [7]. This should also enable reforms on existing financial procedures and the use of the new “activity-based” costing techniques that highlight where and where not value is added and by which activity.

6. THE INFORMATION INFRASTRUCTURE FOR AGILE MANUFACTURING – THE CONCEPT OF AGENTS

As mentioned earlier, there are no differences based on size or location between partners in an agile environment. A partner could be a worldwide supplier of material or a provider of production services, or even a small work-cell or a machine at the shop floor of a factory around the globe. The only criterion for accepting such a partner is its capability to provide the needed service, whenever needed, with minimum lead time, minimum cost, and the right quality and performance specifications. This means that any partner should be identified at any time by three attributes: Cost, Capability, and Availability (CCA) [12].

On the other hand, the high degree of flexibility and rapid responsiveness to changes are assured by the ability of the agile system to add, substitute or take out partners at any time but only with the objective of incremental impact on the capacity of the whole system. This requires certification and standardisation procedures that every partner should undergo upon joining the venture. The collaboration between partners in a virtual infrastructure is realised through the use of electronic telecommunication means that link the partners with each other as well as extend information and business processes uniformly throughout all enterprise levels. An example of such, already available, information infrastructure that can be used to form such virtual enterprise is the Internet and the world-wide-web. The question remains however, as to how partners should remain operational in such a virtual environment and how they should interface with the system. The answer is through the introduction of “agents”.

Agents, as defined in [6] are an “autonomous software code that takes independent action or response to local conditions” with a reliable knowledge-based system and “represents factory resources, systems and jobs.” This makes the “smart” [15] or “intelligent” agent [6] capable of coordinating with other agents by interchanging information about cost, capability and availability. Thus, agents should “encapsulate production resources at any level, transforming them into suppliers capable of responding to service requests” [12], and should be capable to seek bids for jobs, find manufacturing service providers, represent factory resources, etc. It therefore becomes quite obvious that the formation of a network of such smart agents leads to a highly interactive virtual agile infrastructure.

Some of the immediate objectives of smart agents are:

- To allocate resources on cost/delivery based criteria,
- To reduce lead time,
- To increase labour and equipment utilisation, and
- To adapt the mass customisation of the market.

Agents have the capability of taking independent actions in response to local conditions. Some benefits of agents in an agile environment are:

- Providing flexibility, rapid responsiveness, and global integration for the whole enterprise.

- Continuously adapting to new conditions and acting autonomously but not independently in a dynamic environment.
- Adjusting schedules in line with available resources.
- Assisting in the recovery from faults in factory breakdowns, management problems or supply interruptions.
- Distributing work according to schedules, and streamlining the flow of material and services from an integrated supply chain.

Among the characteristics of smart agents is the fact that they operate on opportunity-based goals rather than constrained-based schedules. They can be upgraded independently with new functions as they are needed or with new technologies as they become available. Agents should integrate with other agents on the basis of a symmetrical scheduling architecture, market-based coordination, continuous response to varying demand, and independent control of its own resources [6]. In addition, agents compete with other agents of similar functions through dynamic, electronic marketplaces where all agents seek attention in the whole system based on their attributes of CCA.

Agents act as mediators and intermediaries between clients and servers. Examples of functions for smart agents in an agile virtual environment are:

- Bidding agents that can offer and advertise available resources.
- Scheduling agents that automate workflow dispatching to various available servers.
- Resource agents that keep track of inventory of material and tools as well as setting reorders.
- Engineering product database agents that help routing requests for part information to appropriate engineering databases.
- Manufacturing control agents that monitor material usage, work-in-progress, and re-order for shortages from stockrooms.

The new infrastructure of agile networks of smart agents is therefore highly dynamic, where agents are linked together tightly through telecommunication means, and where information extends uniformly through all levels of this virtual enterprise.

7. IMPLICATIONS OF AGILITY ON MANUFACTURING IN DEVELOPING COUNTRIES

Although the new concept of agility has been evolving in leading industrial economies, its effect will eventually tackle every manufacturer in the world one way or another. This is mainly due to the trends of globalisation and the fact that the whole world is turning into a single market. Those trends, being inevitable, are pushing the developing countries to deal with them sooner better than later. This can engage these countries into keen commitments to the modernisation of their production systems and laying down the necessary infrastructure that will help them integrate with the worldwide recent developments. Several actions that can help those economies to move on this track are:

- Understanding the new trends that lead to globalisation and to consider them as opportunities for progress rather than threats against previous achievements. Taking advantage of information technologies and computing telecommunication, for instance, is an immediate must to improve manufacturing capabilities and enhance global marketing.
- Getting convinced that using state-of-the-art production systems based on information technology and knowledge management is of imminent priority. The example of the agile virtual enterprise in this paper shows the usefulness of those powerful tools for producers to strategically benefit from.
- Attempting to form partnerships with suppliers, customers as well as other manufacturers regionally and worldwide, and to achieve a satisfying degree of agility while working at the same time towards achieving internal agility through the introduction of necessary information infrastructure in each manufacturer's work environment, and conducting a comprehensive review of each other's business processes and practices.
- Concentrating on ensuring the continuous and fast development of new and evolving products, and on improving the characteristics of existing ones in accordance with what is satisfying to customers' changing requirements. This means the adaptation of advanced tools like concurrent engineering, product data base knowledge systems and computer-assisted design tools for rapid design, development and deployment of the new products.

- Getting involved in case studies and research activities with regional and global partners, and which aim at improving cooperation with each other to develop means and ways that help face the new developments of economic globalisation. Such coordination can easily be set to be very efficiently conducted on the infrastructure of electronic telecommunication and advanced information technologies.

8. CONCLUSION

In conclusion, this paper introduced the new trends in global manufacturing systems and the impact of information technology on the formation of agile virtual enterprises. This is a new era that is still under formation and is taking shape year after year, where coordination between multinational partners is the new strategy to survive in a single new global market, full of fierce competition and renovating opportunities. Agility concepts are the eventual consequences of taking advantage of the widely spread, efficiently proved information technologies such as the Internet. Leading industrialists are currently using these technologies in their continuous pursuit of their new cutting edge developments as well as for winning new markets and sustaining growth.

NOTES

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