Advanced manufacturing technologies for improved competitiveness of the South African manufacturing industry

N S. TLALE
MSM, CSIR, PO Box 395, Pretoria, 0001
Email: NTlale@csir.co.za

Abstract

In this paper the manufacturing environment with regards to technology and market is discussed. Both the South African and global view are given, together with technology management strategies. Value added products are described and determined as an important factor for competitive manufacturing industry. Manufacturing systems that support high value added products such as FMS and RMS are discussed. Factors and technologies that enable FMS and RMS are also presented. These technologies are important in the achievement of factories of the future.

1. Introduction: Manufacturing Environment and Technology of South Africa

South Africa's industry is characterized mainly by being present in the manufacturing stage of the product life-cycle rather than having a big stake in the research and development (R&D) phase as it was found in a survey about industrial innovation in South Africa (Oerlemans et al. 2001). A typical activity level over the product life cycle can be seen in Figure 1.

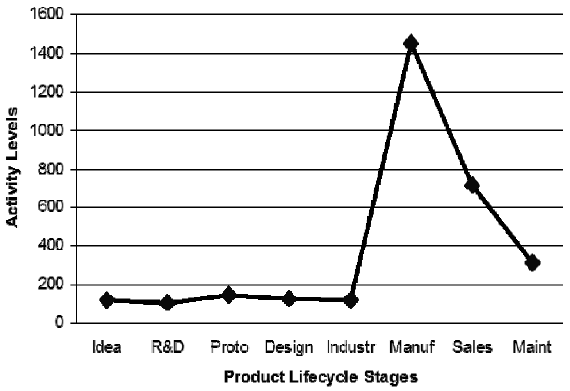

Figure 1: Product lifecycle activities for the SA transport sector (Source: Pretorius, 2002).

The manufacturing industries are mostly dependent on imported foreign technology. De Wet (2001) describes countries with such a characteristic as "technology colonies". As one reason for being a technology colony, Buys (2004) identifies the National System of Innovation (NIS) in South Africa as "deficient" or "poorly developed". The performance of the NSI is in this respect measured in terms of the resources employed in each sub-system and their efficiency. The sub-systems are systems such as the research sub-system, the technology development sub- system, the product development sub-system and so on; which form a linear model of the innovation process.

From this deficit in the R&D phase of the life-cycle and from the previously described need for technological innovation it becomes obvious that a country like South Africa has to adopt strategies to obtain technologies that enable the country to compete in a global market. One of the strategies is backwards integration. With backwards integration a country tries to adopt foreign technologies in a late stage of the product life-cycle (e.g. in the manufacturing stage) and develops skills from using and understanding these technologies. By a process of imitation and learning the industry then moves backwards in the life-cycle and is able to generate own "innovations". Buys (2002) proposed a five-stage process of backwards integration of the NIS:
Stage I: Local distribution, marketing, sales and after-sales services of foreign products and services
Stage II: Local production and manufacture of foreign products and services
Stage III: Local improvement of foreign products and processes
Stage IV: Local development of new products and processes
Stage V: Local technology development.

Most sectors of the South African industry are currently at the second stage. The automotive industry is one example, where almost all vehicles have foreign designs and use mostly foreign technologies. That means production is mostly done under license agreements with the multi-national corporation. While at this stage employment is at least generated due to manufacturing, technological capabilities are only rarely developed. The innovative capability development is a learning process which is promoted by backwards integration. (Moos, 2006)

The three long-term economic growth components (capital, labour and technical innovation) should be reconsidered here. The generated returns at any stage of the backwards integration strategy can be reinvested and therefore comply with the capital component for long-term economic growth as identified by the National Advisory Council on Innovation (2001). This strategy has, however, certain drawbacks. First, it leads mostly to incremental innovations rather than to radical innovations. Second, it is unlikely that backwards integration is able to evolve backwards through the whole product life-cycle until it reaches the research phase.

To overcome these drawbacks, another strategy, namely forward integration, can be applied. While backwards integration relies largely on FDI, forward integration has to be stimulated by government funding. Possible breakthrough technologies have to be identified and money has to be invested by the government to advance the development of these technologies/innovations. In contrast to the incremental innovations described previously, this strategy is able to generate radical innovations. In addition, it also fosters skills development on a higher level than backwards integration does. Since the identification of the technologies to be funded is not a straightforward task, the risk associated with this procedure is higher than with the one previously described. To sum up: it is not a question of having either forward or backwards integration. Both strategies have to co-exist: backwards integration for delivering short-term success through incremental innovations and forward integration for delivering long-term success with radical innovations. (Moos, 2006)

The South African government is already doing much to support backwards and forward integration using programmes like the Advanced Manufacturing Technology Strategy (AMTS), Support Programme for Industrial Innovation (SPII), Partnership in Industrial Innovation (PII) (stimulates the industrial research and innovation in the technological development of products and processes that have a high market potential) Innovation Fund (IF), Motor Industry Development Programme (MIDP), etc.

Furthermore, with research institutes like the CSIR, the establishment of innovation hubs, technology incubators or techno parks, where government tries to get research institutes as well as companies together, it tries to support the creation of technological capabilities. However, the component supplier sector of the automotive industry in South Africa, which is regarded in more detail in this work, shows certain problems that are not inherent to the country but have to be addressed in order to have a successful component supplier industry.

2. Global View: Contract Manufacturing

In developing countries, because of underdeveloped innovation systems and resources, many countries have pursued a strategy of contract manufacturing based on low-costs. Contract manufacturing is estimated to amount close to US$149 billion in the middle of the period 2000-2010, and is expected to grow to US$500 billion by 2010. India, for example, has positioned itself to be a major recipient of contract manufacturing. (Tlale, 2008)

However, contract manufacturing alone is not a sustainable economic growth strategy as can be seen from what happened with China. Manufactured goods' exports in China rose during the 1990s at a 15% annual rate to about US$220 billion in 2000. In the same period, China was manufacturing around 50% of the world's telephones, 17% of refrigerators, 41% of video monitors, 23% of washing machines, 30% of air conditioners and 30% of colour TVs. Many companies in the USA, Japan, Taiwan and elsewhere were, and are still, moving operations there. The building space of foreign contract manufacturers increased from 0.16 million m^2 in June 1999 to 0.5 million m^2 two years later. However, manufactured imports of China were almost as big as its exports, which amounted to about US$180 billion in 2000. This was caused mainly by machinery imports in an environment of rapid capacity growth, and increased demand for cars and luxury goods as the population's wealth increased. Machinery imports were important in order to produce the goods to be exported. The net result was that in 2000, China had a positive balance of manufacturing trade of about US$40 billion; an amount that is less than one percent of total world industrial production. Factors that will keep China from sustaining a large manufacturing trade surplus include a growing domestic market, which will continue to generate demand for imports, and lagging technical competence that will take some time to redress (Rowen, 2003). Figure 1 shows the contribution of the different countries in the total manufacturing output of the world from 1750 – 2000 (Tseng et al, 2003).

Moreover, a healthy manufacturing industry is seen to be characterized by both productivity and innovation. Productivity is dependent on innovation. Innovation results in value-addition. Thus, economic growth and a rising standard of living are both dependent on productivity. (Manufacturing in America, 2004)

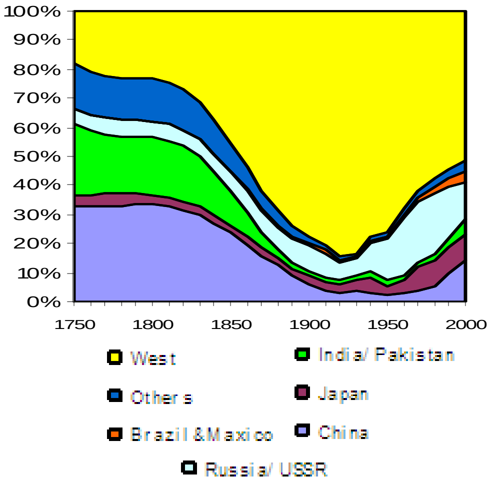

Figure 2: Global Manufacturing output by country (1750-2000). (Source: Tseng et al, 2003)

3. Manufacturing as a Value Adding Process

The manufacturing process transforms the raw inputs (or individual manufacturing products/sub-systems) into output products (or assembled products) with attributes that the customer is willing to pay a certain price for (refer to Figure 3). Manufacturing is intrinsically a value-adding process. However, differentiation should be made with regards to degree of value adding. Low value added products are those products that are simple (in terms of how many manufacturing processes are required to manufacture the product), and do not require any substantial engineering design for their development. High-value added products are those products that are complex, and require substantial engineering (design and system integration). Advanced manufacturing technologies are mostly useful and suitable for high-value added products. Advanced manufacturing technologies are technologies such as automation and control, information technology, e-manufacturing, complex manufacturing machinery, etc. Manufacturing of high value-added products is a sustainable economic growth strategy. Thus, the strategy should be based on a culture of re-invention i.e. the mother company must make its products obsolete before the competitor can. Manufacturing systems and technologies that enable manufacturing of high-value added products are discussed in the sections that follow.

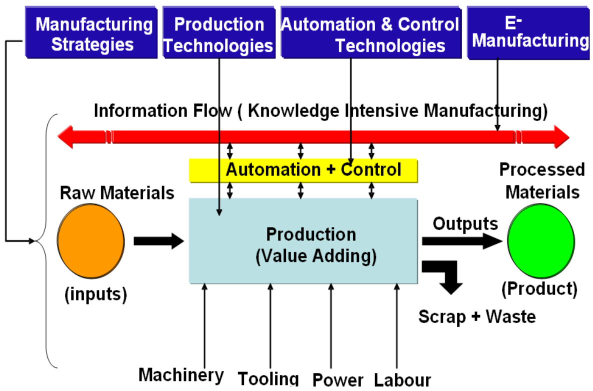

Figure 3. Schematic of manufacturing process as a value-adding process and related processes

4. Current Manufacturing Challenges

The current manufacturing environment is characterised by the following:

- Short product lead-time: This refers to the time it takes for the product to be developed and introduced in the market. The reduction in the product lead-time is caused by advantages of being first in the market.
- More product variation: This is driven by customisation/personalisation.
- Low, fluctuating product volumes: This is driven by fragmentation of niche markets and personalization.
- Low product prices: This is caused by active consumerism and market competition.
- Other factors: the minimum standards for competitiveness in the manufacturing industry such as quality, durability, etc.

In order to address the pressures resulting from the manufacturing environment, different manufacturing systems have been developed (refer to Figure 4).

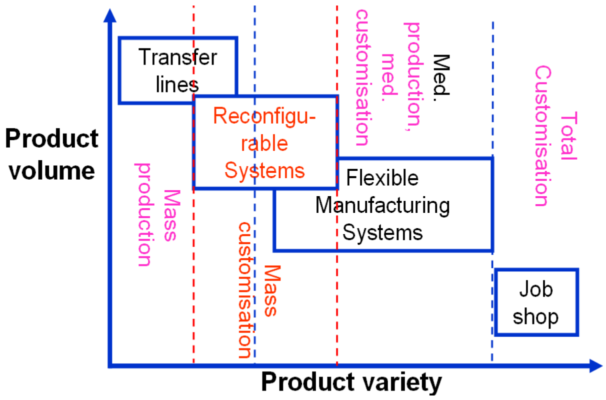

Figure 4. Different manufacturing systems and their attributes

Flexible manufacturing systems have allowed manufacturing of batches of different sizes and attributes on one manufacturing system. The trend is towards development and implementation of flexible and reconfigurable manufacturing systems (FMS and RMS respectively). With these manufacturing systems, product variation and product quantities can be achieved with respect to market demands.

The main differences in the technologies that are used for FMS and RMS are as follows:

- FMS uses machines that are designed to manufacture different variety of products.
- RMS uses machines that are designed to manufacture a family of products that have the same attributes.

In this paper, flexibility and reconfiguration will be treated as the same.

5. Different Kinds of Flexibilities

At least 50 different terms for various types of flexibilities have been identified by (Sethi A. K and Sethi S. P., 1990). These can be catergorised into the following three categories:

- Economic view e.g. Lavington (1921) drew a connection between random changes and the value of flexibility by considering the "risk arising from the immobility of invested resources"
- Organisational view: This can be defined as the ability of an organisation to suffer limited change without severe disorganisation. Atkinson (1985) differentiates three types of labour flexibility: numerical flexibility – readiness with which the number of people employed can be adjusted to meet fluctuation in the level of demand; functional flexibility – the readiness with which the tasks performed by workers can be changed in response to varying business demands; and financial flexibility – the extent to which compensation practices encourage and support the other two flexibilities that the firm seeks.
- Manufacturing view: Diebold (1952) recognised flexibility to be essential for medium and short-run manufacturing of discrete parts. Instead of economies of scale, efficiency in batch production is captured by the term economies of scope (by drastic elimination or reduction of setup costs and times required for switching from the production of one product to another).

It should be noted that humans are more flexible than machines. To make machines flexible, we either have to change the environment to reduce the level of complexity in the environment or to develop smart machines that have the sensory, reasoning and motion capability of humans.

By definition, FMS is a highly automated conglomerate of machine cells interconnected by an automated material handling and storage system, and controlled by a distributed computer system. An example of FMS is shown in Figure 5.

Flexibility can be achieved at different enterprise levels (refer to Figure 6). Flexibility at lower organisation levels is mainly achieved by changing hardware resources. At higher levels, it is achieved by changing software resources, or choosing alternative methods, or organisational structures by flexible people. However, they usually work together so that system flexibility can be maximised.

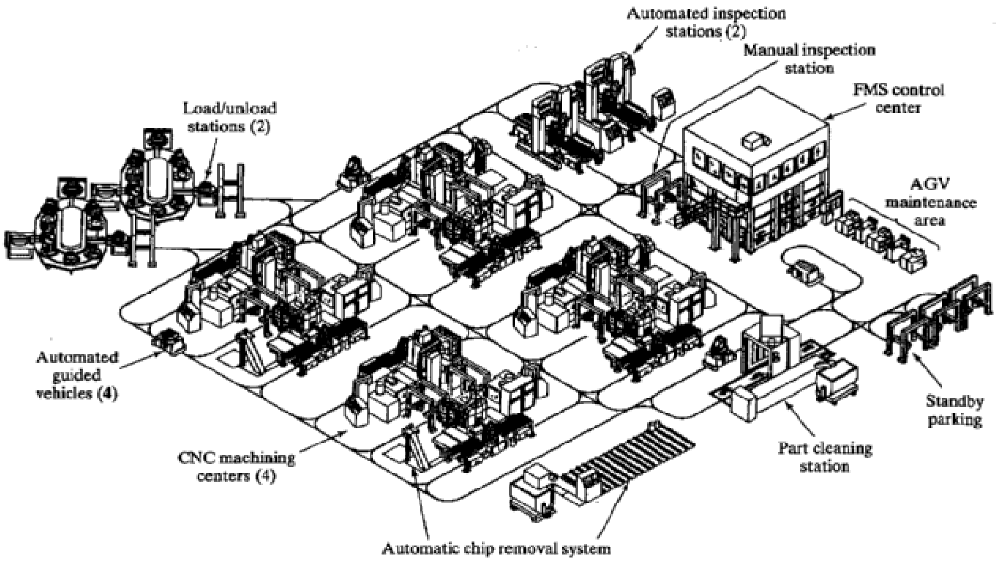

Figure 5. Example of FMS at Vought Aircraft

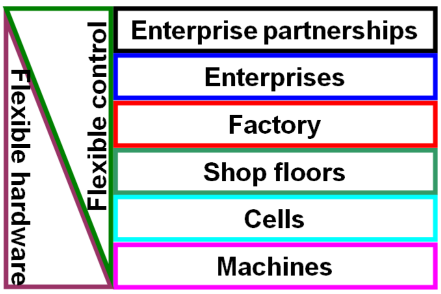

Figure 6. System organisation and flexible resources (Source: Bi Z. M., Lang Y. T, Shen W. and Mang L., 2008).

6. Enablers of Flexible and Reconfigurable Manufacturing Systems

Figure 7 shows the different levels of flexibilities in the manufacturing system and their relationship. Basic flexibilities enable system flexibilities, system flexibilities enable enterprise flexibilities. In this paper, because of space restrictions, only the three basic flexibilities will be covered as presented in (Sethi A. K. and Sethi S. P. 1990); machine, material handling and operation flexibilities.

6.1 Machine Flexibility

Machine flexibility refers to the various types of operations that the machine can perform without requiring a prohibitive effort in switching from one operation to another. Prohibitive effort is normally

(Source Groover M. P., 2008)

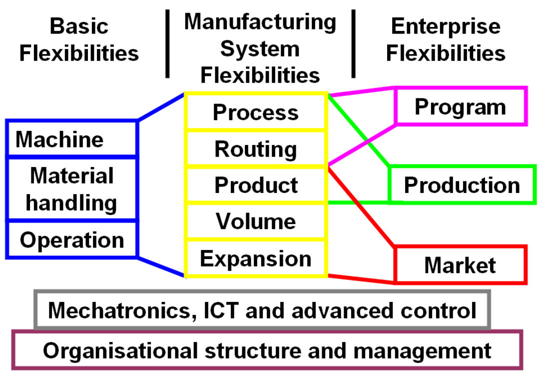

Figure 7. Different kinds of flexibilities in a manufacturing system and flexibility enablers (Source: Sethi A. K. and Sethi S. P. 1990).

expressed in terms of time and cost. It provides a basic framework for flexibility. Software functions cannot help or provide extra flexibility if machines are hard and expensive to change (Source: Ranta, 1989). Machine flexibility can be measured by the number of different operations that a machine can perform without requiring more than a specified amount of effort.

The following are enablers of machine flexibility: numerical/computer control, easily accessible programs, rule-based languages, sophisticated part-loading and tool-changing devices for work-pieces and tools, size of the tool magazine, availability of sufficient pallets and fixtures, number of machine axes (mechanical flexibility), automatic chip removal, adaptive control to optimize metal removal, diagnostic software, integration with CAD/CAM, etc.

Industrial robots and machine tools are the most prominent machines that are used in FMS and RMS and that have revolutionized the manufacturing technology and industry. Industrial robots pose mechanical flexibility that is required in order to achieve process flexibility. However, they suffer from low rigidity that is dependant on the pose of the robot. CNC (computer numerically controlled) machines have high stiffness which is suitable for applications that require high stiffness such as turning and milling. Recently, five-axis machine tools have been developed in order to improve mechanical flexibility of machine tools. New types of mechanical machines, parallel kinematics machines (PKMs), have the stiffness of machine tools and mechanical flexibility of robots, but have small workspace. This limits the application of PKMs in the industry. Research is on-going for developing PKMs with improved workspace. Both industrial robots and machine tools are used in FMS.

RMS uses robots and machines that have been designed from the outset for rapid change in structure by using modular hardware and software components (Koren et al, 2002). Modular design principles improve re-use of modules and inter-changeability of modules. This promotes the design and achievement of different machines using the same machine modules. RMS also uses traditional machines used by FMS when required.

Machine flexibility allows for the following advantages: lower batch sizes (this will result in savings of inventory costs), higher machine utilizations, production of complex parts, shorter lead times for new product introductions, and better product quality. (Sethi A. K. and Sethi S. P. 1990) The challenge with machine flexibility lies in the unavailability of automated fixture assembly and mounting. Moreover, if the technical reliability of lasers can be realised, it will provide an effective means of increasing machine flexibility (milling, drilling and turning will be achieved by the same tool).

6.2 Material handling flexibility

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Material handling flexibility of a manufacturing system refers to its ability to move different part types efficiently for proper positioning and processing through the manufacturing facility it serves. This definition encompasses loading and unloading of parts, transporting them from machine to machine, and eventually storing them under varying conditions of the manufacturing facility. The definition also assumes the pallet fixture flexibility. This flexibility determines the degree of freedom available to part loading schedules. A universal material handling system is a material handling system that can link every machine to every other machine. The material handling flexibility of a given manufacturing system can be expressed by the ratio of the number of paths that the system can support to the number of paths supported by the universal system. (Sethi A. K. and Sethi S. P. 1990)

Material handling flexibility can be achieved by using transporting devices such as forklift trucks and push carts and an appropriate manufacturing plant layout design. In highly automated facilities, devices such as automated guided vehicles, robots, and computer control, which can send parts to new paths in cases of blocking and machine breakdowns, would be needed to acquire material handling flexibility. Autonomous systems will further increase material handling flexibility by allowing material handling systems to work autonomously in unstructured environments and to interact with human beings.

Flexible material handling systems increase availability of machines. This in turn increases machine utilisation and reduces throughput times. Industrial robots and automated storage and retrieval systems increase the information processing capabilities of the manufacturing system. Industrial robots with flexible grippers and intelligent interfaces (tactile sensors, vision, signal processing) have improved material handling flexibility of robots.

6.3 Operation flexibility

Operation flexibility refers to the ability of a part to be manufactured using different ways of production. It is not a property of the manufacturing systems (like the previous two types of flexibilities), however it is a property of the part. It means that the part can be produced with alternate process plans. Here a process plan means a sequence of operations required to produce the part. An alternative process plan may be obtained by either an interchange or a substitution of certain operations by others. Thus, a part that permits operations to be performed in alternate orders or using different operations in an inter-changeable fashion would possess operation flexibility. A process will be considered to have operation flexibility if parts that are being produced in the system possess operation flexibility and if the material handling system is able to deliver parts to machines in different possible orders. The operation flexibility of a part can be measured by the number of different processing plans for its fabrication. (Sethi A. K. and Sethi S. P. 1990)

Operation flexibility of a process allows for easier scheduling of parts in real time and increases machine availability and utilization, especially when machines are unreliable. Operation flexibility of a part is derived from its design. The design should allow the parts to have surfaces that are easily accessible for various operations. Parts that are assembled from standardized components or parts that are modular are likely to exhibit operation flexibility. Systems such as CAD/CAM, computer-aided process planning (CAPP), and group technology make it easier to design parts possessing operation flexibility. Design methodologies such as Design for Manufacture have played a part in increased part flexibilities.

6.4 Note on automation and control

In developing countries such as South Africa, it is often argued that automation results in job losses which are required in such industries. However, this is only a local view on the effects of automation. A global view of the effects of automation is that if companies do not automate (in order to gain the advantages of automation), those companies will lose market share as competition is global, and competing companies are reaping the rewards of automation. In this section, the advantages and disadvantages of automation are presented. The main advantages of automation are as follows:

- increased accuracy and repeatability (quality can be controlled)
- increased throughput

Main advantages of human labour:

- complex, intricate components can be achieved
- can learn and become better at the task
- highly flexible

Automated-labour plants combine the advantages of both. Future factories will comprise of highly autonomous machinery and humans. It is suggested in this paper that manufacturing systems incorporating both automation and human labour are more productive than those that employ automation only, or human labour only.

7. Conclusion

Factories of the future will comprise of machines that will be able to make and repair other machines depending on the product that must be manufactured. An operator will interface with the manufacturing system through a computer, where the software that determines the manufacturing processes and their relevant machines are determined from the product. This computer, after determining the manufacturing processes, the machines and their layout, will send commands to the manufacturing system. The manufacturing system and its machines will then decompose the current machine and manufacturing system layout, and compose the new machines and manufacturing layout for the new product to be manufactured. The machines comprising the manufacturing system will comprise of reusable software and hardware modules. In this paper, technologies that will enable this are presented and discussed. The South African manufacturing industry and technology with respect to manufacturing systems is also discussed. FMS and RMS are paving the way to future manufacturing systems.

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