The Design And Implementation Of Integrated Manufacturing Strategy In China

by

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An **Executive Summary**

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Declaration

I declare that this submission entitled "The Design and Implementation of Integrated Manufacturing Strategy in China" which I am submitting represents my own work and has not been submitted to this or any other university, polytechnic, college or educational institution in application for admission to a degree, diploma or any other qualification.

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Abstract

This report describes a process which one company adopted to enhance its manufacturing system in a step-by-step manner. In order to increase the competitiveness of the company, the author has identified a number of improvement strategies which were specific to the economic and political environment in China. The centre of the strategies is a vision of an integrated manufacturing strategy. The detailed design and implementation of this vision is conducted through the proposed systematic manufacturing strategic analysis. The integration process encompasses various elements such as Total Quality Management (TQM), Manufacturing Resources Planning (MRPII) and Real-Time Monitoring System (RTMS), and emphasises not only the use of appropriate modern technology but also the management of technological and cultural change. In this report, a model is used to describe the integration process, and the detailed implementation is also elaborated upon, using a proposed implementation process model. By adopting the integrated manufacturing system, and through continuing improvement, the productivity and, hence, the profit of the company is increased. It is anticipated that the integration approach to the design and implementation of manufacturing systems will prove an important contribution towards the type of manufacturing strategy that prevails in labour-intensive environments such as China.

1. Background and introduction

The Research Engineer works in Kingtronics Industrial Co., Ltd. as the Managing Director. He is the founder and sole owner of the company.

Kingtronics Industrial Co., Ltd. was established in 1986. Over the past 10 years, since starting from scratch, it has now become recognised as the most reputable Original Design Manufacturer (ODM) in the consumer electronic products business.

The Head office of Kingtronics Industrial Co., Ltd is located in Hong Kong and occupies 2,600 sq. metre. of office area housing 100 employees where the crucial tasks of marketing, research and development (R&D), global material sourcing, financial control and cost analysis are performed. Kingtronics maintains constant communications with its production plant and close relationships with its global customers. The company has a professional R&D team, supported by advanced equipment for research, development and product design, in order to fulfil its customer needs. The company launches numerous new products each year to satisfy market demand.

Kingtronics Industrial (Xiamen) Ltd. is located in the Special Economic Zone (SEZ) of Xiamen, which is one of several SEZs in China. The Kingtronics Science and Industrial Park is built on 25,000 sq. metre. of land. This park upon completion will provide 90,000 sq. metre. of total usage area which comprises three industrial buildings, two training, R&D buildings and one administration building. Several buildings were completed during the period 1990 to 1995, with a total usable area of 50,000 sq. metre, being brought into use since 1990. In its manufacturing base in Xiamen, Kingtronics has over 3,000 workers and staff. Incorporating many state-of-the-art production facilities, including Autoinsertion Machines, Surface Mount machines, Computer In Circuit Testing facilities, Automatic Wave Soldering Machines, etc., several million telecommunications and audio products are produced and sold every year. These products are sold to more than 15 countries, which include the seven major industrial countries. Kingtronics is one of the largest telephone-answering machine manufacturers in the world, as well as one of the hundred top export manufacturers in China. In 1995, the total industrial turnover exceeded US$ 100,000,000. Kingtronics is an ISO 9002 certified company, and has BABT approved manufacturing facilities.

Kingtronics exemplifies a typical Hong Kong based manufacturing company. It initially started its business in ODM manufacturing, and then shifted its focus to develop its own brand name in China. It is also one of the 80% of Hong Kong companies that have their production plants located offshore, and is situated in one of the world's most popular and profitable sites - China.

Ten years ago, China opened up to foreign investment (Davies and Whitla 1995) and this investment is based on its competitive labour and inexpensive land prices, and the huge potential market in China. The total overall productivity of Hong Kong is said to have been enhanced by the relocation of assembly processes to China. In mainland China, the average living and educational standards are lower than those in the West; technical standards in the southern regions are not as high as those in the North; and the labour force remains basically unskilled. Before 'the open-door policy' in China, all enterprises, organisations and factories were state owned. At that time, no matter how hard anyone worked or, how lazy anyone was, his reward was exactly the same. In other words, workers lacked any incentive. Seniority was considered the key factor for promotion.

Essentially no motivation existed among the working force at large. Consequently, productivity remained at a very low level. These problems are addressed and further elaborated upon in *portfolio 1*. The project structure is shown in Figure 1.

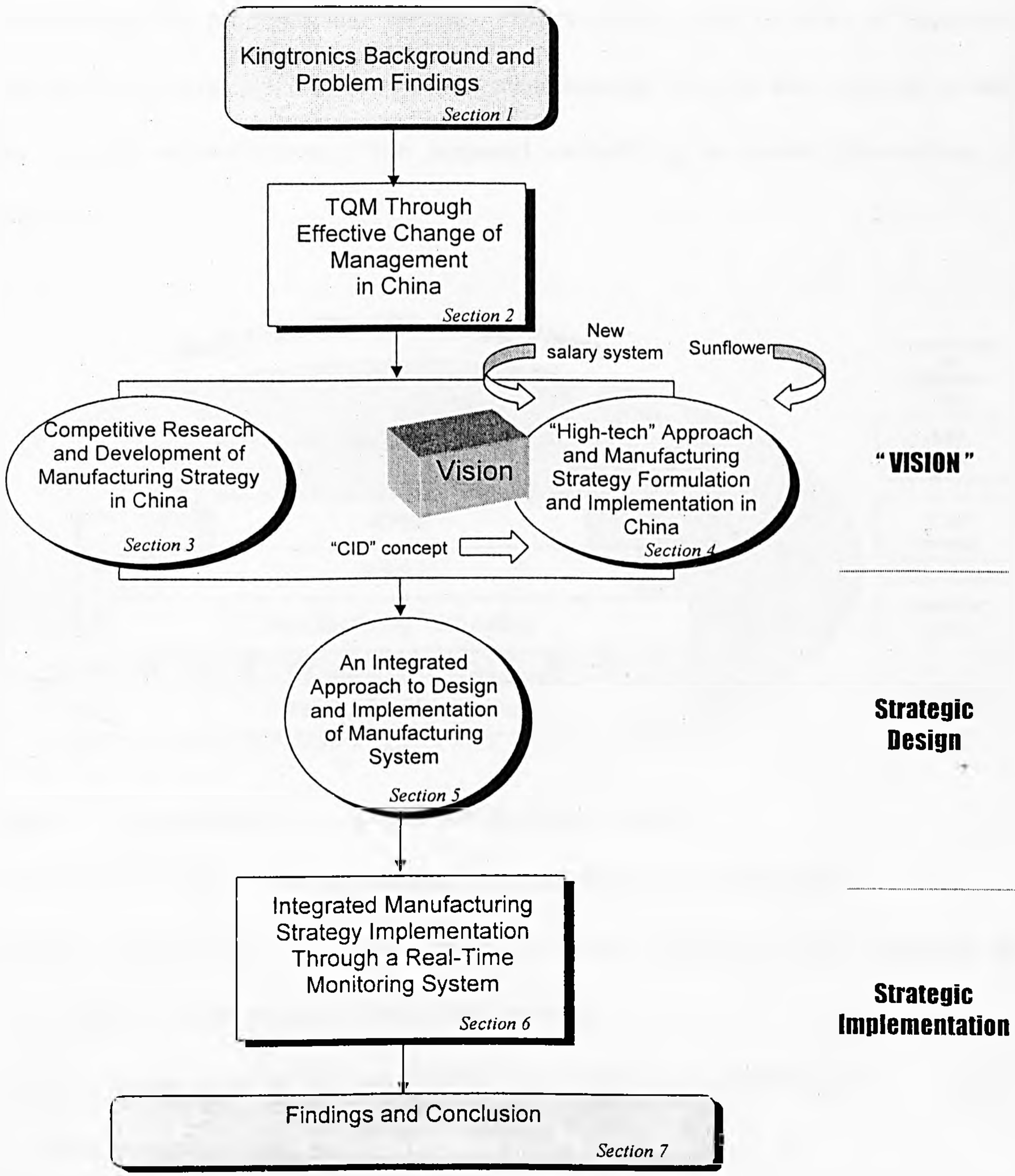


Figure 1. Project structure.

2. Innovative aspects of the research project

The author has designed and implemented an integrated manufacturing strategy in this research project. This innovative manufacturing strategy and its implementation methodology are proposed and verified. The strategic vision involves a "high-tech" manufacturing technique; a state-of-the-art manufacturing vision is also proposed to meet the competitive environment. The proposed methodology is shown schematically on Figure 2.

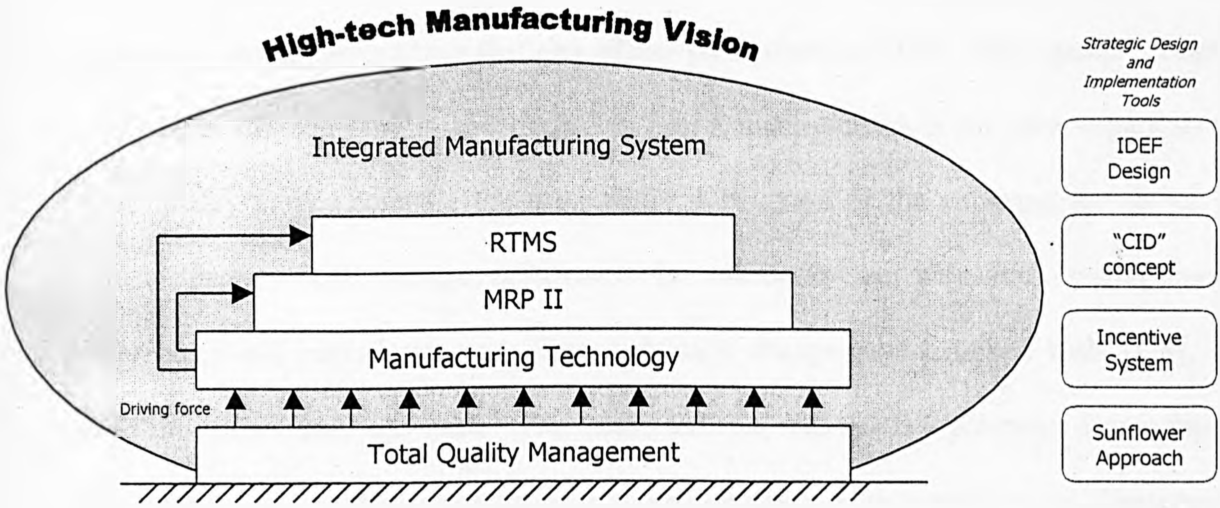


Figure 2. Methodology for integrated manufacturing strategy.

Three novel elements in the implementation process are proposed as follows:

(1) The implementation of TQM using an innovative approach which comprises the Sunflower Approach and a new incentive scheme;

(2) The integration of RTMS and MRPII with TQM to be a driving force in a labour-intensive environment;

(3) Making use of the **"CID"** concept and **IDEF** design to design and implement the integrated manufacturing system.

A detailed discussion on the above elements can be found in the following sections.

3. TQM through effective change management in China

In order to cope with the problems stated in *portfolio 1*, the implementation of TQM within the company is considered to be the key strategic issue. Successful implementation of TQM is closely linked with a change in attitude, culture and values of people in an organisation. This section addresses the approach in TQM which emphasises the social and cultural background of mainland China. The approach involves considering major factors such as loyalty, hierarchy, organisation structure, Chinese incentive methods, and designing a change programme that can effectively implement TQM. For example, every employee in the company is encouraged to join a quality circle in his own department. These quality circles compare the organisational structure of the company to that of a political party. The change programme is linked to the personnel, management performance and payroll systems. This systematic change model, linked with TQM, is called the "Sunflower" approach. The results indicate that this is a powerful programme, whose approach can make manufacturing organisations in China much more effective in pursuit of TQM goals.

TQM is an approach to improving the flexibility and effectiveness of a business as a whole (Dale and Barrie 1991), and can provide a good quality atmosphere for making technological changes within a company in China. TQM takes quality beyond the realms of "It is not my problem, I am responsible for production" and educates people to recognise that a quality product is the result of many differing processes, ranging from design to manufacturing, from marketing to accounts. In other words, quality is no longer the inspector's business, quality is everyone's business. To be effective, an organisation must ensure that everyone works together as a team and must recognise that every person and every activity affects and, in turn, is affected by others. This will lead to people taking responsibility for the quality of their own workmanship, accepting the technological changes within the company, and eliminating the need for an independent inspection process, i.e. inspection will be 'built in'.

3.1 The "Sunflower" approach

The company, after careful analysis and evaluation of the existing culture in China, and an evaluation of the economic and organisational environment, follows the major steps (see *portfolio 2*) to develop a TQM approach called "Sunflower".

The fundamental basis of this approach is that individuals inside a division or department form a larger quality centre, which has to undergo the same never-ending improvements in serving its own customers, and communicating this with its suppliers. Its functions form a bridge to other departments and to the whole company. It is very important to build up a communication bridge between the lower level workers/operators and the management during the implementation of any manufacturing system within a company, since many problems in changing situations can be solved effectively by communication. Finally, all the departments unite to serve one objective, to grow in the light of customers' satisfaction as the "Sunflower" does. Figure 3 depicts a representation of the sunflower approach.

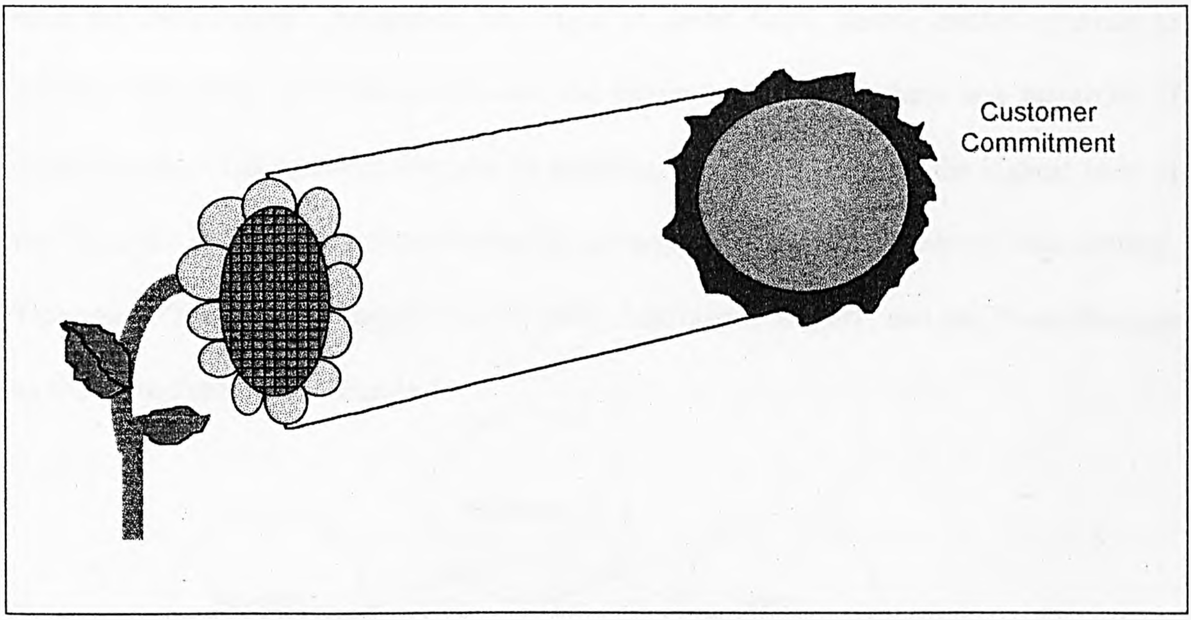


Figure 3. A representation of the "Sunflower" approach.

Continuous improvement is considered to be the key factor for success (Deming 1982). This approach concentrates on continuous improvement of the processes rather than the customer at the first sight, but when you think about the growth of a sunflower, you notice that it is always blossoming and moving towards the sunlight. Every single element, every petal of the flower, is completely open to the sunlight and moves towards it. The driving force (Sunflower motion) of the company (the sunflower) to work towards customer commitment (The Sun) is generated and directed from various types of customer feedback, (the sunlight) such as field information, product needs, price target and quality performance, etc.

Besides sunlight, all the features that build up the flower must be attached to each other seamlessly in order to remain strong and healthy. This can only be done by eliminating the barriers, that is the departmental barriers within an organisation. It is necessary to look at one's own quality situations through other people's observations, ideas and thoughts. Quality development has to take place in a group situation where insight, experience and actions are shared and created jointly. It follows that the establishing of quality circles is a must for the purpose. Integrated into TQM as useful tools, quality circles continue to develop, and work in collaboration with the hierarchy. Hence, there is a hierarchy of quality circles. Taking Kingtronics as an example, the quality circle at the highest level of the hierarchy is formed by circle leaders in the areas of 'Moulding Factory', 'Accounting', 'Operation', 'Marketing', 'Engineering', 'Quality Assurance', 'Export', and the Plant Manager as shown in Figure 4 and Figure 5.

Figure 4. "Sunflower" of Kingtronics in top management level.

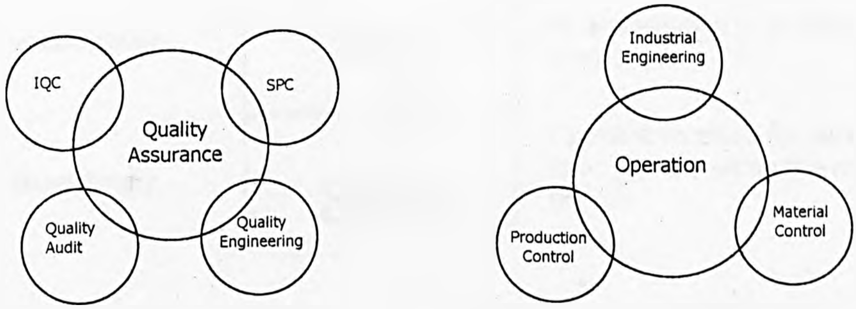


Figure 5. Second level of "Sunflower" with Quality Assurance and Operation in details.

3.2 New salary system

Various literature (Gopal K.K. et al. 1990, Greg B., Lyle Y. 1991, Shiba S. et al. 1993) stresses that financial reward is completely counter to the philosophy of TQM. However, in this research, the author successfully introduced a new payroll scheme to reinforce the group incentives of the labour force in China. Regarding this financial system, 20% of the monthly basic salary of the line workers is pooled out, to re-allocate as a variable salary among each of the production lines, according to their performance which is weighted by the factors of productivity, quality and material wastage during production. In addition to this, the company contributes extra financial awards for production line staff whose performance exceeds the company standard. Figure 6 illustrates the principal elements of the salary system. The system is designed, such that a balance is struck between how easy the system is understood by those who are remunerated by it, and the sensitivity of the system to reflect the aspects of work which must employ substantial amount of effort together with team work spirit. The elaboration of the new salary system can be found in *portfolio 2*.

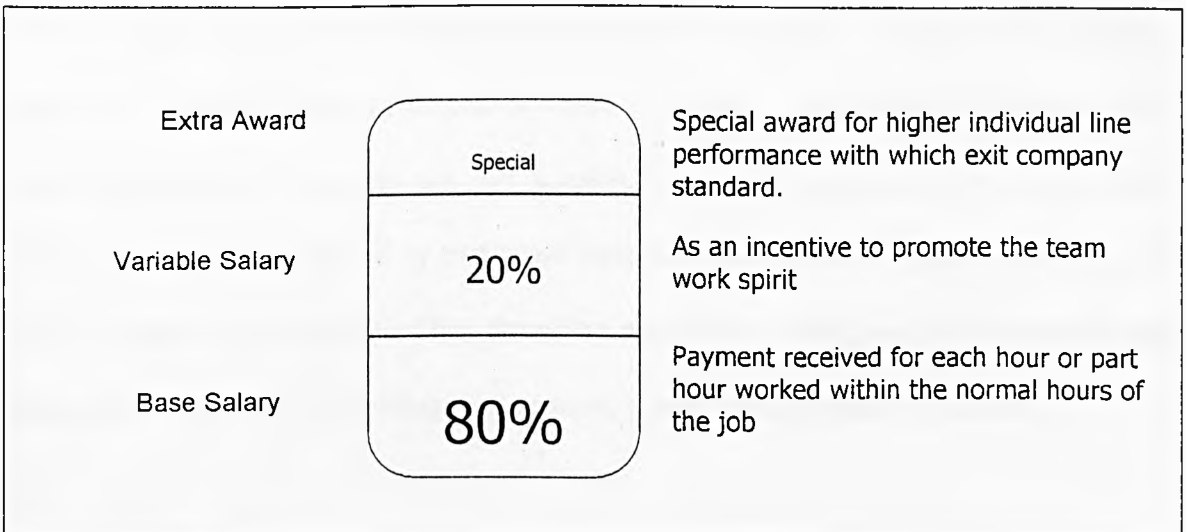


Figure 6. New salary scheme.

4. Competitive research and development of manufacturing strategy in China

After 20 years of industrial development, manufacturing plants of consumer electronics firms have been moving away from the USA, to Japan, then from Japan to Korea, Singapore, Taiwan, Hong Kong (Asian "Four Dragons") and now from Asian "Four Dragons" to Malaysia, Thailand, Philippines and China. This resulted from the fact that those companies were becoming non-competitive in terms of production cost. Owing to keen global competition within the consumer electronics industry, these countries had also lost their edge of low production costs. To remedy this situation, a Far East manufacturing strategy became increasingly important (Krugman 1994). To identify our competitive edge, a systematic manufacturing strategy is required. TQM is identified as one of the important competitive weapons, however it is not enough to face today's competition. Companies demand further innovative strategies to meet the competition from other Far East countries. Therefore, an investigation regarding the competitiveness of research and development has been conducted (see *portfolio 3*). There are two major points of view. According to one view, it has been suggested that consumer electronics products will no longer be appropriate for the Asian "Four Dragons"; instead, **"High-tech" products** should be developed and produced in these countries. According to another view, consumer electronic products are still suitable for Far East countries, however, these should no longer be produced by traditional manufacturing methods; (labour intensive, and manually-controlled systems). They should be replaced by **"High-tech" manufacturing systems** (i.e. CIM, high technology automation, modern management system, etc.).

4.1 Competition of electronic industries in the 60s and 90s

In the 1960s, competition in consumer electronic industries was not manifest, although an upsurge of consumer electronic products was created in the 60s. Before this era, electronic products were treated as status symbols for minorities such as rich people who could afford to buy them. The majority, such as working class people, were solely demanding basic needs, e.g. food, clothes, etc. During this period, people were also easily satisfied with electronic products simply because they were status symbols, which were expensive and had offered little in the way of choice. Despite the fact that the majority of these products were very basic, and their quality was not very good, only a few manufacturers could produce these kind of products in Hong Kong.

In July 1980, NEC carried out a major organisation reform of its R&D system, the first such reshuffling since May 1965 (Koji Kobayashi 1991). At that time, R&D existed only in American, Europe and a few Japanese companies. The design blueprint of the local products was usually directly copied from either America, Europe or Japan, and even so, there were only a few companies that were able to do this. Since there were hardly any R&D activities in these companies, competition in the electronic products market was very low. The saturation rate of the market was also very low, and thus any company was able to obtain a market share provided that it had the ability to produce an electronic product. In general, the competition at that time was in terms of the availability of such products, rather than their quality and price.

In the 90s, living standards are much higher (World Bank 1993). Consumers have been educated to select merchandise, and after 30 years of experiencing consumer electronic products in their lives, the requirements demanded of these products are much higher. There are increasing numbers of suppliers in this market, therefore, as a result, competition is becoming stronger year after year. Companies that succeed in electronics do so in a remarkably demanding atmosphere (Jelinek and Schoonh 1990). In general, real prices drop by 10%-25% per year and have done so for decades in the USA customer electronics market. For example, in our design and production of telephone answering machines for the American market, some 10 years ago, the manufacture was initially very simple, and the FOB price was around US$60. Nowadays, a low end product that offers better features and quality is sold at a quarter of the price. Continuing technological change has driven firms to maintain R&D expenditure. In the semiconductor industry, R&D has hovered at nearly 10% of sales for decades. Competition is currently very strong and companies are competing on terms of price, quality, and features. Because of today's technology, most companies can produce these products with similar quality, and similar features. As a result of similar standards in features and quality, a keen "price" competition in manufacturing industries has been created.

4.1.1 Product life cycles in the 60s and 90s

The importance of R&D has been further investigated by the author and a variation of conventional project lift cycle has been conceptualized. The modified life cycle is called "CID" and is explained in the following section. The product life cycle has changed between the 60s and 90s. Figure 7 depicts the shapes of product life cycles in the 60s and 90s. In the 60s, the new product could stay longer at its mature stage, so the company producing it could enjoy gaining profit during the "cash cow" stage without the need for further R&D. Moreover, the competition in R&D was not so keen in the 60s. In the 90s, more and more companies are able to research and develop new products of high quality and low cost, so the companies must continue R&D in order to sustain their competitive advantages.

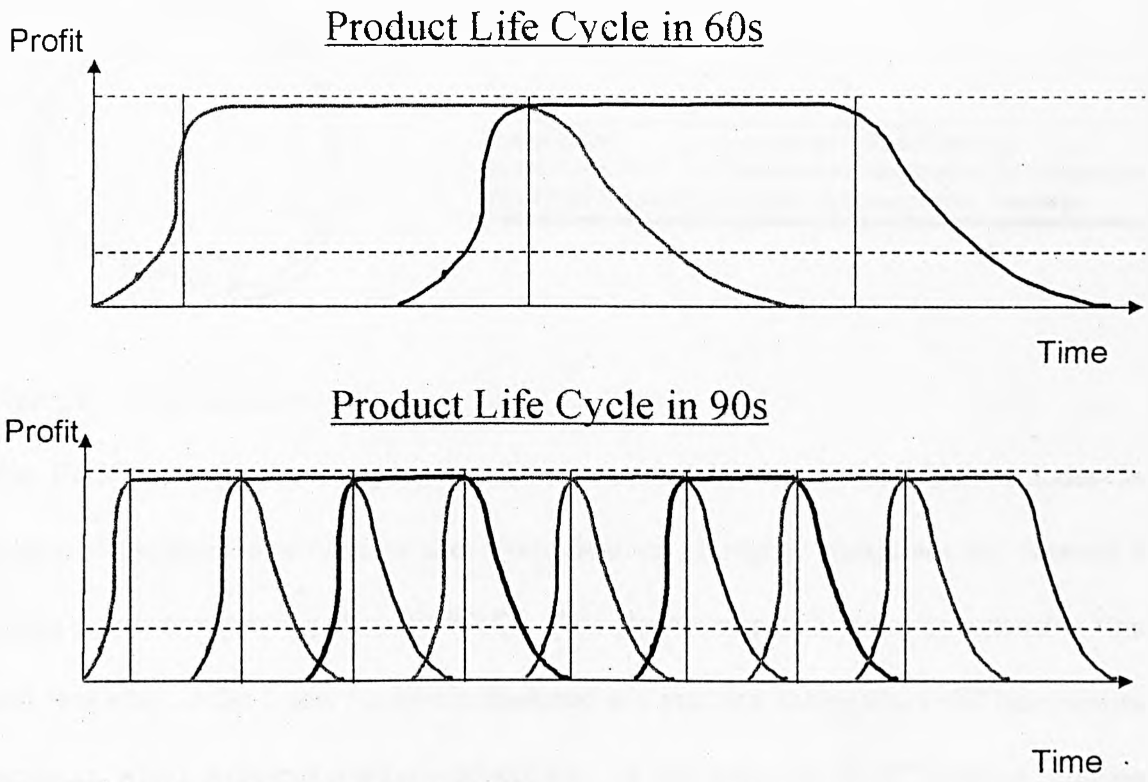
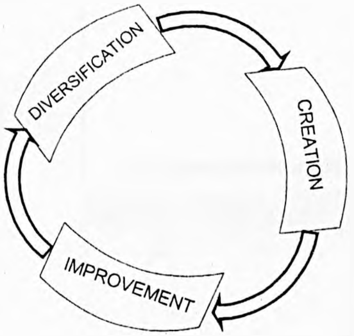


Figure 7. Product life cycle in 60s and 90s.

R&D is a very important weapon to sustain the competitive edge of a company. Moreover, it is considered to be more significant in the 90s compared to the 60s. So, the next section will discuss the R&D strategy.

4.1.2 "CID" Concept

R&D is a very important aspect in the keen global competition environment in the manufacturing industry, because the business nature of Far East manufacturer is gradually moving from OEM-oriented to ODM-oriented. Without strong R&D it is very difficult for a company to participate in this keen global competition. Therefore, an innovative concept is proposed as follows to meet the competition.



CREATION	-To create new product concept.
IMPROVEMENT	-To improve existing product for competition.
DIVERSIFICATION	-To divert when competition is extreme.

Figure 8. "CID" concept

The R&D strategy of a company can be represented by the model which includes the stages of creation, improvement and diversification. Initially, companies are deemed to create innovative product through R&D. This stage necessarily requires extensive time and resources. After a new product is launched and matures, competitors will have similar products, which increases market competition. At this stage, the "CID" concept proposes that companies should improve the product so as to sustain the competition. However, competitors continuously improve and develop their products to withstand head-to-head competition, therefore companies should diversify in order safeguard their current market position, then attempt to expand further. Diversification is considered to be the first step of creation in the "CID" concept. So, these three steps can be represented in a closed loop model as shown in Figure 8. Figure 9 describes the relationship between the "CID" concept and product life cycle. The "CID" concept is considered very important in the keen global competition environment.

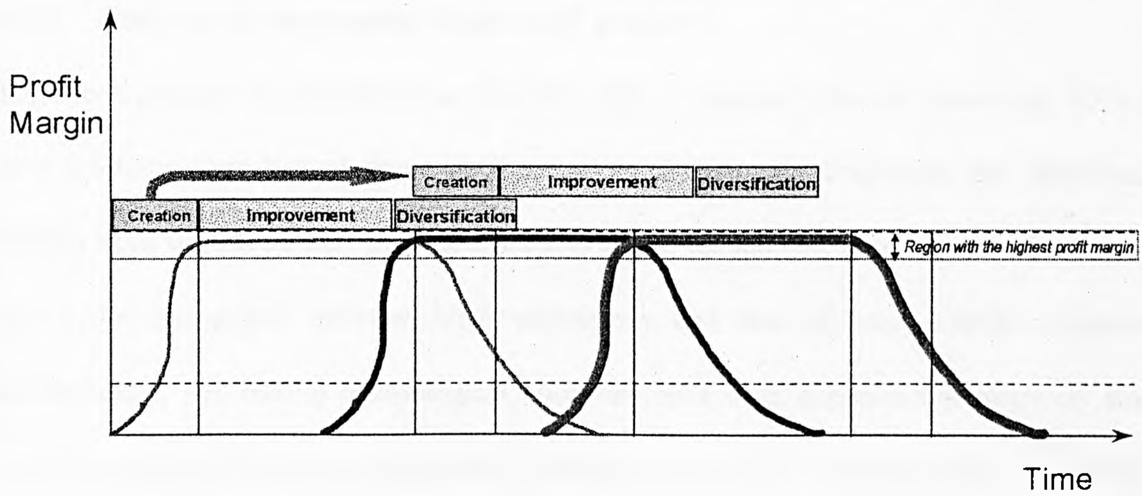


Figure 9. "CID" concept in product life cycle

4.2 "High-tech" products in the Far East manufacturing industry

A "high-tech" product is one which has incurred leading edge technologies. Such products have gone through huge amounts of engineering development, incurred a tremendous amount of resources, both financial and human. To develop these leading edge technologies, essentially a suitable peripheral environment is required to support high technology development and manufacturing, as well as the inevitable high levels of financial resources that must be prepared for huge expenditure. The author contemplated that medium-to small-sized companies in Hong Kong cannot afford to develop leading edge technologies for producing "high-tech" products, and lack an intensive technological involvement to support manufacturing high tech product in the Far East. The argument is supported by the next sections (*4.2.1 - 4.2.3*).

4.2.1 "High-tech" product development expenditure

There are many examples provided by OECD (1990) to testify that implementation and development of new technology requires abundant financial resources.

4.2.2 High risk in developing "high-tech" products

High-tech product development can be very risky. In major industrial countries, 90% of new products were turned down by the market prematurely. Englander and Mittelstadt (1990) have suggested that there is a slow down in technological advance at the frontier and a decreasing gap between USA technology and that of other OECD countries. Nevertheless, the leading technological countries have been experiencing relatively slow technological advancement and growth mainly due to a low success rate in developing high-tech products. The author suggests that financial resources planning is an important factor to consider in the development of high-tech products in Far East.

4.2.3 Capability of Hong Kong manufacturers to develop "high-tech" products

At the end of the 1970s, a Government-commissioned report (Krugman 1994) suggested that local manufacturers should upgrade themselves and that the Government should re-orientate its industrial policy, and give more support to local industry. This has become a routine part of the rhetoric emanating from senior government officials, academics, and industry leaders in Hong Kong. However, the actual investment being made in this direction is very inadequate and, so far, no significant positive results have been seen. Therefore, the author assumes that it is virtually impossible for Far East manufacturers to support high-tech product development.

4.3 The role of the Research and Development in a Far East Manufacturer

4.3.1 Major aspect of R&D in the Far East

- Market research
- Innovative Product
- New Product Development

- Cost improvement of current product
- Research and Develop of new manufacturing technology

4.4 "High-tech" manufacturing system for Far East

In the past 15 years, owing to lower production costs, the majority of consumer products have been produced in the Far East for major American and European markets. This has led to the rapid growth of consumer product manufacturing in the Far East. Despite the fact that these companies are unable to develop and produce "high-tech" products, they are however able to enhance their existing manufacturing systems with sufficient financial ability, and to draw on existing, matured front-end technology, which is considered new in Far East countries. The author believes that it is the appropriate strategy for Far East manufacturers to produce high-quality, but low-cost products by the high-tech manufacturing system (see *portfolio 3*).

5. "High-tech" approach and manufacturing strategy formulation and implementation in China

As mentioned in the earlier sections, the majority of writers believe that Far East manufacturers must adopt the "high-tech" product approach to sustain their competitiveness in the industry. However, the author believes that the approach of a "high-tech" manufacturing system to produce high quality with low cost products is more appropriate for Far East manufacturers. This approach was further supported by a review of the history of the high-tech manufacturing system in the global environment, which can be seen in *portfolio 4*. It has been concluded that the "high-tech" manufacturing system encompassed not only high-technology facilities, but included a wide range of elements, such as modern manufacturing strategies, i.e. MRPII, Real-Time Monitoring System, etc. After further investigation, an integrated manufacturing system in China is therefore proposed and identified as the most favourable manufacturing strategy. The design of the integration strategy is identified through a step-by-step approach from the strategic level to operational levels.

The following section elaborates upon the "High-tech" manufacturing system approach in a labour-intensive environment, and describes a systematic process to develop and implement the integrated manufacturing strategies that are consistent with a company's overall business strategies as well as the particular characteristics existing in China.

With the increasing global competition and pressure for higher productivity, world-wide interest in manufacturing strategy has escalated. One of the first researches to make a systematic study of manufacturing strategies was Skinner (1969). Since then much research has been published on the subject. As a result, many large and small manufacturing firms began to develop manufacturing strategies. Wheelwright (1978), Hayes and Wheelwright (1984), Fine and Hax (1985), Hill (1985) were some of the authors who published the most well-known literature. However, few of them describe the application of a strategic manufacturing process in China.

5.1 Survey on manufacturing strategy

A survey on manufacturing strategy was conducted during the period November 96 to February 97 to identify the current use of methods for improving manufacturing efficiency in China, and to determine the future plans for a manufacturing strategy. The number of questionnaires distributed resulted in 31 of these being are collected. The response rate was about 31%. A general analysis was done on these returned questionnaires.

The research was divided into two levels. The first was the 'general level'. This level was used to collect the general concepts and ideas on the manufacturing strategy of the China manufacturers. There were 31 respondents at this level. The second was the 'specific level'. Since there are new concepts involved, a brief explanation of high-tech manufacturing systems, such as real time monitoring, was included in the survey document to allow a better understanding. This level analysed in-depth the "high-tech" manufacturing system, i.e., Real-Time Monitoring System (RTMS), Total Quality Management (TQM) and Integrated Manufacturing with respect to the survey result of the general level survey.

Most respondents were companies which have been established for more than five years. This reflects that these companies are well developed. All the respondents believed that TQM could help them to improve their manufacturing efficiency and this is the strategy that all of the companies will adopt as their future manufacturing strategy. Innovative product and manufacturing systems, large product range and low cost manufacturing were also identified as manufacturing strategies for the companies to adopt. Regarding RTMS, more than 90% of the respondents thought that this was important and could be very important. About 34% of the companies in the sample considered this as the future manufacturing strategy in China.

Some research figures are illustrated in Figure 10 and more results are discussed in *portfolio 4*. Over 95% of respondents thought that RTMS was important and more than 50 % of them believed that RTMS was very important to their company growth. It can be stated that RTMS is a very important aspect to manufacturers in China.

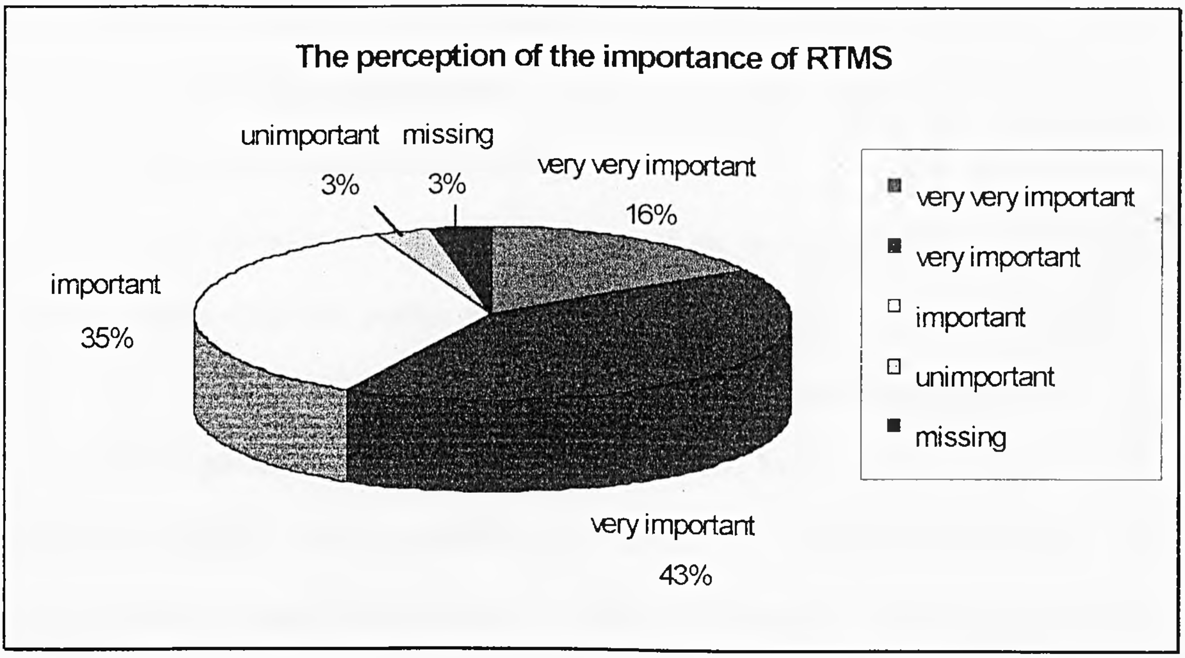


Figure 10. The perception of the importance of RTMS.

5.2 Strategic planning process

Having identified a manufacturing strategy for China, it is necessary to further investigate the strategic planning and implementation process. The survey results from the above sections identify some major strategic components which are consistent with the long-term company goal. The next step is to propose a strategic planning process to implement the above components in a systematic way. The process should describe the steps to be used, who should be involved, what information is needed, and what are the outputs. This process should be simple enough so that it can be easily followed. From 1993 onwards, the author has identified the process for developing a manufacturing strategy. Essentially, it follows four major phases:

I. Establish the present position

II. Analyse strategic requirements

III. Develop strategic improvements

IV. Formulate an implementation strategy

This process is conducted by a team consisting of the managing director, managers of factories, engineering and quality, marketing, human resources and information system staff. In addition, external consultants are employed as facilitators who provide the experience and guidance of an objective, third-party view. Much of the planning is done in small group meetings which allows time for the exchange of ideas and discussion. The author is very involved in this process, in order to establish his views concerning the implications of the business strategy for manufacturing and, in particular, to explain his vision of the “high-tech” manufacturing system. The manufacturing strategies become apparent when going through the steps, which are addressed as follows:

- Manufacturing strategies are needed to respond to business strategies
- Comparison of present levels of manufacturing performance with future requirements

- Strategies that remedy present weakness and exploit strengths.
- Strategies to cope with the political, economic and social environment in China
- Competitive advantages to sustain business growth

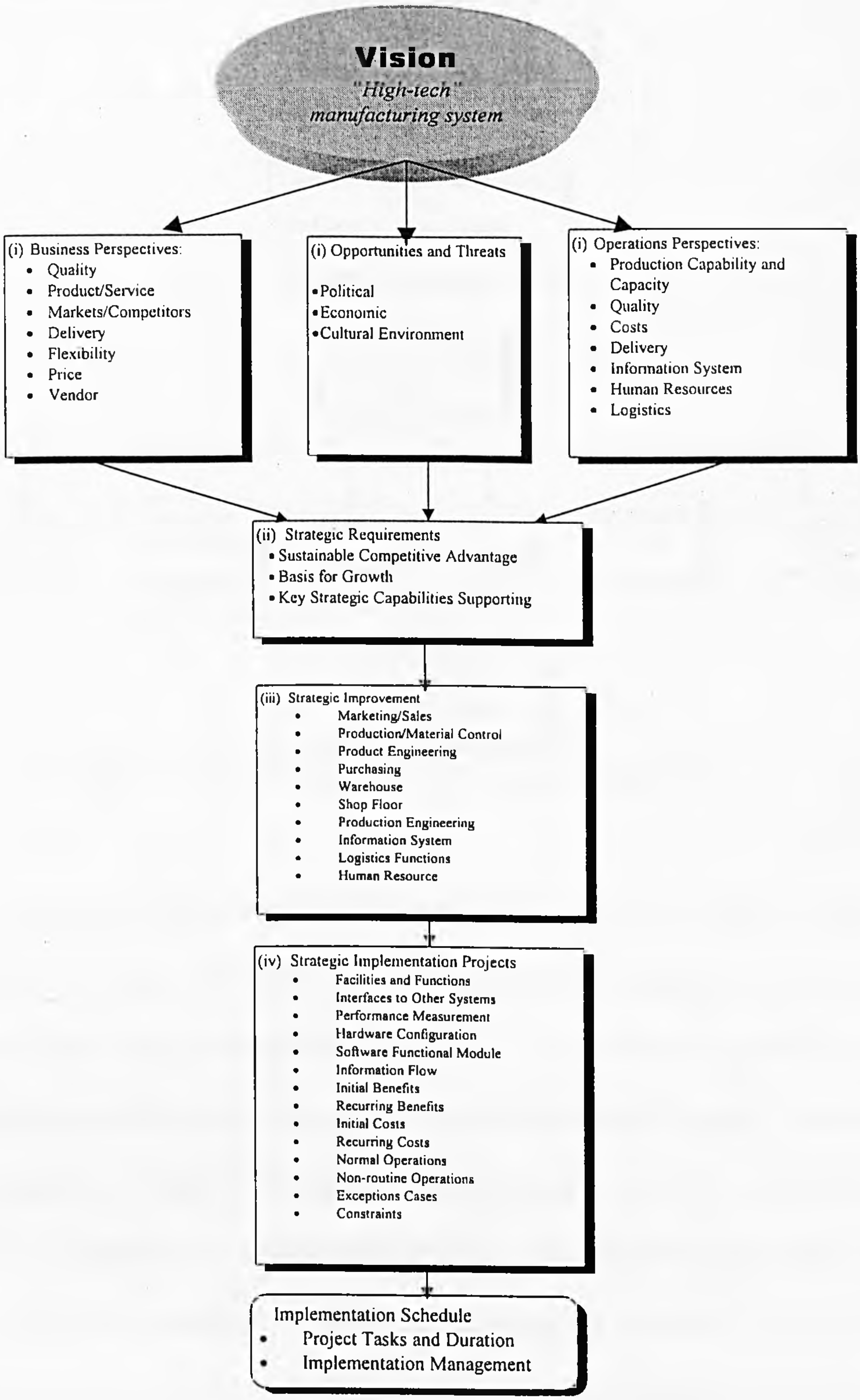


Figure 11. The process of manufacturing strategy development and implementation.

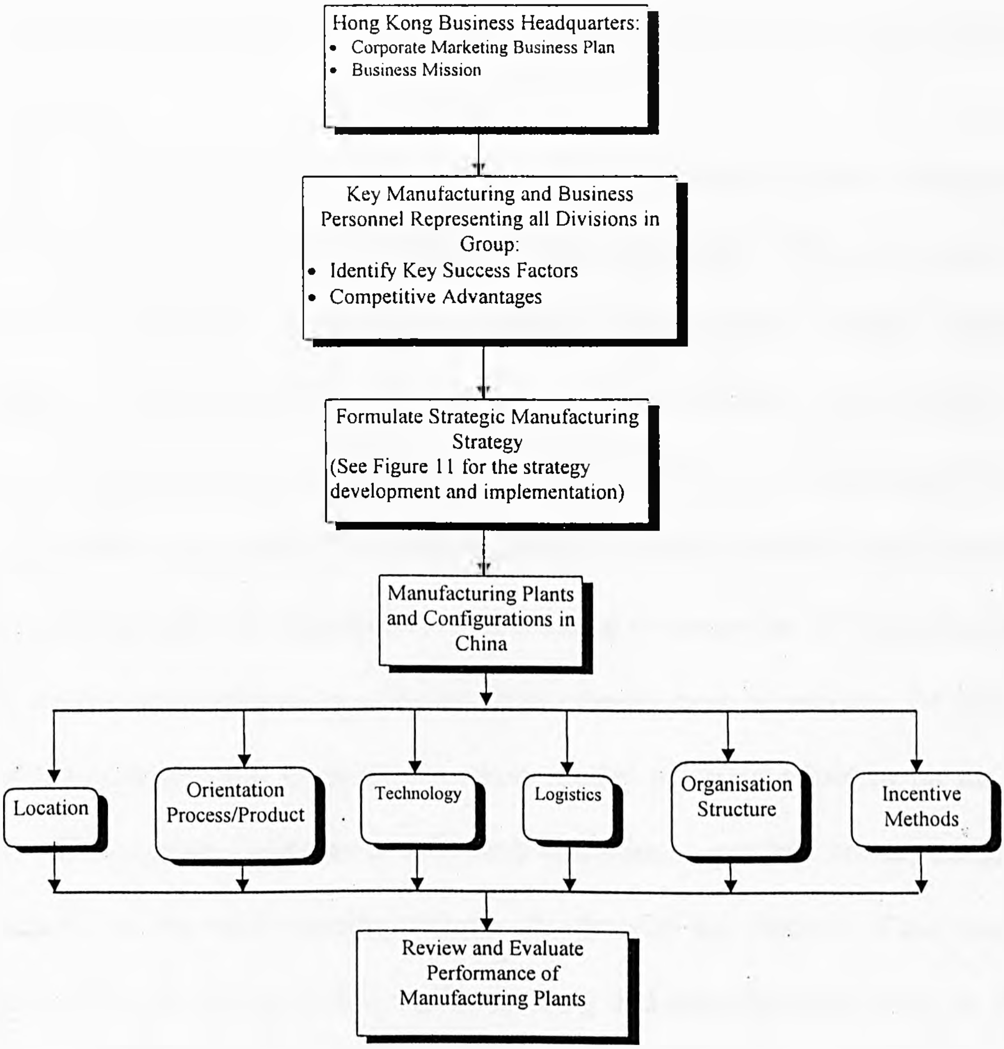


Figure 12. Strategic/manufacturing operation of Hong Kong and China.

Figure 11 illustrates the four steps in the manufacturing strategy development process and implementation. Figure 12 illustrates the strategic manufacturing operations in Hong Kong and China that link the business objectives to manufacturing. After the strategic planning process was followed, the company identified that the "high-tech" manufacturing system approach, through an integrated manufacturing design, was appropriate (see *portfolio 4*). Regarding the implementation strategy, the implementation of RTMS and MRPII systems are identified as being the integration programmes. The systematic integration approach and the technology components will be discussed in the following sections.

6. An integrated approach to the design and implementation of a manufacturing system

The rapidly changing business environment is a problem faced by the manufacturing industry, which has been discussed in detail in the earlier sections. The way to cope with these substantial changes is to use a "high-tech" manufacturing system approach. According to a recent survey (Whitla and Davies 1995), more than 80% of Hong Kong manufacturers have invested in China, up to 90% of which is in Guangdong Province. Hence, the production operations and logistics become complicated and involve substantial changes in management and organization. It is essential to ensure that all these changes are properly planned and implemented. Though these changes must be suited to the particular needs of the company, the integration method applied has been found to be the most effective. This section illustrates a systematic integration approach to the design and implementation of the manufacturing strategy. It identifies key features of the operation and logistics between its main office in Hong Kong and manufacturing plants in China. Various aspects including marketing, logistics, information flow and production process flows are planned. The design of a manufacturing system is achieved through hierarchy models. Emphasis is placed on the total integration of the MRP II and RTMS.

A task force was formed to design the initial manufacturing system integration. Integrated computer-aided-manufacturing DEFinition (IDEF) method technology was chosen to be the design and integration methodology. IDEF, derived from the US Air Force Integrated Computer Aided Manufacturing (ICAM) (Wisnosky 1987) initiative, is a modelling method used to describe systems (Hill 1995) and a structured analysis and design method based on graphic and text descriptions of functions, information and data. The IDEF method is widely understood and well documented (Hill 1995, Benjamin et al. 1993, US Air Force) and the method originally defined by the 'Architects Manual' includes guidance for modelling, together with rules for model syntax, diagram and model format and text presentation, as well as structured model validation, document control procedures and interview techniques. A key concept of IDEF modelling is the definition of a 'Context' and the modeller's 'Viewpoint' to establish an explicit common understanding of the boundary and aspect of the system being modelled.

IDEF0 is very similar to SADT (Ross 1977, 1985), Structured Analysis and Design Technique, which was developed by the SofTech Corporation in the 1970s. It is a powerful tool that can be used for communication as well as analysis purposes. By helping the modeller to identify the functions performed, exactly what is required to perform these functions, as well as what the system (being modelled) accomplishes, can be established. As a communication tool, the IDEF0 model allows the manufacturing organization, or any other user, to describe what the organization does. It is a top-down modelling method which starts from general to specific, from a single page that represents an entire system to more detailed pages that explain how the subsections of the system work.

6.1 Shop floor control system integration

Figure 13 depicts the design of a shop floor control system. The technology of real time interfacing between two systems is proposed by Cooling (1986). The integrated manufacturing system, integrated MRP II system and RTMS is proposed by the author. The operation of the shop floor includes a series of activities such as material requirement planning, re-order list generation, issue of work orders, packing list generation and time scheduling. Within this system, the most important control aspect is the material control, since this is considered to be a serious problem. An RTMS is implemented to resolve this problem in order to enhance the product quality as well as the productivity. The control layer is the hardware system, which includes Programmable Logic Controllers, sensors, data capturing devices, etc. The RTMS provides the real-time material/assembly flow information. The real-time data collected are fedback to the overall MRP II system and the resources distribution centre for rescheduling.

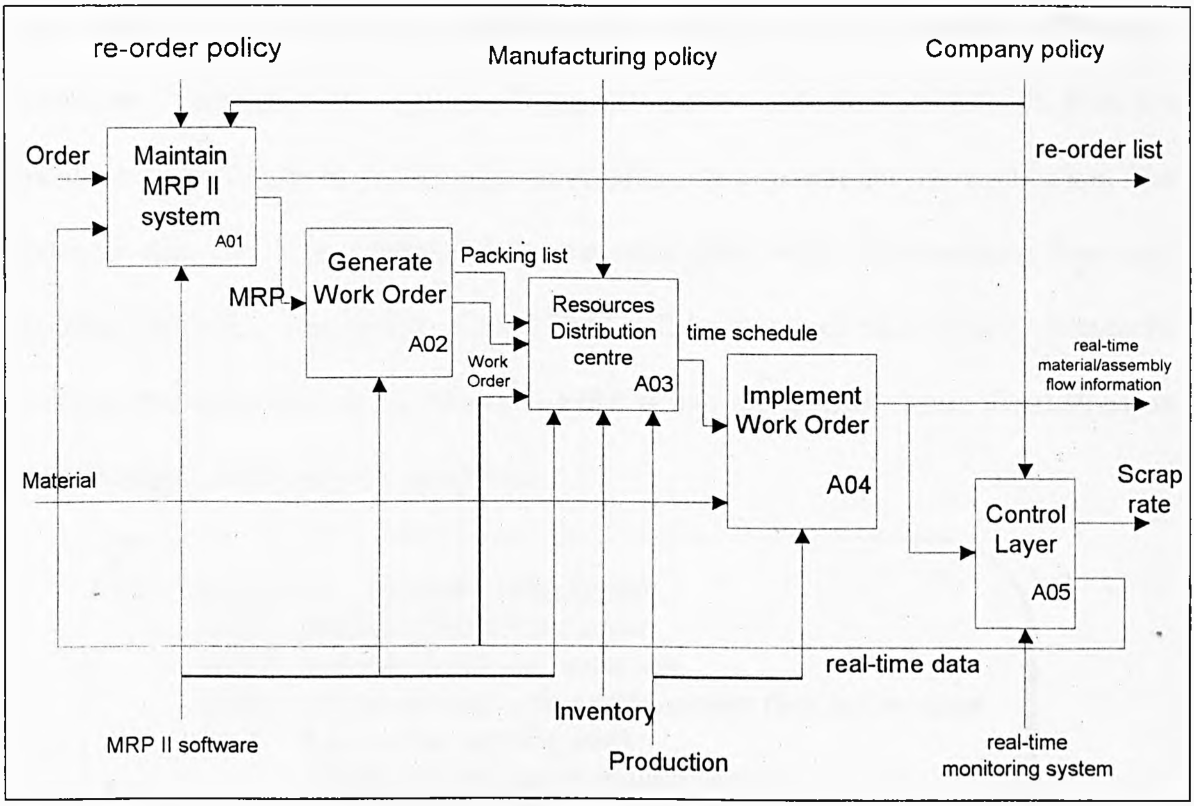


Figure 13. IDEF0 model of shop floor control system.

6.2 Real-time monitoring technology

The essential part of this integration strategy is the RTMS. The real-time information is considered to be a valuable tool for analysis within the manufacturing environment (Levi 1990). The shop floor control system involves data collection and quality control, while the office monitoring and planning aims to improve the entire manufacturing cycle by sharing factory floor data with MRP II.

Programmable Logic Controllers (PLCs) work as the major control device on the shop floor. Sensors, machines and data collection devices are physically connected with the PLCs. Real-time software is used to interface with the computers and PLCs. Accordingly, the shop floor supervisor can stay in his office and monitor the situation of the shop floor in order to make real-time decisions such as shutting down the machines or identifying which jobs have recently been completed, thus making them available for subsequent operations. The head office in Hong Kong can receive up-to-date information from the mainland China factory floor, through transmission via a special hot line connection. The real-time data are extremely useful in the integration with manufacturing resources planning (MRP II). The details of the RTMS will be discussed in *section 7*. Figure 14 illustrates the node tree which integrates MRP II into the RTMS. More discussions on IDEF0 designs can be seen in *portfolio 5*.

- A05 Run Real-Time Monitoring system
  - A051 Process MRP II work order
  - A052 Generate detail list/operations
  - A053 Collect real-time material/assembly flow information
  - A054 Run control and diagnostic
    - A0541 activate communication layers
    - A0542 fault detection
    - A0543 statistical process control
    - A0544 quality analysis
    - A0545 line balancing
    - A0546 real time costing
  - A055 re-schedule analysis
  - A056 activate higher level control layers

Figure 14. IDEF node tree.

6.3 Integrated manufacturing system

After the hierarchical analysis using IDEF0, an integrated manufacturing system depicted in Figure 15 is proposed. The system can be divided into three individual levels, namely strategic level, tactical level and operational level.

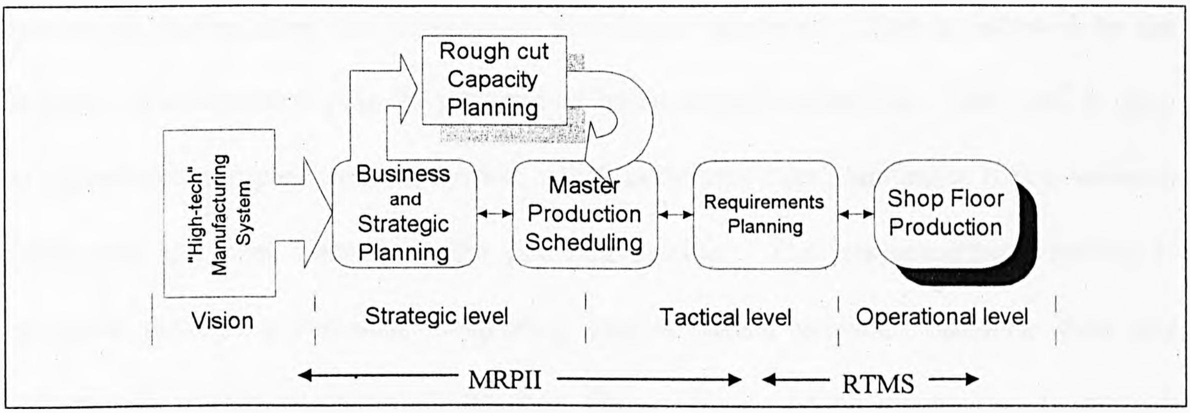


Figure 15. Integrated manufacturing system.

The strategic level mainly concerns the overall company planning which relates to the transformation of customer needs into the product design and its verification, the design of products to facilitate manufacturing.

The tactical level relates to the completion of the master production schedule (MPS), the verification of the MPS in terms of its capacity requirements using rough cut capacity planning procedures and the transfer of the confirmed MPS to the requirement planning system. The requirements planning procedure, implemented using Materials Requirements Planning (MRP) software, translates the MPS requirements, normally stated in terms of end level or at least very high level items, into detailed time phased requirements for individual assemblies, subassemblies and components. Coupled with this, Capacity Requirement Planning (CRP) is used to verify the proposed requirement plan from the point of view of the resource requirements.

The operational level is the shop floor control system. The shop floor control system is broken down into six individual blocks which can be seen in Figure 16, namely co-ordination, planning, implementation, production, material handling and remote monitoring. Planning guidelines are given to the planning section by the shop floor co-ordination section after the requirement planning is approved. This is followed by the creation of a short-term plan for the product-based manufacturing cell. This plan, in turn, is passed to the implementation section, which is the real-time planning in that it seeks to implement the plan created by the planning section. The implementation section is achieved through a real-time monitoring system, which provides real-time data and information on the condition of the shop floor. The real-time information is used to identify which resources are available for work, and which jobs have recently been completed, thus making them available for subsequent operations.

The remote monitoring section tracks the flow of work through the shop floor by capturing data on the condition of production and material handling. These data are fed back from the control devices which are installed on the shop floor.

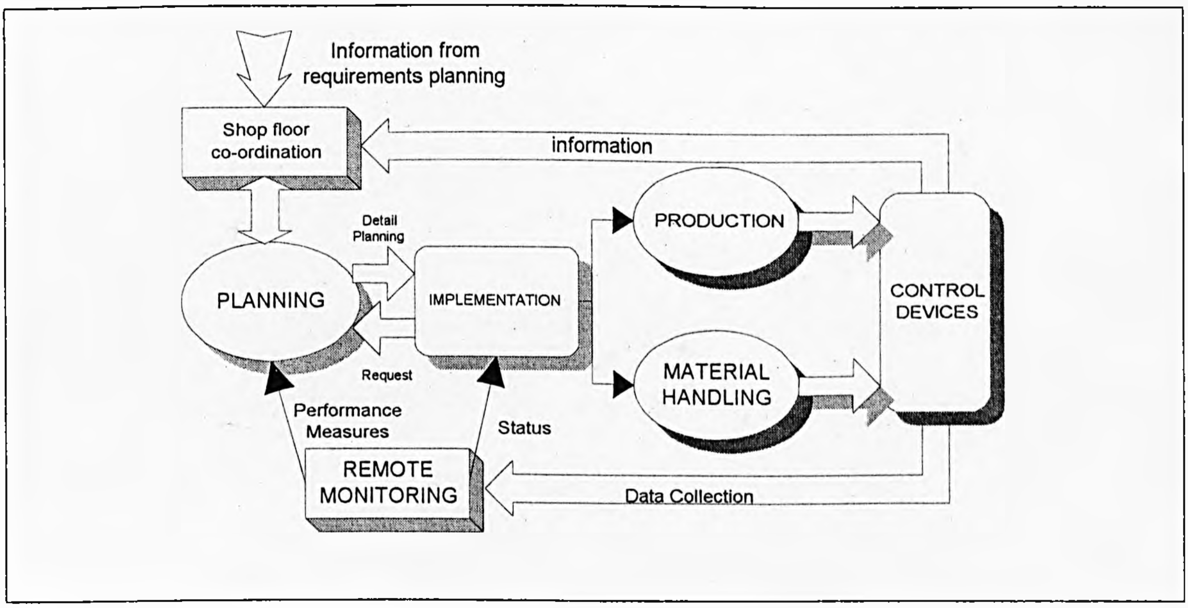


Figure 16. Shop floor control system

In this section the author has illustrated the hierarchy methodology which breaks down the manufacturing process into sub-level requirements and the procedure levels. It has been found to be an invaluable tool which helps management to identify and plan overall production and logistics. In particular, this company has successfully integrated MRP II and RTMS in order to achieve the "high-tech" manufacturing system proposed by the author. The details of the implementation will be discussed in the next section. It is anticipated that the integration approach to the design and implementation of production and logistics integration will be an important contribution towards the manufacturing strategy in China.

7. Integrated Manufacturing Strategy Implementation Through a Real-Time Monitoring System

Research into the real-time monitoring can be dated back to the early 1940s. By about the 1960s, this technology had begun to be studied and gradually utilised in manufacturing processes, with the main objective of monitoring various abnormal cutting states by making use of sensors. In order to achieve more advanced levels in the manufacturing field, many countries in the world are commiting considerable financial support to foster, advance and speed up their manufacturing technologies. To deal with the technological bottlenecks in advanced manufacturing techniques, the real-time monitoring technique was thereby strongly emphasized and quickly developed. Research into the real-time monitoring technique, aimed at monitoring manufacturing processes, reached its summit around 1990 (Villa 1985; Yusuf 1988; Liu & Ko 1990; Lau 1992; Fu 1992). Various kinds of new monitoring theories, principles and signal sensing methods have been put forward and employed constantly. At the same time, new data analysis methodologies and processing techniques have also been suggested and developed, e.g. Kalman Filter theory (Catlin 1989), time series analysis (Chatfield 1989), Dynamic Data System (DDS) (Kashyap 1976), fuzzy pattern recognition technique (Kandel 1982), artificial neural network (Choi 1990), as well as expert system theory (Boose 1986). Various published papers have been concerned with the subject of the intelligent monitoring system (Lopez et al. 1986; Basanez et al. 1989; Milberg et.al. 1992; Syed et al. 1993; Camarinha et al. 1994). In addition, the monitoring techniques have also been finding wide applications in production management (Charalambopoulas et al. 1993), underground coal-mining (Raman et al. 1988), steel production (Coudel et al. 1988). Umscheid (1991) even suggested using RTMS to enhance SPC in a plastic moulding machine.

7.1 Interrelationship of RTMS and TQM

The fundamental reason underlying the proposed approach is based on a belief in TQM, this being the driving force of the company to achieve higher quality and productivity. The "Sunflower" approach to TQM employed by the author provides a framework for further development (see section 3).

Total quality means that everyone should be involved in quality, at all levels and across all functions, ensuring that quality is achieved, according to the requirements, in everything they do. This injects a systematic meaning of wholeness into quality. Every job is crucial and adds to, or detracts from, the quality culture. By integrating team management, the value of management responsibility is projected into quality and the wholeness established. Management responsibility does not necessarily refer to a company's managers as it does in the entire quality literature that we have met. It can refer to the need for everyone to be responsible for managing their own jobs, and incorporates managers who oversee workers and anyone else associated with the organization. The main principles of TQM can be demonstrated from the philosophy suggested by Flood (1993).

These 10 main principles provide a concise understanding of TQM as it stands today. In fact, TQM is no more than a kind of philosophy or thinking which is appropriate to a variety of management systems. Its essence may be comprehensively understood from different aspects and different points of view. For example, the quality principles may be interpreted either through traditional management and organization theory or through viable system thinking, as well as through social-cultural systems thinking. The interrelationships of TQM and RTMS can be derived as follows:

- *real-time control* helps effective decisions to be made on up-to-date information; those who have a commitment to quality objectives will seek out and wish to dispose of redundancy.
- the future is planned to enable properly *co-ordinated* and *controlled procedures*.
- intelligence provides *information* to aid the planning process.
- *jobs and tasks are organized to be effective* in achieving customer requirements.
- *everyone has the visibility and shares in the quality* concept.
- *learning* provides the basis for continuous improvement.
- with intelligence and learning functions in place throughout the recursive organization, and *with plenty of relevant real-time information*, an organization is prepared for and can encourage creativity.

The representation of interrelationships is shown on Figure 17.

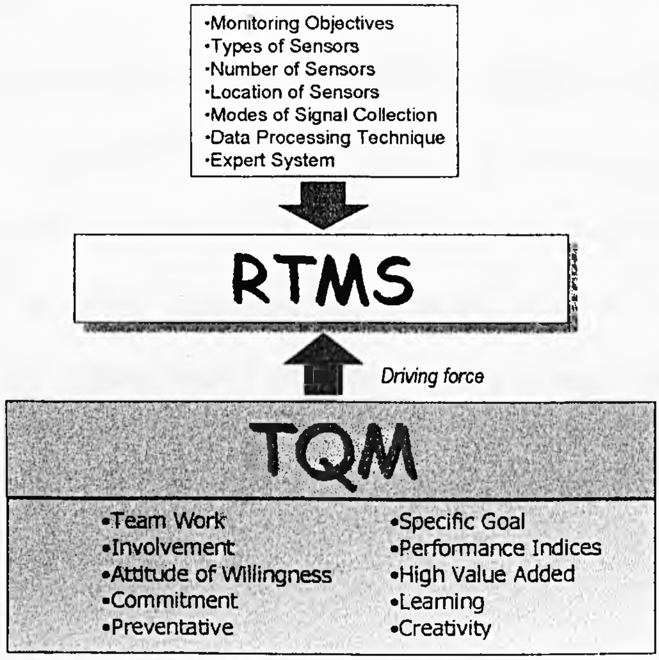


Figure 17. Interrelationships of RTMS and TQM.

7.2 The implementation

The implementation of RTMS requires two major elements; reliable sensors and data processing technology with expert systems. Therefore, the following concerns have been addressed in order to develop the RTMS:

- *Monitoring objectives*
- *Choosing types of sensors*
- *Number of sensors*
- *Location consideration of sensors' installation*
- *Consideration on working modes of signal collection*
- *Data processing technique*
- *Expert system*

7.2.1 System overview

The system is broken down into two parts illustrated in Figure 18. The first part is the shop floor control and the second part is the office monitoring and planning. The shop floor control system mainly concerns data collection, quality control and manufacturing cost control, while the office monitoring and planning aims to improve the entire manufacturing cycle by sharing factory floor data with planning, distribution, financial systems and MRP II.

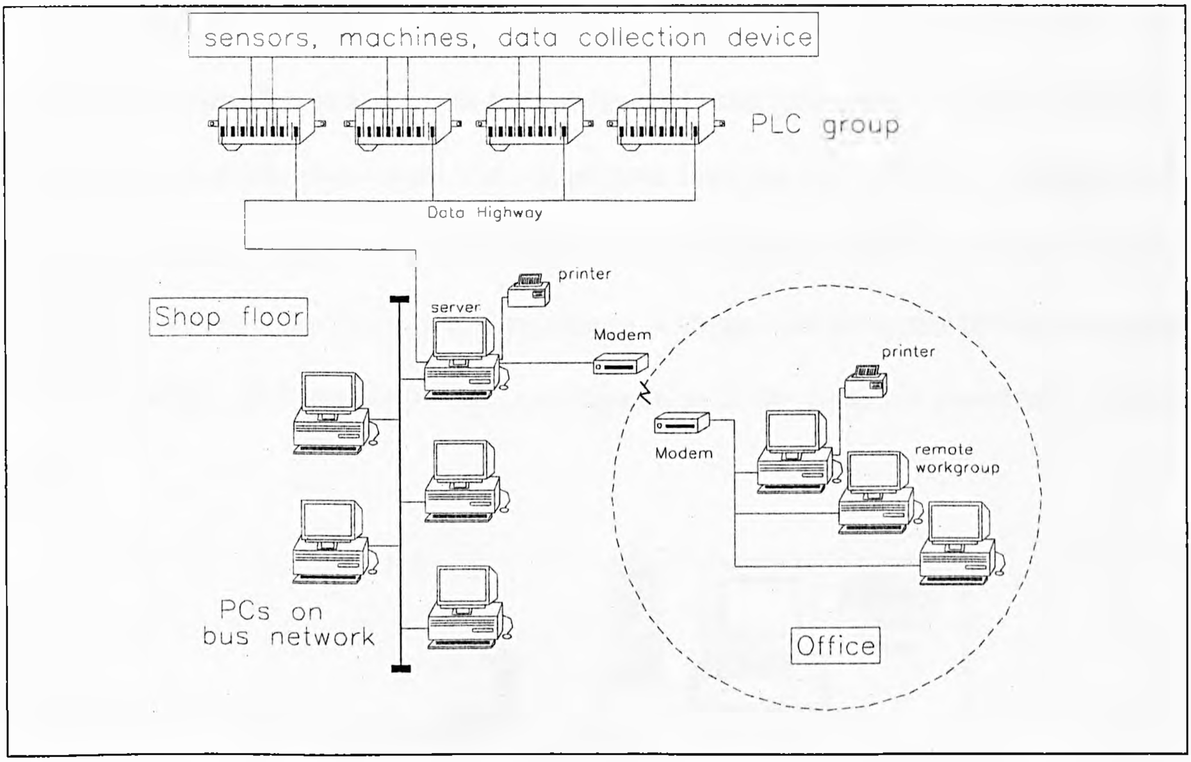


Figure 18. Real-time monitoring and control system architecture.

7.2.2 Real-time data collection system based

In the implementation, there are over 100 work stations as well as several manual quality test stations (QC checkers) and trouble shooting stations are intermixed among them in an assembly line. The worker performs assembly tasks assigned to him at the workstation. Final quality testing of the products is carried out automatically by a computer-controlled test station.

The evaluation of the workers' performance depends on how much time he spends on assembling one unit and the amount of units that have been assembled. It is obvious that at least two kinds of signals are measured; one is the number of assembled units and the time they spend in assembly and the station idle time; the second is to record the status of work in progress. The details can be found in *portfolio 6*.

Similar to the information from the assembly workstations, the report information from QC test stations must also be sent to the host computer in real time. However, the contents of this report are much more varied and complicated than just a photoelectric switch signal. Dedicated key-in devices and bar code readers are therefore used for the data capture. These devices use a parallel data bus to connect with the host computer through a special buffer interface. The current hardware configuration of the system is presented in Figure 19.

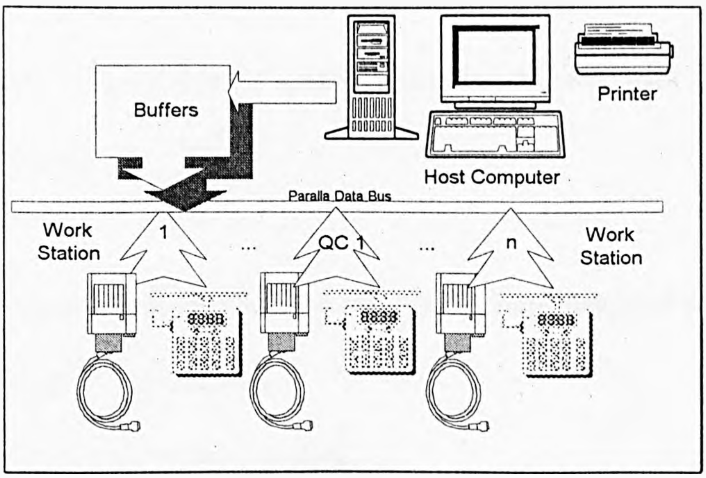


Figure 19. Hardware configuration of the monitoring system.

7.3 System features

The system is configured to be controlled by a host computer. After the raw data are received, the master system will process the data and update all graphic screens on the master computer and other optional user computer consoles. A dual host standby feature adds reliability to the overall system configuration. If the processed data are configured for logging, the data are logged to the printer and the historical alarm/event database. If the processed data are in alarm mode, an alarm record is generated and a message also shows up on the alarm banner. At each point, data can be configured as an alarm point, and this alarm point can be set as acknowledgement required or an audible signal.

7.3.1 Statistical process control

SPC is the quality management tool that monitors the quality level at which a manufacturing process produces products. SPC measures, inspects and evaluates a product's quality based on pre-defined criteria. The SPC is used to automate the quality management in real time so that manual tracking of the measurements is no longer needed. The implementation includes the following functions:

- Collect real-time product data from real-time database
- Calculate various statistics to indicate the state of production
- Graphically display data in statistical control charts in real time, with historical data and ad hoc query scenarios

Raw data are collected through the PLC and QC booth controllers and stored in data base format. Raw data computation includes:

- Individual value of each group of raw data
- Average value of a group of data
- Range of the smallest and largest raw data values in a sub-group
- Standard deviation
- XBAR/R chart using range calculation
- XBAR/S chart using standard deviation calculation
- Kurtosis - Relative plateauness or peakness of the distribution values in a population
- Skewness - Population's symmetry on each side of the mean

7.4 System administration

A schematic diagram of the production process when integrated with RTMS is shown in Figure 20. Every work station is monitored by the RTMS when products are manufactured. The integration of RTMS and an expert system can capture the essential knowledge from the production line on a real-time basis. The captured knowledge is used for on-line troubleshooting and worker training during the next cycle of producing the same product. This dramatically increases the overall throughput of the production line since the workers can solve most of the problems themselves. As regards quality, information obtained from QC and troubleshooting station passes through the SPC and expert system, where a diagnostic function will perform, hence assisting manufacturing process control. The system can efficiently reduce the time needed to perform the SPC task. Since both of the data capturing processes are done automatically. The supervisor can also clearly monitor the production status from the monitor screen, through the dynamic simulation function of the monitoring system.

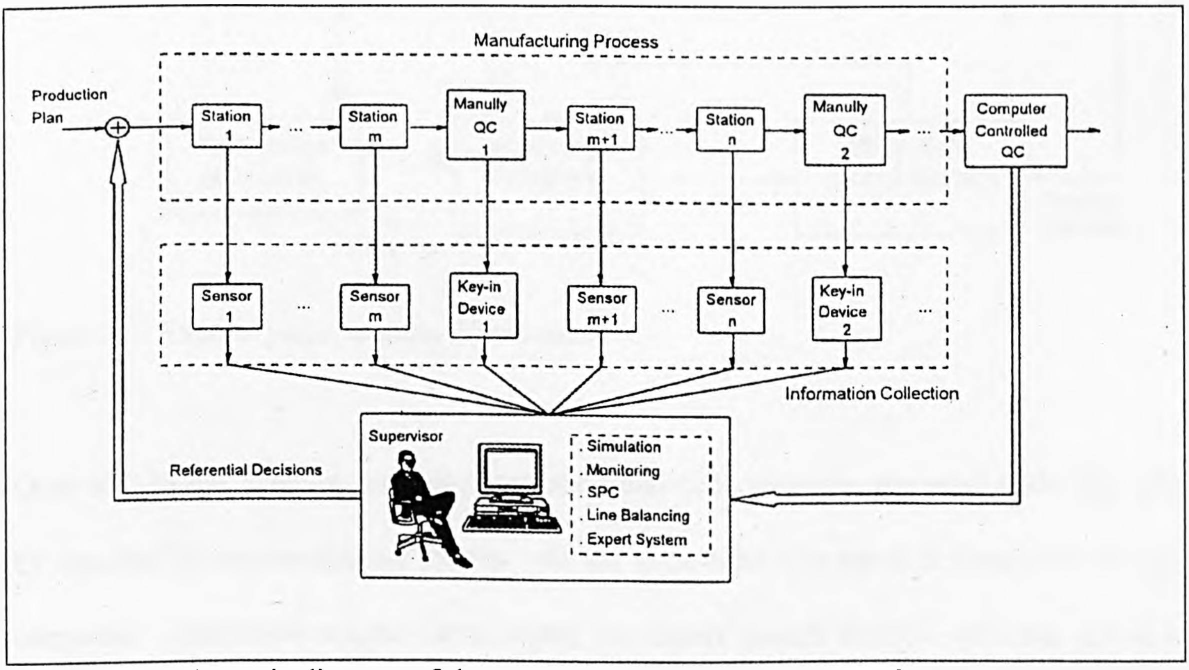


Figure 20. Schematic diagram of the production process using RTMS

7.5 Expert system in the integrated manufacturing

An expert system is essential to an integrated manufacturing system, since it can be used to reduce the setup and troubleshooting time in the production line. The implementation of the expert system is the result of our manufacturing integration strategy. New experience and knowledge on production must be amassed and then added to the knowledge base as the system continues to run. The designed expert system has the ability not only to upgrade its knowledge, but also to learn new knowledge based on the data recorded during the system operation, and the ability to self-organize this knowledge. The simplified flow of the expert system is represented in Figure 21.

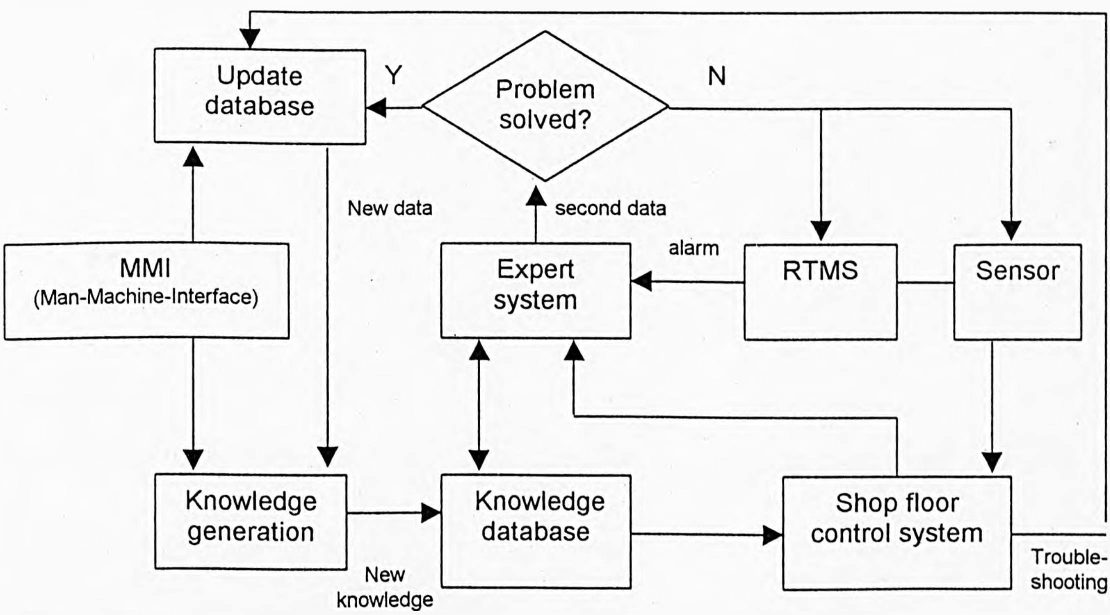


Figure 21. Expert system in shop floor control.

Once RTMS has been implemented, any abnormal occurrences in the production line will be signalled by the monitoring system. At the same time, the signal is transferred to the computer. After receiving the alarm signal, the expert system starts to activate, giving a second signal, or removes the original alarm while providing a troubleshooting service at the same time. If the system is not implemented with RTMS, the fault diagnosing and removing process is carried out by the industrial engineer with the help of the expert system. When either of the above mentioned processes is over or some equipment in the system changes, the corresponding data will be put into a database. Thus, new troubleshooting knowledge can be produced through the adoption of the knowledge capturing technique.

8. Findings and conclusion

8.1 Findings

Short-term benefits offered by the design of the "high-tech" manufacturing system and its implementation through integrated manufacturing system (i.e. modern manufacturing strategy, RTMS, MRPII) include reduced manufacturing cost, i.e. speeding up the process for problem solving, maximising output in the optimum line balance, improving product quality, and shortening ramp up time during the next production shift, especially for batch production. It also reduces manufacturing overheads included in the elimination of operational documents replaced by computer control information system. The automation of stock evaluation can generate information on patterns of material consumption in a much more cost-effective manner. The whole system can also provide the manufacturing real time costing for management purposes.

The author considered this project as a conceptual design at the corporate level. To complete a full implementation, it will require a longer period of time. The Real Time Monitoring System and MRPII has been implemented on a single production line as a pilot study. A remarkable time saving can be derived from error analysis especially in the labour intensive environment of China, which is now completely automated in this production line. Figures 22 exhibits the improvement in customer delivery service. It illustrates the total number of committed shipments awaiting completion and the number of committed shipments completed during the month. After the integrated manufacturing system is implemented, the number of committed shipments awaiting completion beyond the committed due date, i.e. past dues, is reduced. Therefore, customer satisfaction is improved. Moreover, Figures 23 and 24 describe the improvements in the product quality and production cost, respectively. The findings are described in detail in *portfolio 7*.

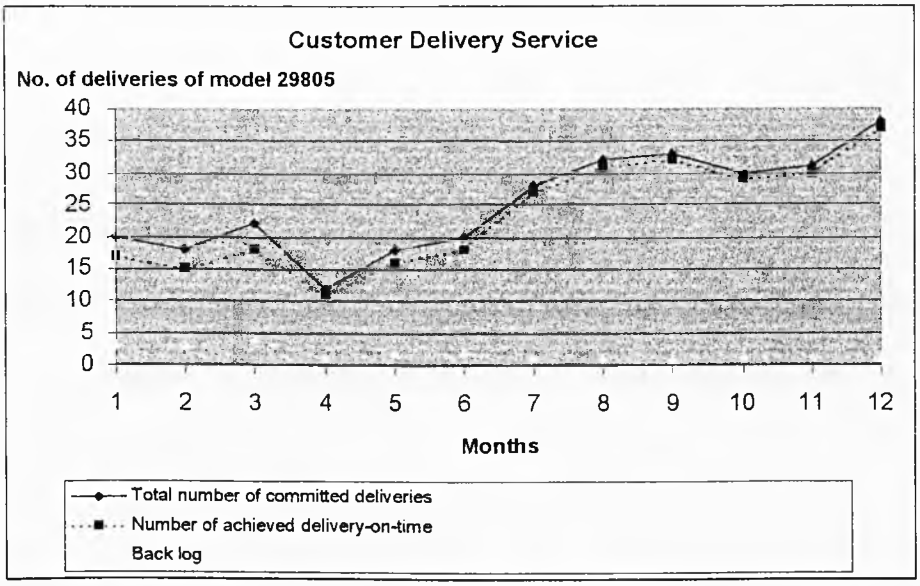


Figure 22. The customer delivery service performance for the year 1996.

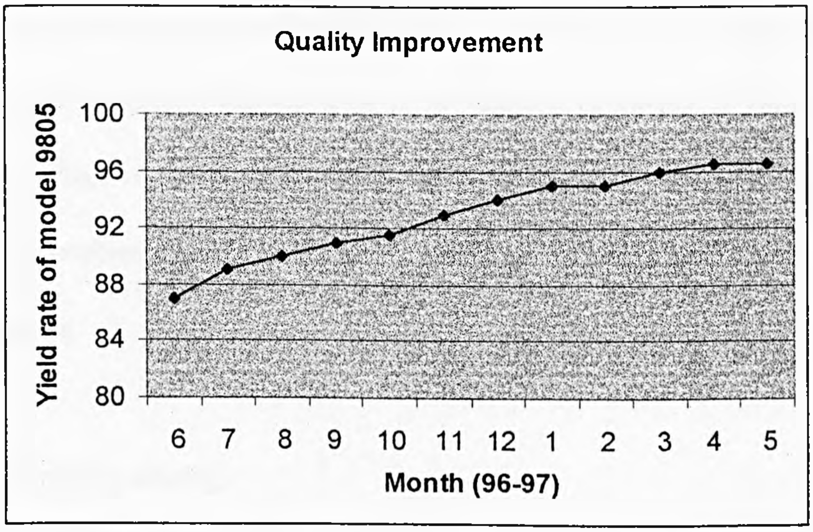


Figure 23. The quality improvement of product for the years 1996 and 1997.

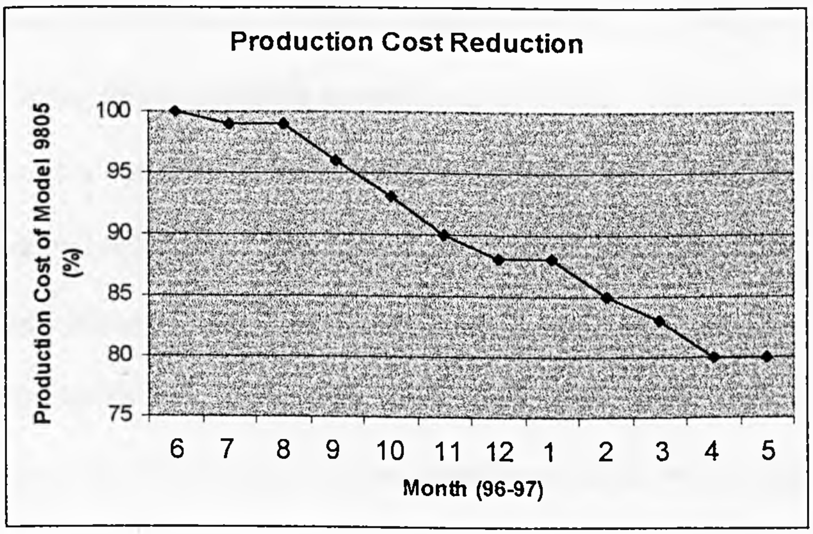


Figure 24. The production cost performance for the year 1996 and 1997.

The long-term impact of the integrated manufacturing system can be summarized as follows:

(a) Production planning

The integration of MRPII with RTMS effectively links together the three major production factors, i.e. materials, machinery and labour, for better utilization of the enterprise's resources.

(b) Production management

Production supervisors from all departments have started to enjoy the benefit of real-time production information. The tracking of production problems of various kinds has never been more effective. Apart from the better control of product quality, the integrated system also enables flexible production planning, which effectively prevents bottlenecks from occurring.

(c) Manufacturing strategy

Based on the TQM culture, the integrated manufacturing system is now able to offer instant access to information on direct production costs, including labour, machinery and materials in the labour intensive environment of China. As for indirect overheads, the system allows a database to be established with little extra cost whereby activity-based costing can be implemented through a Cost-Based Product Classification (CBPC) model (Zhuang and Burns 1993). The overall result is more accurate information on product costing, with which the company will quickly be able to identify changes in product mix as they take place and to reshape its product portfolio to improve its overall profitability.

8.2 Conclusions

In this research, the author has designed and implemented an innovative manufacturing strategy in order to compete in the consumer electronics industry. This integrated manufacturing strategy and its implementation methodology are proposed and verified. The strategy includes not only the technological aspects, but also considers the labour-intensive factors in China. The consequences of the implementation of the proposed integrated manufacturing strategy in the subject production line are found as follows:

- Delivery commitment of model 29805 – improved by 66%
- Production yield of model 29805 – from 87% increased to 96.5%
- Production cost of model 29805 – reduced by 20%

Furthermore, this research has shown that a "high-tech" product approach is far too risky and unaffordable for Far East manufacturers. Instead, the strategic vision of the "high-tech" manufacturing; an innovative manufacturing vision is proposed to meet the competitive environment.

In the methodology as presented in Figure 2, the author has proposed three elements in the implementation process as follows:

(1) TQM with the **Sunflower Approach** and **New Salary System** for the incentive scheme;

(2) RTMS and MRPII integration with a TQM approach in the labour-intensive environment for the integrated manufacturing system;

(3) Using the **"CID"** concept and **IDEF** design as tools to implement the integrated manufacturing system.

The selection of these tools was based on the economic and political environment of China. In particular, the Sunflower Approach and new incentive system were used to establish the quality culture of the company for the effective integration of RTMS and MRPII. One of the important features of this RTMS and MRPII integration is its capability to capture the data from the production line on a real-time basis, which can be used for on-line troubleshooting and worker training during the next cycle of producing a similar product. As regards quality, information obtained from QC and troubleshooting stations passes through the SPC and expert system, where a diagnostic function is performed, hence assisting manufacturing process control. In the pilot production line, the supervisor can clearly monitor the production status from the monitor screen, through the dynamic simulation function of the integrated system. This dramatically increases the overall throughput of the production line, improves product quality and shortens the production downtime. Furthermore, the utilization of manpower and production equipment can also be improved by the system.

The vision of "high-tech" manufacturing strategy, and hence the integrated manufacturing system was successfully designed and implemented in a pilot line. The result indicates that the application of an integration methodology is a critical component in future manufacturing industries, especially in a labour-intensive environment such as that in China. TQM is found to be valuable in the implementation of the integrated manufacturing system in China, since it provides the basic culture for new technology implementation. In addition, through the implementation of RTMS, the TQM culture within the company will be further strengthened.

In conclusion, a "high-tech" manufacturing vision together with the integrated manufacturing system has increased the quality consciousness of all employees, hence involving everyone in the company in improving working quality, and enhancing customer satisfaction. Through this significant improvement, the company's competitiveness, and profitability has increased. I am committed to this innovative vision and integration strategy, and will continue to upgrade and implement the system design and features in the future.

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