Case study

A model for an integrated manufacturing system implementation in China: a case study

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Abstract

This paper describes a process which a company adopted to enhance her manufacturing system in a step-by-step manner. In order to increase the competitiveness of the company, the authors have identified a number of improvement strategies which were specific to the economic and political environment in China. The center 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), it emphasises not only the use of appropriate modern technology but also the management of technology change. In this paper, a concept model is used to describe the integration process, the detailed implementation is also elaborated using a proposed implementation process model. By adopting the integrated manufacturing system, and through continuing improvement, the productivity and hence the profitability of the company is increased. It is anticipated that the integrated approach to the design and implementation of manufacturing systems will be an important contribution towards the manufacturing strategy in a labour intensive environment such as China. © 1999 Elsevier Science B.V. All rights reserved.

Keywords: Integrated manufacturing; Manufacturing strategy; Total Quality Management; Real-Time Monitoring; Manufacturing Resources Planning

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1. Introduction and company background

Ten years ago, China has been opened for foreign investment (Davies and Whitla, 1995) and the investment is based on its competitive labour, inexpensive land and the potential market of China. The total productivity of Hong Kong at large is said to have been raised due to the moving of the assembly processes to China. In mainland China, the average living standard and the educational standards are still low; the technical standard in the southern regions is not as high as in the north; and the huge labour force is basically unskilled. Before ‘the open-door policy’ in China (Ayala and Lai, 1996), all the enterprises, organisations and factories were state-owned. At that time, regardless of how hard anyone worked or, to the other extreme how lazy anyone was, the reward was exactly the same. In other words, workers lacked incentive. Seniority was the key consideration for promotion. Essentially there was no motivation among the working force at large. Consequently, productivity remained at a low level. With the increasing world competition and pressure for higher productivity, world-wide interest in manufacturing strategy has escalated. One of the early research studies to make a systematic investigation of manufacturing strategy was Skinner (1969). Since then hundreds of articles and books have been written on the subject. As a result many large and small manufacturing firms began to develop manufacturing strategies. Examples include studies by Wheelwright (1978), Hayes and Wheelwright (1984), Hax and Fine (1985), Hill (1985). However, few of them describe the application of strategic manufacturing process and how they can be successful implemented in China.

The company described here was established in the year 1986. In the past 10 years, it has started from scratch, and is now recognised as the most reputable Original Design Manufacturer (ODM) in the consumer electronic products business. The Head office of the company is located in Hong Kong and occupies 26,000 ft\(^2\) of office area housing over 100 employees where the crucial task of Marketing, R\&D, Production Planning and Control, Financial Control and other functions are performed. The company maintains constant communication with its production plant and close relationships with its global customers. It employs a professional R\&D team, supported by advanced equipment for research, development and product design, to fulfill its customer needs and, therefore, launches numerous new products each year to satisfy market demand. The plant of is located in the Special Economic Zone (SEZ) of Xiamen, which is one of several SEZs in China. The Science and Industrial Park of the company was built on 250,000 ft\(^2\) of land which comprises three industrial buildings, a training building, an R\&D building, and an administration building. Part of the buildings were completed during the period 1990 to 1995, with a total usage area of 500,000 ft\(^2\), being brought into use since 1990. As a manufacturing base in Xiamen, the company has over 3000 workers and staff. Several million telecommunication and audio products are produced and sold every year. It is one of the biggest telephone answering machine manufacturers in the world, as well as one of the hundred top export manufacturers in China. It is a typical Hong Kong-based manufacturing company which started its business in ODM manufacturing at the very beginning, and shifted its focus to developing its own brand name in China. It is also amongst the 80% of companies which have their product plants.
2. Reviews on competitive environment of manufacturing industry 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 and China. This resulted from the fact that American production was becoming uncompetitive in terms of production cost. Until now, owing to keen global competition within the consumer electronics industry, these countries had also lost their edge of low production cost. To remedy this situation, Far East manufacturing strategy became increasingly important (Krugman, 1994). To identify the competitive edge, a systematic manufacturing strategy is required. Although TQM (Total Quality Management) is identified as one of the most competitive weapons (Deming, 1982, 1986; Gopal and Raymond, 1990), companies demand further innovative strategies to meet the competition from other Far East countries. There are two major points of view regarding the competitiveness of research and development in China. According to one view, it has been suggested that consumer electronics products will no longer be appropriate for the Asian four Dragons (Sung et al., 1995), instead, 'High-tech' products (i.e., high-end products) should be developed and produced in these countries. The other view maintains that while consumer electronics products are considered appropriate, however, they should no longer be produced by traditional manufacturing methods; (labour intensive, and manual controlled system). Rather, they should be replaced by a 'High-tech' manufacturing technology (e.g., automation with high technology machinery, flexible manufacturing system and computer-integrated-manufacturing, etc.) (Wong, 1997). Alternatively, the authors contemplated that the 'Integrated Manufacturing System' which encompasses technology and people is most appropriate to China, this approach will be elaborated in the following sections.

Due to the low production cost, the majority of consumer products had been produced in the far east for major American and European markets in the past 15 years. The growth of these consumer markets has resulted in the fast growth of far east manufacturing business. Products worth billions of US dollars are provided from the far east region to the global consumer market. Therefore, the number of companies in the far east had increased a lot in the past 15 years (Kim and Lau, 1994). Despite the fact that these companies are unable to develop and produce 'High-tech' products described earlier, they are able to enhance their existing manufacturing systems by investing in modernised manufacturing equipment and systems, such as automated machines, precision machining centres, and automatic assembly lines, etc. In the past 20 years, large numbers of medium to large sized companies in the far east have achieved considerable financial ability to support these investments. The far east countries are able to draw on the existing stock of technology; 'High-tech' manufacturing technology from the developed countries on the technological frontier, but considered new to the far east. Through these modernised manufacturing technologies, it arises a high quality, high efficiency manufacturing environment, of low unit cost. However, failure of 'High-tech' manufacturing technology is not uncommon (Tuan and Ng, 1995). Alternatively, an
integrated approach to manufacturing system which uses appropriate manufacturing technology and management that fulfil the strategic requirements for far east medium to large sized companies will enable these countries to sustain keen competition. Through the integrated manufacturing system, the products produced by these companies are not necessary to be ‘High-tech’ products and it is not necessarily to be ‘High-tech’ manufacturing technology (Liu, 1995), but the products are high quality, and low cost.

In order to achieve such integrated manufacturing system, the proposed STEP model is shown in Fig. 1. This conceptual model can be divided into four majors steps. The integration process starts with by the implementation of TQM. Real-Time Monitoring System (RTMS) is proposed to be the hardware ingredient for the integration with TQM ideology. Furthermore, the Manufacturing Resources Planning (MRPII) is integrated with RTMS in order to enhance the internal communication of the shop floor and production planning and control. Appropriate ‘High-tech’ manufacturing technology can be used to assist the integration process. Finally, the vision of an integrated manufacturing system can be achieved.

TQM is identified as an essential element for the integration to be successful since it provides the company with a good quality culture which prepares for system and technology changes. This model was implemented step-by-step in the company and the results were found to be satisfactory.

3. Strategy formulation and implementation

As mentioned in the earlier sections, the authors suggested the use of integrated manufacturing system to produce low cost and high quality products, the integrated manufacturing system encompasses not only appropriate high technology, but it also includes a wide range of elements, such as modern manufacturing strategy, MRPII, RTMS, etc. The detailed design of the integration process is further identified through a
Fig. 2. The implementation process.
step by step approach from the strategic level to operational levels in order to implement the STEP model.

Section 4 elaborates the STEP model and describes the detailed systematic process to develop and implement the integrated manufacturing strategies that are consistent with the company’s overall business strategies as well as the particular characteristics of labour intensive environment in China.

The initial step is to propose a strategic planning process to implement the above integration in a systematic way. The process should describe the steps to be used, who should be involved, what information is needed, and what the outputs are. This process should be simple enough so that it can be easily followed. Since 1993, the company has identified the process for the implementation of integrated manufacturing strategy.

Fig. 3. Strategic manufacturing operation of Hong Kong and China.
Essentially, it follows four major phases: (i) establish the present position, (ii) analyse strategic requirements, (iii) develop strategic improvements, and (iv) formulate implementation strategy. This process is conducted by a team consisting of the general manager, manufacturing director, plant managers, engineering, quality, marketing, human resources and information system. In addition, an external consultant is employed to act as the facilitator who provide the experience and guidance. Much of the planning is done in small group meetings which allows time for interchange of ideas and discussion. The authors are involved to establish their views concerning the implications of the business strategy for manufacturing in particular to explain their vision of an integrated manufacturing system. The integrated manufacturing strategies become apparent when going through the steps, which are addressed as follows:

- Manufacturing strategies needed to respond to business strategies
- Comparison of present levels of manufacturing performance with future requirements
- Strategies that remedy present weaknesses and exploit strengths.
- Strategies to cope with the political, economical and social environment in China
- Competitive advantages to sustain business growth

Fig. 2 illustrates the four steps in the integrated manufacturing strategy development process and implementation. Fig. 3 illustrates the strategic manufacturing operations in Hong Kong and China that link the business objectives to manufacturing. With refer to the proposed STEP model, the implementations of TQM, RTMS and MRPII system are identified to be the major integration elements, these elements are further elaborated and evaluated by following the step-by-step analysis illustrated in Figs. 2 and 3.

4. The implementation

4.1. TQM and RTMS

The core element underlying the integrated process is based on the doctrine of TQM, this being the driving force of the company to achieve higher quality and productivity. 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 endeavour. By integrating team management through the implementation process, the value of management responsibility is projected into quality and the ‘wholeness’ is established. Management responsibility does not necessarily refer to a company’s managers as it does in the entire quality literature that we have reviewed. It refers 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 organisation. 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 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.
On the other hand, the studies of real-time monitoring technology, which began in about 1960s, were utilised gradually 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 delivering considerable financial support to foster, advance and speed up their manufacturing technologies. As one of the technological bottlenecks in advanced manufacturing technologies, the real-time monitoring technique is thereby strongly emphasised and developed quickly. Research into the real-time monitoring technique aiming at monitoring manufacturing processes almost reached its summit around 1990 (Villa et al., 1985; Yusuf, 1988; Liu and Ko, 1990; Lau, 1992; Fu, 1992). Various kinds of new monitoring theories, principles and signal sensing methods have been put forward and employed constantly, and at the same time, new data analysis methodologies and processing techniques have also been suggested and developed speedily, such as Kalman Filter theory, time series analysis, Dynamic Data System (DDS), fuzzy pattern recognition technique, artificial neural network as well as expert system theory among others (Choi, 1990). Various published papers have been concerned with the subject of intelligent monitoring system (Lopez-Mellado and Alami, 1986; Basanez et al., 1989; Milberg and Wisbacher, 1992; Syed et al., 1993; Camarinha-Matos et al., 1994). In addition, the monitoring techniques have also been finding wide application in production management (Charalambopoulos and Vathis, 1993), underground coal-mines (Raman et al., 1988), steel production (Coudal, 1988) and so on. Umscheid (1991) even suggested that using a real-time monitoring system enhances Statistical Process Control (SPC) in a plastic moulding machine.

The interrelationships of TQM and RTMS can then 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.
- intelligence provides information to aid the planning process.
- jobs and tasks are organised to be effective in achieving customer requirements.
- everyone has the visibility and share in the quality concept.
- learning provides the basis for continuous improvement.
- with intelligence and learning functions in place throughout the recursive organisation, and with plenty of relevant real-time information, an organisation is prepared for and can encourage creativity.

The representation of interrelationships is shown on Fig. 4.

4.2. MRPII and RTMS

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 has production facilities in GuangDong province and with their main offices in other parts of counties such as Hong Kong. Hence, the production operations and logistics become complicated and involve substantial changes in management and organisation to cope with the communications among various functions and facilities. It is essential to ensure that all
these changes are properly planned and implemented. The proposed STEP model enables the integration of communication through the RTMS and MRPII.

Essentially, a task force was formed to implement the integration (refer to stage (iv) of the implementation process). IDEF technology was chosen to be the design and integration tool. IDEF, Integrated computer-aided-manufacturing DEFinition method, is a modelling method used to describe systems (Hill, 1995). IDEF0 is very similar to SADT (Ross, 1977, 1985), Structured Analysis and Design Technique, which was developed by SofTech in the 1970s. It is a powerful tool that can be used for communication as well as analytical purposes. By helping the modeller identify functions performed, what is required to perform those functions as well as what the system (being modelled) accomplishes, IDEF0 serves as an analytical tool. As a communication tool, the IDEF0 model allows the manufacturing organisation or any other user to describe what the organisation 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.

4.2.1. Shop floor control system integration

Fig. 5 depicts the detailed design of shop floor control system identified in the implementation process. The technology of real time interfacing between two systems is proposed by Cooling (1986). The integrated manufacturing system using MRPII system and RTMS is implemented. The operation of the shop floor includes a series of activities such as material requirement planning, re-order list generation, issue of work orders, picking list generation and time scheduling. Within this system, the most important control aspect is the material control which is considered to be a serious logistic
problem. A real-time monitoring system 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 real-time monitoring system provides the real-time material/assembly flow information, scrap rate and real-time data. The real-time data collected are feedback to the overall MRPII system and the resources distribution centre for re-scheduling.

4.2.2. Real-time monitoring technology

The essential part of this integration 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 the data collection and the quality control, while the office monitoring and planning aims to improve the entire manufacturing cycle by sharing factory floor data with MRPII. Programmable Logic Controllers (PLCs) work as the major control device in the shop floor. Sensors, machines and data collection devices are physically connected with the PLCs. A real-time software is used to interface the computers and the PLCs. Accordingly, the shop floor supervisor can stay in his office and monitor the situation of the shop floor in order to make the real-time decision such as shutting down the machine or identifying which jobs have recently been completed, thus, making them available for subsequent operations. The head office in Hong Kong can receive the up-to-date information from the Mainland China factory floor through the transmission by modem. Fig. 6 illustrates the node tree which integrates MRPII into the RTMS.
4.2.3. Hardware overview

The system is broken down into two parts illustrated in Fig. 7. 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 and quality 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 MRPII.

4.2.4. Real-time data collection system based

In the implementation, there are over 100 work stations as well as several manual quality test stations intermixed among them in an assembly line. The worker performs an assembly task assigned to him or her at the work station. Final quality testing of the products is carried out automatically by computer-controlled test station. The evaluation of the workers’ performance depends on how much time he or she spends on assembling one unit and the amount of units that have been assembled. The tester supplies a test report on product quality. There are two important types of signals which are measured; one is the number of assembled units and the time they spend in assembly; and the second is to detect the existence of objects and counters to count the number of assembled units of each work station, and at the same time, noting down the assembly time the worker has spent.

Similar to the information from the assembly work station, the report information from Quality Control 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 Fig. 8.

4.2.5. System features

The system is configured to be controlled by a host computer (Pentium-Pro grade 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 acknowledge required or audible signal.

4.2.5. 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 and which is a method for determining the cause of variation. The SPC is used to automate the quality management in real-time so that manual tracking of the measurements is no longer needed. It is an important tool for TQM implementation (Ahmad and Kimberly, 1992). 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

Raw data are collected through the PLC and QC booth controllers and stored in dBASE IV 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 flatness or peakedness of the distribution values in a population
- Skewness—population’s symmetry on each side of the mean.

4.3. Integrated manufacturing system

The integrated manufacturing system depicted in Fig. 9 is implemented according to the STEP model (Fig. 1) and the implementation process (Figs. 2 and 3). 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, purchasing, production planning, material control, information flow and production process flow are planned and executed. The system can be divided into three individual levels: strategic, tactical, and operational.

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 product 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 proce-
dure, implemented using MRPII software, translates the MPS requirements, 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 requirements plan from the point of view of the resource requirements.

The operational level is the shop floor control system, which is further broken down into six individual blocks which can be seen in Fig. 10, namely coordination, planning, implementation, production, material handling and remote monitoring. Planning guidelines are given to the planning section by the shop floor coordination 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 completed operations 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 in the shop floor.

Fig. 11. Schematic diagram of the integration manufacturing system using RTMS.

Fig. 12. The customer delivery service performance for the year 1996.
A schematic diagram of the totally integrated manufacturing system is shown in Fig. 11. Using the inputting production plan, every work station is monitored by the RTMS when products are manufactured and the shop floor information can be feedback to supervisor’s office in real-time basis. The supervisor can therefore clearly see what is happening in the assembly line from the monitor and evaluate the alternative plans and make decision.

5. Implementation findings

Benefits offered by the design and implementation of the integrated manufacturing system using the STEP model include savings on overheads, an increase in productive
hours and product quality, and enhanced motivation. Savings on overheads mainly include the elimination of an analysis report sheet, travel ticket, time sheet for payroll proposes, and the reduction of expenses on quality control, stock evaluation and payroll staff. The automation of stock evaluation now generates information on patterns of material consumption in a manner which is more much more cost effective than before. With real-time production information linked to accounting and payroll sections, the cost incurred is now corrected accurately. Another remarkable time saving comes from error analysis which is now completely automated. Fig. 12 exhibits the improvement in customer delivery service. It illustrates the total number of promised shipments awaiting completion and the number of promised shipments completed during the month. After the integrated manufacturing system is implemented, the number of promised shipments awaiting completion beyond promise due date, i.e., past dues, is reduced. Therefore, the customer satisfaction is improved. Moreover, Figs. 13 and 14 describe the improvements on the product quality and production cost, respectively.

6. Conclusion

The figures (Gilley, 1995) indicated that the expenditure of developing the ‘High-tech’ product is very large. Moreover, the risk in this product development is unacceptably high. The concern is that Hong Kong manufacturers are incapable of competing in the technological development with the Western developed countries (Liu and Chu, 1991). Accordingly, the adoption of an integrated manufacturing system is preferable to the manufacturing of ‘High-tech’ product or ‘High-tech’ manufacturing technology in Hong Kong. By adopting the integrated manufacturing system, and through continuing improvement and integration, the company has avoided the costs and risks of fishing in the diminishing pool of invention potential. The company has given herself time to learn and adopt to change business environment and technology. As a result, the productivity, and hence the profitability of the company is increased.

The vision of an integrated manufacturing system, and hence the design of the STEP model was adopted in the company to implement the productivity improvement scheme. The detailed design and implementation of this vision is conducted through the systematic manufacturing strategic analysis. The results indicate that the use of integration methodology will be a critical component in the developing manufacturing industries, especially in a labour intensive environment such as China. Moreover, the management of technology is extremely important in the case of implementing integrated manufacturing system, the TQM approach is valuable in this situation. The TQM approach, provides the basic atmosphere or culture for new technologies implementation, within the company. On the other hand, the RTMS in the shop floor is a driver which assists the implementation of TQM. The aim of this integrative approach is to enhance the quality mind as well as the motivations of the workers in shop floor in order to cope with the new strategic vision. The integrated manufacturing system would also serve as a driving force in carrying out the essence of the company culture, it gets everyone in the company involved in improving products’ quality, hence increasing the
application of technology consciousness of all employees. It is anticipated that the integrated approach, which encompasses management and technology to manufacturing system design and implementation, will be a major contribution to the development of manufacturing strategy in China.

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References

Tuan, C., Ng, L.F.Y., 1995. Evolution of Hong Kong’s electronics industry under a passive industrial policy. Managerial and Decision Economics 16 (6).