Development of an RFID-based quality management system in distributed manufacturing network

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**DEVELOPMENT OF AN RFID-BASED QUALITY
MANAGEMENT SYSTEM IN DISTRIBUTED MANUFACTURING
NETWORK**

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SCHOOL OF MECHANICAL AND AEROSPACE ENGINEERING

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Summary

Due to globalization and outsourcing, products are fabricated by different parties in the distributed manufacturing network and enterprises face the challenge of assuring the quality of semi-finished product in each manufacturing process in different geographical locations. A Radio Frequency Identification (RFID)-based quality management system in the distributed manufacturing network has been proposed in this research. The feature of the proposed system is to model and simulate large distributed manufacturing networks to streamline the mechanical and production engineering processes with RFID technology, which can keep track of process variants

The proposed RFID-based quality management system consists of three sub-systems including Petri-net modeling system, fuzzy quality management system and RFID system.

In Petri-net modeling system, the components of the manufacturing systems we consider exhibit concurrency or parallelism, which means that activities of one component may occur simultaneously with other components. To deal with concurrency and synchronization, the Hierarchical Colored Timed Petri Net formalism for modeling is described in this study. This method can help to model graphically and test the discrete events of concurrent operations.

Fuzzy quality management system can help for knowledge representation, so as to provide knowledge-based decision assistance in distributed manufacturing environment. The skill and experience of quality from production engineers was acquired and stored in knowledge bases, to ensure the product with verifiable quality. Fuzzy clustering approach is adopted by in this research. In the first stage, the raw data during manufacturing process can be classified based on its own nature, and with the classification results, operation decision can be made in the second stage by running fuzzy inference engine without relying on highly skilled expert. As the information transmitting in the system is with vague information, fuzzy quality engine becomes a more useful tool for represent knowledge in the real world with an approximate method. In the thesis, how to define the fuzzy rule for the system and the associated membership functions' development is presented. In the RFID system, a new RFID-based CPN modeling method where the colored tokens are evolved to color tagged tokens carrying the product information of real-time status. With this new real-time modeling method, the performance of manufacturing systems such as yield rate and throughput can be realized. RFID enable automatic data capture and monitor the quality of the production process in the distributed manufacturing environment.

In order to illustrate how the proposed quality management system works, two case studies in a worldwide company with the alias name as GG Ltd , is presented in the last part of the thesis. This research is contribute to design and develop a RFID-based quality management system with the distinct feature of fuzzy logic and statistics analysis to achieve progressive knowledge acquisition and creation to the entity it is associated with, thereby assuring the quality of the products. In particular,

this proposed system is characterized by the inclusion of RFID technology which has been recognized as one of proven technology that can streamline the logistics operations. This proposed RFID-based quality management system may have significant impact on the smart track and control the manufacturing process by virtue of its capabilities to progressively introduce machine intelligence to support relevant activities within the distributed manufacturing network.

Chapter 1

1.Introduction

In this chapter, the introduction of our research will be presented. Section 1.1 shows the background study including the evolution and history of quality management, and the necessity of a good modeling method as well as data capture technology. Section 1.2 states research problems; research motivation is given out in the section 1.3, and section 1.4 is about the objectives of the proposed research, the last section outlines the layout of the thesis.

1.1 Background

Using statistical methods for production quality control was first proposed by Dr. Walter Shewhart in 1924. Since then it had become the foundation of statistical quality control. Later, applied statistical process control methods successfully improved quality in the manufacturing industry of munitions and other crucial products in United States. After that, Japan decided to make quality improvement a national imperative as a part of their economy rebuilding, and sought the help of the scientists. Over time their quality initiatives began to be successful to achieve a very high level of quality in products from the 1970s onward (Mangelsdorf, D. 1999). Until 1980s, when Dr Julian developed the trilogy of

quality management, Quality Management theory had become more and more mature. Afterward, a number of highly successful quality initiatives had been invented, and many of the methods provide not only techniques but also associated with quality culture.

Currently, customers realize that the quality is an important attribute in products and services. Suppliers also recognize that the quality can be an important differentiator between their own offerings and those of competitors. As the result, the manufacturers have raised their own standards of quality in order to meet International standards and customer demands. ISO 9000 series of standards are probably the best known International standards for the quality management. In the past two decades, the quality of products and services has been regarded more and more important.

To develop a good quality management system for large complex distributed manufacturing networks, a corresponding modeling and simulation has to be done so as to assist to the analysis of the manufacturing concurrent system. Furthermore, an efficient and effective quality system requires a lot of data to do the analysis and it is important to monitor the quality and the performance of processes within the dispersed manufacturing networks. Existing data capture methods are mostly manual and paper-based, so some mistakes and errors are unavoidable. RFID is the recent advance technique to capture the data so as to track and trace the quality of the WIP at each production unit at every stage. Compared with a traditional technology---barcodes, RFID tags can store large amounts of information in real-time without the line of sight. Additionally,

multiple tags can be identified simultaneously, and information can be overwritten. Therefore, RFID, as a highly accurate data tracing and tracking technology, can be a best choice for the efficient and effective quality management system.

1.2 Problem Statement

In a distributed manufacturing network, the production value chain is being dissected and rationalized to take advantage of dissimilar core competencies of geographically isolated firms. It is important to have a system which is able to provide decision support functions so as to provide quality products and services.

1. Complexity in modeling distributed manufacturing network

As it is known that the modeling activity has a crucial role in the development of the manufacturing system, the modeling formalism influences the way how a problem is approached and how the solution is shaped. Once a modeling formalism has been chosen, it limits the available methods for analysis and fault detection. Generally, the manufacturing systems we consider are often complex, large, discrete dynamic systems consisting of many interacting components. The components of such a manufacturing system exhibit the concurrency or parallelism, which means that the activities of one component may occur simultaneously with those of other components. The components of the system interact and sometimes they have to synchronize, which means one component waits for the other in order to execute an activity simultaneously. Therefore, it is difficult to design, to evaluate and to analyze such a manufacturing system. To deal with the concurrency and synchronization, the Petri Net formalism for modeling was one of the firstly introduced approaches. The basis of Petri Nets is

to model graphically and test analytically the discrete events of concurrent operations within a system. Of course, the fundamental constructs of Petri Nets are useful to model and analyze manufacturing systems.

2. Difficulty to realize efficient data and information communication so as to transform as corporate knowledge

In current quality management practice, there are many data and information communication problems. As large amounts of data is collected manually, the data input is not accurate or tampered to show the high conformance. Quality is not the responsibility of a certain unit, but all the units of the whole system, so a high quality can be only achieved by good coordination and cooperation of all units. However, the legacy system provides neither integrated nor same platform, which leads to the difficulty of exchanging data. Naturally, it is not easy to find the solution for solving the defect problems even though the similar problems had happened before. The problem solving approach is still trial and empirical or highly depends on the experience staff. What's more, there is no formal process and method to analyze and verify the cause of defect by statistically monitoring process performance.

3. Dysfunction and Unsynchronized decision-making result in inconsistency

Many quality systems can provide a Group Support System (GSS) for such strategy planning and help to make the final decision. Whether the system is efficient enough depends on the quality of rules in the system. However, the information in the real practical systems is not always so precise that it can't fulfill the requirements of the traditional system technique. Moreover, the

uncertainty increases as the problem becomes more complex. Under such condition, a fuzzy system is a good tool similar to other engineering and practical theories, because it characterizes the real world in an approximate way. The core problem here becomes how to define the fuzzy rules for the system and the associated membership functions' development.

RFID is more and more widely used in the logistical, planning and supply chain process as well as the manufacturing because of its high performance in information capture. To make this proposed quality system more efficient, RFID technique is introduced in this research, while how to combine it with the collaborative quality system will be further studied and developed to suit the environment of distributed manufacturing networks.

1.3 Motivation

Different disciplines may have different interpretations about quality product. According to the study of Garvin (Garvin, 1984), the quality can have transcendent, product-based, user-based, value-based and manufacturing-based definition. From user viewpoint, the quality is the specific function and feature to satisfy the customers' want, while from manufacturers' viewpoint the quality means the conformance to the predefined specifications and requirements.

Manufacturing firms nowadays need to collaborate with one another to produce the quality products that provide value for the customers. The products are not solely produced by one manufacturer. Instead, many manufacturing firms are involved to produce the products and any discrepancy of the WIP to the design specifications

may cause the deviation from the predefined performance. In order to minimize the performance deviation through a series of production processes, it is necessary to keep tracking and tracing the production performance as well as the quality of the WIP. As the production processes can be concurrent or sequential, it is important to have a modeling system to illustrate clearly the dependence and independence of each process. Therefore, Petri net is used to understand the interrelationship of the processes.

A comprehensive quality management system is required and it is estimated that a quality management system accounts for 35% of the total expense of a company (Crosby, 1995). It is important to maintain the quality output in distributed manufacturing environment with scientific performance during outsourcing and offshoring. Another important aspect of assuring the quality is tracking and tracing, which requires large amounts of data within settling time for analysis. RFID can help to track and trace the product quality so that it has been increasingly used in supply chain management and it is expected to be applied in the manufacturing environment to monitor the product quality. According to the searching result from engineering village electronic database, it has been found that there are 307 papers applying RFID in quality management from 1990-2009. Therefore, it motivates the author to explore the possible applications of RFID in the quality management systems to keep tracking the performance of the production processes. The real time data can be used for corrective and preventive measures. The preventive actions can be conducted when data captured by RFID show the tendency of beyond the acceptable level while the corrective actions can be carried out when the data has been beyond the acceptable level.

Quality management relies on pursuit of a full inter connection of all the activities in a firm. Such an integrated system of all workers, employees from production, through administration, ordering of materials and sale, guarantees full efficiency of operations, and also allows to reach economic benefits and customer's satisfaction. Generally, companies always need to do the quality decision-making things to determine the quality level of a certain product, so the corresponding quality control and improvement activities can be applied accordingly. Currently, most companies rely on the experience and intuition of highly skilled engineers or experts, which is human-interfered and subjective. On the other hand, in the practical situation, the collected data may be vague and not precise. Hence, the introduction of fuzzy logic solves these problems. The first significant advantage of fuzzy logic modeling over other approaches is that it is easier for the end-user to understand, through its linguistic fuzzy terms, fuzzy values & logical reasoning process. For the qualitative attributes like reconfigurability, the outstanding easy-to-understand feature of the model makes it useful for non-numerical or insufficient input-data assessment feasible to meet real-life needs. Its second advantage is the ability to adopt end-user's domain knowledge or business logic into the measurement process through refining or customizing its fuzzy systems. The proposed system adopts RFID and quality enhancement techniques to monitor and predict the process performance carried out concurrently in a distributed network.

As a result, it is crucial to have a quality management system (QMS) which enables quality assurance, quality control and quality improvement with a framework comprising input, processes, and output over a long period. Therefore,

designing and building a sophisticated QMS that assures to manufacture the high-quality products and support company to make right decision is demanded for the industry.

1.4 Objectives and scope of the research

Based on the existing problems and the significance for the RFID-based quality management system, the objectives of the research are depicted in Fig. 1-1

Fig. 1-1 The objectives of the proposed system

The objectives of the proposed RFID-based QMS are shown below:

- having an appropriate modeling to deal with concurrency and synchronization;
- realizing accurate real-time data collection;
- possessing quality control/ assurance/ improvement function as traditional QMS;

- managing knowledge with linguistic expression within the system ;
- solving the fuzzy and vague information;
- improving the efficiency of data exchange/ communication between all units;
- developing a formal process for analysis and verification.

Fig. 1-2 The scope of the research

To realize the functions of the proposed system, the corresponding scope of the research has been described in Fig. 1-2

Fig. 1-2, it is shown that the scope of the research can be presented by the solutions to three clusters of problems. Firstly, to deal with the concurrency and the synchronization in a practical system, Petri Net method is adopted for modeling. Secondly, to deal with the inaccurate data and data exchange difficulty, a RFID-based system is designed and developed. Finally, a fuzzy quality

management system based on RFID technique is developed. Apart from solving the traditional quality problems, more work will be done on processing vague and fuzzy information, as well as evaluating the fidelity of the quality rules. Furthermore, the formal processes and the methods for analysis and verification will be done by the combination of QMS and fuzzy tools.

1.5 Layout of the thesis

In Chapter 1, the introduction of the study is presented, including background, motivation and problem statement of the research;

Next, the results of literature review about distributed manufacturing network, RFID technology, Modeling method, quality management, and fuzzy theory are shown in Chapter 2;

In chapter 3, the overview of proposed RFID-based Fuzzy Quality Management System is briefly presented.

In Chapter 4, Hierarchical Colored Petri Net is developed as the modeling method for large distributed manufacturing networks.

In Chapter 5, How the RFID-based colored tokens are applied in quality management system is explained.

In Chapter 6, a new fuzzy QMS with the combination of the fuzzy logic theory and the quality management is discussed;

In Chapter 7, a simple case study of a worldwide energy services Pte Ltd is conducted to prove the feasibility of the proposed methods;

In Chapter 8, a conclusion has been drawn based on the research finding. The contributions of the research and the future work are stated.

Chapter 2

2 Literature Review

Distributed manufacturing systems (DMS) allow various machines and tools to run in parallel at different geographical locations to achieve better product quality, lower production cost and reduced management risk. However, for larger and more complex manufacturing environment, quality management systems (QMS) face fiercer challenges as it may collect vague and fuzzy information. Radio frequency identification (RFID), as a highly accurate auto data capture technology, can help input, output and exchange data or other information under DMS environment. Fuzzy logic, as a good tool to handle fuzzy information, will be the first choice. In this chapter, literature reviews on DMS, system modeling RFID, QMS and fuzzy tools for QMS will be given, respectively.

2.1 Distributed Manufacturing Network

Increasing product varieties and product customization, and a shorter lead-time are the key challenges for a manufacturing company. The traditional manufacturing systems cannot adequately conform to these requirements because of their inflexibility, the deterministic approaches of decision-making in a stochastic environment, and insufficient communication and exploitation of expertise. In

order to meet the new challenges, a shift of the manufacturing paradigm from deterministic to a new manufacturing perspective is needed (Panetto et al, 2008). Several influencing approaches are emerging, such as the fractal factory (Shin et al, 2009), bionic manufacturing systems (Quinn et al, 2010), holonic manufacturing systems (Giret et al, 2009), distributed manufacturing systems (Leitão, 2009), etc. Much investigation and study (Mahdavi et al, 2008) has proven that the distributed manufacturing enables the enterprises to achieve better product quality, lower production cost and reduced management risk.

In a distributed manufacturing shop (DMS) environment, factories with various machines and tools run in parallel at different geographical locations. Different manufacturing capacities are often employed to achieve the highest level of production quality. Distributed manufacturing can economize several benefits of off-shore outsourcing; better product quality, lower production cost and reduced risk. Studies that compared manufacturing costs between in-house (single location) and outsourced (multiple offshore location) production indicate that in-house production tends to be more costly.

Despite such advantages, there is a critical administrative challenge to overcome: assessing and improving the overall performance across multiple distributed shops. Without accurate and timely data an enterprise-wide synchronization of processes simply becomes an impractical mission. This is why the collaboration among distributed shops has gained importance (Giovanni et al, 2010, Mönch et al, 2005, Trentesaux et al, 2001). In addition, the distributed operational shops are easily scattered beyond the boundary of a country. For example, during the late 1980s,

many Japanese manufacturers aggressively distributed shops into several Asian countries due to the sharp increase in domestic labor costs. When various engineering activities are implemented at geographically distributed locations (Zhou et al, 2002), such heterogeneous activities need to be carefully integrated to ensure a seamless interoperation and collaboration over the network.

Traditional manufacturing control systems have a very limited capacity to respond to the dynamic changes in the environment (Butala, 2002). However, significant changes have been made to enable efficient collaboration among DMSs. The network-type processing method facilitates the adoption of a real-time system under a distributed computing environment. In addition, the manufacturing execution system enables information-based collaboration so that the distributed organizations can virtually act like a single enterprise from the perspective of customers (Hao et al, 2005, Jagdev et al, 2001).

A network-based DMS model integrates several technologies such as computer-aided design/manufacturing/test (CAD/CAM/CAT), computer-aided process planning (CAPP), product data management (PDM) and enterprise resource planning (ERP) (Tarantilis et al, 2008). The implementation of such DMS architectures requests for a coordinated control of quality over the network of shops. Since late 1980s, researchers have applied various techniques to optimize the control of production process. For example, Beiter et al. (Beiter et al, 2000) provide a comprehensive discussion of the methodologies useful for defect prediction. They summarize the application procedures of the methodologies and strategic uses of defect information for globally distributed manufacturing. The

level of complexity of the manufacturing process also has a strong correlation with the occurrence of defects (Beiter et al, 2000, Tsai et al, 2005). The management of quality focuses on the reduction of process variance, which has a direct impact on the performance of a supply chain such as inventory costs and the lead-time (Chung 2012, Temponi et al, 2006). The amount of process variance is also related to the level of required safety stocks and cycle stocks (Flynn, et al, 2005). The quality management problem can be formulated in many different ways (Longhurst et al, 2006, Sarker et al, 2008, Mehra et al, 2001).

To improve the level of quality in a DMS shop, it is necessary to design an effective quality information system that helps to control the manufacturing activities, analyze information, and support real-time policy making (Ormandjieva et al, 2008). The implementation of a distributed quality information system requires gathering, processing, storage and the distribution of quality-related data among shop floors and the central control office (Woo et al, 2002, Molina et al, 2002, Chin et al 2004). Real-time quality control involves the processes, metrics, techniques, and systems which are appropriate to measure and manage the quality of a manufacturing process. An e-based DMS is defined as "an Internet-based computational architecture that supports the sharing and transfer of knowledge and information about products and manufacturing processes amongst geographically distributed shops" (Mario et al, 2011, Rodriguez et al, 2002). An e-based DMS can be an option for an automated and user-friendly quality control information system.

Real-time quality control information system (RTQCIS) solutions capture up-to-the-minute manufacturing data, establish an operating context of the data,

and ensure that it is stored to be accessible whenever needed at a later time for a variety of uses. The data should provide enterprise-wide visibility of the whole manufacturing process and quality measures.

Key elements of the competitiveness for the manufacturing industry in future will be methods for rapid product and process realization, early integration of design with manufacturing operations and the technical integration of the supply chain (Scholz-Reiter et al, 2010). Integration efforts should be focused on the early stages of product development, where the majority of product lifecycle cost is decided (Hu et al, 2009). Planning technology to link the early stages of product design with manufacturing operations within the extended enterprise is not commercially available at present (Maropoulos, 1999). This frequently results in lengthy product development periods, uncompetitive manufacturing operations and increased lifecycle costs. The tendency for reduced product lifecycle and increased product variety places additional strain on the integration of design with manufacturing operations.

Concurrent engineering systems aim to achieve the parallel development of the products and of the manufacturing processes (Ahmad et al, 2011). Successful early planning implementations have been reported using decomposition of CAD models into critical areas (Zhou et al, 2007). Design for specific goals (DFX) methods are also usefully employed to improve manufacturing realization (Tsai et al, 2001). The specification and realization of "intelligent and resource aware" distributed enterprises requires substantial development of the underpinning modeling, information management (Lutters et al, 2001) and knowledge retrieval,

representation and classification technologies (Thannhuber et al, 2001, Bramall et al, 2001). This is a very large, and still largely ill-defined technical area and as such, it is a fertile domain for the application of "emergent synthesis methodologies" (Ueda et al, 2001), in order to consolidate recent advances in life cycle management and distributed, co-operative systems that employ virtual and augmented reality technologies (Lu et al, 1999).

In manufacturing, companies may form strategic partnerships for outsourcing some of their operational activities, share resources or joint development of products and services etc., leading to formation of virtual manufacturing enterprises which operate in distributed manufacturing environment. To facilitate the creation of virtual manufacturing enterprises, potential partners must be quickly able to evaluate whether it will be profitable for them to participate in the proposed enterprise. Simulation provides a capability to conduct experiments rapidly to predict and evaluate the results of manufacturing decisions (McClean et al, 2001).

Simulation is not a strange tool for decision making in manufacturing. Law and McComas (Law et al, 1998) pointed out that manufacturing is one of the largest application areas of simulation, with the first use dating back to at least early 1960s. However, traditional sequential simulation alone may be not sufficient to simulate these highly complex Distributed Manufacturing Enterprises (DMEs). In such situations, distributed simulation provides a promising alternative to construct cross enterprise simulations. Each partner can use a simulation of its own operation to make sure that it has the capability to perform its individual function in the DME. Later these simulation models can be integrated into a distributed simulation

to simulate the whole enterprise, and evaluate the feasibility and profitability of the proposed partnerships. The use of distributed simulation allows each partner to hide any proprietary information in the implementation of the individual simulation, simulate multiple manufacturing systems at different degrees of abstraction levels, link simulation models built using different simulation software, to take advantage of the additional computing power, simultaneously access to executing simulation models for users in different locations, reuse of existing simulation models with little modifications etc.(Gan et al, 2000, McLean et al, 2000, Taylor et al, 2001, Venkatesvaran et al, 2001). However, Peng and Chen (Peng et al, 1996) noted that as a technique, the parallel and distributed simulation is not successful in manufacturing.

Distributed simulation combines distributed computing technologies with traditional sequential simulation techniques. Although there are drawbacks such as low communication speed and shortage of network bandwidth, the popularity have increased in recent years due to the availability of powerful but low cost desktop workstations and the improvement in networking technologies. In distributed simulation, the simulated system is partitioned or decomposed into a set of subsystems that are simulated in interconnected workstations. Bargrodia (Bagrodia et al, 1996) considered distributed simulation as a collection of sequential simulation models, which communicate each other with time-stamped messages. A synchronized simulation system makes sure that each individual simulation model processes arriving messages in their time-stamped order and not in real-time arriving order. This requirement is referred to as local causality constraint (Fujimoto, 1999). To satisfy the local causality constraint, a number of

synchronization protocols have been proposed in the literatures. These protocols can be broadly classified as conservative or optimistic protocols. Conservative approaches strictly impose the local causality constraint and guarantee that each model will only process events in non-decreasing time-stamp order. In contrast, optimistic approaches allow violations of the local causality constraint to occur, but are able to detect and recover by rolling back to the point where the violation occurred and reprocessing events in time-stamped order.

Geographically distributed simulation models communicate with each other only by message passing, which is generally achieved through the middleware. Middleware is a connectivity software that contains a set of enabling services that allow multiple processes running on one or more machines to interact across a network. Based on significant standards or products available, middleware can be divided into several categories including Sockets, Remote Procedure Calls (RPC), Remote Method Invocation (RMI), Distributed Object Component Model (DCOM) and Common Object Broker Request Architecture (CORBA) (Tari et al, 2001). During past few years DCOM and CORBA based tools have managed to gain a wide acceptability than others.

2.2 Modeling Method for Distributed Manufacturing System--- Petri Nets

The doctoral dissertation of Carl Adam Petri discussed the basis for a theory of communication between synchronous components of a computer system (Petri, 1962). Petri was particularly concerned with describing the causal relationships between events (Peterson, 1981). This work thus began the development of Petri

Nets into the large body of research and development existing today. Initially, many researchers studied Petri Nets with respect to the theories and the applications. Further, the research areas of Petri Nets have spread and expanded to depth in theory and width in application on the basis of the mathematical as well as the graphical tool. Recently, many authors who have entered the research of Petri Nets have provided not only suitable platforms in the areas of modeling and design of concurrent systems, information system, manufacturing systems, and performance analysis, but also their own experience and understanding of various extended models and applications (Al-Jaar, 1988, 1989, Hsieh, 2009).

Applications of PN in the manufacturing are varied. The usefulness of PN logic in system design, control, testing, simulation, and analysis is demonstrated using PN systems. Petri's dissertation (Petri, 1962) came to the attention of project MAC at MIT in 1972; numerous reports and dissertations resulted. Hack (Hack, 1972) brought together many facets of the production environment and provided a broad approach for manufacturing systems overview and design in PN. Most importantly, the work describes the use of free choice PN and their definitions. Since that time, work has branched into several different areas such as manufacturing systems, flexible manufacturing systems or cells, and controllers.

Nowadays, Petri Nets have been used successfully to model, control, and analyze discrete event dynamic systems that are characterized by concurrency or parallelism, asynchronous process, deadlocks, conflicts, and event-driven processes. Petri nets also provide accurate models and efficient analysis methods because they (1) capture interactions of concurrent and sequential events, (2) can

be derived from the knowledge of how systems work, (3) give concise models for conflicts and buffer sizes and (4) allow implementation of real time analysis (Al-Jaar, 1989, Peterson, 1981).

2.3 RFID Technology

Radio frequency identification (RFID), a small tag containing an antenna and an integrated circuit chip, possesses the ability to send, process, and store information by responding to radio waves transmitted from the RFID reader (Wu et al, 2006). RFID tags use a memory storage device to store some data such as the product identification number, cost, price, location, manufacture date and inventory on hand (Chao, et al, 2007). As technologies continue to develop in antenna technology, radio spread spectrum and microchip fabrication, RFID is commonly used in the existing markets with various applications, such as, animal identification and tracking, automatic tariffs payment in public transport, automated manufacturing and logistics control (Wong et al, 2006). The potential of RFID to change the way of business all around the world is remarkable (Ranky et al, 2006). Many business enterprises are applying RFID into experimental projects to improve the operational efficiency and to gain a competitive productivity (Bilge et al, 2004). Now RFID has become a hot topic in the fields of manufacturing and logistics (Ngai et al, 2008)

RFID is an emerging technology that has been successfully applied in supply chain management, manufacturing, and logistics, but its range of application extends far beyond these areas. Based on the various industry areas that are

featured in the reviewed literatures, we sub-classify this category as follows (Liao et. al, 2011).

- (1) Animal detection
- (2) Building management
- (3) Enterprise feedback control
- (4) Food safety warranties
- (5) Health
- (6) Library services
- (7) Logistics and supply chain management
- (8) Museums
- (9) Retailing
- (10) Manufacturing
- (11) Casinos

As mentioned in section 2.1, to realize good quality management of distributed manufacturing system, it's necessary to build up an effective quality information system. To guarantee precise data and information transfer, RFID can be a no-better choice with the high accuracy on product tracking and tracing. Nowadays, more and more manufacturing systems implement RFID technology so as to monitor the quality of products. Take for instance, Patrizia has developed an integrated system of an electronic tracking system with a non-destructive quality analysis system for the single product of a typical Italian cheese. The tracing and quality information are combined on a web platform to obtain a complete procedure so as the quality analysis can be easily carried on. Vergara (Vergara et al, 2007) reported his development of an RFID reader with onboard micro-machined metal oxide gas sensors aimed at monitoring climacteric fruit

during transport and vending. Many other researchers also studied the application of RFID in quality management of products in manufacturing (Johnson, 2002).

2.4 Quality Management System

Quality management is the process of identifying and administering the activities necessary to achieve the organization's quality objectives, which will fall into one of the four dimensions (Pyzdek , 2003, ch.2). Quality management is focused not only on product quality, but also the means to achieve it. Quality objective is a statement of the desired results to be achieved within a specific time. Objectives can be created to achieve stability or unprecedented new levels of the performance; can be either short-term or long-term (Ramezani et al, 2013).

According to Dr Juran (Juran, 1988), Ahire and Landeros (Ahire et al, 1995), and Harvey (Harvey, 1998), quality management (QM) can be conveniently divided into four dimensions: quality planning, quality control, quality assurance and quality improvement. In this study, QM is defined as the process of identifying and administering the activities necessary to achieve the organization's quality objectives through the sequent flow of all the four dimensions:

- 1) Quality Planning establishes the design of a product, service, or process that will meet customer, business, and operational needs to produce the product before it is produced (Juran, 1970). The elements of quality planning involve a number of universal steps:
 1. Determine who are the customers and target markets.
 2. Determine the needs of the customers.
 3. Develop product features which respond to customers' needs.

4. Develop processes which are able to produce those product features.
 5. Transfer the resulting plans to the operating forces (Juran, 1970).
-
- 2) Quality control is the process used by the operating forces as an aid to meet the product and process goals. It is based on the feedback loop and consists of the following steps:
 1. Evaluate actual operating performance
 2. Compare actual performance to goals
 3. Act on the difference between goal and performance (Pyzdek, 2003)
-
- 3) Quality assurance is all those planned and systematic actions necessary to provide adequate confidence that a product or service will satisfy given requirement for quality (Hoyle, 1994).
-
- 4) Quality improvement aims to attain levels of performance which are unprecedented— levels which are significantly better than any past level (Juran, 1988). Generally, the methodologies implemented in quality improvement are following the phases below:
 1. Identify a business problem-something wrong with a product, service, or process that impacts the performance of the business;
 2. Establish a project
 3. Measure and analyze the current process to establish precise knowledge of baseline performance
 4. Generate and test theories as to the causes of the poor performance
 5. Prove root causes of the poor performance

6. Develop remedial improvements-changes to the process that remove or manage the causes of poor performance
7. Establish new controls to prevent recurrence and to sustain the new standards
8. Deal with resistance to change
9. Replicate the result and start a new project (Juran, 1988)

2.5 Fuzzy tools applied in Quality Management System

Fuzzy number: As an extension of a regular number which does refer to one single value, a fuzzy number refers to a connected set of possible values, where each possible value is assigned its own weight between 0 and 1. The weight is named by the membership function. A fuzzy number is a special case of a convex fuzzy set (Hanss, 2005). As fuzzy logic is an extension of Boolean logic (which has only 'yes' and 'no', and nothing between them), fuzzy number is also an extension of real number. The incorporation of uncertainty on parameters, geometry, properties, initial conditions, etc, is allowed in fuzzy numbers' calculations. When solving quality problems in service and engineering, linguistic information usually appears as an important output of the process. This information is definitely more difficult to measure throughout a classical mathematical function. As a result, fuzzy number is introduced.

Fuzzy AHP: The Analytic Hierarchy Process (AHP) is one of the most commonly used multi-criteria decision making methods. Fuzzy AHP, a fuzzy extension of AHP, was developed to solve imprecise hierarchical problems. There are many fuzzy AHP

methods developed by various authors. Most of them propose systematic approaches to the alternative selection and justification problems using the concepts of fuzzy set theory and hierarchical structure analysis (Wang et al ,2008). The application of fuzzy AHP is always accompanied with fuzzy decision making. When analyzing whether an element has a significant effect on the output quality, it is necessary to develop a system consisting of product modules, and then dividing the modules into components to produce a hierarchical structure model. Generally, the evaluation of quality performance is thus a multi-criteria decision making problem which can be solved by fuzzy AHP.

Fuzzy decision making: Decision making is essentially an important aspect in all aspects of life. It is the fundamental activity of human beings to make decisions. In any decision process we consider the information about the outcome and choose among two or more alternatives for subsequent actions. If good decisions are made, then we may get a good expected output. Decision making is defined to include any choice or selection alternatives. A decision may be made under certainty, where the outcome for each action can be determined precisely. However, many decisions which are faced by quality engineers daily are usually made with risk and uncertainties. The only available knowledge regarding the outcomes comprises their conditional probability distributions. The existing uncertainty is the prior domain for fuzzy decision making. There are various ways in which the fuzzy decision can be made: Fuzzy Ordering, Individual Decision Making, Multiple-person Decision Making, Multiple-objective Decision Making and Fuzzy Bayesian Decision Method (Sivanandam et al. 2006).

Fuzzy programming: Fuzzy programming includes both fuzzy linear programming and fuzzy non-linear programming. A classical model for linear

programming (crisp LP), may follow the formula : $\{ \max Cx ; \text{ s. t. } A_i x \leq b_i, i = 1, 2 \dots m \}$. However, in the real world the constraints coefficients are typically imprecise numbers because of the insufficient information, for instance, demands, available capacities, cost requirement and technological coefficients. Many researchers formed fuzzy linear programming of various types, and developed approaches to convert them in crisp LP and finally solved the problems with the available methods, which is the process for CFMOLP.(Susanto et al, 2011). Similar to fuzzy linear programming, the fuzzy parameters are introduced in non-linear programming problems.

Fuzzy data analysis: Data analysis is a process beginning with some existing data sets, which contain the information on the respective generated application. Fuzzy data analysis is using fuzzy techniques to solve the data analysis problems. It's the application of fuzzy systems in the analysis of crisp data. In a quality management system, the input data is not accurate or tampered to show the high conformance, as large amounts of data are collected manually with the checklist. Just because of the unavoidability of the fuzzy data, fuzzy data analysis is especially important in QM system.

Fuzzy optimization: QM system always tries to establish performance of methods, regulatory guidelines, or even inspect each process to assure that good quality management practices have been implemented. The final goal is to guarantee the quality of products and processes, and meanwhile to optimize the cost and the efficiency. With the existing fuzzy information in the practical QM system, fuzzy optimization can solve an optimization problem with a fuzzy objective function and fuzzy constraints. The results obtained from classical optimization methods

involving deterministic variables exhibit various shortcomings. In particular, the effects of the uncertainty attached to input information is often ignored altogether or only taken into account to a limited degree. In contrast, fuzzy optimization considers uncertain parameters as fuzzy variables (Moller et al, 2004).

Fuzzy clustering: Data clustering is the process of dividing data elements into classes or clusters so that items in the same class have high similarity, and items in different classes are dissimilar to one another. When monitoring the quality in a system, data clustering of different error disturbances or product quality levels can simplify the monitoring tasks. Depending on the nature of the data and the purpose for which clustering is being used, different measures of similarity may be used to place items into classes, where the similarity measure controls how the clusters are formed. In hard clustering, data is divided into distinct clusters, and each data element belongs to exactly one cluster. In fuzzy clustering, data elements can belong to more than one clusters, and a set of membership levels are associated with each element. These indicate the strength of the association between that data element and a particular cluster. Fuzzy clustering is a process of determining these membership levels, and then using them to assign data elements to one or more clusters (Liu et al, 2008).

Fuzzy QFD: QFD is a "method to transform user demands into design quality, to deploy the functions forming quality, and to deploy methods for achieving the design quality into subsystems and component parts, and ultimately to specific elements of the manufacturing process." (Yoji, 1994). Fuzzy QFD proposed a fuzzy procedure to examine the sensitivity of the ranking of HOWs to the defuzzification strategy and degree of fuzziness of fuzzy numbers. All these works aim to determine

a rating of the HOWs (Shen et al. ,2001).

Fuzzy inference system: Fuzzy inference system consists of a fuzzification interface, a rule base, a database, a decision-making unit, and finally a defuzzification interface. The two most important types of fuzzy inference method are Mamdani's fuzzy inference method (Mamdani et al, 1975) and Sugeno or Takagi-Sugeno-Kang method of fuzzy inference process (Takagi et al, 1985). The Mamdani's fuzzy inference method is the most commonly used inference method. The Takagi-Sugeno-Kang method of fuzzy inference process method is also called as TS method. The main difference between the two methods lies in the consequent of fuzzy rules. Mamdani fuzzy systems use fuzzy sets as rule consequent whereas TS fuzzy systems employ linear functions of input variables as rule consequent. All the existing results on fuzzy systems as universal approximators deal with Mamdani fuzzy systems only and no result is available for TS fuzzy systems with linear rule consequent. Under quality environment, especially for qualitative assessment for products or processes, introducing fuzzy rules and developing fuzzy inference system will always make the problem clear and pellucid.

Fuzzy control: Classical control aims to solve problems and unanswered questions, while the fuzzy control was introduced in order to mimic the control actions of the human operator in the fuzzy controller (Verbruggen et al, 1997). In quality control, human operation factor is always the most difficult part to be controlled. Conventional control theory hires an analytical model of a process and specifications of the desired closed-loop behavior to design a controller. However, this approach may not be so appropriate if the modeling of the process is difficult due to unknown or highly nonlinear model. To solve this problem, the fuzzy rule-based control, a specific type of knowledge-based control is introduced, in

which the control actions corresponding to particular conditions are described in terms of fuzzy if-then rules. In fuzzy control, fuzzy sets are employed to give a definition to the qualitative values of controller inputs and outputs including small error and large control action. Moreover, the continuous nature of human decision processes can be captured using fuzzy logic, which is definitely an improvement over methods based on binary logic.

2.6 Classification framework for fuzzy theory techniques applied in quality management of distributed manufacturing system

To know more about current progress for fuzzy techniques in quality management, this study finished an articles-searching within the relevant field and completed a broad classification for selected articles. Those findings help justify which fuzzy tool is most applicable for various dimension of quality management, as well as what fuzzy tools are usually applied together for a certain quality management activity.

2.6.1 Taxonomy of Quality Management

According to section 2.3, QM can be divided into four parts:

1. Quality planning,
2. Quality control,
3. Quality assurance,
4. Quality improvement.

These four dimensions can be seen as a sequent flow in a quality management system. They share the common quality goal to achieve` it when in a quality organization. When applying such a quality management system into a large

distributed manufacturing system, the system will be highly complex whose behaviors are not well known and some approximate situations would happen. Hence, fuzzy theory is feasible to be implemented, which is very useful in two general contexts: (1) in situations involving highly complex system whose behaviors are not well understood, and (2) in situations where an approximate, but fast, solution is warranted (Ross et al, 1999). Fuzzy techniques based on fuzzy theory can be applied in various of aspects to help solve the uncertain problems. Within the quality management area, each technique can perform one or more of the following functional models referring to the selected articles (Al-Kandari et al, 2006, Bergman et al, 2005, Boo et al, 1994, Catania et al, 1999, Ghahfarokhi et al, 2007):

1. Fuzzy numbers
2. Fuzzy AHP
3. Fuzzy decision making
4. Fuzzy programming
5. Fuzzy data analysis
6. Fuzzy optimization
7. Fuzzy clustering
8. Fuzzy QFD
9. Fuzzy inference
10. Fuzzy control

A graphical classification framework on fuzzy theory techniques applied in the quality management of the distributed manufacturing system is proposed and shown in Fig. 2-1; it is based on a review of the relevant literatures (Al-Kandari et al, 2006,

Bergman et al, 2005, Boo et al, 1994, Catania et al, 1999, Ghahfarokhi et al, 2007).

For all the QM dimensions and fuzzy techniques, a brief description and some references for further details are discussed in the following sections.

Fig. 2-1 Classification framework for fuzzy theory technique applied in quality management of distributed manufacturing system

2.6.2 Classification Results

2.6.2.1 Distribution of articles by QM dimensions and fuzzy theory technique

Fig. 2-2 Distribution of articles based on QM dimensions

The distribution of articles classified by the proposed classification model is shown in Fig. 2-2 and Table. 2-1 shows detailed reference classifications.

Based on the hierarchical in Fig. 2-2, it can be found that the articles fall into quality planning dimension covering 21.3%. The applied fuzzy tools mainly include fuzzy numbers, fuzzy AHP, fuzzy decision making, fuzzy optimization, fuzzy QFD, fuzzy programming and fuzzy inference; While the fuzzy techniques such as fuzzy control, fuzzy inference, fuzzy decision making, fuzzy data analysis,

fuzzy clustering, and fuzzy AHP can be used for quality control, and the relevant articles account for 26.2%; Quality assurance related articles are 18.0% out of all, which introduces fuzzy inference, fuzzy numbers, fuzzy decision making, fuzzy clustering and fuzzy data analysis; Finally the selected articles for quality improvement covering the most with 34.4%, the involved fuzzy techniques are fuzzy optimization, fuzzy data analysis, fuzzy numbers, fuzzy inference, fuzzy QFD, fuzzy decision making, fuzzy programming and fuzzy clustering.

Table. 2-1 Reference classification

Quality Dimensions	Fuzzy theory Technique	Reference
Quality Planning	Fuzzy numbers	Amin, S. H. and J. Razmi (2009); Tseng, M.-L. (2009).
	Fuzzy AHP	Chang, C.-W., C.-R. Wu, et al. (2008);
	Fuzzy decision making	Dalalah, D. and O. Bataineh (2009); Deb, S. K. and B. Bhattacharyya (2005); Yang, T. and C.-H. Hsieh (2009)
	Fuzzy optimization	Dereli, T., A. Baykasoglu, et al. (2007); Kahraman, C., T. Ertay, et al. (2006)
	Fuzzy QFD	Liu, H.-T. (2009)
	Fuzzy programming	Karsak, E. E. and O. Kuzgunkaya (2002)
	Fuzzy inference	Mun, J., M. Shin, et al. (2009); Nada, O. A., H. A. ElMaraghy, et al. (2007)
Quality Control	Fuzzy decision making	Aliev, R. A. (1987); Kahraman, C., A. Beskese, et al. (2004); Lou, H. H. and Y. L. Huang (2003); Ozgur Unver, H. and G. Wendel (2009)
	Fuzzy data analysis	Engin, O., A. Celik, et al. (2008); Tahera, K., R. N. Ibrahim, et al. (2008)
	Fuzzy clustering	Chen, J. C. and J. T. Black (1996);
	Fuzzy AHP	Göleç, A. and H. TaskIn (2007); Lee, A. H. I., W.-C. Chen, et al. (2008)
	Fuzzy control	Suhail, A. and Z. A. Khan (2009); Tsourveloudis, N. C., E. Dretoulakis, et al. (2000)
	Fuzzy inference	Lau, H. C. W., E. N. M. Cheng, et al. (2008); Moon, H.-S. and S.-J. Na (1996); Melin, P. and O. Castillo (2007); Pacella, M., Q. Semeraro, et al. (2004); Zarandi, M. H. F., A. Alaeddini, et al. (2008);

Quality Assurance	Fuzzy inference	Hsu, B.-M. and M.-H. Shu (2008); Lee, S. R., Y. J. Choo, et al. (2001); Mehrabi, M. G. and E. Kannatey-Asibu (2001); Perrot, N., I. Ioannou, et al. (2006)
	Fuzzy numbers	Li, R.-z., M. Shigeki, et al. (2007); Wang, Y.-M., K.-S. Chin, et al. (2009)
	Fuzzy decision making	Liu, H., W. Chen, et al. (2005).; Xu, W. and T. Frantti (2002)
	Fuzzy data analysis	Wang, Y.-M., Y. Luo, et al. (2009)
	Fuzzy Clustering	Giampietro, M., K. Mayumi, et al. (2006); Pfeufer, T. (1997)
Quality Improvement	Fuzzy decision making	Abdi, M. R. (2009); Ertugrul Karsak, E. and E. Tolga (2001); Kuo, T.-C., H.-H. Wu, et al. (2009); Zhang, Z. and X. Chu (2009); Temponi, C., J. Yen, et al. (1999); Önüt, S., S. S. Kara, et al. (2009).
	Fuzzy numbers	Beskese, A., C. Kahraman, et al. (2004); Bottani, E. (2009); Chang, H. C. H.-C. (2004); Chen, L.-H. and M.-C. Weng (2003); Chen, Y., R. Y. K. Fung, et al. (2006)
	Fuzzy QFD	Celik, M., S. Cebi, et al. (2009); Lee, Y.-C., L.-C. Sheu, et al. (2008);
	Fuzzy data analysis	Chang, R.-S., C. S. Lin, et al. (1994); Kulak, O. (2005); Liu, S.-T. (2008)
	Fuzzy optimization	Chang, Y.-P. and C. Low (2008);
	Fuzzy (linear/non-linear) programming	Chen, L.-H. and W.-C. Ko (2009); Chen, L.-H. and M.-C. Weng (2006); Karsak, E. E. (2004)
	Fuzzy inference	Kim, K.-J., H. Moskowitz, et al. (2000); Lau, H. C. W., G. T. S. Ho, et al. (2009); Lee, K. K. (2008)
	Fuzzy Clustering	Yang, M.-S., W.-L. Hung, et al. (2006)
	Fuzzy optimization	Yang, F., S. Wu, et al. (2006)

Table. 2-1 shows the detailed classification and distribution of reference information, and together with Fig. 2-2, we can clearly find that the different fuzzy tools could be implemented in various QM dimensions. Among all this 10 fuzzy tools, fuzzy decision making is the most commonly used fuzzy technique and then the fuzzy inference system. The search and classification results here can provide the hints when choosing feasible fuzzy tools for quality management system in this study.

2.6.2.2 Fuzzy tools association based on QM related articles

From the distribution result of articles in session 2.6.2.1, we have obtained the most commonly used fuzzy tool for QM dimensions and all the other related fuzzy tools' application frequency, which helps us narrow the range within the relevant area. However, for the association between each individual fuzzy tool, we are still unclear. Hence, this part is mainly focused on the fuzzy tools association.

As mentioned, the clustering analysis method can be used to analyze the association among set elements. In this session, the agglomerative nesting (AGNES) is chosen to figure out the fuzzy tools association. And the analysis results are shown in Fig. 2-3.

In Fig. 2-3, the bottom 10 fuzzy tools are the extracted fuzzy techniques based on the study 61 articles. From the bottom 10 fuzzy tools clusters to the top one cluster, the dissimilarities are increasing. From the figure level 1, we can know that the fuzzy programming is always combined with fuzzy optimization, the same as fuzzy data analysis and fuzzy inference as well as fuzzy AHP and fuzzy control. For the similar type articles with fuzzy programming and fuzzy optimization as their fuzzy techniques, fuzzy QFD may also be implemented sometimes. Similar situation may occur for the cluster including fuzzy data analysis, fuzzy inference and fuzzy decision making and the cluster consists of fuzzy AHP, fuzzy control and fuzzy clustering according to figure 7 level 2. Seen from the level 3, it can easily found that the first 4 fuzzy tools are more similar with a higher association and the so as the last 6 fuzzy tools. Finally, the level 4 shows all the fuzzy techniques merge together for all are applied in the 61 studied QM related articles.

Fig. 2-3 Clustering of Fuzzy tools based on smallest dissimilarities

The results can help us develop more complex combined fuzzy tools for the target quality management system in the future.

2.6.2.3 Distribution of articles by year of publication on the basis of QM dimensions

The distribution of articles by year of publication based on four QM dimensions is shown in Fig. 2-4. It is obvious that the publications are fluctuant since 1995 but with an increase trend recently on quality planning, quality assurance and quality improvement. Especially for quality improvement, the publications increase largely. While for quality control, the related publications increase from 2005 to 2007 but decrease recently. In Fig. 2-5, the whole distribution of articles by year of publication is shown, easily to see, the trends is always increasing.

Fig. 2-4 Distribution of articles by year of publication based on four QM dimensions

Fig. 2-5 Distribution of articles by year

From the distribution results, it's clear that our study topic is still a hot topic which grabs many researchers' attention with an increasing trend.

2.7 Research Gap

To have in-depth study on manufacturing system, a good modeling method is always the first step to success. Form the reviewing articles, it's found that DMS, as a collection of independent companies with complementary technology and skillful manpower which integrates and collaborating transportation and storage systems, information and financial flows, and many other entities to meet the market demand, The traditional modeling methods cannot fulfill the modeling requirement. Hence, a more efficient modeling method is required.

Researchers have conducted comprehensive research about the application of RFID in different domains. However, there's less research about modeling the dynamic status of the objects in the workflow with RFID for quality improvement.

It is expected to have the synergy of combining RFID together with color token for manufacturing system by improving the yield rate and throughput simultaneously. It is realized that enterprises find difficulty to improve yield rate and throughput at the same time with same amount of resource. Also, there is lack of methodology to analysis the system through exchanging the real time information with ubiquitous technology so as to enable system analysis by a newly developed modeling method.

In practical environment, fuzzy and vague information is unavoidable existing. Fuzzy logic method has been selected as an efficient tool to handle quality problems via reviewing large number of articles. And from the trends analysis in section 2.6.2.3, it's realized the fuzzy logic applied for QM is an emerging research which attracts many researchers' attention. So a RFID-based quality management system in the distributed manufacturing network consisting of three sub-systems--- new Petri-net modeling system, fuzzy quality management system and RFID system is proposed in this research.

Chapter 3

3 RFID-based quality management system in Distributed Manufacturing Network

In this chapter, an overview of proposed RFID-based fuzzy quality management system will be briefed in section 3.1. Features and functions of each module for the whole system is introduced section 3.2.

3.1 Overview of proposed RFID-based Fuzzy Quality Management System

As aforementioned, this study aims at developing a RFID-based quality management system that assures to manufacture the high-quality products and support company to make right decisions. For this system, more detailed objectives are included: (1) establishing a model referring to the practical system with the Petri Nets modeling method to illustrate the complex relation inside so as to deal with the concurrency and synchronization in distributed manufacturing networks; (2) setting up a standard quality management system for manufacturing

system based on the model built in (1), meanwhile, choosing appropriate fuzzy tools in different steps within the whole quality management process; (3) establishing a fuzzy quality management system based on the selection of fuzzy tools in (2), with the smart combination of fuzzy techniques and the standard quality management system; (4) applying RFID technique for the fuzzy quality management system so as to fulfill the data communication, and furthermore promoting quality management.

Fig. 3-1 A framework of the proposed RFID-based quality management system in distributed manufacturing network

Accordingly, a framework of the RFID-based quality management system in distributed manufacturing networks is proposed in Fig. 3-1.

The proposed system consists of three mainly subsystems, a petri-net modeling system, a fuzzy quality management system and a RFID system.

3.2 Features and functions of the proposed System

3.2.1 System Modeling and Simulation

To deal with concurrency and synchronization, Petri Net formalism for modeling was one of the comprehensive approaches. The basis of Petri Nets is to model graphically and test analytically the discrete events of the concurrent operations within a system. The fundamental constructs of Petri Nets are useful to model and analyze manufacturing systems. Kamath and Viswanadham (Kamath et al, 1990) have introduced several positive aspects of Petri Nets for general dynamic systems:

However, the distributed manufacturing system is larger and more complex, it's necessary to develop a more suitable modeling method which fulfills the following requirements:

- (1) The modeling method should enable the system analyst to model the distributed manufacturing network with many subnets with the occurrence of substitution transitions in the overview net.
- (2) When modeling similar parts in a system, there is no need to build many separate nets as the original Petri Net .
- (3) The modeling method can be a real recurrence of a manufacturing system with discrete and concurrent information. The process of acquisition and transmission of information can describe the transmission of tokens in different places.

- (4) The modeling method can model very complex system and simulate the flow inside so as to figure out the system internal relationship, and can also use color set token to model the system so as to reduce the system size, which is manageable for large size network and has a short development cycle.
- (5) The modeling method can represent deterministic firing durations which can help obtain exact performance estimates.
- (6) The modeling method helps rank processing sequence for different jobs or products which are more accordant with the real situation since different jobs got distinguishing priorities.

3.2.2 Process Monitoring and Automatic Identification and Data Capture

For the manual data record or exchange, it has been realized the inconvenience and time consuming of data entry and mistakes by manual entry. Therefore, new Automatic Identification and Data Capture (AIDC) technology needs to be introduced.

As automatic identification and data capture technology, barcode and RFID both have their advantages. The most important advantage of barcode over RFID is the low investment cost. It cannot be denied that cost is a very important factor especially for a manufacturing company. However, companies need to consider both the cost and the benefit of adopting automatic identification and data capture technology. In manufacturing environment, barcode's lifecycle is short because printed barcodes must be put on the products or machines which are exposed in the harsh environment. Undoubtedly, it may lead to a higher rate of wear and tear. The line of sight limits the ruggedness and reusability of barcodes. On the contrary,

RFID tags can be rugged with electronic components protected by plastic cover and implanted inside the product itself so as to guarantee greater ruggedness and reusability. In addition, unlike barcodes RFID doesn't require direct line to read information and can read within a longer distance. The most important reason of using RFID is that RFID can totally avoid human intervention so as to minimize the input errors and human judgment errors. Moreover, RFID system can capture data at a higher-speed, and enable simultaneous data processing with larger data capacity. A barcode can only identify a certain type of the product from a certain manufacturer or source, but not at the item level. Products need to be handled differently with special processing procedure, and RFID reader can write on the tag placed on each item after some processes. Therefore, tracking and tracing the progress of the production flow can be fulfilled.

3.2.3 Quality Management with Fuzzy Logic

After data collection and modeling the distributed manufacturing network, the corresponding quality management activities need to be done as follow:

1. For efficient and effective quality management, systematic and comprehensive quality standard need to be firstly determined, normally for practical cases, each company has its own standard for different products;
2. Fuzzy clustering is introduced to help classify a typical sample of collected data so as to help further quality analysis of the products. The clustered data can be labeled by distinguishing linguistic words so as to be easily recognized by the end-operator.
3. Based on the cluster center and corresponding quality standard, the quality rules for the systems can be developed and then set up with the inference

process of fuzzy logic. With the input of modeling results and if-then rules, the decision-making results can be gained after inference engine.

All of the above modules will be explained detailed in the Chapter 4-6.

Chapter 4

4 Modeling distributed manufacturing system with Petri Nets

In this chapter, a new modeling methodology for distributed manufacturing systems is proposed. Section 4.1 provides a brief introduction of traditional Petri Net (PN). Section 4.2 describes the extensions of Petri Nets. Section 4.3 depicts an explanation of Hierarchical Timed Colored Petri Net (HTCPN). Section 4.4 presents how to model a Distributed Manufacturing System (DMS) using HTCPN.

4.1 Distributed Manufacturing Network

The distributed manufacturing system (DMS) structure can be considered as a set of facilities with materials which flow from the sources of raw materials to manufacturers and onwards to assemblers and consumers of finished products. These facilities of DMS are connected by transporters of materials, semi-finished goods and finished products. Generally, the DMS entities can be described as follows (Butala et al, 2002):

(1) **Manufacturers and assemblers:** manufacturers and assemblers are facilities that transform raw materials into desired output products.

- (2) **Suppliers:** a supplier is a facility that provides raw materials, components and semi-finished products to manufacturers who want to use them.
- (3) **Logistics and transporters:** storage and handling capacities, transportation times, operation and inventory costs are the attributes of logistics facilities.
- (4) **Retailers or customers:** retailers or customers are sink nodes of material flows.

4.2 Introduction to Traditional Petri Net

To deal with concurrency and synchronization, Petri Net formalism for modeling was one of the comprehensive approaches. The basis of Petri Nets is to model the discrete events of concurrent operations within a system graphically and analytically. Early in the 1990s, Righini (Righini, 1990) developed a Petri-Net based system for the simulation of complex manufacturing systems. In his study, he used Petri Net to characterize a manufacturing system by a lower degree of detail and a higher level of abstraction in real system representation. It emphasizes the importance of the easier and more efficient production plans, economic factors or work shifts. However, in his study, Righini didn't consider the variability of products which has a significant effect in real practical systems. Recently, Petri Net has been extended to include different features and functions for specific modeling purposes such as Object-Oriented Petri Nets (Liu et al, 2009), Colored Petri Net (Stotts et al, 1989), Stochastic Petri Net (Molloy, 2006). Among these methods, Colored Petri Net (CPN) combining ordinary Petri Net implemented by a high-level programming language has been proven powerful for modeling and analysis of a complex system.

The basis of Petri Net is to model graphically and test analytically the discrete events of concurrent operations within a system. The fundamental constructs of Petri Nets are useful to model and analyze manufacturing systems. Kamath and Viswanadham (Kamath et al, 1990) have concluded the advantages of Petri Nets for general dynamic systems:

1. They describe the modeled system graphically and hence enable an easy visualization of complex system.
2. Petri Net can model a system hierarchically, and system can be represented in a top-down fashion at various levels of abstraction and detail.
3. A well-developed Petri Net analysis technique provides a systematic and complete qualitative analysis of the system.
4. The existence of well-formulated schemes for Petri Net synthesis facilitates system design and synthesis, and timed Petri Nets can evaluate system performance.

Petri Net offers convenient ways of expressing system behaviors which are both asynchronous and distributed, compared with other common graph models of dynamic behaviors. Petri Net also provides a solid platform for modeling the precedence constraints among operations and relaxed couplings associated with shared resources, as well as the repetition or sequences of certain operations.

A Petri net is a 5-tuple, $PN = (P, T, F, W, M_0)$ where:

- $P = \{p_1, p_2, \dots, p_m\}$ is a finite set of places,
- $T = \{t_1, t_2, \dots, t_n\}$ is a finite set of transitions,
- $F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs (flow relation),
- $W: F \rightarrow \{1, 2, 3, \dots\}$ is a weight function,

-- $M_0 : P \rightarrow \{0, 1, 2, 3, \dots\}$ is the initial marking,

-- $P \cap T = \emptyset$ and $P \cup T \neq \emptyset$.

A Petri net structure $N = (P, T, F, W)$ without any specific initial marking is denoted by N .

A Petri net with the given initial marking is denoted by (N, M_0) (Murata, 1989).

4.3 Extensions of Petri Net

4.3.1 Colored Petri Net

Colored Petri Net (CPN) has been developed for supporting hierarchical construction of the large models representing real systems (Liu et al, 2009). The link with hierarchical CPN is established with reference to the modular and hierarchical structures of distributed manufacturing systems. A formal definition of CPN is as follows (Haddad, 1990)

A Colored Petri Net $R = \{P, T, C, I^+, I^-, M\}$ is defined by:

-- P is a finite set of places,

-- T is a finite set of transitions with $P \cup T \neq \emptyset$ and $P \cap T = \emptyset$,

-- C is the color function from $P \cup T$ to W , where W is some finite set of finite and not empty sets. An item of $C(s)$ is called a color of s and $C(s)$ is called the color set of s ,

-- $I^+ (I^-)$ is the forward (backward) incidence matrix of $P \times T$, where $I^+(p, t)$ is a function from $C(p) \times C(t)$ to N . N is the set of non-negative integers,

-- M is the initial marking of the net which is a vector of P , where $M(p)$ is a function from $C(p)$ to N .

Fig. 4-1 A simple Petri net for a manufacturing process

Fig. 4-2 A simple CPN example for a manufacturing process

Fig. 4-1 and Fig. 4-2 show the advantages of using CPN for size reduction. When modeling similar parts in a system, there is no need to build many separate nets as original Petri Net, and CPN can integrate all in one.

4.3.2 Timed Petri Net

Timed Petri Net was developed based on the traditional Petri Net. In timed Petri nets, each transition takes a "real time" to fire, i.e., there is a firing time associated with each transition of a net which determines the duration of the firing of a transition.

A conflict-free timed Petri net is a pair $N_{\text{timed}} = (M, f)$, where:

- M is a conflict-free marked Petri net, $M = (N, M_0)$, $N = (P, T, F, W)$,
- f is a firing time function which assigns the nonnegative (average) firing time $f(t)$ to each transition t of the net, $f: N_{\text{timed}} \rightarrow R^{\oplus}$, and $R^{\oplus}$ denotes the set of nonnegative real numbers (Zuberek, W.M. et al, 1999).

4.4 Hierarchical Timed Colored Petri Net (HTCPN)

4.4.1 Definitions

In this study, a hierarchical timed colored Petri net models the dynamic evolution of a system (Villani et al, 2005). It is composed of a set of HTCPN sub-nets. The first definition for the HTCPN is:

Definition 1. A Hierarchical Timed Colored Petri Net (HTCPN) is composed of a finite set of HTCPN sub-nets, i.e., $N_{\text{HTCPN}} = \{N_{\text{HTCPN}_1} N_{\text{HTCPN}_2} \dots N_{\text{HTCPN}_n}\}$, where n is the number of classes that model the system dynamics.

The definition of the HTCPN subnet is based on the identification structure of a certain net. Generally, the dynamic part of a system is presented when the place is marked, and the transition is fired only when required conditions are satisfied. Within a complex hierarchical system, when modeling from the holistic perspective, there can be several substitution transitions, and each of them is related to a complex HTCPN named subnet. The subnet allows one to go into a more specific and precise explanation of the activities in the substitution transitions. Each subnet can be considered as a unique integrated HTCPN, but its input and output are closely connected with other subnets as shown in Fig. 4-3.

Fig. 4-3 General Structure of a HTCPN

Definition 2. A HTCPN sub-net is a structure as a 4-tuple $NHTCPN_i = \{A_i, NTCN_i, V_i, M0_i\}$, where:

- A_i is the name of sub-net,
- $NTCN_i$ is a Timed Colored Petri Net (See Definition 3),
- V_i is the set of variables in NHTCPN,
- $M0_i$ is the initial marking of the sub-net (See Definition 4).

Fig. 4-4 shows the HTCPN with two sub-nets of workstation 1 and workstation 2. These sub-nets model the dynamic behavior of a system where a product experiences two different manufacturing processes.

Fig. 4-4 An example of HTCPN sub-net

The new concept Timed Colored Petri Net (TCPN) is developed based on the traditional Petri Net, Colored Petri Net and Timed Petri Net, so it should contain all the elements of these three existing Petri Nets. Besides that, a new element R, priority for different products or jobs, is introduced for the new Petri net in Definition 3. In real case, different products or different production lines will adjust the processing sequence based on its current significance such as customer wanted date or the importance index of the customers, and so on.

Definition 3. A Timed Colored Petri Net (TCPN) is a structure: $N=(P, T, C, F, W, M0, f, R)$

- $P=\{p_1, p_2, \dots, p_m\}$ is a finite set of places,
- $T= \{t_1, t_2, \dots, t_n\}$ is a finite set of transitions,

-
- $F \subseteq (P \times T) \cup (T \times P)$ is a set of arcs (flow relations),
 - $W: F \rightarrow \{1, 2, 3, \dots\}$ is a weight function,
 - $M_0: P \rightarrow \{0, 1, 2, 3, \dots\}$ is the initial marking,
 - C is the color function from $P \cup T$ to W , where W is some finite set of finite and non-empty sets. An item of $C(s)$ is called a color of s and $C(s)$ is called the color set of s ,
 - f is a firing time function which assigns the nonnegative (average) firing time $f(t)$ to each transition t of the net, $f: N_{\text{timed}} \rightarrow R^{\oplus}$, and $R^{\oplus}$ denotes the set of nonnegative real numbers,
 - R is the priority index for different products or jobs

As marking denotes the state of the place, it is the most important element which reflects the dynamic evolution of a certain system. For this study, the definition for marking is specially listed out.

Definition 4. The marking of a HTCPN sub-net is composed of a set of markings, each of which models the state of a place:

where:

- $MO.i$ is the set of $\{OO.i, YO.i\}$,
- $OO.i$: the name of the place,
- $YO.i$: denotes the tokens.

In Fig. 4-3 the initial marking $MO.0$ for workstation 1 subnet is $(1,0,0,0,0)$ with corresponding places being $P1.1$ --- $P1.5$. After the first transition firing, the marking $MO.1$ becomes $(0,1,1,0,0)$.

4.4.2 Features of HTCPN

(1) As shown in Fig. 4-4, HTCPN can be composed of many subnets with the occurrence of substitution transitions in the overview net. The overview set can perceive holistically the entire system. Detailed analysis of activities can be found in each subnet with a specific structure.

(2) Fig. 4-5(a) shows a very simple manufacturing process of a part. Even for such a simple process, engineers need at least 3 nets to describe it clearly. If there is more than one part for processing, the nets have to be replicated according to the number of parts. Under this condition, even a simple process will lead to a considerably large net. Fig. 4-5(b) shows the advantages of using CPN for size reduction. When modeling similar parts in a system, there is no need to build many separate nets as the original Petri Net and CPN can integrate all in one (Aized, T., 2009)

Fig. 4-5 (a) A simple PN example for a manufacturing process ; (b) A simple CPN example for a manufacturing process.

(3) HTCPN provides the advantages of CPN, which can be a real recurrence of a manufacturing system with discrete and concurrent information. The process of acquisition and transmission of information can describe the transmission of tokens in different places. Acting the code segment of the transition can achieve the goal with the data.

(4) HTCPN can model very complex system and simulate the flow inside so as to figure out the system internal relationship. HTCPN can also use color set tokens to model the system so as to reduce the system size. Better than normal CPN, hierarchical CPN is manageable for large size networks and has a short development cycle.

(5) HTCPN reduces the net size even more compared with the normal CPN with a clear hierarchical level. Furthermore, since HTCPN provides a very clear framework of a target system, the relation analysis can be much easier.

(6) HTCPN can represent deterministic firing durations which can help obtain exact performance estimates.

(7) HTCPN ranks processing sequence for different jobs or products which is more accordant with the real situation.

4.5 Modeling Distributed Manufacturing Network with HTCPN

In this section, the steps to model distributed manufacturing network with HTCPN are generalized.

4.5.1 Modeling Process

4.5.1.1 The DMS Description

The distributed manufacturing network structure can be considered as a set of facilities in which materials flow from the sources of raw materials to manufacturers and onwards to assemblers and consumers of the finished products (Butala, P. et al, 2002). These facilities of DMS are connected by transporters of materials, semi-finished goods and finished products. Under this circumstance, the whole distributed manufacturing network can be derived from distributors (suppliers) to the manufacturing network (manufacturers and assemblers), the connectors between which are the transporters of materials. And inside the manufacturing network, there exist the transportation of semi-finished goods. The end of the distributed manufacturing network is the receivers (retailers or customers), and the structure can be seen in Fig. 4-6.

Fig. 4-6 Structure of distributed manufacturing network

4.5.1.2 Modeling DMS in Hierarchical way

The distributed manufacturing process is complicated and interconnected, thereby increasing the complexity of modeling and simulation. System decomposition can aid an analyst to find out the main building block, and hierarchical modeling allows users to have an overview of the system structure. Fig. 4-7 depicts the difference among the steps for hierarchical modeling and sequential modeling. The main

difference is the degree of abstraction in hierarchical level. Subnet, as the basic element providing detailed information of a cluster of activities, is identified by the hierarchical modeling method.

Fig. 4-7 Modeling DMS in both Hierarchical and Sequent way

Fig. 4-8 shows the hierarchical model of a distributed manufacturing network. A cluster of machines constitutes a production workshop where a group of production workshops are included in the factory. The production facilities for distinct manufacturing processes with different locations form a manufacturing network.

Fig. 4-8 Hierarchical model of Distributed Manufacturing Network

The advantages of hierarchical modeling over sequential modeling are shown as following:

1. Hierarchical modeling provides a holistic structure of DMS;
2. The module (subnet) function includes aggregated data and information.
3. Backup subnet can be set in a large distributed manufacturing network.

Additional production resource can be included in the backup subnet in case of any disruption.

4. Hierarchical modeling has a flexible way to handle the change of function of subnet. In case that any subnet needs to be modified, the functional module can replace the original subnet without affecting the existing modules.

4.5.1.3 General Steps for modeling method with HTCPN

The general steps for HTCPN are as follows:

Step 1: Outline the overview structure of object distributed manufacturing network, and transform all the elements into CPN elements to build up first-level Petri Net.

Step 2: Further define the subnet for first level HTCPN. The subnets are always the substitution for transition element of last level.

Step 3: Repeat step 2 until the transition elements are no need further development which means the basic elements in distributed manufacturing network has been modeled.

Step 4: Make sure all the links between the levels are consistent through the entire HTCPN.

Chapter 5

5 RFID-Based Colored Tokens Applied in Quality Management System

Product quality is difficult to be traced and monitored in the distributed manufacturing network. This chapter proposes and develops a new RFID-based CPN modeling method where the colored tokens are evolved to color tagged tokens carrying the product information of the real-time status. With this new real-time modeling method, the performance of manufacturing systems such as yield rate and throughput can be realized. In this chapter, a case study has been conducted to examine the feasibility and effectiveness of the proposed method. The simulation results show that the new modeling method is able to complete the preliminary real-time quality status analysis of a manufacturing system so as to handle dynamic and stochastic manufacturing network effectively and enable decision making for process improvement.

5.1 Radio Frequency Identification

RFID is a form of Automatic Identification and Data Capture (AIDC) technology that has been developed since more than half a century ago. In the last few years,

RFID shows its tremendous potential which has begun to be used to deliver new century solutions to the way how manufactures and retailers do business in the food and Consumer Packaged Goods (CPG) industry. RFID (Radio-frequency Identification) is utilizing an RFID tag for the objectives of identifying and tracing a person, an animal, or a product with radio wave. RFID tags, which contain an integrated circuit chip and an antenna, are integrated into objects such that these objects can be identified and their label information can be read. Radio frequency identification involves detecting and identifying a tagged object via radio waves transmitting data from tags to a reader. Fig. 5-1 shows a typical RFID system architecture with, from left to right, RFID tags, an RFID reader antenna (Reader Antenna), RFID reader (Reader), RFID middleware and host application (Host AP). One key operation in RFID is data transfer between tag and reader that also known as coupling – through the antennae on either end. The overall radio frequency system is identified from the RF antenna reader information then transmitted to the radio identification reader and subsequently through RFID middleware. The host AP then integrates applications according to different needs (Lyu, 2009).

Fig. 5-1 RFID system architecture diagram

RFID shows its huge advantage and breakthrough in information tracking applications (Kleist, 2004, Weinstein, 2005, Want, 1991). RFID technology has the important features such as real time, prompt read/write, portability, good penetration, long life time, good environmental resistance, and high-capacity store and thus it may be applied in both automatic production and business management (Curty et al., 2005).

Tracking goods in the supply chain and manufacturing system is the most important application for RFID technology. Regattieri (Regattieri, 2007) mentioned that the RFID technology had been currently introduced to improve information accuracy and data transmission speed throughout the business flow, including shop floors management system, marketing system, and management processes system. RFID also can find its application in controlling the access to buildings and networks. Companies all over the world implement RFID technology to improve production efficiency and security features. Meanwhile, RFID applications are used to be integrated in some intelligent softwares to help fulfill the automatic routine decision-making. Compared with the other most commonly used AIDC technology---bar code, Keskilammi (Keskilammi et al., 2003) have proven that for some application systems which could replace bar code with RFID, they might raise the overall management efficiency.

Based on the various industry areas that are featured in the related literature (Ngai et al., 2007), the RFID applications appear outstanding in aviation, building management, library, service, construction, health and logistics and supply chain management. Lee (Lee et al, 2010) proposed a genetic algorithm to determine the

location of collection point and RFID is used so as to count the quantity of collected items in collection point and it can send the signal to central return center so as to arrange the vehicle or resource to ship back from collection point to return center. With the high accuracy on product track and tracing, more and more manufacturing system implements RFID technology so as to monitor the quality of products. Lyu et al.(2009) have given out a framework of quality assurance system integrating RFID technology that allows on-site staff to monitor complicated variations in production process by handling numerous possible abnormalities simultaneously. As RFID can capture enormous amount of data, researchers work on data framework and architecture to achieve data aggregation and optimization (Traub, 2005; Wang and Liu,2005; Chalasani and Boppana, 2007) .

5.2 RFID Tag associated with Colored Token

This section proposed RFID-based CPN to improve the quality of the system without scarifying any one of the performance (either throughput or yield rate). Researchers have conducted comprehensive research about the application of RFID in different domain. However, there's less research about modeling the dynamic status of the objects in the workflow with RFID for quality improvement. It is expected to have the synergy of RFID together with colored tokens for manufacturing system by improving the yield rate and throughput simultaneously. It is realized that enterprises find difficulty to improve yield rate and throughput at the same time with the same amount of resource. Also, there is lack of methodology to analysis the system through exchanging the real time information with ubiquitous technology so as to enable system analysis by CPN.

Fig. 5-2 Information representation and exchange between RFID and CPN

Fig. 5-2 shows the structure of RFID system and Colored Petri Net respectively. RFID system elements, which are connected bidirectional with CPN, can update information promptly with real-time action. The traditional Colored Petri Net, which acts as a modeling and simulation method, is a single direction flow analysis and decision can only be obtained after running out the simulation.

Fig. 5-2 shows the roles of the elements in both RFID and CPN. RFID tag and color token stored the information of the product in manufacturing system, and both of them can update the status of the product simultaneously. The proposed approach is to combine RFID and CPN so that RFID tag can easily realize the accurate real-time data collection, and the color token is effectively implemented

for simulation analysis such that the synergy of combining both technologies can be obtained. Under this situation, simulation results from CPN can help update the RFID database so in a more precise way, and both databases can be synchronized. This research develops the RFID-based Colored Petri Net to finish the accurate real-time analysis for manufacturing system so as to realize automatic abnormality handling and enhance decision making.

5.2.1 Colored Token---Product Status

In Colored Petri Net, a token can have a color to represent a certain particular type of product when modeling a manufacturing system. A certain colored token can contain all the information of a corresponding product. Fig. 4-1 shows a simple manufacturing process which illustrates the manufacturing process of a part. Even though it is a simple process shown below, engineers need at least 3 nets to describe it clearly. If there is more than one part for processing, the nets have to be replicated according to the number of parts. Under this condition, even such a simple process will lead to a considerable large net.

A formal definition of CPN is as follows (Haddad, 1990):

A Colored Petri Net $R = \{P, T, C, I^+, I^-, M\}$ is defined by:

- P is a finite set of places;
- T is a finite set of transitions with $P \cup T \neq \Phi$ and $P \cap T = \Phi$;
- C is the color function from $P \cup T$ to W , where W is some finite set of finite and not empty sets. An item of $C(s)$ is called a color of s and $C(s)$ is called the fcolor set of s ;

- $I^+ (I^-)$ is the forward (backward) incidence matrix of $P \times T$, where $I^+(p, t)$ is a function from $C(p) \times C(t)$ to N . N is the set of non-negative integers;
- M is the initial marking of the net is a vector of P , where $M(p)$ is a function from $C(p)$ to N .

Similar as original Petri Net, each place in CPN is associated with a local state or condition of the system, while each transition is associated with an event of the system. The set of place markings is the marking of the CPN. Unlike original Petri Net, the connections between places and transitions are labeled by a function of color. Each place can contain a set of tokens with colors. The place's marking is the number of each color in that place (Desrochers, 1995).

Fig. 5-3 shows a simple process how the colored token represents the status of the product. In initial marking M_0 , there are 3 colored tokens---2 units of Part 1 (blue) and 1 unit of Part 2 (green) in the start place. One part 1 goes into the processing activity first, and there are 2 left in the start place. If the processing activity goes smoothly, the M_1 shows there will be one part 1 available after processing. However, if there are something wrong happened during the processing activity, the output token color will change as shown in M_2 , which means there is one part 1 failure after processing. In summary, within the colored token running process, the color will stay the same if the processing activity goes smoothly, while color changing indicates failure modes' happening in last transition activity.

Fig. 5-3 Color token represent product status

5.2.2 RFID-based Colored token link with RFID System

In RFID-based Colored Petri Net, the colored token needs to be tagged so as to bridge with the RFID system.

Fig. 5-4 shows the linkage between them. The tokens color information inside this system are stored and synchronized with the RFID tag, once the color of token change, the reader antenna sensor receives signal that the status of the product changed. Then the reader will rewrite the stored information and sent the new data to host application. Host applications will feedback a corresponding processing activity on the colored changed token (for example, the failure part need rework by reentrant).

Fig. 5-4 The linkage between CPN and RFID

5.3 RFID-based HTCPN

5.3.1 The Architecture of RFID-based HTCPN

To integrate the two technologies, the synchronization needs to be considerate; the

RFID-base Colored Petri Net architecture is show in Fig. 5-5.

Fig. 5-5 RFID-based Colored Petri Net architecture

Color Tagged Token: is the first time introduced concept. Tokens with various colors in manufacturing system can represent different job types and store the job information including the customer data, job processing routine or any related information. So called Color Tagged Token actually means all the colored tokens' information will be real-time synchronized with the RFID tag. Hence, the color tagged tokens can get the real-time information from the RFID system so as to update the information promptly.

CPN Network & Color Token: Fig. 5-6 shows an example how CPN network works with colored tagged token. As shown in Fig. 5-6, the color tagged token will go through the CPN network, after a certain processing activity, a necessary quality rule will be checked so as to guarantee the products are qualified, among which the color respects the status of the product. And then the RFID reader will read the color change signal and decoding. In Fig. 5-6, the first figure shows the structure of an example CPN network, with the color tagged tokens in the input place. In the output place, the connected RFID display part will show the visualized results "one '74018' job is unqualified".

Fig. 5-6 The CPN network application

Real time simulation analysis: The value after symbol "@" shows the time stamp. When the model starts running, tokens will be transferred from one place to another, and at each place a certain time stamp for each token is recorded. Under this condition, a simulation report on the processing time and throughput can be obtained when corresponding time function and time delay was preloaded. When connected with RFID system, the time function and time delay can be obtained promptly. And also the simulation report can export a real-time analysis or decision making. Simultaneously, the simulation report will directly be imported to the RFID middleware so as to give a signal to host application. When host application gets the analysis results, a corresponding feedback will be sent to RFID

reader so as to confirm the status updating. Meanwhile, the simulation report will be updated again.

RFID Tag: All the items will be tagged after first quality check in manufacturing system by QC team, the initial information are updated in database. A RFID tag consists of a microchip, which connected to an antenna, contains a certain amount of data. In this system, the RFID tag contains all the information from color tokens. Once the color tokens' color changed, the stored information in color tokens will update again. Meanwhile the corresponding RFID tag will get the information so as to update the linked data table in database. After that, the host application will feedback a necessary activity to deal with the abnormality which induces the color changing.

RFID Antenna/Reader: The antenna broadcasts the RF signals generated inside the reader's transmitter into the immediate environment. It also receives responses from tags within defined range. The RFID reader sends and receives RF data to and from the tag via antennas, containing a transmitter, a receiver and microprocessor.

Electronic Product Code (EPC) information Sever: EPC network is the gateway between any requester of information and the database. The EPC information Server receives and sends messages with any requester of information (Leong, 2004). It plays the role as "interpreter" between databases and applications in RFID system.

RFID Middleware/ Host Application: Every RFID system consists of an enterprise subsystem that is composed of a middleware and enterprise applications, which are

critical components to the RFID system. The data information collected by the RFID readers needs to create value, such as more supply chain visibility or better planning, hence, the important role of the RFID middleware software to bridge the gap between the RFID data coming from the RFID readers and the existing host applications. In this new RFID-based CPN network, the CPN simulation report will be real-time updated and connected with the middleware part bidirectional.

5.3.2 Theoretical Example

In this part, a simple theoretical example will be given to explain the proposed system. Fig. 5-7 shows a flowchart for a very simple process flow. There are two types of products “M01” and “M02” with each type of two units are ready to go through this flow. It is assumed that any processing activity with the capacity larger than 4, all the product units can enter at the same time in this example.

Fig. 5-7 Simple Process Example

Once the process has been given, the model can be developed with CPN network as shown in Fig. 5-8. As mentioned, there are four product units with two different type, so the tokens in place 1 are two ("M01", true) and two ("M02", true). In this example, "M01" and "M02" are the ID for products and true shows the normal status of the product. As for processing activity 1 T1 will last a time as firing function discrete (4, 6) for each token while T2's firing function is discrete (2,3). All the tokens in CPN are tagged which can be detected by RFID reader antenna.

Fig. 5-8 CPN network for simple example

After development for CPN network, it's necessary to set up the RFID middleware so as to bridge the received simulation process information to host application. Fig. 5-9 is the interface for middleware setting for different devices (reader, rules, and integrator).

In the proposed RFID-based CPN network, the tagged tokens are encoded with Electronic Product Code (EPC). This is an object identification scheme which is used to uniquely identify objects and facilitates for tracking throughout the product lifecycle. The most commonly used scheme is a 96-bit code with a fixed, 8-bit header. This header defines the number, type and length of all subsequent data partitions. Thus, a single byte provides 256 ways to partition the remaining bits.

Fig. 5-9 Middleware Setting Interface

In this proposed system, the first EPC configuration, EPC Type I, is employed to work as a public object identifying number. The EPC Type I has three data partitions, EPC manager, object class and serial number which are shown in Fig. 5-10. The first data partition identifies the EPC manager; that is the manufacturer, company or entity, responsible for maintaining the subsequent codes. The next partition, object class, indicates the product type. The final partition encodes a unique object identification number for each product. Together with the product code, this provides each manufacturer with 1.1×10^{18} unique item numbers – currently beyond the range of all identified products (Brock, 2001). Fig. 5-10 shows EPC tag detected by the middleware.

Fig. 5-10 EPC Type I

Fig. 5-11 is the recorded tags after the configuration for RFID middleware is finished.

Fig. 5-11 EPC tags Viewer

After the experiment has been run, the whole process flow with different marking can be obtained as shown in Fig. 5-12. At the beginning, there are 4 tokens in place 1 respected two M01 and two M02, and then all the tokens are entering transition processing activity 1. One M01 and one M02 are firstly finished this part while the M01 color token stay the same and M02 color token changed which means this unit failed. As mentioned in Section 3.2, the reader will receives the signal the tagged. The token's color has been changed and then the signal goes through the RFID system. After that, the host application will feeds back to the failed token. For the next processing activity 2, it's similar as activity 1 with the 3 color-unchanged token go inside. Finally, the output place 3 got another one tagged token "M01" unit's color changed.

Fig. 5-12 RFID-based CPN for whole process flow of the simple example

The simulation results from the RFID-based CPN are shown as following Fig. 5-13

At time 0, there are two normal M01 tokens and two normal M02 tokens in place 1; at time 4, one normal M01 token and one abnormal M02 token arrived in place 2; at time 5, there is another one normal M02 token arriving in place 2; at time 6, the last one normal M01 token arrived in place 2; at time 7, there are one normal M01 token and one normal M02 token arriving in the output place 3; at time 8, one abnormal M01 token arrived in the output place 3.

Fig. 5-13 Timestamp for tokens in each place

Chapter 6

6 Fuzzy Logic Applied for Quality Management in DMS

Since there is unavoidable vague and fuzzy information, fuzzy logic is selected to apply for quality management in DMS. In this chapter, the introduction of fuzzy logic is initially given out in section 6.1. And then in section 6.2, fuzzy number is introduced as the data in practical case may be collected in the form of fuzzy number. In section 6.3, several fuzzy clustering methods are elaborated and a new fuzzy hierarchical clustering method is developed. In section 6.4, fuzzy inference system is built up based on clustering method as well as the selection of quality rules so as to make the quality management decisions.

6.1 Fuzzy Theory

Fuzzy sets theory was introduced by Zadeh in 1965. Different from in classical sets, in fuzzy sets the values assigned to the elements of the universal set fall within a specified range and indicate the membership grade of these elements in the set. Larger values denote higher degrees of set membership called a

membership function (Toth, 1987). Therefore, the elements in a fuzzy set have varying degrees of membership in the set. This idea is in contrast with classical or crisp set, because members of a crisp set would not be members unless their membership was full or complete, in that set (i.e., their membership is assigned a value of 1) (Zadeh, 1965). Elements in a fuzzy set, without necessity of memberships being complete, can also be members of other fuzzy sets on the same universe. Fuzzy sets are denoted by a set symbol with a tilde under strike. Fuzzy set is mapped to a real numbered value in the interval 0 to 1.

As more and more in-depth study on this area by large quantity of scholars, fuzzy logic has reached a relatively mature level. Fuzzy logic is a precise logic of imprecision and approximate reasoning. More specifically, fuzzy logic may be viewed as an attempt at formalization/mechanization of two remarkable human capabilities.

First, the capability--- to converse reason and make rational decision in an environment of imprecision, uncertainty, incompleteness of information, conflicting information, partiality of truth and partiality of possibility - in short, in an environment of imperfect information.

And second, the capability--- to perform a wide variety of physical and mental tasks without any measurements and any computations (Zadeh, 2008).

6.2 Fuzzy Number

Good data collection with effective information provision leads efficient analysis results. In the real cases, however, the collected data may be vague which is not easy to be precise and usually represented in term of fuzzy number. Fuzzy number can effectively express imperfect data without information loss in a more

realistic way. Fuzzy number can be regarded as the extension of real number and there are many different types of fuzzy number like triangular fuzzy number, trapezoidal fuzzy number as well as bell-shaped fuzzy number. In this section, trapezoidal fuzzy number will be studied as the focus.

6.2.1 Trapezoidal Fuzzy Number

In general, a generalized fuzzy number A is described as any fuzzy subset of the real line R , whose membership function μ_A satisfies the following conditions (Chen, et al 2006) (According to Fig. 6-1).

- (1) μ_A is a continuous mapping from R to the closed interval $[0, 1]$,
- (2) $\mu_A(x) = 0, -\infty < x \leq c$,
- (3) $\mu_A(x) = L(x)$ is strictly increasing on $[c, a]$,
- (4) $\mu_A(x) = w, a \leq x \leq b$,
- (5) $\mu_A(x) = R(x)$ is strictly decreasing on $[b, d]$,
- (6) $\mu_A(x) = 0, d \leq x < \infty$,

Fig. 6-1 Trapezoidal Fuzzy Number

where $0 < w \leq 1$, a, b, c , and d are real numbers. We denote this type of generalized fuzzy number as $A = (c, a, b, d; w)_{LR}$. When $w = 1$, we denote this type of generalized fuzzy number as $A = (c, a, b, d)_{LR}$. When $L(x)$ and $R(x)$ are straight line, Then A is a trapezoidal fuzzy number, we denote it as (c, a, b, d) :

$$\begin{cases} \mu_A(x) = 0, & x \leq c \\ \mu_A(x) = L(x) = w \left(\frac{x-c}{a-c} \right)^k, & c < x \leq a \\ \mu_A(x) = w, & a < x \leq b \\ \mu_A(x) = R(x) = w \left(\frac{x-d}{b-d} \right)^k, & b < x \leq d \\ \mu_A(x) = 0, & x > d \end{cases} \quad \text{--- (6-1)}$$

6.2.2 Graded Mean Integration Representation (GMIR)

The fuzzy numbers, with given fuzzy set and corresponding fuzzy membership grade, are not easy to be compare based on the fuzzy form. Hence, it's necessary to defuzzify the fuzzy numbers under comparison. The concept of maximizing set to defuzzify fuzzy numbers has been introduced by Jain early in the 1970s (Heilipem, 1997), there are many other defuzzification methods such as weighted fuzzy mean, mean of maximum etc (Van Leekwijck et al, 1999).

In this research, Graded Mean Integration Representation (Chen, S.H et al 2006) selected to represent fuzzy numbers because of its simplicity and accuracy. In Chen's work (Chen et al 2007), graded mean integration representation method are applied to calculate the optimal economic production quantity in the fuzzy inventory model, which obtained good results and should be also applicable for quality management issues. The GMIR can be described as follow (Chen, and Wang, 2006):

Based on section A, suppose L^{-1} and R^{-1} are inverse functions of functions L and R , respectively, and the graded mean h -level value of generalized fuzzy number $A = (c, a, b, d; w)_{LR}$ is $h[L^{-1}(h) + R^{-1}(h)]/2$ as

Fig. 6-2. Then the graded mean integration representation of generalized fuzzy number based on the integral value of graded mean h -levels is

$$P(A) = \frac{\int_0^w h \left(\frac{L^{-1}(h) + R^{-1}(h)}{2} \right) dh}{\int_0^w h dh}, \quad \text{--- (6-2)}$$

where h is between 0 and w , $0 < w \leq 1$.

Fig. 6-2 The graded mean integration of a generalized fuzzy number

$$A = (c, a, b, d; w)_{LR}.$$

Suppose $A = (c, a, b, d; w)$ is a trapezoidal fuzzy number, based on equation (6-1), to simplify the calculation, let $k=1$: Since,

$$L(x) = w \left(\frac{x-c}{a-c} \right), \quad c < x \leq a, \quad \text{--- (6-3)}$$

and

$$R(x) = w \left(\frac{x-d}{b-d} \right), \quad b < x \leq d, \quad \text{--- (6-4)}$$

then

$$L^{-1}(h) = c + \frac{(a-c)h}{w}, \quad 0 \leq h \leq w, \quad \text{--- (6-5)}$$

$$R^{-1}(h) = d + \frac{(d-b)h}{w}, \quad 0 \leq h \leq w, \quad \text{--- (6-6)}$$

and

$$\frac{L^{-1}(h)+R^{-1}(h)}{2} = \frac{c+d+(a-c-d+b)h/w}{2} \quad \text{--- (6-7)}$$

The graded mean integration representation of A is

$$P(A) = \frac{\int_0^w h \left(\frac{L^{-1}(h)+R^{-1}(h)}{2} \right) dh}{\int_0^w h dh} = \frac{c+2a+2b+d}{6}. \quad \text{--- (6-8)}$$

Fuzzy Dissimilarity

The distance of two real numbers is a new real number, while the distance of two fuzzy numbers should be another fuzzy set. In this paper, the fuzzy dissimilarity is defined as defuzzified fuzzy distance as follow:

Definition: Let $A = (a_1, a_2, a_3, a_4)$, $B = (b_1, b_2, b_3, b_4)$ be two trapezoidal fuzzy numbers, and their Graded mean integration representation are $P(A)$, $P(B)$ respectively.

In this thesis, s_i and c_i are defined as following so as to facilitate fuzzy distance and fuzzy similarity $s_i = (a_i - P(A) + b_i - P(B))/2$, $i=1, 2, 3, 4$;

$$c_i = |P(A) - P(B)| + s_i, \quad i=1, 2, 3, 4;$$

then the fuzzy distance of A,B is $C = (c_1, c_2, c_3, c_4)$

then the fuzzy dissimilarity of A, B--- $d_{\wedge}(A, B)$ is the Graded Mean integration representation of the new fuzzy number --- $P(C)$.

Example:

There are 2 trapezoidal fuzzy numbers X (less or greater than 5)=(3, 4, 6, 7), Y (less or greater than 8)=(6,7, 9, 10)

then

$$s_1=-2, s_2=-1, s_3=1, s_4=2. \text{ Therefore.}$$

$c_1=2, c_2=3, c_3=5, c_4=6$; So the fuzzy distance of A, B is

$C=(2, 3, 5, 6)$, We can say C as greater or less than 4.

$$d_\wedge(X, Y)=3$$

6.3 Fuzzy Clustering

6.3.1 Fuzzy C-means Clustering

Fuzzy c-means (FCM) is a data clustering technique wherein each data point belongs to a cluster to some degree that is specified by a membership grade. This technique was originally introduced by Jim Bezdek (Bezdek, 1981), as an improvement on earlier clustering methods. It provides a method of how to group data points that populate some multidimensional spaces into a specific number of different clusters.

To develop these methods, a family of fuzzy sets $\{A_i, i = 1, 2, \dots, c\}$ needs to be defined as a fuzzy c-partition on a universe of data points, X. Because fuzzy sets allow for degrees of membership, memberships can be assigned to the various data points in each fuzzy cluster. Therefore, a single point can have partial membership in more than one cluster. It will be useful to describe the membership value that the k^{th} data point has in the i^{th} cluster with the following notation:

$$\mu_{ik} = \mu_{A_i}(x_k) \in [0,1] \quad \text{--- (6-9)}$$

With the restriction that the sum of all membership values for a single data point in all of the clusters has to be unity:

$$\sum_{i=1}^c \mu_{ik} = 1 \text{ for all } k = 1, 2, \dots, n \quad \text{--- (6-10)}$$

What's more, there can be no empty cluster and no cluster that contains all the data points. This qualification is shown in the following expression:

$$0 < \sum_{i=1}^n \mu_{ik} < n \quad \text{--- (6-11)}$$

Because each data point can have partial membership in more than one cluster, the restriction is as follow:

$$\mu_{ik} \wedge \mu_{jk} \neq 0$$

$$\bigvee_{i=1}^c \mu_{A_i}(x_k) = 1 \quad \text{for all } k \quad \text{--- (6-12)}$$

$$0 < \sum_{k=1}^n \mu_{A_i}(x_k) < n \quad \text{for all } i$$

A family of fuzzy partition matrices M_{fc} can be defined, for the clustering involving c clusters and n data points,

$$M_{fc} = \{U | \mu_{ik} \in [0,1]; \sum_{i=1}^c \mu_{ik} = 1; 0 < \sum_{k=1}^n \mu_{ik} < n\} \quad \text{--- (6-13)}$$

Where $i = 1, 2, \dots, c$ and $k = 1, 2, \dots, n$.

Any $U \in M_{fc}$ is a fuzzy c -partition, and it follows from the overlapping character of the classes and the infinite number of membership values possible for describing cluster membership that the cardinality of M_{fc} is also infinity, i.e., $\eta M_{fc} = \infty$

An effective algorithm for fuzzy clustering called iterative optimization was proposed by Bezdek (Bezdek, 1981), the steps in this algorithm are as follows: Fix c ($2 \leq c < n$) and select a value for parameter m' . Initialize the partition matrix, $U^{(0)}$. Each step in this algorithm will be labeled r , where $r = 0, 1, 2, \dots$.

Calculate the c centers $\{\vec{v}_i^{(r)}\}$ for each step.

Update the partition matrix for the r th step, $U^{(r)}$ as follows:

$$\mu_{ik}^{(r+1)} = \left[\sum_{j=1}^c \left(\frac{d_{ik}^{(r)}}{d_{jk}^{(r)}} \right)^{2/(m'-1)} \right]^{-1} \quad \text{for } I_k = \emptyset \quad \text{--- (6-14)}$$

or

$$\mu_{ik}^{(r+1)} = 0 \quad \text{for all classes } i \text{ where } i \in I_k \quad \text{--- (6-15)}$$

where

$$I_k = \{i | 2 \leq c < n; d_{ik}^{(r)} = 0\} \quad \text{--- (6-16)}$$

and

$$I_k = \{1, 2, \dots, c\} - I_k \quad \text{--- (6-17)}$$

and

$$\sum_{i \in I_k} \mu_{ik}^{(r+1)} = 1 \quad \text{--- (6-18)}$$

If $\|U^{(r+1)} - U^{(r)}\| \leq \varepsilon_L$, stop; otherwise set $r = r + 1$ and return to step 2.

This thesis adopts the fuzzy hierarchical clustering and proposed the novel fuzzy rules for quality management. This study uses MATLAB fuzzy tool box to help solve such clustering problems.

Fuzzy clustering is a very good methodology for classify overlapping data sets. Naturally, for different conditions, the model and the steps should be adjusted respectively. The proposed fuzzy clustering method can help divide an enormous amount of the data from the database to a specified number of clusters so as to enhance the analysis for each cluster. However, what if the number of clusters cannot be provided?

6.3.2 Hierarchical Clustering

6.3.2.1 Agglomerative Nesting

Agglomerative nesting (AGNES) is the hierarchical clustering method using the agglomerative approach. AGNES can be described as a bottom-up approach. It starts clustering with a small piece of data object representing an individual cluster, followed by merging a series of clusters together. The cluster will increase continuously until the conditions for termination are met.

Variations of the dissimilarity matrix

Corresponding dendrogram drawn:

Fig. 6-3 Example for the step-by-step process flow of hierarchical clustering by single-linkage approach
Basic steps for AGNES can be summarized as follows (Lv et al, 2011):

1. Initially, each cluster contains one object. Two most similar clusters are selected
2. Two “most similar” clusters are chosen at each step
3. The dissimilarity between two clusters can be estimated in various ways: single-linkage, complete-linkage, and average-linkage.
4. The steps 2 and 3 will be repeated until every object is in one cluster.

The above steps are normally represented by dendrogram referring to the dissimilarity matrix as shown in Fig. 6-3.

6.3.2.2 Fuzzy Hierarchical Clustering

The generalized fuzzy hierarchical algorithm for trapezoidal fuzzy number can be summarized as follow:

1. Initially, each cluster contains one fuzzy number;
2. Calculate the fuzzy dissimilarity between each fuzzy number and create the dissimilarity matrix for fuzzy numbers;
3. Two “most similar” clusters are chosen at each step
4. The dissimilarity between two clusters can be estimated in various ways: single-linkage, complete-linkage, and average-linkage;
5. The steps 2 and 3 will be repeated until every object is in one cluster.

There are 5 trapezoidal fuzzy numbers A' (less or greater than 3)=(1, 2, 4, 5), B' (less or greater than 7)=(5, 6, 8, 9), C' (less or greater than 4)=(2, 3, 5, 6), D' (less or greater than 5)=(3, 4, 6, 7), E' (less or greater than 8)=(6,7, 9, 10), now use the proposed fuzzy hierarchical method to do the clustering:

- (1) Get the fuzzy distance matrix as shown in Table. 6-1.

Table. 6-1 Fuzzy Distance Matrix of 5 Trapezoidal Fuzzy Numbers

	A'(1,2,4,5)	B'(5,6,8,9)	C'(2,3,5,6)	D'(3,4,6,7)	E'(6,7,9,10)
A'(1,2,4,5)	0				
B'(5,6,8,9)	(2,3,5,6)	0			
C'(2,3,5,6)	(-1,0,2,3)	(1,2,4,5)	0		
D'(3,4,6,7)	(0,1,3,4)	(0,1,3,4)	(-1,0,2,3)	0	
E'(6,7,9,10)	(3,4,6,7)	(-1,0,2,3)	(2,3,5,6)	(1,2,4,5)	0

(2). Get the fuzzy dissimilarity matrix

Table. 6-2 Fuzzy Dissimilarity Matrix in term of Graded Mean Integration

Representation					
	A'	B'	C'	D'	E'
A'	0				
B'	4	0			
C'	1	3	0		
D'	2	2	1	0	
E'	5	1	4	3	0

(3). Clustering the data based on dissimilarity matrix with dendrogram in Fig. 6-4.

From Fig. 6-4, it can be seen A, C with smallest fuzzy dissimilarity are merged into one cluster first, then B, E, and sequently A, C,D , finally all merge into one cluster the clustering stops.

Fuzzy Dissimilarity Matrix in term of Graded Mean Integration Representation

	A	B	C	D	E
A	0				
B	4	0			
C	1	3	0		
D	2	2	1	0	
E	5	1	4	3	0

Corresponding dendrogram drawn:

dendrogram

1a. Merge of A and C to cluster (AC)

	(AC)	B	D	E
(AC)	0			
B	3	0		
D	1	2	0	
E	4	1	3	0

1b. Merge of B and E to cluster (BE)

	(AC)	(BE)	D
(AC)	0		
(BE)	3	0	
D	1	2	0

2. Merge of (AC) and D to cluster (ACD)

	(ACD)	(BE)
(ACD)	0	
(BE)	2	0

3. Merge of (ACD) and (BE) to cluster (ABCDE)

Fig. 6-4 Clustering of fuzzy numbers based on fuzzy dissimilarity

6.4 Fuzzy Inference System

Fuzzy inference is the process of formulating the mapping from a given input to an output using fuzzy logic. The mapping then provides a basis from which decisions can be made, or patterns discerned. The process of fuzzy inference involves all of the pieces that are described in the previous sections: Membership Functions, Logical Operations, and If-Then Rules.

Fuzzy inference systems have been successfully applied in fields such as automatic control, data classification, decision analysis, expert systems, and computer vision. Because of its multidisciplinary nature, fuzzy inference systems are associated with a number of names, such as fuzzy-rule-based systems, fuzzy expert systems, fuzzy modeling, fuzzy associative memory, fuzzy logic controllers, and simply (and ambiguously) fuzzy systems. There are two types of fuzzy inference systems that is used in application, Mamdani-type (Mamdani et al, 1975) and Sugeno-type (Takagi, 1985), and Mamdani's fuzzy inference method is the most commonly seen fuzzy methodology. Mamdani's method was among the first control systems built using fuzzy set theory. It was proposed in 1975 by Ebrahim Mamdani as an attempt to control a steam engine and boiler combination by synthesizing a set of linguistic control rules obtained from experienced human operators. On the other hand, in general, Sugeno-type systems can be used to model any inference system in which the output membership functions are either linear or constant.

The basic structure of an example of a fuzzy inference system is shown in Fig. 6-5. For the two-input, one-output, three-rule tipping problem, information flows from left to right, from two inputs to a single output.

Fig. 6-5 The basic structure of an example of a fuzzy inference system

The parallel nature of the rules is one of the more important aspects of fuzzy logic systems. Instead of sharp switching between modes based on breakpoints, logic flows smoothly from regions where the system's behavior is dominated by either one rule or another. In a fuzzy inference system, there are five parts of the fuzzy inference process: fuzzification of the input variables, application of the fuzzy operator (AND or OR) in the antecedent, implication from the antecedent to the consequent, aggregation of the consequents across the rules, and defuzzification. These sometimes cryptic and odd names have very specific meanings that are defined in the following steps.

Step 1. Fuzzification of Inputs

The first step is to take the inputs and determine the degree to which they belong to each of the appropriate fuzzy sets via membership functions. In this step, the

input is always a crisp numerical value limited to the universe of discourse of the input variable and the output is a fuzzy degree of membership in the qualifying linguistic set (always the interval between 0 and 1). Fuzzification of the input amounts to either a table lookup or a function evaluation. This example is built on three rules, and each of the rules depends on resolving the inputs into a number of different fuzzy linguistic sets. Before the rules can be evaluated, the inputs must be fuzzified according to each of these linguistic sets. In this manner, each input is fuzzified over all the qualifying membership functions required by the rules.

Step 2. Apply Fuzzy Operator

After the inputs are fuzzified, you know the degree to which each part of the antecedent is satisfied for each rule. If the antecedent of a given rule has more than one part, the fuzzy operator is applied to obtain one number that represents the result of the antecedent for that rule. This number is then applied to the output function. The input to the fuzzy operator is two or more membership values from fuzzified input variables. The output is a single truth value. As is described in Logical Operations section, any number of well-defined methods can fill in for the AND operation or the OR operation.

Step 3. Apply inference engine

Before applying the implication method, you must determine the rule's weight. Every rule has a weight (a number between 0 and 1), which is applied to the number given by the antecedent. Generally, this weight is 1 (as it is for this example) and thus has no effect at all on the implication process. From time to time you may want to weight one rule relative to the others by changing its

weight value to something other than 1. After proper weighting has been assigned to each rule, the implication method is implemented. A consequent is a fuzzy set represented by a membership function, which weights appropriately the linguistic characteristics that are attributed to it. The consequent is reshaped using a function associated with the antecedent (a single number). The input for the implication process is a single number given by the antecedent, and the output is a fuzzy set.

Step 4. Aggregate All Outputs

Because decisions are based on the testing of all of the rules in a fuzzy inference system, the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Aggregation only occurs once for each output variable, just prior to the fifth and final step, defuzzification.

The input of the aggregation process is the list of truncated output functions returned by the implication process for each rule. The output of the aggregation process is one fuzzy set for each output variable. As long as the aggregation method is commutative (which it always should be), then the order in which the rules are executed is unimportant.

In the following diagram, all three rules have been placed together to show how the output of each rule is combined, or aggregated, into a single fuzzy set whose membership function assigns a weighting for every output (tip) value.

Step 5. Defuzzification

The input for the defuzzification process is a fuzzy set (the aggregate output fuzzy set) and the output is a single number. As much as fuzziness helps the rule evaluation during the intermediate steps, the final desired output for each variable is generally a single number. However, the aggregate of a fuzzy set encompasses a range of output values, and so must be defuzzified in order to resolve a single output value from the set. Perhaps the most common defuzzification method is the centroid method, which returns the center of area under the curve.

6.4.1 Fuzzy Rules for Quality Management

Quality control is the process used by the operating forces as an aid to meet the product and process goals. In this period, it is based on the feedback loop and consists of 3 steps:

1. Evaluate actual operating performance;
2. Compare actual performance to goals;
3. Act on the difference between goal and performance (Pyzdek,2003).

Simply to say, these process is controlling the performance to guarantee it to meet the goal, during which fuzzy inference system can be introduced to help make the decision whether the quality is under control or satisfying.

As explained in this subchapter, by following the fuzzy inference system developing steps, a quality related fuzzy inference system can be built up. In general, productivity, yield rate and cost are regarded as the most basic measures to evaluate the manufacturing performance. In industry field, every factory expects high productivity, high yield rate and low cost. Such linguistic words are broadcasted widely as slogan within the whole manufacturing area. How to fulfill

it at most is the everlasting problem, while for such linguistic words fuzzy technique can be a good alternative to deal with it. Here also use Matlab fuzzy toolbox to help start this project:

Identify the variables. This system is to measure the manufacturing performance, so the output is the manufacturing performance or quality. As mentioned above, productivity, yield rate and cost are the basic measures for manufacturing performance; as a result here the three measures are the inputs.

Table. 6-3 Inputs and outputs variables

Input variables	Outputs variables
Productivity	Manufacturing performance (quality)
yield rate	
cost	

Select fuzzy set and membership functions. According to the identified variables, fuzzy sets associated with each variable are defined as follow:

Table. 6-4 Fuzzy sets of input and output variables

Fuzzy sets of input variables			Fuzzy sets of output variables
productivity	yield rate	Cost	Manufacturing performance
Low	Small	Cheap	Unqualified
Medium	Medium	expensive	Regular
high	Large		Good
			Excellent

Membership function was introduced in the foundation part. The common use membership function includes trapezoidal, triangular and Gaussian and so on. A triangular fuzzy number is a specialized form of trapezoidal fuzzy number with $b=c$ and is usually denoted as $A=(a, b, b,d)$.

A simple Gaussian membership function is defined as:

$$\mu(x) = \exp\left(\frac{-(x-m)^2}{2\sigma^2}\right) \quad \text{--- (6-19)}$$

Where:

$\mu(x)$; the degree of membership of x ;

m : mean location;

σ : Width of Gaussian function

In section 6.1, it has been said that to determine membership function can follow many methods, and for a certain problem, there is no unique solution. Based on the previous experience, Gaussian membership function is chosen here. This part can process in Matlab toolbox with assignation for membership function directly.

Develop fuzzy rules. The if-then rules has been introduced, which can be expressed as:

IF (antecedent), THEN(consequent)

The rules determine the calculation operators : conjunctions (AND), disjunctions (OR), negations (NOT). In this project, it can be expressed as:

{Manufacturing performance (M)}={productivity (P)} AND {Yield rate (SA)}
AND {Cost (c)}

In fuzzy set notation this is written as : $M = P \cap SA \cap C$

The membership function of the output is computed as :

$$\mu_M = \mu_P \cap \mu_{SA} \cap \mu_C \text{ or } \mu_M = \min(\mu_P, \mu_{SA}, \mu_C)$$

Since there are 3, 3, 2 subsets of the 3 input variables, there will be a total of $3 \times 3 \times 2 = 18$

Productivity is () and

If Yield rate is () and Then manufacturing performance is ()

Cost is ()

For example:

Productivity is (high) and

If Yield rate is (high) and Then manufacturing performance is (excellent)

Cost is (cheap)

Set the inference process. Many different fuzzy inference processes have been put into implementation. The most important and common-used fuzzy inference process is Mamdani type which has been introduced in last subchapter. The Mamdani fuzzy logic operator is given as :

$$f(\mu_A(x), \mu_B(y)) = \mu_A(x) \wedge \mu_B(y) \quad \text{--- (6-20)}$$

where $\mu_A(x)$ is the membership function of x.

The Mamdani type process follows the rules below:

The “max” operator replace the “or” connective in a rule while the “and” connective in a rule is replaced with the “min” operator.

The maximum of the two membership functions is evaluated for the antecedent part of the fuzzy rules.

The Mamdani type process operator is applied between the resulting antecedent membership function and the consequent membership function.

6.4.2 Fuzzy Clustering based Inference System

In this part, fuzzy clustering will be applied for data identification, and then corresponding fuzzy rules will be defined.

The normal steps are the same as mentioned in 6.4.1:

- 1. Identify the variables.**
- 2. Select fuzzy set and membership functions.**
- 3. Develop fuzzy rules.**
- 4. Set the inference process.**

While in fuzzy clustering based fuzzy inference system, the steps will be updated as following:

1. Identify the variables including input parameters and the output goal;
2. Select fuzzy set and membership functions;
3. Classification of sample data with fuzzy clustering method
4. Define the fuzzy rules based identified cluster centers;
5. Set the fuzzy inference process.

Chapter 7

7 Case Study

In this chapter, the manufacturing processes in a repairing company are studied. Section 7.1 is the description of case company manufacturing processes. In section 7.2, the proposed methodology structure will be built up with HTCPN as the modeling tool, RFID as data captured technology, and Fuzzy QMS as the quality inspection system. Section 7.3 will show how the proposed methodology applied for real practical case. The final section 7.4 is the discussion part.

7.1 Case Description

In this section, a case in Energy Services Pte Ltd (with an alias name as GG) will be discussed and studied. GG company repairs, modifies, and upgrades a wide range of machinery, such as buckets, nozzles and turbines. GG has its own certified total quality management system in which highly skilled personnel ensure that products and service meet or exceed specified quality standards and engineering requirements.

In GG Company, to repair any components, the defects need to be figured out first. Generally, the component defects in GG mainly include crack, wear and corrosion, and they will use welding, machining, coating, furnace and renewalloy to repair different defects as shown in Fig. 7-1:

Fig. 7-1 Repair methods for defects in case companyl

GG company can be regarded as a typical distributed manufacturing company, because once GG receives the repairing order on the headquarter in Singapore, they will distribute the corresponding parts to different locations for specific processes like Batam or Vietnam after initial inspections. Due to confidential request in this project, the geographical locations will be expressed in term of place 1, place 2... and place n. All the case models are referring to the original conditions in GG, but some of their particular technology terms will be paraphrased.

7.1.1 Manufacturing Processes Introduction

In this case, the coated bucket repairing process is selected for study. This process is geographically distributed in five different locations. Due to the complex repairing process and its scattered distributed machinery network which accords with the characteristic of distributed manufacturing network, the repairing flow can be considered as a typical case study for our research.

Fig. 7-2 shows the complicated flowchart for the repairing coated buckets.

There are five different jobs under processing as shown in

Table. 7-1 when studying the case:

Table. 7-1 Current job information

Job ID	Customer	Tech	Shop	Want Date
73449	Tri Energy	S2B	2/10/2010	
73608	Sakra	S1B	10/10/2011	
73817	Um Alnnar	S2B	22/10/2010	
74018	West Coast Pwr	S2B	1/11/2010	
73816	Zhangjiagang B	S1B	30/9/2010

Fig. 7-2 The repairing process for Coated Bucket

7.1.2 Problem Definition

1. Adverse effect on decision making with inaccurate data

In GG company, they have a formal data record way, and every week on the regular meeting they report important data to confirm the real-time situation. However, even for important data, they only record by manual. During the field study, on the data report meeting, there are unavoidable manual mistakes such as inaccurate data and data updated late or inputted wrongly. This probably influences the quality management department's decision making.

2. “One size fits all” repairing process

For manufacturing company, most of them prefer standard uniform manufacturing procedure so as to meet the standard requirement and it helps avoid different types of products repair work. GG, as a manufacturing company, is unlike the product manufacturing company to produce products but are mainly responsible for repair work. Although the same standard is applied for the repaired product, the process can be totally different because of various defects. Under such condition, only adopting one uniform repair procedure is not so feasible because defects of components vary from serious or minor. With all the components experience utterly the same repair process, it leads to high cost which is another problem in GG.

3. Vague information communication

GG, which is a partial automatic manufacturing environment, processes the order by oral or paper-based. Some orders are processed based on experience which includes fuzzy linguistic words. For example, they may say components with few

and minor defects only needs low repair. How to interpret the implicit knowledge to solve the engineering problems is an important study area for both industrial and academic.

7.2 Proposed Methodology Mechanism

The following Fig. 7-3 shows the process flow for this case study:

Fig. 7-3 Proposed Methodology Structure for GG Company

As pointed out in section 7.1, GG Company faced data collection and storage problems, RFID is proposed to be the data captured technology. The proposed HTCPN in chapter 4 will be the processes modeling method in order to in-depth

analyze the manufacturing network in GG company. Since GG company is a repairing manufacturing company, quality management is the key step to guarantee the quality of repaired products. Fuzzy quality management system will help to filter unqualified productions and provide corresponding defects handle solutions. The final results will be verified by the experienced engineers and highly technique experts.

7.3 Case Study with Proposed Method

7.3.1 Modeling with HTCPN

In this section, the real case in GG company will be studied in the proposed method in section 7.2.

With the repairing process flow for coated buckets in Fig. 7-2, the holistic HTCPN model is built up in Fig. 7-4. There are totally five substitution transitions which are linked to five sub-HTCPN models. The five sub-net models represent five production processes distributed in five different locations respectively. The global color set declarations are also given in Table. 7-2.

Fig. 7-4 The overview HTCPN model for coated buckets

Table. 7-2 Declaration of color set

```

Colset INT= int;  Colset DATA= string;

Colset TECH=S1B|S2B

Colset INT×DATA=product INT*DATA

Colset INT×INT=product INT*INT;

Colset TECH×INT=product TECH*INT;

Colset E= with e;

Var n,k:INT    Var p:DATA; Var x: TECH

```

From the overview HTCPN model, it is found that there are five transitions with detailed substitutions. The transition substitutions for GATE 1, GATE 3A, GATE 3B, GATE 3C and GATE 4 with the corresponding used colored sets are given in Fig. 7-5 , Fig. 7-6, Fig. 7-7, Fig. 7-8 and Fig. 7-9 respectively.

Fig. 7-5 The sub-HTCPN in GATE 1

Fig. 7-5 shows the simple process in Gate 1. There are 100 pieces of products with five different types in the input place. The value 0.0 after symbol "@" indicates the time stamp. When the model starts running, tokens will be transferred from one place to another, and at each place one will get a certain time stamp for each token. In this model, to show the capability of the method for dealing with complex product repairing simulation, the incoming tokens are defined as those which enter the system randomly, and then follow the determined processes. The counter place is responsible for counting the incoming tokens and giving a sequence index for each of them. The token in this subnet is in (INT, DATA) pair color type, which is composed of two parts: variable n indicates the sequence index in integer type and variable p denotes the job ID in string type. The time delay function is given by DEL (k). Tokens will go through this first subnet then enter another subnet Gate 3A.

Fig. 7-6 shows the sub-HTCPN in GATE 3A.

In Fig. 7-6, a token comes in this subnet with the color token type (INT, DATA). At the beginning of each repairing process, the operator will conduct the incoming quality check first in order to ascertain the quality in the last step and to determine the subsequent repairing works. Once the token enters into quality check stage, the token color is updated to (INT, DATA, BOOL) type, which consists of three parts: n, p and b. The new color variable b is added as BOOL type. While (b = "true") indicates a satisfactory quality level, (b = "false") means unsatisfaction.

Fig. 7-6 The sub-HTCPN in GATE 3A

When satisfied tokens go into the repairing processes in GATE 3A, the token color returns to be (INT, DATA) form. Token color type will be updated as needed when

Chapter 7. Case Study

Fig. 7-7 The sub-HTCPN in GATE 3B

Similar to GATE 3A subnet, the repairing process is modeled in GATE 3B 3C and GATE 4 as shown in Fig. 7-7, Fig. 7-8, Fig. 7-9. When the simulation is running in iterations, the color type of the tokens will be updated as needed and the time stamp will be shown clearly in each place.

The interpretation of the places and transitions for each sub-HTCPN are given in Table. 7-3 and Table. 7-4 and the firing time and function are given in the model.

Fig. 7-8 The sub-HTCPN in GATE 3C

Fig. 7-9 The sub-HTCPN in GATE 4

Table. 7-3 Interpretation of the places in the HTCPN for coated bucket repairing process

P1	Parts in Workstation 1	P18	Parts in Workstation 16
P2	Parts in Workstation 2	P19	Parts in Workstation 13 A waiting for touch up
P3	Parts in Workstation 4	P20	Parts in Workstation 20
P4	Parts in Workstation 5	P21	Parts in Workstation 21
P5	Parts in Workstation 8	P22	Parts in Workstation 13A waiting for open holes
P6	Parts in Workstation 9	P23	Parts in Workstation 23
P7	Parts in Workstation 10	P24	Parts in Workstation 24
P8	Parts in Workstation 11	P25	Parts in Workstation 13A waiting for polishing
P9	Parts in Workstation 12 waiting for preparing welding	P26	Parts in Workstation 26
P10	Parts in Workstation 12	P27	Parts in Workstation 27

	waiting for welding		
P11	Parts in Workstation 13B waiting for CNC-backcut/tipping	P28	Parts in Workstation 28
P12	Parts in Workstation 13B waiting for CNC-angel wing	P29	Parts in Workstation 25
P13	Parts in Workstation 14	P30	Parts in Workstation 29
P14	Parts in Workstation 13A waiting for blend angel wing	P31	Parts in Workstation 29A
P15	Parts in Workstation 13A waiting for blend hardface	P32	Parts in Workstation 30
P16	Parts in Workstation 13A waiting for blend rail/ tip	P33	Parts in Workstation 31
P17	Parts in Workstation 15	P34	Parts in Workstation 32

Table. 7-4 Interpretation of the transitions in the HTCPN for coated bucket repairing process

T1	Unbox, Identify Parts in workstation 1	T20	Post-weld HT in workstation 15
T2	Parts in Remove wax injection/ Mask Buckets in workstation 2	T21	Post HT FPI in workstation 16
T3	ACR TBC Strip Grit Blast AO36 in workstation 4	T22	Touch Up Weld/Touch Up Blend-S1B in workstation 13A
T4	Strip-Dip 1 in workstation 5	T23	Touch Up Weld/Touch Up Blend-S2B in workstation 13A
T5	DIP 2 Thermal Etch in workstation 5	T24	Etching in workstation 20
T6	Pre-weld HT in workstation 8	T25	Coot Buckets with Closs A GT33 in workstation 21
T7	100% FPI in workstation 9	T26	Open Holes in workstation 13A
T8	Blend Airfoil – S1B in work station 10	T27	Post coot diffusion HT in workstation 23
T9	Blend Airfoil – S2B in workstation 11	T28	Coot Buckets DVC TBC in workstation 24

T10	Prep Weld Tip/ Weld Tip-S1B in workstation 12	T29	Polishing Inspect Cooling Holes in workstation 13A
T11	Prep Shroud/ Rail Weld Shroud/ Rail-S2B in workstation 12	T30	Solution & Age HT in workstation 26
T12	Robot Weld in workstation 12	T31	Blend excess coating in workstation 27
T13	CNC – backcut/tipping in workstation 13B	T32	Post coat fpi in workstation 28
T14	CNC Angel Wing workstation 13B	T33	Tumbling in workstation 25
T15	Edm in workstation 14	T34	Shot Peen in workstation 29
T16	Blend Angel Wing in workstation 13A	T35	Seal Strip in workstation 29A
T17	Blend Hardface in workstation 13A	T36	Water Flow Engraving in workstation 30
T18	Blend Rail-S1B in workstation 13A	T37	Moment Weight Hot Glue in workstation 31
T19	Blend Tip-S2B in workstation 13A	T38	Final Inspection Pack to ship to customer in workstation 32

7.3.2 Quality Inspection with Fuzzy Clustering-based Fuzzy Inference System

Fig. 7-10 Fuzzy QMS Engine embedded in HTCPN

As shown in Fig. 7-10, after modeling the whole system in HTCPN, 5 fuzzy QMS engines are proposed to implement at the beginning of each gate. Due to time limitation, in this case only the initial fuzzy QMS engine is completed.

Initial inspection starts with customers' name, serial number, part number and part serial number once components received. After that the necessary value inspect is carried on for the defect type and value. The next step is pre-disassembly flow test for the defects, and then disassembly. When each individual part of components distributed to different repair lines, the corresponding repair work is beginning. In this case, bucket, as one of the largest quantity repair components, is our target object for discussion. A particular live repairing process for bucket is shown in Fig. 7-11.

In this case, the proposed fuzzy QMS system will be implemented for initial checking of bucket repair, for the purpose to do some improvement.

Fig. 7-11 Welding process

GG now has an applicable and complete quality management system, so that during the repairing process, everything can be under good quality control. As introduced in 6.2, GG adopts standard repairing process for almost all the components to shorten the pretreatment time. Meanwhile, the standard repair for serious defected or minor defected components consumes a high labor and machine cost. In fact, the technical leader in GG also wants to improve the situation, and they began to classify the repair part into two type. As the experienced engineers classify the repair parts by visual , the results is not so ideal.

In the study, RFID-based Quality Management Systems are proposed for the case company so as to facilitate efficient data collection and accurate defect parts clustering.

➤ **Data collection**

Welding repair work is determined by the crack defects, in which the main value for bucket on crack is the number of cracks (N) and the distance to bottom(h). Generally, the fewer number of cracks and the larger distance to bottom, the repair work can be easier. In this case, a random sample of data on bucket crack defects was captured.

N: the number of cracks on a certain bucket

h: the minimum distance between crack and bottom on a certain bucket (unit: cm)

The collected value for N and h is shown in Table. 7-5:

Table. 7-5 Random data sample about bucket

No	N	h	No	N	h
1	7	5.1442	26	2	8.154
2	7	8.8428	27	10	8.7901
3	7	5.8803	28	7	9.8891
4	10	1.5475	29	5	0.0052
5	3	1.9986	30	7	8.6544
6	8	4.0695	31	6	6.1257
7	3	7.4871	32	7	9.8995
8	2	8.2558	33	6	5.2768
9	7	7.8996	34	8	4.7952
10	5	3.1852	35	6	8.0135
11	5	5.3406	36	10	2.2784
12	7	0.8995	37	3	4.9809
13	8	1.1171	38	2	9.0085
14	4	1.3629	39	2	5.7466
15	7	6.7865	40	1	8.4518
16	5	4.9518	41	5	7.3864
17	9	1.8971	42	5	5.8599
18	9	4.9501	43	4	2.4673
19	3	1.4761	44	8	6.6642
20	7	0.5497	45	7	0.8348
21	6	8.5071	46	8	6.2596
22	6	5.6056	47	10	6.6094
23	9	9.2961	48	10	7.2975
24	3	6.9667	49	2	8.9075
25	4	5.8279	50	2	9.823

➤ **Fuzzy clustering based on the collected data sample**

As introduced previously, fuzzy clustering can lead to identify natural groups of data from a large data set. Here we try to use Matlab toolbox help to identify the natural groups of the random data sample from and the results shows in Fig. 7-12:

Fig. 7-12 Clustering result for raw data

As shown in Fig. 7-12, after fuzzy clustering for the raw collected data, we can find 5 centers, they are (6, 6.1256), (2, 8.2558), (8, 1.1170), (9, 9.2960) and (4, 1.3629), which means we can divide all the collected data into 5 clusters. For all the data in the sample, the nearest distance from the point to each certain center decides which cluster the points belong to.

➤ **Fuzzy inference based on clustering results**

In this welding repair work, we attempt to use categorized repair instead of standard repair, the repair types are mainly divided into "low repair", "medium repair" and "high repair".

The welding repair is based on the crack defect features. Referring to the clustering results, we can describe each feature with three linguistic words. For the number of cracks, we can use (few, medium, many), while for the distance from crack to bottom we can use (small, medium, large). According to the five centers (6, 6.1256), (2, 8.2558), (8, 1.1170), (9, 9.2960) and (4, 1.3629), we fuzzify them into linguistic words as (medium, medium), (few, large), (many, small), (many, large), (medium, small), which also represent the attribute of each cluster. Since the repair decision is determined by the clustering results, we can develop the rules on the basis of the clustering five centers:

If N is medium and h is medium, then medium repair;

If N is few and h is large, the low repair;

If N is many and h is small, then large repair;

If N is many and h is large, then medium repair;

If N is medium and h is small, then large repair.

Since this sample data is randomly obtained from all the bucket data record, it can be used as the reference for this batch of the components. The first step to test the data information is to determine which cluster it belongs to according to the distance to the center point. While just because the centers are resulted from the sample data when it used for the whole data, the imprecision exists. Due to this reason we can't define the linguistic attribute crisply according to the value of these samples' centers, we can assign a membership function for each attribute.

Here we choose Gaussian membership function; with the axis value for the function as the center values above.

Input all the information into Matlab fuzzy inference toolbox, we can get the system we need. E.g. The incoming repair parts with $N=5$ and $h=23$, we can realize that the incoming repair parts only need “low repair” based on the results shown in **Error! Reference source not found.** This result was verified by the highly skilled and experienced engineer in GG company.

7.4 Simulation Results

Processing Time

In this part, the operation of the job units in the developed model in CPN Tools is simulated. Due to the complex structure of the repairing process, only five units for each job are presented for analysis. Moreover, within this part, the quality test step will not be taken into consideration. This means that the quality of all the job units is satisfactory after processing. As aforementioned, traditional methods always adopt FIFO dispatching rules, while the priority, in this proposed method, is determined in a way that is more accordant with the real world cases. The following tables show the comparison of the throughputs between two different conditions--- with and without priority setting for job units:

Fig. 7-13 Results of the fuzzy tools

Without priority setting for job units

Table. 7-6 shows the simulation result for five jobs under FIFO dispatching rules and the total processing time of each job can be estimated by simulation and the corresponding technology has been adopted for different types of job. FIFO is a simple scheduling method based on the arrival sequence of the job and it is regarded as non-preemptive discipline. However, if the job with long processing time is dispatched first, it may keep the subsequent jobs with shortest processing time waiting

With priority setting for job units

In the real situation, most manufacturing firms will set different priority for different jobs. shows the priority setting according to the earliest due date and the

customer's priority. As shown in Table. 7-7, the priority for each job is:
 "73816">"73449">"73608">"73817">"74018"

Table. 7-6 Simulation results for five jobs under FIFO dispatching rule

JOB ID	TECHNOLOGY	TOTAL PROCESSING TIME(H)
73449	S2B	1244.5
73608	S1B	1309.5
73817	S2B	884.5
74018	S2B	1274.5
73816	S1B	1311.5
TOTAL		6024.5

Table. 7-7 Priority setting according to the shop want date

Job ID	Customer	Tech	Shop Want Date	Priority
73449	A	S2B	2/10/2010	4
73608	B	S1B	10/10/2011	3
73817	C	S2B	22/10/2010	2
74018	D	S2B	1/11/2010	1
73816	E	S1B	30/9/2010	5

After the priorities have been determined for each job, the system is rebuilt with the new priority dispatching rule. It collects the processing time and for throughput for each job as shown in Table. 7-8.

Table. 7-8 Simulation results for five jobs under priority dispatching rule

JOB ID	Technology	Total Processing Time(H)
73449	S2B	845.5
73608	S1B	1083.5
73817	S2B	634.5
74018	S2B	1260.5
73816	S1B	1524.5
Total		5348.5

From Table. 7-7 and Table. 7-8, the total processing hour tracking has been obtained. To clearly compare the results between the two different dispatching

rules, we put the data in the column chart as shown in Fig. 7-14 Throughput under different Job working

Fig. 7-14 Throughput under different Job working

From Fig. 7-14, it can be clearly seen that jobs "73449", "73608" and "73816" are all taking considerably less time under Priority dispatching rule compared with FIFO. Job "73817" takes almost the same but still a little bit less time under Priority rule than FIFO. Although for job "74018", the FIFO rule takes less time, it doesn't affect the results that the new priority dispatching rule helps reduce the processing time so as to decrease the labor hour costs, because the total processing hour tracking for 5 jobs leads to a 10.6% decrease on processing time.

Waiting Time

In this part, the previous model for processing time is used to analyze the waiting time under two different dispatching rules.

In this study case, there are five subnets ---Gate1, Gate3A, Gate3B, Gate3C and Gate4. Except Gate1, all the gates have a buffer queue at the beginning of each

subnet to carry out the pre-processing. The pre-processing capacity is 4. Since different job has different pre-processing time, there will be a queue in the buffer place. The time for each unit to stay in the queue (i.e., the waiting time) will be recorded as shown in Table. 7-9.

Table. 7-9 Average waiting time under two different dispatching rules

JOB ID	Technology	Average Waiting Time Under FIFO rule	Average Waiting Time Under Priority rule
73449	S2B	90.4	10.6
73608	S1B	82.4	37.2
73817	S2B	48.4	45.6
74018	S2B	43.4	86.4
73816	S1B	61.4	10.2
Total		320	190

(the priority for each job is: "73816">"73449">"73608">"73817">"74018")

To compare the waiting time for each job between two dispatching rules, the graph is shown in terms of column chart with the decreasing priorities from left to right as shown in Fig. 7-15

From Table. 7-9 and Fig. 7-15, it is clearly shown that the waiting time for high priority job units (e.g., job "73816" and job "73449") has been substantially decreased. On the contrary, those job units with lower priority have little advantage on this point. Specifically, job "74018" that has the lowest priority even takes a longer waiting time under priority rule than under FIFO dispatching rule. All in all, the total waiting time has been shortened by adopting the priority dispatching rule.

(the priority for each job is: "73816">"73449">"73608">"73817">"74018")

Fig. 7-15 Average waiting time for each job under different dispatching rules

Cumulative Yield

To simulate a yield condition, the priority dispatching rule is selected. Based on the previous priority model, the real quality testing step will also be taken into consideration. In this distributed manufacturing network, components are repaired in different workshops including GATE 1, GATE 3A, GATE 3B, GATE 3C and GATE 4. Each workshop processes one special repairing work such as crack repairing, crossion repairing etc. The components that finsh one repairing work will go to the next workshop. Before repairing work begins in the buffer for each workshop, quality test will be conducted for the products from the last step and the unqualified components will be removed. The company in this case study has its own quality standard to guarentee that the products meet the quality requirements. To simplify the model, for the processing in each workshop, there is only one major parameter that needs to be taken into consideration. Together with the

confidential factors in the model, the major parameters as parameters 1-4 are set. Fig. 7-16 shows the quality check model at the beginning of each workshop, and the quality check rules are determined based on this practical case because of the confidential factors

Fig. 7-16 Quality Check model in the beginning of each workshop

Based on the specified quality standard as well as the setting rules, the simulation results on cumulative yield is obtained in Table. 7-10. Since each quality check at the beginning of the workshop is to inspect the quality of the product processed in the last repairing step and in GATE 4 after the final inspection, there are only packing and shipment works. It is assumed that there is no loss in this final workshop. From the table, it can be concluded that GATE 3A has a highest quality on repairing coated buckets while GATE 3C with relatively high yield loss needs to be improved in the future. The total yield rate for coated buckets is 85.8% which meets the company's quality standard

Table. 7-10 Simulation cumulative yield for five main workshops

	Yield Loss(unit)	Cumulative Yield(unit)	Step Loss Rate(%)	Total Yield Rate (%)
GATE1	NA	100	4.8	
GATE 3A	8, 2, 6, 4, 2, 5, 5, 4, 8, 4 Ave.= 4.8	95.2	1.0	95.2
GATE 3B	0, 1, 0, 1, 1, 3, 1, 1, 0, 1 Ave.= 0.9	94.3	4.2	94.3
GATE 3C	4, 3, 2, 3, 4, 4, 7, 4, 5, 3 Ave.= 3.9	90.4	5.1	90.4
GATE 4	5, 4, 3, 5, 3, 7, 3, 3, 6, 7 Ave.= 4.6	85.8	NA	85.8

7.5 Discussion

In this part, based on the generic DMS model, a hierarchical CPN protocol is built up. The results of a case study show the feasibility of the proposed modeling method for simulating and analyzing the large complex distributed manufacturing systems.

The new priority dispatching rule aids the system to recognize the urgent job units in order to fulfill customers' requirements. The simulation results show that the use of the priority dispatching rule decreases the waiting time for the job. This in turn leads to the increase of throughput. As the total processing time can be decreased, the labor costs can be decreased accordantly. The contribution of the proposed

method is to simulate the yield of the distributed manufacturing system and production yield. This can help engineer maximize the efficiency of the production system. HTCPN can help track and trace the production unit that has quality problem through the indication of the yield loss. The simulation results show that the system performance records provide engineers with information to plan the production under different constrained scenario. To be sure, this new HTCPN method is priority based so how to determine the priority will become a new problem. In practical case, companies may have their VIP customers who will get high priorities and some urgent order may have high priorities as well. How to quantitate the priority value will be another important issue which is not very detailed developed in this thesis due to progress limitation. Future works include the examination of concurrency of production processes and identification of bottleneck as well as the determination of priority. The configuration of production line and routing sequence can be determined with the help of the simulated results. To conclude, this chapter has introduced the hybrid Petri Net which can achieve the optimal output under different transition states and places for sub-HTCPN. Fuzzy clustering method helps to reduce the number of quality rules initialization in Fuzzy Quality System. The fuzzy inference system can provide effective decision making based on quality requirements.

Chapter 8

8 Conclusion and Future Work

This chapter summarizes the conclusion, contributions of the thesis as well as the limitations of this research. The possible extensions of this research are proposed to provide directions for further research.

8.1 Summary of the Research

Quality management is a crucial issue for nowadays manufacturing environment. Distributed manufacturing network, larger and more complex, whose production value chain is being dissected and rationalized to take advantage of dissimilar core competencies of geographically isolated firms relies on a more effective and efficient quality management system to guarantee the quality of both the products and manufacturing processes.

Modeling methodology is developed to support system analysis. Traditional Petri Net was selected to show the feasibility and advantage when modeling manufacturing processes. To certain extend, traditional Colored Petri net has more advantages for solving the concurrent and synchronization problems. Inspired by the traditional Petri Net, a new Hierarchical Colored Timed Petri Net is proposed and the new definitions are set. Meanwhile, the generalized modeling steps with

HTCPN are also listed. The new priority dispatching rule in HTCPN aids the system to recognize the urgent job units in order to fulfill customers' requirements. The simulation results show that the use of the priority dispatching rule decreases the waiting time for the job. This in turn leads to the increase of throughput. As the total processing time can be decreased, the labor costs can be decreased accordingly. The contribution of this modeling method is to simulate the yield of the distributed manufacturing system and production yield. This can help engineer maximize the efficiency of the production system.

In this research, a new RFID-based colored token assistant HTCPN modeling method is proposed where the colored tokens are evolved to color tagged tokens carrying the product information of real-time status. With this new real-time modeling method, the performance of manufacturing systems such as yield rate and throughput can be realized. In real situation of distributed manufacturing environment, the system may often go through hundreds of tasks and activity and it is difficult to track and trace which activities lead to non-conformance items. The proposed method is able to examine the real-time quality status of the repair components so as to diagnosis the weak point of the repairing system. Under this circumstance, the corresponding signal of abnormality will be sent back from the host application and decision maker can diagnosis the fault and plan for further improvement. RFID-HTCPN allows engineers to estimate the throughput and the cumulative yield so as to have efficient and accurate production planning. The significance of this study is to incorporate system modeling method HTCPN with the latest ubiquitous technology RFID to track and trace the product status and evaluate the manufacturing system performance.

Fuzzy logic is selected to apply for quality management in DMS solving vague and fuzzy information. In practical manufacturing environment, the system analyzer always confront with large amount of raw data. To facilitate the system analysis, data clustering becomes a very important step prior to data analysis. Different clustering methods are studied in this chapter and based on existing clustering methods, a new fuzzy hierarchical clustering method is developed. Fuzzy inference system is selected to handle the quality issues, while normally the fuzzy quality rules' built-up is based on the quality inputs information, and it will lead rules complexity and large amount. In this study, the rules developing processes are simplified by the clusters attributes. Hence a fuzzy clustering based inference system is built up to process the quality problems so as to help make the corresponding decisions.

A case study in a repairing company is studied. An application case of DMS with HTCPN modeling method is initially studied, RFID as data captured technology. A detailed welding repairing process of fuel nozzle is studied and corresponding fuzzy clustering based inference system is built up so as for decision making.

8.2 Contributions of the Thesis

In the thesis, a RFID-based quality management system utilizing Fuzzy Logic Theory has been proposed. The main contributions of the thesis are as follow:

- (1) Present the first literature review about the current development of the RFID technology and Fuzzy Logic Theory applied in Quality Management System
- (2) Introduce the Petri Net method to model a distributed manufacturing system dealing with the concurrency and the synchronization. And based on the traditional Petri Net,

- a new hierarchical timed colored Petri Net (HTCPN) is developed, inside which priority is highlighted as the key parameter.
- (3) Establish the seamless connection between RFID and Colored Petri Net so as to easily fulfill the application of data-capture and system modeling as well as monitoring for the products with time stamps.
 - (4) Develop new fuzzy hierarchical clustering method which can help divide an enormous amount of the data from the database to a specified number of cluster so as to enhance the analysis for each cluster. Moreover, the corresponding fuzzy rules can be simplified based on the clusters.
 - (5) Realize the quality management based on the fuzzy logic tools with imprecise and vague information.
 - (6) Propose the system to worldwide repairing company, and realize the feasibility of applying the system in the industrial environment.\

8.3 Limitations and Future Work

This proposed system aims at solving manufacturing process quality problems for large distributed manufacturing network as accurate as possible, and can somehow automatically fulfill problem handling during the manufacturing processes. Hence, it's unavoidable to lead high cost to implement the whole system for practical manufacturing environment.

This RFID-based quality management system can help solve the practical quality issues systematically. However, the input captured data from RFID to HTCPN modeling system cannot directly synchronized at current stage, which leads to time-consuming for data transfer from RFID system to modeling system. Future works should focus on the synchronization of information capture and HTCPN

modeling so as to make the proposed quality management system more consistent. On the other hand, the quality rules collected from experienced and highly skilled engineers can be further improved based on the professional advices, since the quality management engine will give out decision-makings based on them. Furthermore, this system tried to deal with different jobs with different priorities accordingly, so how to set up and quantify the priority will be another important direction of future work. The testing works for stabilization of the whole system together with its applicability in real practical manufacturing environment are also involved in future work.

9 Publications

1. Lee C K M, Lv Y, Hong Z. Risk modelling and assessment for distributed manufacturing system. International Journal of Production Research, 2013 (ahead-of-print): 1-15.
2. Lv, Y.; Lee, C.; Wu, Z.; Chan, H.; IP, W.; , "Priority based Distributed Manufacturing Process Modeling via Hierarchical Timed Colored Petri Net," Industrial Informatics, IEEE Transactions on , vol.PP, no.99, pp.1, 0 doi: 10.1109/TII.2012.2215043
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5. Lv, Y., C. K. M. Lee, et al."RFID-based Colored Petri net applied for quality monitoring in manufacturing system."The International Journal of Advanced Manufacturing Technology: Volume 60, Numbers 1-4 (2012), 225-236,
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