Chapter 1
Intelligent Manufacturing Systems

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Abstract This chapter provides information on intelligent manufacturing systems including an analysis on change and historical progress of manufacturing systems as well as a brief review of traditional manufacturing systems. Fundamental technologies of artificial intelligence are also reviewed in order to establish the baseline for intelligent manufacturing systems. Following that, basic characteristics of intelligent manufacturing and respective architectures are provided. Some examples of the applications of intelligent manufacturing systems are highlighted.

Keywords Artificial intelligence, manufacturing system, fuzzy logic, genetic algorithm, holonic manufacturing system

1.1 Introduction

Automation is one of the major indicators of the change in manufacturing. Machines behaving themselves not only decrease the cost but also produce the products to be more compliant with the needs and specifications of the customers. Although technologies such as flexible manufacturing systems provide various advantages, automation itself is not enough to provide competitive advantage. In most of the modern manufacturing facilities, machines are capable of making decisions and exhibiting intelligent behaviour. That is to say that the manufacturing-related activities starting from the design to product shipment are being carried out through intelligent manufacturing technologies. As traditionally known, manufacturing systems are the integrated combination of various functions such as design, process planning, production planning, quality assurance, storing and shipment etc. In each of these functions several activities are carried out. Intelligent behaviour is exhibited by the machines in all of these functions. This diverted the attention of the researcher to “unmanned factories” and there have been quite interesting studies and implementations along this line. In this chapter, a general overview

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of the change in manufacturing and intelligent manufacturing systems with some example applications is provided.

Manufacturing organizations have been facing a very challenging environment with dynamic and increasing complexity of activities. There is still a need for more flexible and dynamically changing systems to cope with the market requirements. Intelligent manufacturing systems are capable of providing this flexibility with increasing performance. They can facilitate highly complex manufacturing systems as well as various degrees of functionality of products. As they can handle design changes as quickly as possible, they can easily adapt themselves to the changes in the market and satisfy customer requirements, which are most of the time too versatile. They can also embed new methodologies and technological progress without any problem. Short manufacturing cycle times, shorter supplier times, adaptation to the changing situations in a short time frame, consistent knowledge flow, etc. provide advantages to global economic competition for which most of the manufacturing organizations need to sustain. Intelligent manufacturing systems are proven to be an effective tool for assuring these advantageous.

Since complexity and functionality of the products are increasing and companies need to sustain advantage in heavy competitive markets, it is not possible to make proper and effective decisions without the help and support of computer-based manufacturing systems. Considering interrelated activities in various manufacturing units, the importance of intelligent systems becomes more obvious than ever before. Since they can foresee problems before they occur and provide respective remedies, intelligent manufacturing systems can be extremely useful in supporting the expected level of competitiveness.

Another aspect of intelligent manufacturing is that, the traditional systems cannot be easily expanded in accordance with the technological achievements. They are now facing very challenging tasks such as the following:

- Automation is possible, but the limited decision-making capabilities of the machines make it nearly impossible to develop learning.
- Re-engineering is not easily achievable.
- Distributed management is hardly possible.
- Decentralized management makes it difficult to sustain overall integration.
- Reusability of systems (especially software components) is not possible.
- Synchronization of material and information flows is always problematic.

Historical progress in manufacturing systems shows several breakthroughs. Among them is the distributed manufacturing system. Due to technological developments in both robotics and information technologies, it is possible to design manufacturing systems in different locations but working in an integrated manner. Intelligent manufacturing systems contribute a great deal of effort to sustain this integrity and make it possible to perform manufacturing functionalities in distributed environments. Sustaining intelligent manufacturing systems can therefore assure both individual decision-making as well as cooperation with other related functions. Combining the advantages of intelligent and distributed systems increases the efficiency and effectiveness of manufacturing systems. Brun and Portioli (1999) highlighted the following benefits of this combination:

1. Complex problems can be divided into more simpler ones and sorted out easily.
2. Uncertain data and knowledge can be tolerated and handled to some extent.
3. Adaptation to the environmental changes can be achieved in shorter times with more effective responses.
4. Borders of the manufacturing systems can be expanded according to the new requirements.
5. Problems of distributed manufacturing systems can be eliminated or sorted out.

Setting up a tie among flexibility, modularity and decentralized control in manufacturing systems makes it possible to utilize limited resources as effectively as possible and prevents delays, which increases the customer satisfaction (Cantamessa, 1997). Especially, intelligent agent technology can be utilized to devise distributed and intelligent manufacturing systems. This is reported to prevent most of the problems of traditional manufacturing systems (Shen and Norrie, 1999a, 1999b). After a complete overview of traditional manufacturing systems (Sects.1.2, 1.3, 1.4, 1.5), intelligent manufacturing systems will be discussed in terms of their architecture (Sect.1.6) and respective components, as well as possible benefits to be encountered upon implementation (Sects. 1.7, 1.8). Section 1.9 concludes the chapter with some perspectives for future work.

1.2 Traditional Manufacturing Systems

It is important to review the traditional manufacturing system in order to comprehend the content of intelligent manufacturing systems and to understand the differences between common approaches.

A manufacturing system receives inputs (raw material, knowledge, energy, human resources, etc.) and transforms those into a set of outputs over several processes as shown in Figure 1.1. A set of activities within each process should be managed carefully in order to create a successful manufacturing environment.

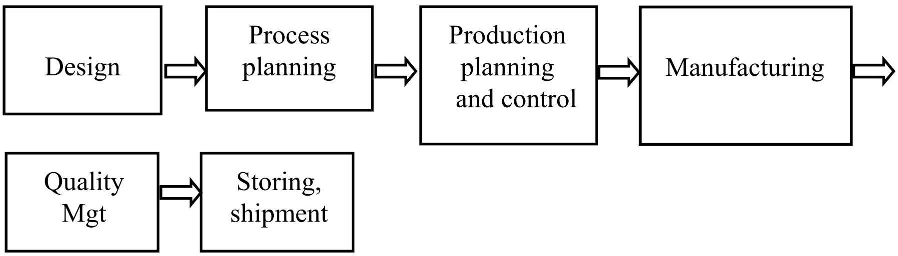

Fig. 1.1 Components of traditional manufacturing systems

Design refers to the process of creating a development plan for a product, structure, system, or component in such a way that specifications (shape, colour, dimensions, material composition, quality characteristics, part combination, etc.) are satisfied with minimum cost and time and that several criteria such as simplification, complying with standards, reliability, maintainability, safety, etc. are assured. A design process may include set of activities, some of which are listed below, depending on the product or service to be produced.

- Pre-production design:
  - defining and analysing the design goals;
  - specifying required solution and defining a set of requirements;
  - creating alternative design solutions;
  - selecting the best (or good enough) solution among the alternatives.
- Design during production:
  - implementing the selected design solution and perform improvements wherever possible;
  - testing the design solution.
- Post-production design:
  - introducing designed solution into manufacturing environment;
  - performing a pilot study and prototype production;
  - creating suggestions for improvements.
- Re-design:
  - improving the current design at any time before, during, or after production.

Process planning covers the selection of processes, equipment and tooling, and the sequencing of operations required by the design process. It is important to define the type of the manufacturing system and related processes. They have severe effects on all of manufacturing related decisions. A typical manufacturing system may be discrete where the system can handle intermediate steps or continuous where no interference is possible until the complete production cycle is implemented. The following manufacturing processes are possible.

- *Fixed production*: products are produced as per the requirement and specification of the customer and delivery schedule as well as the respective costs is fixed prior to the contract.
- *Batch production*: only a limited amount of each type of product is produced on the same set of machines.
- *Mass or flow production*: larger amounts of the same product are manufactured at a time. Since one line can produce only one type of product, this process is also called flow line production.

The main issues, which have an effect on the process plans, can be listed as the following:

1. effect of volume/variety of production;

2. capacity of the plant;
3. lead time;
4. required flexibility and efficiency.

Production planning and control includes decisions on production and inventory quantities. It generally consists of the planning of routing, scheduling, dispatching, inspection, and coordination and control of materials, methods, machines, tools and operating times. The ultimate objective is to define the organization of the supply and movement of materials and labour, and machine utilization and related activities in order to bring about the desired manufacturing results in terms of quality and quantity in expected time and place.

Production planning is usually done at an aggregate level, for both products and resources. Products to be manufactured are combined into aggregate product families that can be planned together so as to reduce planning complexity. Similarly production resources, such as machines or man-hours, are aggregated. While performing this aggregation, specific attention is required to assure that the resulting aggregate plan can be reasonably disaggregated into feasible production schedules.

Production planning is considered differently in various levels of the organizations. At the operational level production scheduling takes place. In order to do so, there is a "need to know" capacity and available resources as well as master production plans indicating the overall production amount for a certain planning period. The master plan should be generated from an aggregate planning which will in turn be based on demand forecasts for particular set of products (see Figure 1.2).

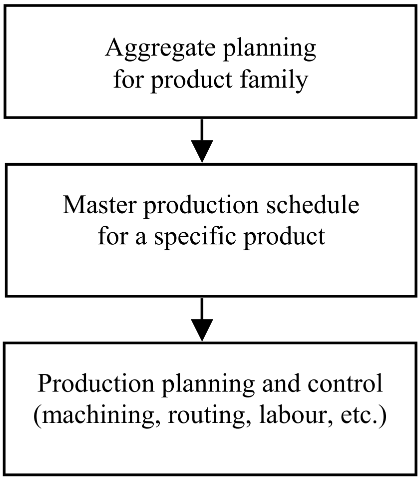

Fig. 1.2 Hierarchy of production planning activities

Manufacturing is transforming the inputs into respective products through several processes as designed in accordance with the process and production plans.

Quality management is a systematic process that translates quality policy into measurable objectives and requirements, and identifies the sequence of steps for realizing them within a specified time period. It includes creating and managing methods, criteria and techniques that ensure an output fits the intended purpose, and meets a stated expectation and is accepted by the programme. It assures that the products produced are within the tolerance limits and shifted to the customer as error free. It also includes making plans and corrections on the process in such a way that faulty products are not produced at all. Quality management mainly includes tree basic set of activities including:

- quality planning;
- quality assurance; and
- quality control.

Each of this set of activities intends to sustain the overall quality of the manufacturing processes as well as products produced by those processes.

Storing and shipment includes keeping the products in stock or transferring them to the customers. Detailed explanations of these, their sub-components and other components of manufacturing systems can be found in Chryssolouris (2006).

1.3 Changes in Manufacturing Systems: a Historical Perspective

Changes in manufacturing systems indicate the historical progress still continues. It is important for the companies and manufacturers to follow the changes in order to keep up with the technological progress and be capable of satisfying the expectations of the customers, which are mainly based upon the contemporary understandings. Due to several factors such as progress in technology, the nature of manufacturing systems has been changing from one form into another such as from manual systems to fully automated and autonomous systems. It is important to note that the changes are occurring more frequently than ever before. It is therefore not easy to follow up the change as it was in the past. It requires not only setting up the new machines but also to know every detail and possible projections towards the future.

It is also important to realize that the progress in manufacturing systems is not only related to the machines and technology but also to several other aspects including:

- manufacturing methods;
- environmental changes;
- managerial changes; and
- customer expectations and requirements.

Technological progress includes the changes in manufacturing technologies and respective infrastructure over the time horizon. Figure 1.3 shows the historical perspective along this line.

Manual
Systems
Semi-manual
---> Systems
Traditional
---> Machines
Automated
---> Machines
Intelligent
---> Machines
Autonomous
---> Machines (holons)

Fig. 1.3 Changes in machining systems

As indicated in Figure 1.3, machining operations are transformed themselves into autonomous systems, which are capable of handling manufacturing related activities taking all aspects of manufacturing, and environmental issues into account. The respective changes are in progress and it is not difficult to foresee fully unmanned factories and virtual machines dominating manufacturing sites.

In parallel to the progress on machining systems, new products and production processes are also being established in the following areas:

- automation and information systems;
- rapid prototyping;
- intelligent and autonomous manufacturing systems;
- intelligent materials;
- nano and biotechnologies;
- innovative and R&D processes and products.

In order to sustain competitive advantage, the progress in these areas should be carefully monitored and manufacturing systems should be redesigned to cope with those.

Changes in manufacturing methods are also apparent in manufacturing systems. Figure 1.4 indicates possible progress along this line.

As seen in Figure 1.4, manufacturing methods are emerging towards fully automated and unmanned manufacturing systems which could be highly flexible, reconfigurable, reusable, and interoperable as well as autonomous and intelligent. Tendency to evolve in this aspect still continues to increase with holonic manufacturing systems.

Hand crafts --> Mass Production --> Group Technology --> JIT Manu-facturing --> Flexible Manufacturing Systems --> Simultaneous Production/ Dynamic Supply chain --> Reconfigurable Manufacturing Systems (holons)

Fig. 1.4 Changes in manufacturing methods

The progress in methodologies of manufacturing systems also triggers new approaches in manufacturing planning systems and their management. Figure 1.5 illustrates the evolution of the respective systems.

Among these, especially lean manufacturing, where limited resources are used as much effectively and efficiently as possible (see Bamber and Dale, 2000) and agile manufacturing, which can be considered as the capability of manufacturing systems to adapt themselves to unexpected or unanticipated situations (see Sanchez and Nagi, 2001) became very popular and attracted significant attention in academic and business environments.

Environmental changes include ecological developments in manufacturing areas. Responsible bodies make every effort to sustain the environmental safety and provide regulations, which binds manufacturing activities as well. Global warming, air pollution, environmental factor analysis, etc. are the main concern of manufacturing facilities. Intelligent systems may be very useful to handle the requirements and to keep the manufacturing locations complying with environmental regulations. This could surely be achieved through implementing environmentally safe manufacturing methodologies and technologies.

Managerial changes are another concern, which has a potential effect on manufacturing organizations. Figure 1.6 illustrates the progress in managerial approaches since the beginning of the industrial revolution. As indicated the managing organizations faced dramatic changes over the last 100 years.

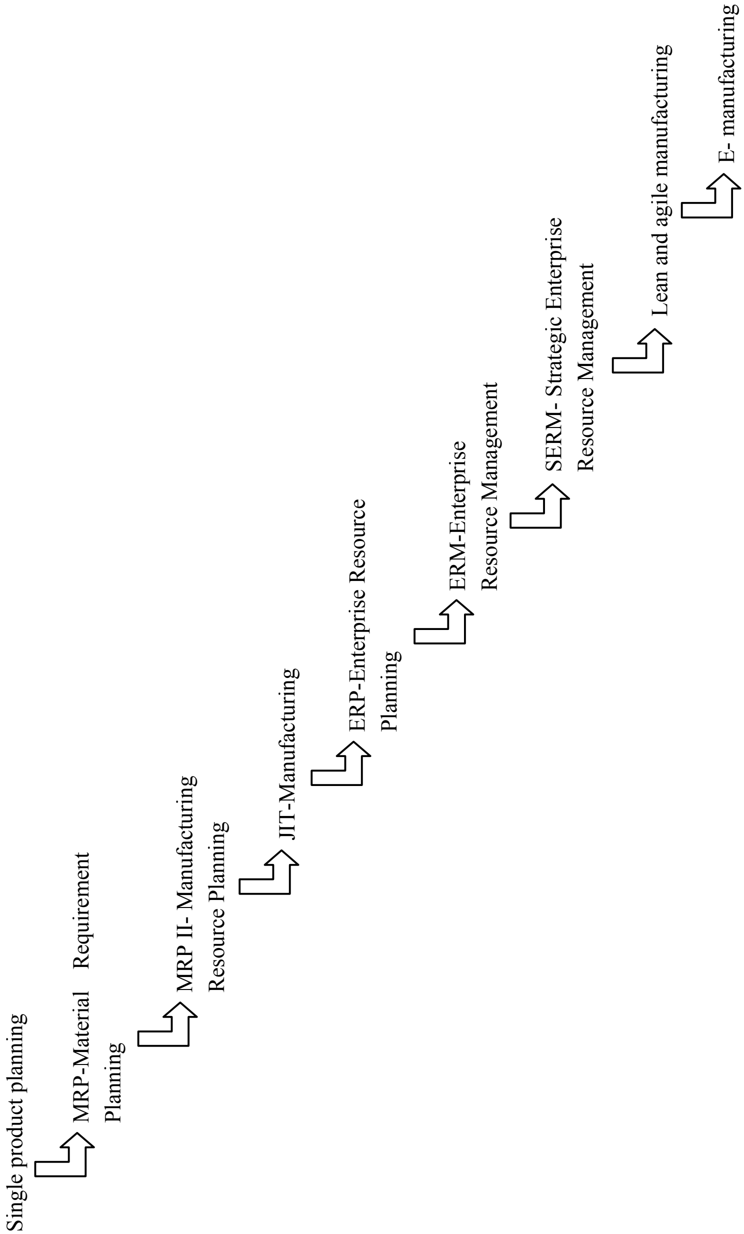

Fig. 1.5 Changes in manufacturing planning and management systems

Workshop management

--> Factory shop management

--> Functional management

--> Process management

--> Performance based management

--> Management by objectives

--> Strategic management

Fig. 1.6 Changes in management approaches

Changes are not only bounded by technology, management or other aspects of manufacturing but also by *customer requirements and expectations*. New manufacturing methods and technologies led to new products with more functionality and more capability to serve the needs of the customer. Some products even diverted the attention of the customers' new expectations, which would in turn drive the new approaches to be implemented in manufacturing systems. This triggered the competition and became one of the basic elements of competitive advantage. Manufacturing organizations cannot only be proud of satisfying their customers anymore. They also need to foresee the future needs of their customers and try to be ready to serve them when the need in question is experienced. It is also recommended to the organization not to wait but to create new expectations to sustain competitive advantage. In the old days, customers used to buy whatever they found in the market. This is not the case anymore. They want to buy products that are capable of satisfying them both today and in the future. Figure 1.7 illustrates the changes in customer expectations.

Customer buys

--> Whatever available in the market

--> Whatever he/she wishes to buy

--> Through selecting among alternative products

--> Products with multifunctional capabilities

--> Products satisfying his future needs

Fig. 1.7 Changes in customer requirements and expectations

Similarly to others, intelligent systems can be considered as one of the useful ways of dealing with customer expectations. Asking customers to design the products they want to purchase and producing exactly the same designs are not fantasy anymore. Integrating virtual reality and manufacturing systems can easily make this happen. This is already being experienced in various companies all over the world.

As explained above, the world is facing a very challenging change and requires manufacturing organizations to cope with those in order to be successful and gain competitive advantage. This necessitates overall integration of manufacturing functions from design up to product shipment. This integration is facilitated through information technology networks with respective information management systems. Figure 1.8 shows the basic components of the integrated manufacturing systems.

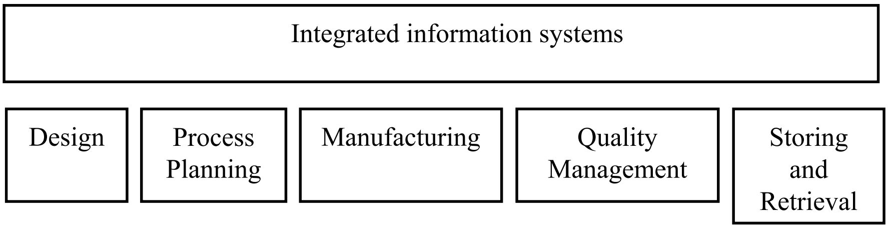

Fig. 1.8 Basic functions of an integrated manufacturing organization (Kusiak, 2000)

Developments in computing systems did not only make information systems capable of integrating manufacturing functions but also created important progress in performing the respective functions as well. Design activities are facilitated through computer-aided design (CAD) systems. Similarly, computer-integrated manufacturing (CIM), computer-aided manufacturing (CAM), computer-aided process planning (CAPP), computer-aided quality control (CAQC) and automated storage and retrieval (AS/R) systems and automated guided vehicles (AGV) are developed with the help of computing systems. Effective utilization of computers in manufacturing created numerous advantages including the increase in productivity and quality as well as flexibility and decrease in lead times, work in process inventories, and costs (Hannam, 1997). Figure 1.9 highlights the progress from very basic traditional manufacturing up to intelligent manufacturing systems.

As can clearly be seen, there are various levels of manufacturing technologies implemented for manufacturing processes. Figure 1.10 illustrates different aspects of manufacturing system with respect to various technologies implemented.

The analysis provided so far brings two important issues into attention. They are the automation and intelligent systems. Both are essential components that drive the changes experienced. They are in fact not only triggering the change but also increasing the speed of the change as well. Changes experienced in every 15–20 years before now can be achieved within 3–5 years. Automation and intelligent systems together develop their performance in manufacturing at a rapidly increasing speed. The following sections of this chapter are devoted to explaining intelligent manufacturing systems and their applications. For the sake of completeness a brief introduction to artificial intelligence (AI) is provided first.

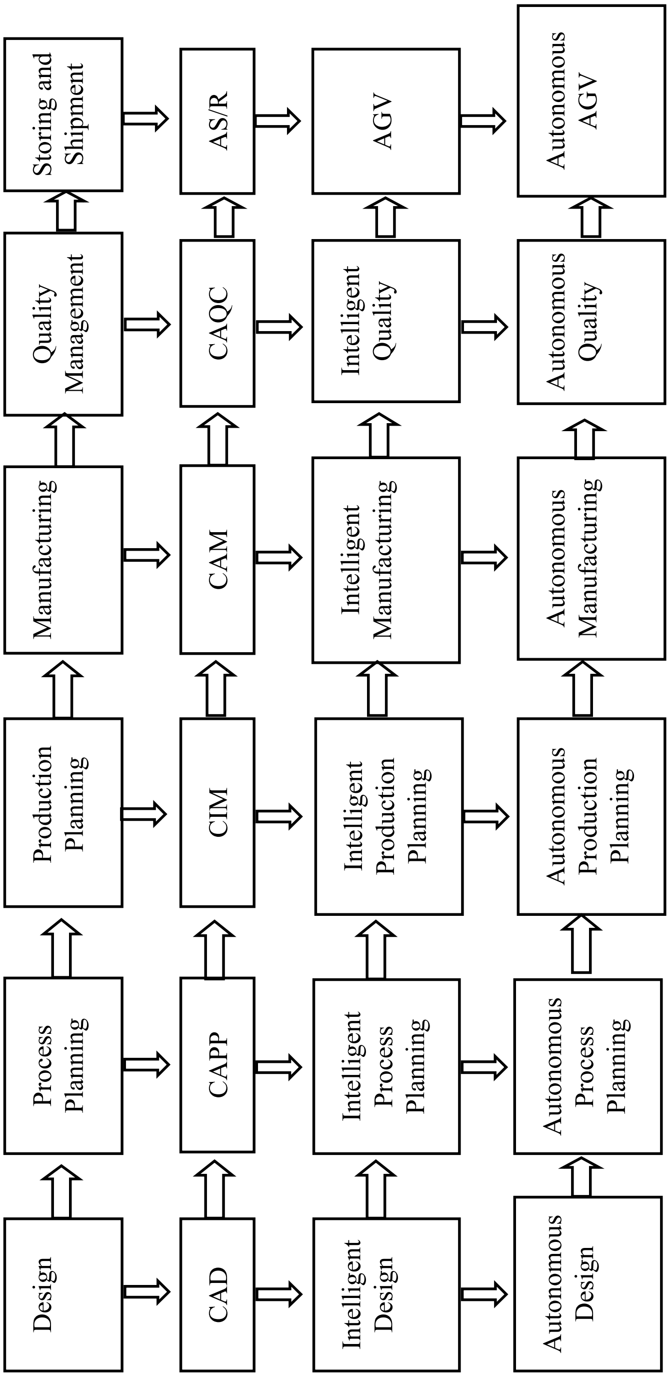

Fig. 1.9 Changes and progresses in manufacturing systems

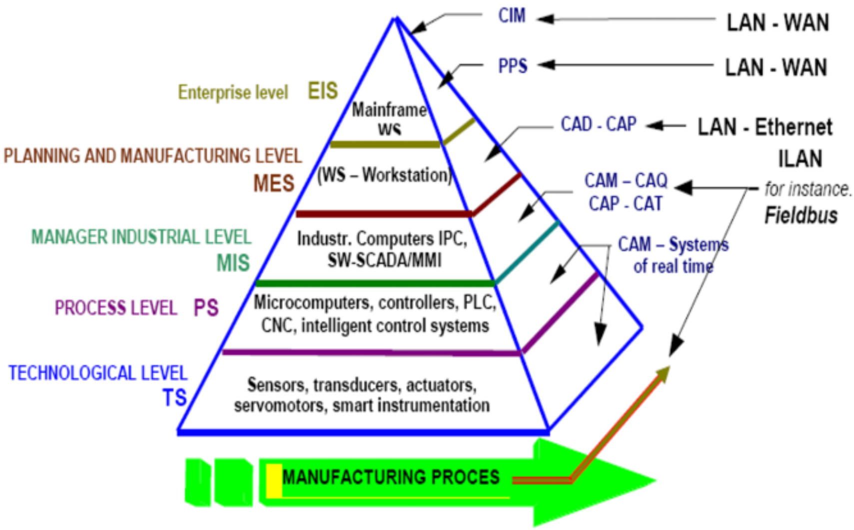

Fig. 1.10 Hierarchical multilevel structure of manufacturing enterprise (Smutny, 2003)

1.4 Artificial Intelligence and Intelligent Manufacturing Systems

Intelligent manufacturing systems are those performing the manufacturing functions as if the human operators are doing the job (Kusiak, 2000). They are equipped with a sufficient level of intelligence to perform such activities. However, it is important to note that none of the intelligent systems is capable of replacing their human counterparts. They are designed to support the operators, not to replace them. They can provide knowledge and respective facts filtered out from the huge amount of stored knowledge and increase the speed of decision-making capability of the operators. They can utilize decision-making capability of computers and make it available to the operators. Since it is necessary to equip the systems with intelligent capabilities in order to accomplish this, it would be wise to briefly review AI technologies at this point.

1.4.1 Technologies of Artificial Intelligence

Although there is no standard definition for AI, it is generally accepted as the branch of computer science dealing with intelligent behaviour and trying to make computers capable of exhibiting it. This necessitates different computing technologies as opposed to traditional approaches. For example, knowledge is processed instead of data. Traditional algorithms are replaced by heuristic algorithms; and instead of numeric representation, symbolic representation is taken as the main focus. Moreover, AI systems may make mistakes as humans would do and can exhibit as much intelligence as their developers. Since they make decisions on the basis of the available knowledge, if the knowledge is not right, the respective decisions would not naturally be erroneous as well. The decisions may obviously be considered to be correct by those who provide the knowledge but wrong by those who disagree with that particular knowledge. Disagreement between experts or knowledge owners is always known to appear in every area. Another aspect, which makes AI different from the other computing systems, is that they can perform actions with uncertain or even inexact and incomplete knowledge.

In order to better understand AI, the concept of "intelligence" should be carefully analysed and understood. Intelligence is to perceive the environment in which the system is operating, to relate events taking place around the system, to make decisions about those events, to perform problem solving and generate the respective actions and control them (Meystel and Albus, 2001). In order to achieve these, the computers or systems should be equipped with the capability of planning, learning, reasoning, monitoring, control, etc. Several methodologies are developed to create these capabilities. Several of them are highly effectively used in manufacturing systems. Note that there are various technologies, which are still in laboratories, and heavy academic research is carried out on them. Some AI techniques, however, show remarkable progress and are utilized in every area affecting human life. Among those that are popularly known are:

1. expert systems;
2. artificial neural networks;
3. genetic algorithms;
4. fuzzy logic; and
5. intelligent agents.

Brief description of each of these is provided below. The readers are recommended to review the respective references for detailed information on each of these.

1.4.1.1 Expert Systems

Expert systems are widely used in most of the industrial applications. Manufacturers may definitely exploit advantages of this technology for their own businesses. Expert systems make it possible to create intelligent software systems capable of solving problems in the same way as human experts would do when facing the same problems. Similarly, to human experts, they utilize their knowledge, experience and talents. This is possible when respective knowledge is stored in a specific format understandable to the computer. The knowledge, which is represented in machine-readable format, is stored in so-called *knowledge bases*. It is utilized by expert systems for a decision-making process similar to that of a human being in order to produce solutions to the problems. Figure 1.11 indicates basic components and architecture of an expert system. Each component is briefly explained below.

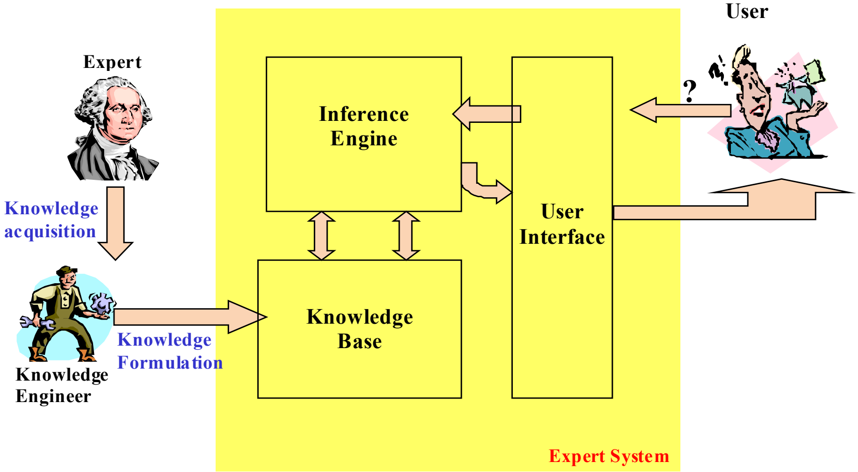

Fig. 1.11 Components of an expert system

- *Knowledge acquisition*: an expert system cannot be called an expert system unless it possesses the knowledge of at least one expert of a specific domain. It is necessary to acquire and elicit respective knowledge from the expert and represent that to the computer in a machine-readable format. This process is called knowledge acquisition.
- *Knowledge base* is the place where acquired knowledge is stored. Traditional ways of knowledge representation may include using IF…THEN… rules, knowledge frames, classes and procedures. The knowledge base is populated with the domain knowledge using these formats. Some other knowledge representation approaches can be used depending on the nature of the knowledge available.
- *Inference engines* search and scan the knowledge base, filter the required knowledge out and reason about those in order to be able to solve the problem posed by the user through the user interface. There are two general approaches for inferencing.
  - *Forward chaining*: this starts with the facts of the domain and tries to achieve a solution through available knowledge in the knowledge base.
  - *Backward chaining*: this starts with a solution and tries to find out respective facts supporting that particular solution.

- *User interface* handles the communication between the expert system and the users. It may explain how and why certain conclusions are reached.

As indicated in Figure 1.11, the expert is one of the key elements of an expert system. There is a need for at least one expert to develop the expert system in his/her area of expertise. Knowledge engineers elicit knowledge from the expert and formulate it in such a way that the system can understand. Once the user is seeking for a solution to his/her problem, the inference engine scans the knowledge base and identifies the solution on the basis of the knowledge articulated by the expert and makes it available in the knowledge base. The content of the knowledge base may increase in time and the system may be able to solve more complex problems. However, it is important to identify and populate the knowledge base with very basic knowledge at the first place in order to start solving the problems. It is also important to note that the expert systems are capable of solving the problems, which are vague even to the manufacturing knowledge. They are proven to be useful especially in:

- planning;
- control;
- maintenance;
- repair;
- diagnosis;
- monitoring; and
- inspection, etc.

Detail descriptions of expert systems can be found in Turban *et al.* (2008).

1.4.1.2 Artificial Neural Networks

Artificial neural networks are mainly designed to perform learning. They can generate new knowledge through learning the manufacturing events using the examples. They are formed by hierarchically connected process elements capable of information processing. Each connection between the processing elements has a weight value indicating the effect of one processing element on the others. These weight values, once the network is trained, are believed to indicate the knowledge of the network. The main purpose of the learning is therefore to find out the right weight values of the connections. Since the weight values are distributed to the overall network, the neural networks are assumed to have a distributed memory. Figure 1.12 shows an example of an artificial neural network.

Artificial neural networks, which created several new approaches to computing science including non-algorithmic, adaptive and parallel computing, proved that the computers could learn. They have various characteristics some of which may include the following:

- They can only work with numeric information.

- They can learn using examples.
- They have the capability to process incomplete information.
- They can perform graceful degradation and they are fault tolerant.
- They have distributed memory.
- They automatically generate information for unseen examples.
- They are mainly used for perceptual information processing.
- They perform learning well on pattern recognition and classification.
- They have a self-organizing capability.

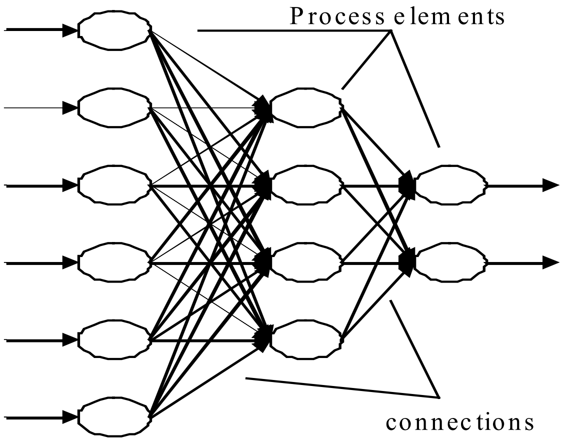

Fig. 1.12 An example of a neural network

Successful applications of artificial neural networks clearly indicate that they can be very effective tools for solving problems which are very noisy, multi-dimensional, non-linear, complex, uncertain, incomplete, or prone to errors provided that sensory information (examples) is available. Several examples of successful manufacturing applications can be realized especially in the following areas:

- probabilistic function estimation;
- pattern recognition and classification;
- pattern matching;
- time series analysis;
- signal filtering;
- data fusion;
- non-linear signal processing;
- non-linear system modelling;
- optimization;
- intelligent and non-linear control;
- data mining;

- optical character recognition;
- optimum path planning for robotics;
- fingerprint recognition;
- robot motions;
- life cycle estimation of mechanical parts;
- sonar signal classification;
- production planning and scheduling.

Detail information on neural networks and how to use them can be found in Bosque (2002). Moreover, applications in various areas are also edited by Rabunal and Dorado (2006).

1.4.1.3 Genetic Algorithms

Genetic algorithms are very popular in solving especially very complex optimization problems. A set of some initial solutions to a specific manufacturing problem is randomly selected. These initial solutions are paired as parents and new solutions are produced (children) out of them. In each production like this, the solutions are aimed to be improved. Once new solutions are generated, some of them are carried out to the next generation in order to produce new solutions. This process continues until no better solution is achieved. The better solutions are sought through genetic operators and a fitness function. Basic elements of a genetic algorithm, which are given in Figure 1.13, are explained below.

Chromosomes and genes indicate possible solutions. There could be *N* solutions for a problem (*N* chromosomes) in the solution space from which the best solution is sought. Each chromosome is formed by *genes*, which are the basic characteristics of the intended solution.

Initial population is the set of randomly selected chromosomes (solution pool). Depending on the type of the problem, there could be certain number of initial solutions required.

Crossover is a genetic operator making it possible to create new solutions using two existing ones. Crossover rate defines how many solutions to be parented.

Similarly, *mutation* is another operator, which is used to direct the searching process to different paths. This prevents going back to the solutions which were encountered before. Mutation rate defines how many chromosomes to be mutated.

Fitness function indicates how good the solution is for the given problem. There is a need to identify this function for every problem. This could be, for example, the total completion time in job-shop scheduling. In this case, each time new solutions are generated, completion time is calculated and new solutions are generated until the total completion time can no more be reduced.

Reproduction is to keep the solution space size fixed for computational efficiency. Whenever new solutions are generated the solution space is updated and some of the newly generated solutions go into the solution pool and some old ones are removed. Generally, the famous Russian-roulette methodology is implemented to reproduce the solution pool. However, there is no limitation in this respect and the designer may develop his own strategy and method for reproduction. Detailed descriptions of genetic algorithms can be found in Revees and Rowe (2004).

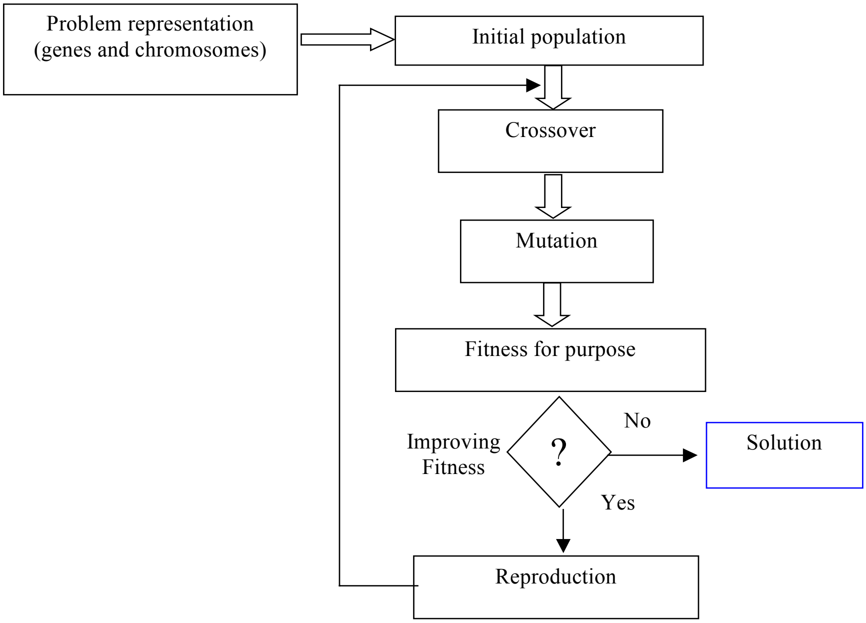

Fig. 1.13 Basic elements and procedure of genetic algorithms

1.4.1.4 Fuzzy Logic

Fuzzy logic is particularly developed to handle uncertain knowledge. Most of the decisions experts make have some sort of uncertainty in them. Experts tend to use vague phrases. Instead of saying for example, "*turn the thermostat off when the temperature of the machine is 25 degrees*", they prefer to direct using the phrases like "*turn the system off when the temperature is high*". The term high, which is called a *fuzzy variable*, may be regarded differently by different people. Some may consider 25 degrees high whereas others do not. Since fuzzy logic is dealing with linguistic expressions like this, it is also referred as *"computing with words"*. Another good thing with fuzzy logic is that it may take a continuum approach and produce solutions for all alternatives and values. For example, suppose that the temperature is to be turned off when the temperature is 25 degrees. What happens if the temperature is 24.99 degrees? Using the crisp logic the system will never turn it off. However, fuzzy logic starts turning the thermostat nearly off in this case as it takes temperature values from $-\infty$ to $+\infty$ into account. This is decided based on a value called *membership value*. This value indicates the possibility and degree of a particular instant to be the member of the fuzzy set. This value is between 1 and 0 where 1 indicates total membership and 0 indicates no membership at all. The designer for each particular fuzzy variable defines this function. Note that membership value does not indicate the *probability* but rather it is the *possibility*. Figure 1.14 provides basic components of fuzzy logic.

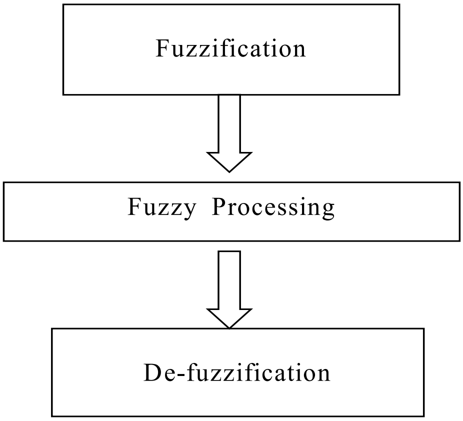

Fig. 1.14 Components of fuzzy logic

An example of a membership function for fuzzy variable “normal” is given in Figure 1.15. As can be seen, every temperature value between $[-\infty, \infty]$ has a membership value.

Fuzzification is to generate fuzzy propositions and identify linguistic variables and their membership functions. *Fuzzy processing* is to generate fuzzy rules and implement them in order to generate a solution space for the given problem. Generally membership functions are laid on top of each other and solution space is defined according to *AND* and *OR* operators of the rules as in traditional logic. Figure 1.16 shows an example of a solution space.

Defuzzification is the process of finding a crisp value for the solution. Fuzzy logic produces a solution space but this may not be applicable in most cases and a crisp value may be needed. There are various methods for defuzzification. Generally the value corresponding to the highest membership value is taken as the solution to the problem. This may be difficult for some solution spaces as there may be more than one value having the same membership value. In this case, the average of those, or a value corresponding to the geometric average of the solution space is taken as the net solution to the problem. Detailed information on fuzzy logic and its applications can be found in Cox (1999).

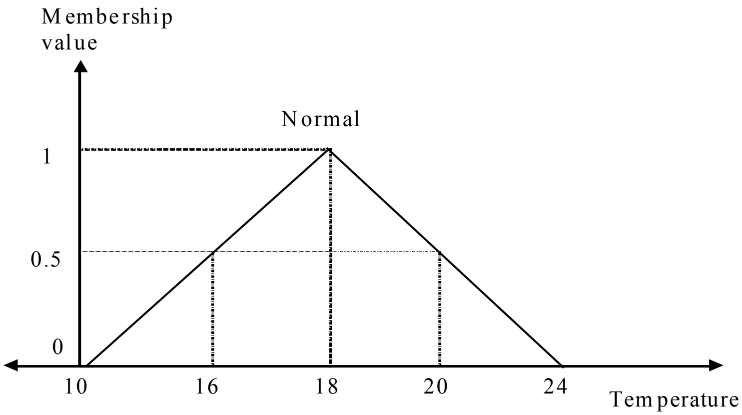

Fig. 1.15 An example of a membership function

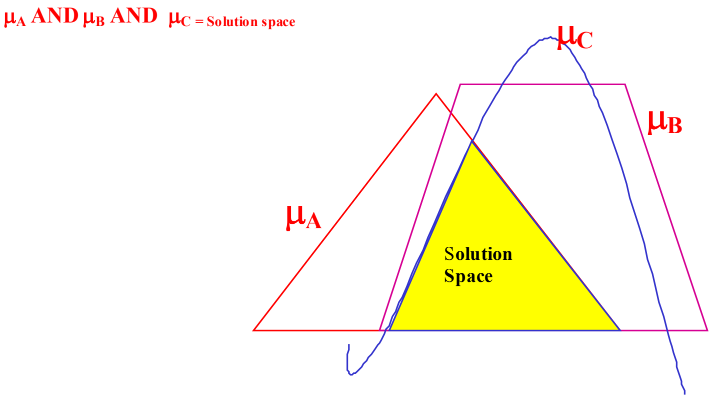

Fig. 1.16 An example of a solution space

1.4.1.5 Intelligent Agents

Intelligent agents are independent and autonomous systems in performing their intended functions. They can be both hardware and software systems and they may incorporate more than one AI technology. They can learn and work concurrently. The general architecture of an agent is given in Figure 1.17. As seen in Figure 1.17, there are three main components such as perception, cognition and action.

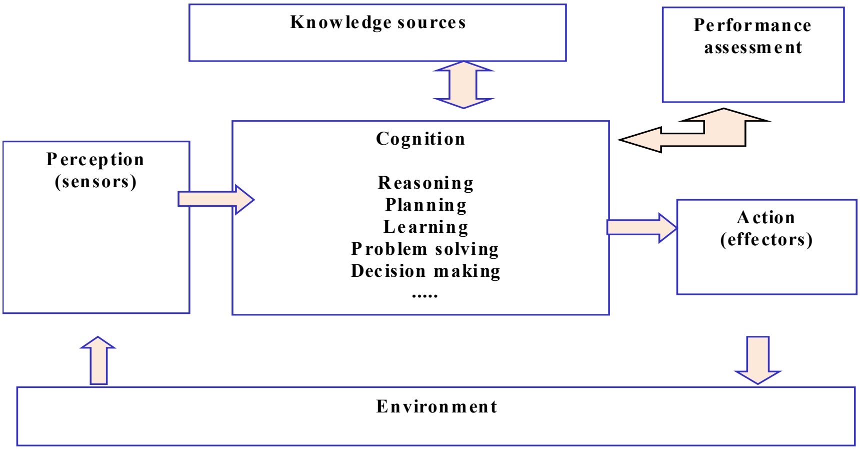

Fig. 1.17 General architecture of an intelligent agent

Perception is to receive the inputs from the environment through sensors and convey them to the cognition module to be processed. This process may include filtering, and prioritization according to the order of importance. *Cognition* is to process the information perceived and making decision accordingly. This process may require various methods of intelligence systems such as learning to be implemented. The cognition mechanism of an agent may also deal with unexpected situations and adapt itself to new situations as quickly as possible. Therefore a highly dynamic and flexible architecture needs to be established. *Action* is to perform the command received from the cognition using the respective effectors. This could for example be to perform walking for a robot or stopping when an immediate barrier in front is encountered. Once the agent acts, this may change the environmental signals and new information is generated. This can immediately be perceived by perception and respective action is generated for the effectors to operate.

There have been various types of agents in the literature and details are provided by Russel and Norvig (2002). Similarly, Wooldridge (2009) has provided information on multi-agent systems.

1.4.2 Intelligent Manufacturing Systems

Intelligent manufacturing systems are those utilizing AI techniques for manufacturing activities. They can exhibit all characteristics of intelligent systems such as learning, reasoning, decision-making, etc. They can utilize several AI technologies in order to perform their intended functions. Intelligent manufacturing systems can be designed in such a way that they can operate when it is difficult to measure the outcomes, where frequent changes in operations are possible and when there are no available prior decisions about the system behaviour (Rzevski, 1997).

Basic characteristics of intelligent manufacturing include the following:

- They minimize human involvement in manufacturing activities.
- They arrange material and production compositions automatically wherever possible.
- They monitor and control production processes and manufacturing operations.
- They recommend and take immediate actions to prevent faulty production.
- They perform maintenance activities.
- They make sure that the processes are working properly and monitor their performance.
- They diagnose machines and sustain manufacturing integrity.

There are numerous examples of intelligent manufacturing systems developed and in use today. Although various approaches have been developed, the fundamental baseline remains the same. Kusiak (1990) provides a general overview of these systems and highlights basic properties.

Applications indicate that intelligent systems and manufacturing systems can be integrated in various ways. Sometimes existing systems are improved with the help of AI technologies. Sometimes intelligent and totally new systems are designed. In order to achieve this integration it is important to note that there is also a need for modelling and algorithm management systems as they are the essential baseline in developing components of the manufacturing systems. Generally three approaches as explained below can be realized in creating intelligent manufacturing systems.

1.4.2.1 Artificial-intelligence-supported Manufacturing Systems

In this approach one or more components of traditional manufacturing systems are turned into or enriched with intelligent systems. As shown in Figure 1.18, all other components of the system work in the traditional manner and AI support is provided only in one or more of those.

An example to this approach can be intelligent scheduling systems where job schedules are created using AI techniques and all other manufacturing activities are carried out in traditional ways. There are many scheduling algorithms. Problem solvers define their problem and select one of the most convenient algorithms for their own plant. When the number of jobs and machines increases, the selection of the problem becomes very complex. The decision will require a huge amount of knowledge to be taken into account. Sometimes this knowledge may not be available in the time needed. Since the knowledge base of an intelligent system is populated beforehand, the computer may take all aspects of the manufacturing systems into account and create implementable schedules for certain manufacturing systems.

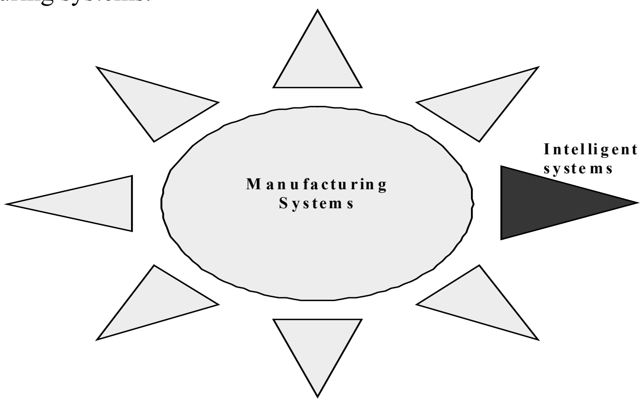

Fig. 1.18 An AI-supported manufacturing system

1.4.2.2 Artificial-intelligence-integrated Manufacturing Systems

In this approach, AI and manufacturing systems are independent of each other but they can provide support to each other (see Figure 1.19). In manufacturing systems, some activities such as creating design for a particular product may be outsourced. Creating rapid prototyping and modelling for manufacturing systems is another example. Intelligent systems and manufacturing systems may not be operating in the same location but need to be integrated for the sake of creating products in accordance with the objectives of the manufacturing systems.

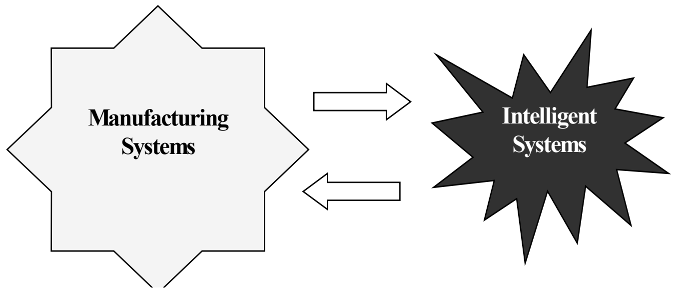

Fig. 1.19 AI-integrated manufacturing systems

1.4.2.3 Totally Intelligent Manufacturing Systems

In this approach, AI is in the heart of manufacturing systems. It keeps the overall control of manufacturing functions and interacts with the operators wherever possible or needed. The basic characteristic of these systems is the ability to explain their own decisions. Figure 1.20 shows the components of these kinds of systems.

Unmanned manufacturing systems are good examples of this approach. In this case, manufacturing activities are totally handled by the robots and they can communicate, cooperate and coordinate their actions together. Manufacturing activities such as path planning for the robots, process plans to work, production schedules to be followed by the machines, etc. are all carried out with the help of intelligent systems. These systems are also capable of correcting themselves in case of a failure or fault. They can utilize all kinds of knowledge, models and data available in the knowledge base, model base and databases respectively.

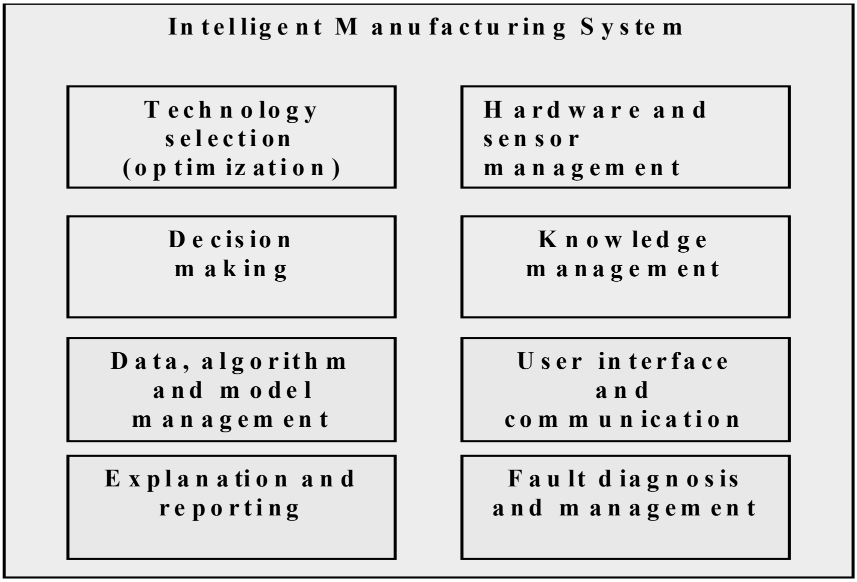

Fig. 1.20 Components of total intelligent manufacturing systems

1.5 Properties of Intelligent Manufacturing Systems

Intelligent manufacturing systems should have the following characteristics (see Rzevski, 1997).

- *Adaptation* is one of the most important features of intelligent manufacturing systems. They should be able to adapt themselves to the environment in which they are operating without compromising the manufacturing objectives.
- *Automated maintenance* is also an important aspect of intelligent manufacturing systems. Systems should be able to identify the failures and take corrective

actions without human intervention (wherever possible). They could be reconfigurable in this sense.

- *Communication* cannot be disregarded in intelligent manufacturing systems, as it is the only way to cooperate among the manufacturing components. The system may produce reports, direct orders to some components and cooperate together with another system to perform certain activities, etc.
- *Autonomy* is the level of independency of intelligent manufacturing systems without which performance of intelligent behaviour could be limited.
- *Learning* is the capability of the systems to improve their knowledge on the basis of the knowledge available in the knowledge bases. This capability seems to be one of the indispensable features of intelligent manufacturing systems.
- *Self-progress* indicates the capability of intelligent manufacturing systems to evolve in time. This can be achieved either by learning or updating the knowledge in the knowledge bases. This can also be triggered by experimenting with the existing knowledge and evaluating the respective performance.
- *Estimation* capability makes intelligent manufacturing systems able to foresee the changes and their possible effects on manufacturing systems.
- *Goal seeking* is the capability of the systems to create goals, refine or update the existing ones in accordance with the progress and mission of the system. In order to achieve a predefined goal, it may be decomposed into smaller ones, which could be managed more easily.
- *Creativity* is also an emerging characteristic of intelligent manufacturing systems. These systems are expected to create new working principles, new theories, forecasts, etc. This capability necessitates interaction with human and other manufacturing components as well as a high degree of autonomy.
- *Reproduction* is to produce or to reuse system component whenever needed. Intelligent manufacturing systems may provide facilities for the same system to be utilized in different places at the same time.

Similarly, Madejski (2008) provided the following properties to become the dominant features of intelligent agents, which establish the baseline for intelligent manufacturing environments.

- *Autonomy*: operating without the direct intervention of humans or others, and having control over their actions and internal state.
- *Social ability*: interacting with other agents (and possibly humans) through an agent-communication language.
- *Reactivity*: perceiving the environment (which may be the physical world, a user via a graphical user interface, a collection of other agents, the internet, or perhaps all of these combined), and responding in a timely fashion to changes that occur in it.
- *Pro-activeness*: exhibiting a goal-directed behaviour by taking the initiative.

1.6 Architecture of Intelligent Manufacturing Systems

As in all kinds of intelligent systems, intelligent manufacturing systems are to be equipped with a self-decision-making capability. In addition to traditional manufacturing functions, they possess knowledge bases and respective software to utilize the existing knowledge. There have been various approaches to designing intelligent manufacturing systems. Among them is the reference model for intelligent manufacturing systems (REMIMS) developed by Tekez (2007) under the supervision of the author of this chapter. As reported in Oztemel and Tekez (2009a), REMIMS is designed to provide a general framework for dynamic integration and standard knowledge exchange infrastructure in distributed environments. It requires a manufacturing enterprise to be organized into management units (modules) each of which consist of a group of intelligent agents. Each of these agents possesses a particular combination of knowledge, skills, and abilities. Taking these into account, REMIMS is reviewed here in three different aspects, namely:

- management of processes and workload (*system view*);
- knowledge and information flow (*knowledge view*); and
- logical inferences and intelligent capabilities (*reasoning view*).

Figure 1.21 shows the relationship of these different views.

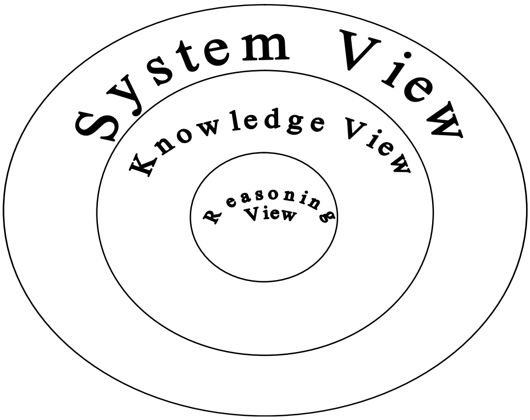

Fig. 1.21 Different aspects of REMIMS (Oztemel and Tekez, 2009a)

System view includes the description of the overall manufacturing systems and concentrates on system functionalities in order to set up smooth interrelationships. As indicated in Table 1.1, REMIMS includes mainly the following manufacturing systems: marketing, design, planning, supply chain management, manufacturing, quality, material management, research and development, and performance monitoring. Also note that REMIMS has a hierarchically nested architecture with four layers each of which is coded as indicated. Although four levels are taken into consideration, the structure of REMIMS allows for the systems to be extended both vertically and horizontally. In this regard, REMIMS offers the flexibility of adding new manufacturing agents, which will support improvement and customization efforts to new requirements if any.

Table 1.1 Main functional components of REMIMS (Oztemel and Tekez, 2009a)

Manufacturing functions			
First level	**Second level**	**Third level**	**Fourth level**
01. Marketing	01.01. Forecasting		
	01.02. Customer relation management	01.02.01. Sales management	
		01.02.02. Customer information system	
02. Design	02.01. Existing product improvement	02.01.01. Prototype production	02.01.01.01. Functional characteristics
			02.01.01.02. Geometric modeling
	02.02. New product design	02.02.01. Generation of bill of material	
03. Planning	03.01. Production planning	03.01.01. Master plan generation	03.01.01.01. Material requirement planning
			03.01.01.02. Capacity planning
		03.01.02. Production plan generation	03.01.02.01. Scheduling
	03.02. Process planning	03.02.01. Process routing	
		03.02.02. Equipment selection	
		03.02.03. Facility layout	
04. Supply chain management	04.01. Purchasing	04.01.01. Supply	
		04.01.02. Material transportation	
	04.02. Supplier evaluation		

Table 1.1 (continued)

Manufacturing functions			
First level	**Second level**	**Third level**	**Fourth level**
05. Manufacturing	05.01. Work flow management	05.01.01. Shop floor management 05.01.02. Assembly management 05.01.03. Maintenance management	
	05.02. Monitoring and control		
06. Quality	06.01. Quality management systems	06.01.01. Incoming inspection 06.01.02. Manufacturing inspection 06.01.03. Assembly inspection 06.01.04. Product audit 06.01.05. After sales	
	06.02. Quality assurance		
07. Material management	07.01. Storage management	07.01.01. Raw material management 07.01.02 Product management	
	07.02. Order management		
08. Research and development			***Horizontal extension (additions)*** →
09. Performance monitoring		***Vertical extension (additions)*** ↓	

In addition to hierarchically distributed agents, REMIMS is enriched with a knowledge form base, external resource base and database management systems. Within the proposed framework, the agents are supposed to communicate their knowledge and even negotiate with each other through a so-called *knowledge network* (*KN*) over a distributed manufacturing environment (see Figure 1.22). It should be noted that the proposed reference model presents an ideal manufacturing environment from which the users or developers can establish their manufacturing systems through a tailoring process based on their needs and particular manufacturing requirements.

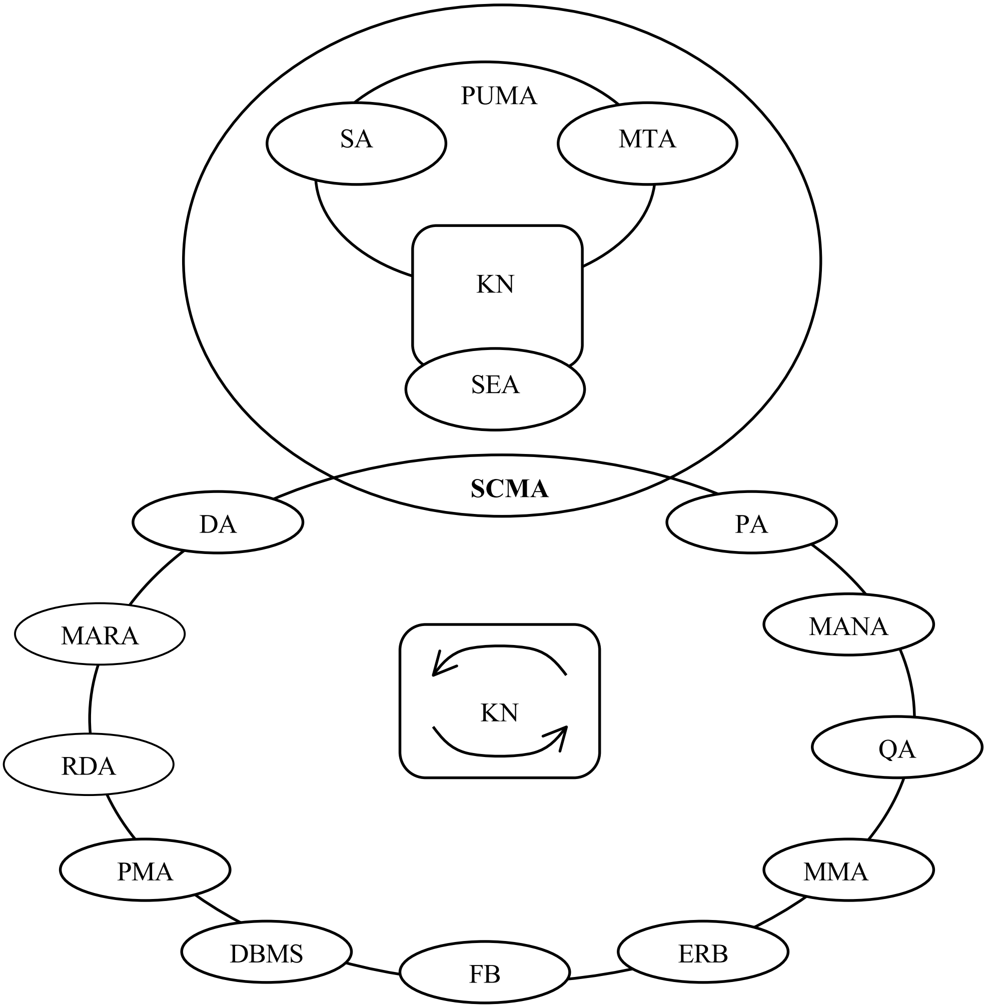

Fig. 1.22 Nested architecture of REMIMS (Oztemel and Tekez, 2009a). *KN: knowledge network, DA: design agent, MARA: marketing agent, RDA: research and development agent, PMA: performance monitoring agent, DBMS: database management system, FB: form base, ERB: external resource base, MMA: material management agent, MANA: manufacturing agent, QA: quality agent, PA: planning agent, SCMA: supply chain management agent, SA: supply agent, MTA: material transportation agent, SEA: supplier evaluation agent, PUMA: purchasing agent*

Knowledge view points out the capabilities of knowledge and information flow among the manufacturing agents. Agents who are equipped with certain manufacturing knowledge should be able to perform their actions as effectively as possible and communicate the results to other agents who may need them. REMIMS provides a certain standard for knowledge exchange among the agents. This is done through a KN as indicated in Figure 1.22. It should be noted that an agent might produce certain knowledge, which would be a strict requirement by some other agents. Similarly it may need some inputs, which could be produced by other agents within the integration framework (see Figure 1.23, for possible information exchanged). A standard knowledge exchange procedure is therefore extremely useful in order to handle automated exchange of information as well as knowledge. In order to facilitate this, REMIMS provides a standard knowledge exchange scheme, which may be called a “knowledge protocol”. The KN therefore can be considered as a distributed information system providing ways of agent interactions by several means, in this case, “knowledge protocols” and “knowledge forms” which are explained in detail elsewhere (see Oztemel and Tekez, 2009b, 2009c).

Reasoning view highlights the basic capabilities of decision making, problem solving and reasoning capabilities of each agent responsible for carrying out a certain manufacturing function. REMIMS is composed of a set of intelligent agents each of which is responsible for performing a different manufacturing activity. Each agent may in turn be composed of several sub-agents. The logical view of the reference model is task dependent and can have different architectures for different tasks. Each agent within the reference model can have a general architecture as shown in Figure 1.24.

In order to perceive and act (reason) about the events, the agents should be equipped with suitable sensors and effectors as well as with the domain knowledge. In other words, the agent should perform whatever action is expected from it to maximize its performance. The actions should be decided on the basis of the evidence provided by the percept sequence and whatever “built-in knowledge” the agent possesses. As seen in Figure 1.24, an agent may be composed of:

1. *situation assessment module* to perceive the events from the environment;
2. *reasoning and decision-making module* to provide solutions to perceived information;
3. *behaviour representation module* to act according to the response produced by the reasoning and decision module.

By being agent-based architecture, REMIMS emphasizes the importance of knowledge because of interdependencies among the agents. Agents interact with each other and coordinate their actions derived from their knowledge. They have to utilize their knowledge in an integrated fashion in order to link the respective tasks carried out by different agents. Each agent can work independently utilizing the required knowledge, which may even have been produced by other agents.

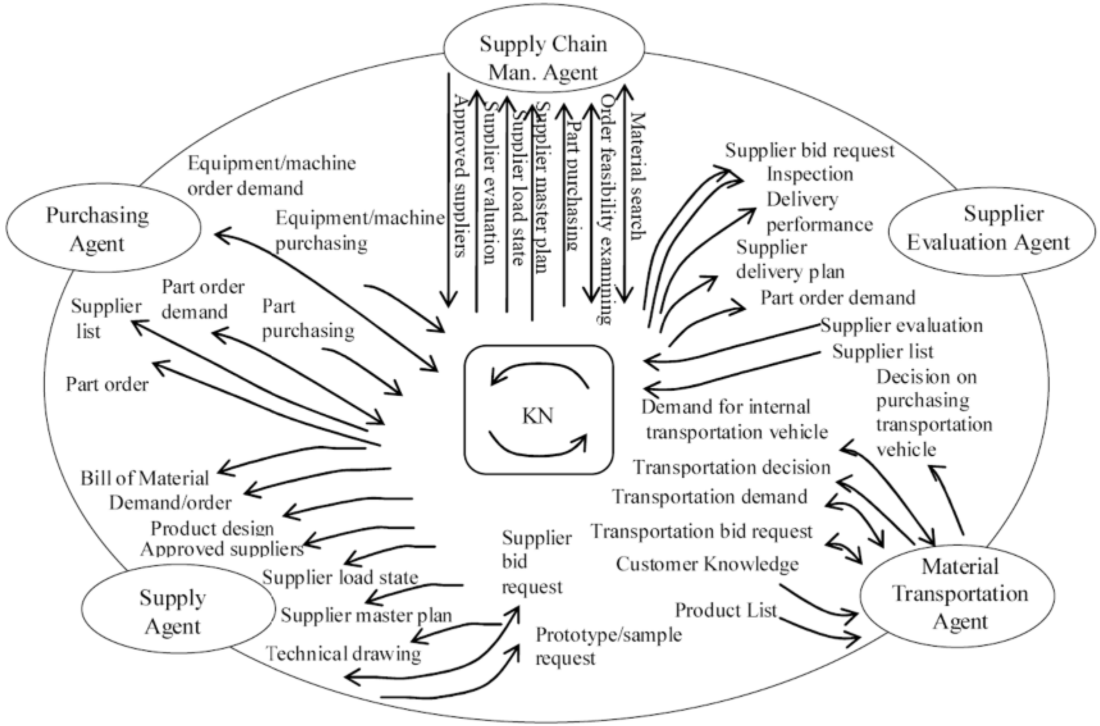

Fig. 1.23 An example of knowledge exchanges on knowledge network of REMIMS (Oztemel and Tekez, 2009a)

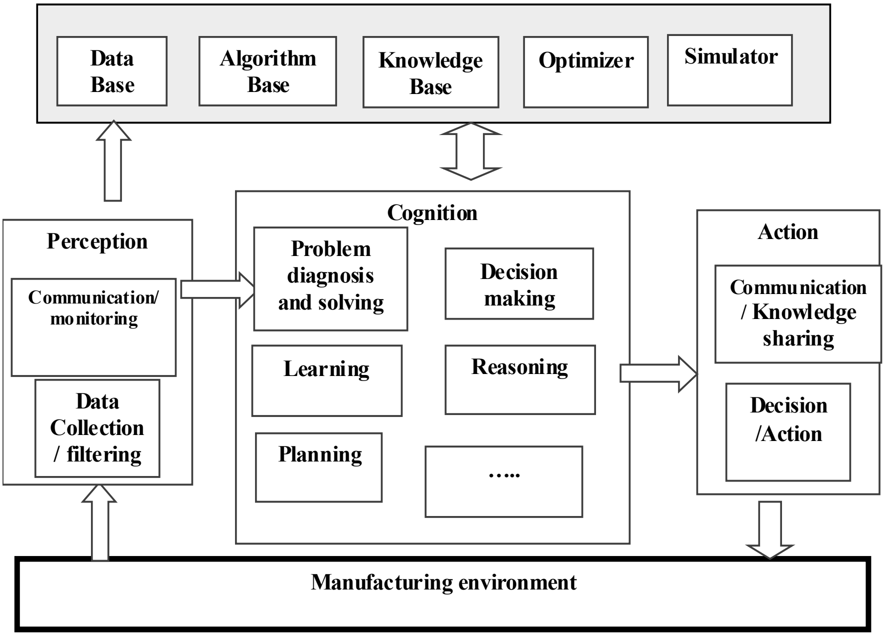

Fig. 1.24 General architecture of a REMIMS agent (adapted from Oztemel and Tekez, 2009a)

1.7 Holonic Manufacturing Systems

Progress in intelligent manufacturing systems promotes the concept of holonic manufacturing which establishes a baseline for autonomous, highly flexible, agile, reusable and modular manufacturing units. That is to say that these systems are designed through autonomous, cooperative, intelligent modules capable of reconfiguring manufacturing systems automatically in response to new system requirements or environmental changes. These systems are constructed using some autonomous structures so called "holons". Holons are capable of working under the control of others as well as independent of others. That means if one manufacturing unit (holon) fails or cannot respond to some problems; other holons create a reroute of operations in order to avoid major disruptions. It is quite similar to the nature of an ant or termite colony. Holonic manufacturing system is believed to make an important breakthrough in the field of decentralized control for intelligent manufacturing systems. It is important to take note of the two aspects of holonic manufacturing which are:

- event-driven real-time control strategies; and
- deliberative non- real-time distributed information processing.

These two characteristics make holonic manufacturing systems capable of altering machine configurations and production schedules in accordance with immediate and imminent requirements. This is important as it allows the manipulation of breakdowns of the machines and real-time re-scheduling. That makes the manufacturing system agile enough to cope with unexpected changes.

The components of holonic manufacturing (so-called building blocks) are designed to reflect the fact that different manufacturing units behave in an autonomous and cooperative manner. The generic principles underpinning holonic systems were first proposed by Koestler (1967). The concept is being reiterated by the researcher with respect to intelligent manufacturing through illustrating each manufacturing unit as different holons which may utilize different type of knowledge.

Bussmann and McFarlane (1999) identified the basic architecture of a holon as shown in Figure 1.25 and highlighted the key properties of holonic manufacturing system as the following:

- autonomy;
- cooperation;
- self-organization; and
- reconfigurability.

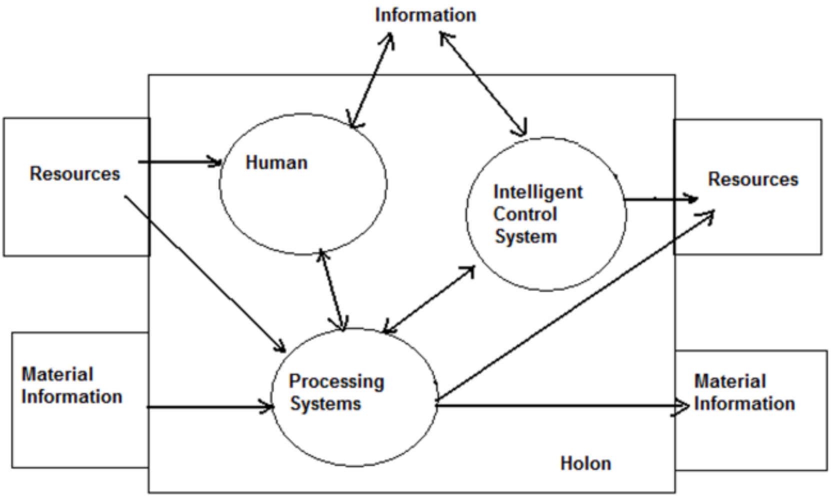

Fig. 1.25 A basic architecture of a holon (Bussmann and McFarlane, 1999)

There are mainly two types of holons in a holonic manufacturing system. They are:

- *Resource holons*, which can provide all the generic resources in the intelligent manufacturing system. Each of these resource holons is an entity that performs an action over an item. They include painting machines, automated guided vehicles (AGVs), inspection stations with video cameras and AI software to recognize any defects in the items, etc.

- *Product holons*, which represent the requirements of operations such as production, assembly and so forth. These holons also provide knowledge on how to achieve the manufacturing objectives. They can provide expert advice, and may also act as an information server to disseminate knowledge among the holons. Each can be re-used in the scope of different operations and each could negotiate with various resource holons in order to secure the desired services. In other words, each product holon is an active entity responsible for performing the manufacturing management work correctly and on time, while explicitly capturing all information processing needed for a specific job.

Holons establish a holarchy which is a system of holons that can cooperate to achieve a certain manufacturing goal or objective. Sigumura *et al.* (1997) indicated the basic structure of a holonic manufacturing system as shown in Figure 1.26.

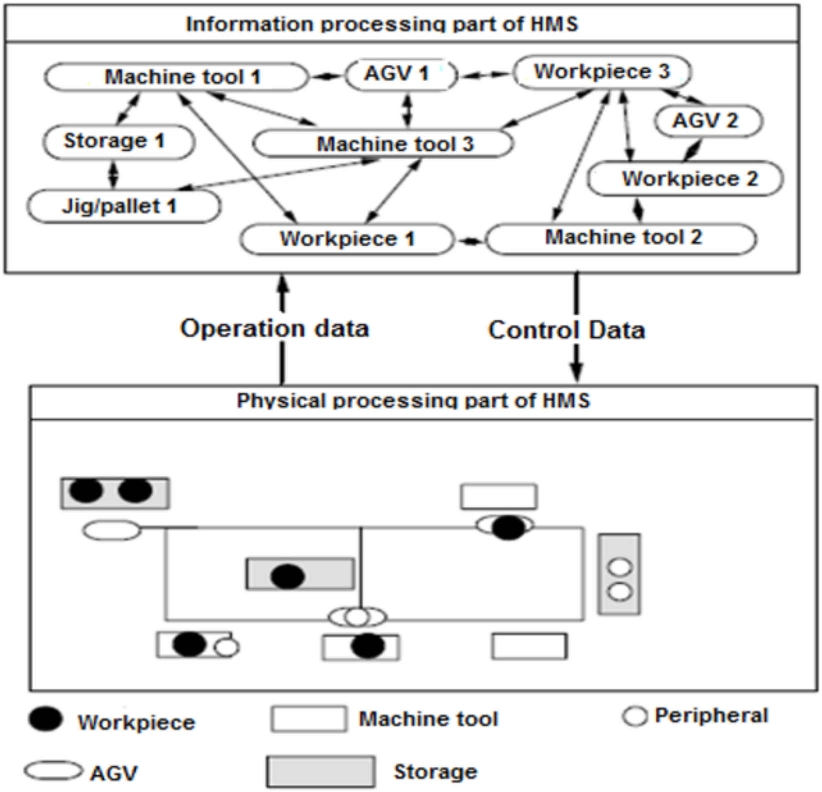

Fig. 1.26 Basic structure of holonic manufacturing system (Sigumura *et al.*, 1997)

As indicated in the Figure 1.26, the system is basically divided into the physical processing part and the information processing part, and both parts consist of a set of holonic components. The physical processing part transforms the blank materials to the final products through the autonomous and cooperative activities of the holonic components. The data required in the physical processes are generated and determined in the information processing part, which also consists of a set of holonic components.

Similarly, Sigumura *et al.* (1997) showed the holarchy of holonic manufacturing systems as illustrated in Figure 1.27.

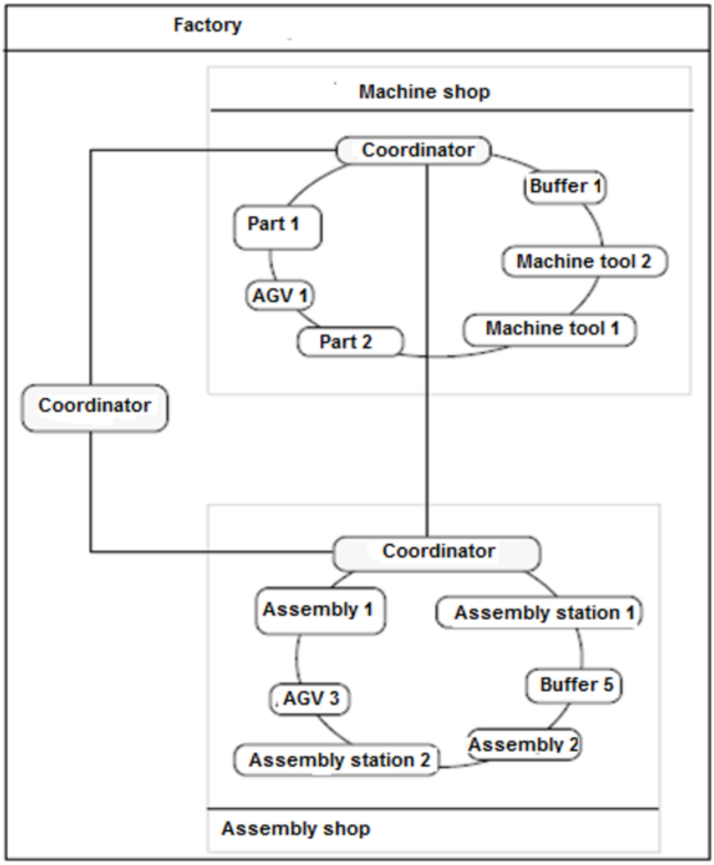

Fig. 1.27 Holarchy of holonic manufacturing systems (Sigumura *et al.*, 1997)

This figure shows an example of the holarchy in holonic manufacturing systems consisting of a machine shop and an assembly shop. The individual shops include such holonic components as machine tools, assembly stations, parts and assemblies. In the holarchy, local-level decisions, such as shop scheduling, are made through the autonomous decisions of holonic components, and their cooperation. The coordinators in the shops coordinate and/or constrain the autonomous activities of individual holonic components. Some more detailed information on holonic manufacturing systems can be found in Jarvis *et al.* (2008).

1.8 Applications of Intelligent Manufacturing Systems

There have been numerous examples of intelligent manufacturing in the last two decades. These are presented in many conferences and papers and can be found in fielded applications in industry. It is not possible to review all of these applications here in this book. Several examples will be provided in order to highlight possible areas and provide some hints on practical use of these systems.

Pham and Oztemel (1996) reported their work on intelligent quality systems in their book. They have reported an expert system called XPC capable of performing statistical process control. XPC, which was developed by Oztemel (1992) constructs control charts automatically, and performs process capability analysis in order to make sure that the process is designed in such a way that it may satisfy customer requirements within tolerances. It is capable of performing on-line monitoring of the process and identifies any faults as well as recommending corrective actions. It updates the chart according to improvements achieved.

Kusiak (1990) wrote a book on intelligent manufacturing systems and reported various intelligent systems from design to equipment selection. Similarly, Norrie et al. (1990) recommended an integrated manufacturing management planning system, which takes process planning, group technology, scheduling, and simulation into account. They created a decision support system called FLEXES utilizing knowledge bases and simulation systems for the sake of efficient and effective manufacturing.

Scherer and Brown (1995) introduced intelligent scheduling in their book. They provided a baseline for the future applications. For example, Monfared and Yang (2005) developed a multi-level scheduling and control algorithm based on the proposed methodologies.

AI is highly utilized in design activities as well. Preparation of manufacturing designs using CAD tools and support of CIM systems have been attracting the developers of CAD. Abouel Nasr and Kamrani (2008) provided an extensive analysis on this issue. Integrating AI and Internet technology for the success of manufacturing design is very popular nowadays. A good example of this is the injection moulding design system developed by Mok *et al.* (2008). In this study, a Java-based intelligent design system equipped with AI technologies is introduced. It is reported that this system increased the design speed and supported the creation of design standards. Similarly, Balic *et al.* (2006) developed an intelligent system for computer numerical-controlled tuning operations using genetic algorithms. Information on other design-related intelligent systems can be found in Jedrzejewski (2007).

Similarly to design systems, intelligent process planning-systems have also been developed. Especially researchers such as Wong (1993) led the studies and provided baselines for the development activities. Main motivations of these systems are reported to be automatic information processing and defining process plans according to design specifications. Mo and Woodman (2005) explained a framework to prepare process plans using the Internet. Deb *et al.* (2006) presented a neural-network-based process-planning system. The research along this line continues with an increasing momentum.

Intelligent manufacturing systems are emerging in hardware-related studies as well. There have been fully automated and intelligent manufacturing systems and manufacturing robots developed and effectively used in manufacturing shops. Balic *et al.* (2003) assessed the work along this line in their book and provided useful information in detail. Tsourveloudis *et al.* (2000) reported a neural network and fuzzy-logic-based robot gripping system. Similarly, Ioannidis *et al.* (2004) introduced fuzzy-logic controllers. A very informative review on robotics technology is also provided by Jarvis (2008).

Attention has also been given to the integration of intelligent manufacturing systems. Agent-based systems are good examples of such applications. There have been countless examples of applications of agents in manufacturing. To mention some, Zhou *et al.* (1999) provided a real-time monitoring system, which could be utilized by agents in an integrated environment. Shen *et al.* (2007) proposed a service-based integrated architecture for agent cooperation, which could be used in manufacturing systems. Tekez (2007) created a general agent-based reference model for integrated intelligent manufacturing systems, naimely (REMIMS) as reported above.

The progress in intelligent manufacturing systems also directed the attention of the researchers towards distributed holonic systems. Aguayo *et al.* (2008) presented a protomodel called FRABIHO which constitutes distributed and intelligent engineering production systems, derived from the synthesis of the models proposed in the frame of the fractal, bionic and holonic intelligent manufacturing systems.

Similarly, Hou and Gong (2008) introduced a knowledge centric intelligent manufacturing system (KCIMS), which is devised to assist in tackling the current challenges posed to the semiconductor manufacturing services industry by the competitive environment and pressure of demanding customer. However, the approach proposed could be adapted to other industrial sectors as well. The overall KCIMS framework can be mainly classified into three parts, namely knowledge management (KM) basic structure, action-doer structure and advance product quality planning process (APQP) based structure. The first part includes the most important structure of control, applications and interface. The second part deals with the repository services. The framework utilizes intelligent agents to facilitate the tasks of repository services at the third part. A modified APQP, called a intelligent quality planning process (IXQP, where X stands for process, material, human resources, efficiency and technology) breaks down the APQP process in small subcomponents so as to link it through a KM-based system and have better control on company supply chain operations.

1.9 Conclusions

Intelligent manufacturing systems are evolving with an increasing speed. New systems are being developed in very short time frames. It is now apparent that intelligent manufacturing systems will be more dominant in industrial and manufacturing areas and:

- They will make it possible to reduce the size of the product but increase their functionality as well as complexity.
- They will be equipped with highly effective sensors for perceiving inputs and acting accordingly.
- They will be capable of collecting/filtering and reasoning about the knowledge and data without any extra burden on the systems.
- They will reconfigure themselves in the light of the progress in manufacturing systems and technologies.
- They will have an extensive capability for learning and planning as well as updating their knowledge accordingly.
- They will be able to adapt themselves to any kind of manufacturing environment.
- They will be able to define the best manufacturing methods for their intended purposes.
- They will increase their performance continuously and reduce the human involvement.

It is now obvious that the next decade will be the decade of unmanned factories and new changes will continue to surprise both the academic and the industrial community.

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