Chapter 2
Introduction to Conventional and Intelligent Manufacturing Systems

2.1 Introduction

According to the rapid changed of technology, both the information and the manufacturing technology, the use and management of information throughout the company will be an important key of success in manufacturing industries. The advent and introduction of Artificial Intelligence, Neural Networks, Genetic Algorithms and Fuzzy Logic into R&D in the area of manufacturing engineering has given a new perspective of Intelligent Manufacturing Systems. Many researches in this area have been conducting on various directions to form a fundamental concept of Intelligent Manufacturing. However, though to construct an ideal intelligent manufacturing is very important and need much more research and development, but to practically implement it into industries is also important. Many manufacturing industries have invested much money into their current manufacturing systems. It is not easy for them to change all, or even some, of their commercial type of ordinary machines to be those intelligent types. For this reason, at the beginning phase of implementation of intelligent systems to the current technology, especially for Thailand's, it is very important to introduce a proper direction and philosophy of Intelligent Manufacturing.

2.2 Evolution of Manufacturing Systems

Before the middle of the eighteenth century, the term `Manufacturing' did not exist since most people lived in rural areas and produced their own clothing and farm implements. Specialization occurred when certain craft men began to produce items for sale to others such as farm implements, kitchen utensils, shoes, candles etc. However, most of the energy used in the production processes was human and animal energy. All communication was verbal and much of work was performed out-of-door.

In the nineteenth century, the widespread application of stream power resulted in the concentration of large numbers of machines in a central location. This made the concept of factory system eventually developed. With so many people involved, factories were forced into more conscious forms of planning and organization. The concept of mass production and other principles of factory and engineering management began to emerge.

By the end of the twentieth century, the advancements in electronics and digital computers have had the greatest impact on manufacturing. The advent of both equipment and factory management concepts such as NC, CNC, Group Technology, MRP, FMS and CIMs began to emerge. This movement was impacted from the desire of companies to have manufacturing facilities that could quickly be modified to meet rapid changing customer demands. Figure 2.1 shows a computer integrated manufacturing environment.

2.3 Toward The Second Millennium

According to a truism, manufacturing is the addition of values to the goods manufactured which finally become the products that other people would be willing to pay for. This somehow show some means that for a particular product, beside the low cost of production and high in quality, manufacturers have to concern about the perceived needs of customers which is obviously extending far beyond only the price and quality.

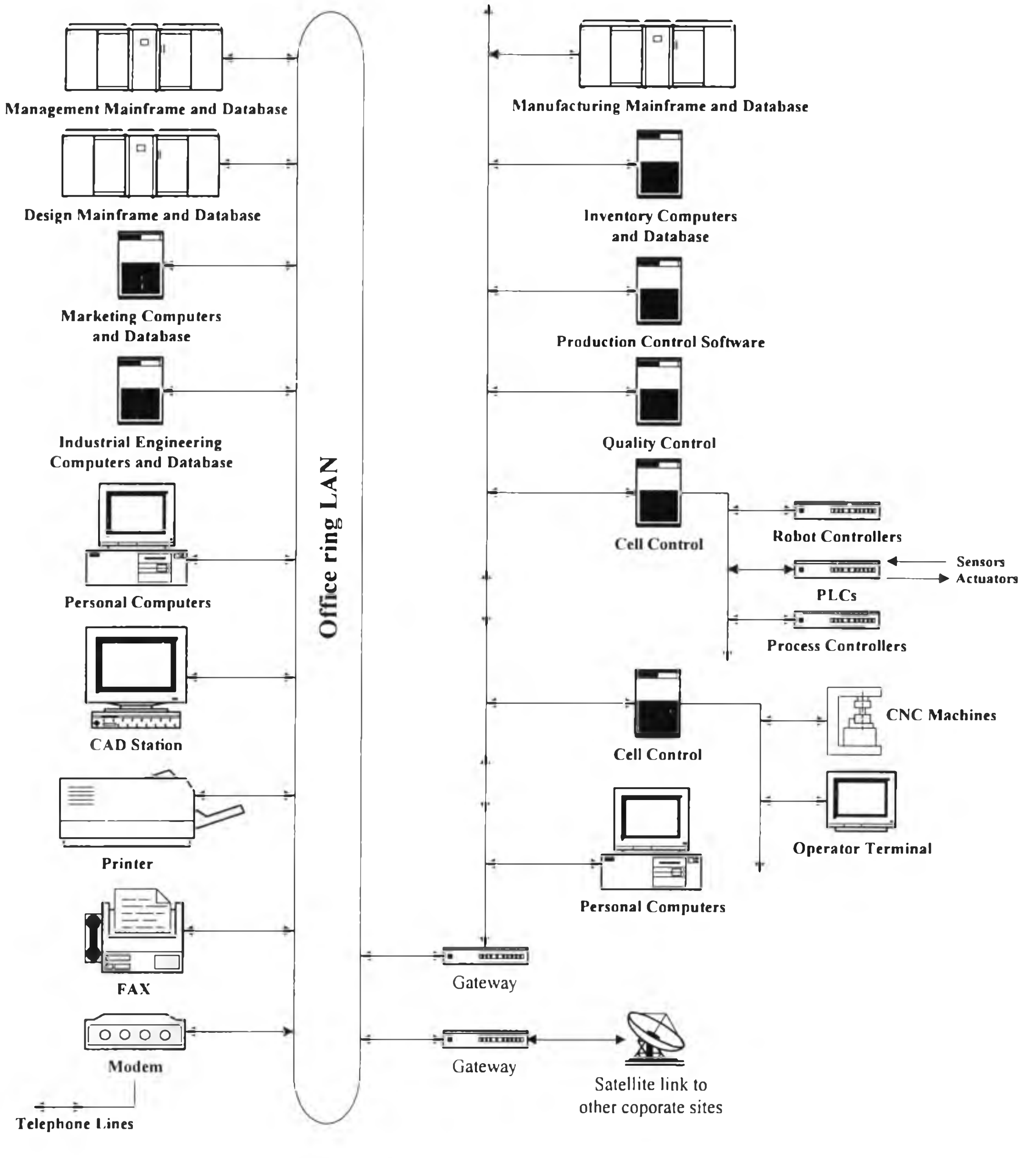

Figure 2.1 : A computer integrated manufacturing environment

View	Key Words
Product	Environment Conscious/Friendly Recyclable, Product Life Cycle One of a kind, a Small Lot Size Quality Precision, Ultra Precision
ProcessSystem	One of a kind Production for order Global Distribution System Flexibility \ Efficiency Open Architecture Human Centered/Resource Factor Low Energy Consumption Low Pollution Automation Virtual Factory/Manufacturing/Enterprise Rapid Prototyping Team Oriented Manufacturing New Process/Machine/Equipment/System New Organization/Management
Society\Market	Environment Conscious/Friendly Ecology Customer Oriented/Driven Globalization Human Factor
Supporting Technologies	Communication Computer, Electronics Information Network Artificial Intelligence Concurrent Engineering Database Sensors Material(Recyclable, Low Pollution) Nano-Technology

Table 2.1 : Key words of New Manufacturing Era

Iwata and Fujii [15] summarized from the questionnaire about `New Manufacturing Era' from 44 members of CIRP that the vision of the new manufacturing era can be classified into four views, Product, Process and Systems, Society and Market, and Supporting Technology. The key words for each view are listed in Table 2.1.

In the next century, the society will become more environment conscious and require the products which will be less pollutant through their life cycle and be almost 100 percent recyclable. In addition, manufacturing processes must also satisfy the environmental issue, too.

The market will become strongly customer driven and all of the efforts in the manufacturing need to be concentrated to respond the market requirement very quickly.

Agile manufacturing, one-of-a-kind or a small lot size product/production will become the key issue for the manufacturing system.

Information Network Technology will become an essential infrastructure to develop a new structure or organization for industries and promote the construction of Globally Distributed Virtual Enterprises.

2.4 The Era of IMS

According to previous sections, **Intelligent Manufactring System (IMS)**, or sometimes known as **Intelligent Sensor-based Manufacturing**, was introduced to be a completely new concept of production system. It concerns with the integration of information technology and various kinds of intelligent machines to create a new production system which is a completely 24-hours unmanned, flexible and easy-to-operate operation [6][11].

With IMS, all kinds of machines will be "information-oriented" which could bring an ordinary production system to a world class or global intelligent manufacturing. This mean, in the near future, products must be produced close to customers, or in a place where the production cost is low enough to compensate for the cost of transportation. The production sites are likely to be scattered throughout the world. Global Intelligent Manufacturing Systems is an important key for this purpose [16].

IMS symbolizes humankind's basic desire to apply modern manufacturing technologies to the benefit and improvement of the quality of life for the peoples of all nations. It also be an issue involved in advancing manufacturing technologies and their implications on international trade and competitiveness [6][16][37][40].

In addition, Intelligent Manufacturing not only realizes the requirements of ordinary manufacturing systems, but also makes manufacturing in contaminated sites, space, or in the atomic-scale environment [6][31].

2.5 Definitions of IMS

IMS can be defined by two approaches, **managerial** and **engineering approach**. With the managerial approach, IMS is the "world class manufacturing". It gives an up-to-date and strategic view of information technology in manufacturing. IMS emphasizes the use of appropriate IT for maximum success. Whereas with the engineering approach, IMS is concerning with the appropriate combination of the various kinds of information-oriented, intelligent machines, and controlled systems. *This research will mainly focus on engineering approach.*

There are many researchers in this area defined the term `Intelligent Manufacturing'. The following are some distinct definitions.

Furness [6] quoted that `Intelligent Sensor-based Manufacturing refers to the integration of sensor signals, process models, and decision-making techniques to improve the productivity and quality of manufacturing systems.'

Rao et al. [34] defined that `IMS is a large knowledge integration environment that consists of several symbolic reasoning systems and numerical computation packages, which are controlled through a meta-system for timely implementation.'

Sohlenius [37] said that, since `Intelligent' means the ability to adapt to unforeseen conditions, this means that an IMS has to be designed to meet the ever changing requirements of customers, the workforce and society. So, in designing an IMS, the level of unexpected conditions should be minimized, by identifying and designing the system with the flexibility to adapt to these conditions.

Suh [40] defined that `IMS is the autonomous or near-autonomous system that can acquire all relevant information through sensing, render decisions for its optimum operation, and implement control functions to achieve the objectives of its manufacturing tasks, including the overhead functions.'

2.6 IMS Technical Framework

There are many potential research areas in the framework of IMS. The following lists some of the possible areas and projects which are in the research and development process.

Total Product Life Cycle

- future general models of manufacturing system
- intelligent communication networks systems for information processes in manufacturing
- environment protection, minimum use of energy and materials
- recyclability and refurbishment
- economic justification methods

Process

- clean manufacturing process that can minimize effects on environment
- energy-efficient processes that can meet manufacturing requirements with minimum consumption of energy
- technology innovation in manufacturing processes
- improvement in the flexibility and autonomy of processing modules that compose manufacturing systems
- improvement in interaction of harmony among various components and functions

Strategy/Planning/Design Tools

- methods and tools to support business process re-engineering
- design support tools to support planning in an extended enterprise or virtual enterprise environment
- modeling tools to support the analysis and development of manufacturing strategies

Human/Organizational/Social

- promotion and development projects for improved image of manufacturing
- improved capability of manufacturing workforce/education, training
- corporate technical memory
- appropriate performance measure for new paradigs

Virtual/Extended Enterprise

- methodologies to determine and support information processws and logistics

- architecture to support engineering cooperation across the value chain
- methods and approaches to assign cost/liability/risk and rewards
- team working across individual units within the extended enterprise

2.7 Fundamental Concept of IMS

Intelligent manufacturing frameworks are designed in two levels [16]. A high level consisting of a manufacturing knowledge base that can be viewed as a meta-CIM systems, and a low level that deals with equipment interfaces, operations and control.

From [5] and [11], it is obvious that there are five important sub-systems to articulate an intelligent manufacturing system.

1. Machines
2. Intelligence
3. Sensors
4. Actuators
5. Technologies for integration

Figure 2.2 illustrates the fundamental structure of IMS. Hatamura et al. [11] explained that if information concerning the fundamental variables that dominate the system behavior is input to a precise model of the system, the information necessary to control the system can be generated. Consequently, the required product can be precisely manufactured.

While an intelligent machine is working, information is extracted by sensors and is input to the physical model. The current state of the process is clarified and the future state can be predicted. These predicted values are compared with the desired values, which are determined from the design specifications. When any discrepancy exists, the parameters are modified in order to satisfy the design values and the required motions of the actuators are calculated and sent to the controller to drive the actuator.

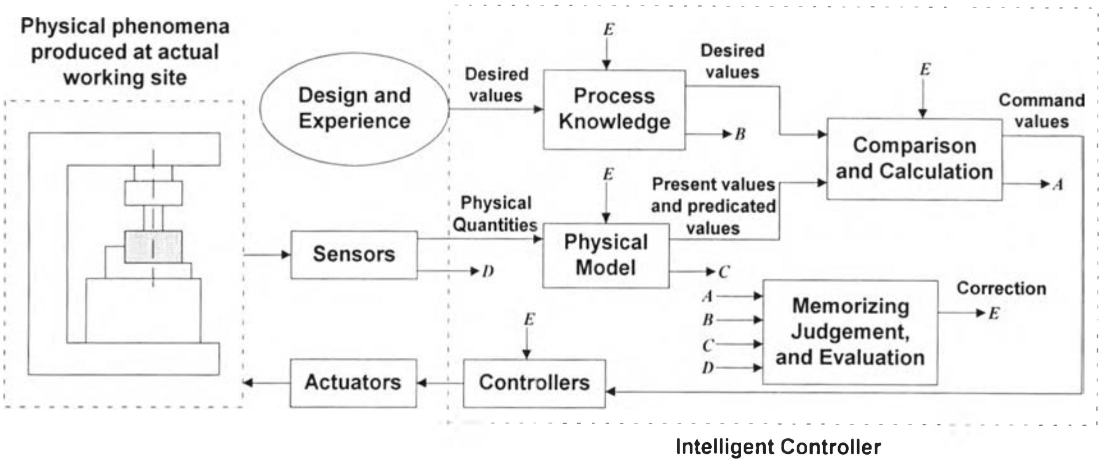

Figure 2.2 : Fundamental Structure of Intelligent Manufacturing Systems

During the above process, all activities are judged, evaluated, and memorized by a separate monitoring function. This function stores all information in a database and modifies the algorithms for each function so as to provide a capability for the self-evolution of the total system.

2.8 Intelligence and Intelligence of Intelligent Machine

2.8.1 Intelligence, AI, and Expert Systems

To successfully design and implement intelligent systems, such as intelligent manufacturing systems which are concerning here, it is very important to clarify what intelligence, artificial intelligence and machine intelligence are. These terms will be defined based on behavior and computer science.

According to *Webster's Second Edition New World Dictionary*, intelligence is **"the ability to learn or understand from experience; the ability to acquire and retain knowledge; the ability to respond quickly and successfully to new situations; or the use of the faculty of reason in solving problems, directing conduct, etc., effectively".**

The above definition was associated with human being intelligence which can be summarized that **intelligence is the ability to acquire knowledge and use it** [33].

In 1950, Turing [45], a pioneer computer scientist suggested that intelligence is a matter of behavior or behavioral capacity: whether a system has a mind, or how intelligence it is, is determined by what it can and cannot do. He proposed a pragmatic criterion or test, which now called **Turing Test**, of what a system can do that would be sufficient to show that it is intelligent. However, he did not claim that a system would not be intelligent if it could not pass his test. In contrast, he only claimed that it would be if it could.

Turing said that **`A non-human system will be deemed intelligent if it acts so like an ordinary person in certain respect that other ordinary people can't tell (from these action alone) that it isn't one.'** He also concluded for his test that `A system is surely intelligent if it can carry on an ordinary conversation like an ordinary person (via electronic means, to avoid any influence due to appearance, e.g. tone of voice, and so on).' This conclusion is very elegant and deep since talking is not merely one intelligent ability among others, but also, and essentially, the ability to express intelligently a great many other intelligent abilities.

Artificial Intelligence (AI) is a segment of computer science attempts to design and implement computer hardware and software which are capable of imitating human cognitive skills, as described above, including problem solving, visual perception and language understanding. The followings are some definitions given by some distinct researchers in this field.

Winston[47] defined that "***AI is the study of the computations that make it possible to perceive, reason, and act***". This definition makes AI become different from most of psychology because it obviously emphasizes on computation, and in contrast, it also become different from most of computer science because it emphasizes on perception, reasoning, and action.

Barr and Feigenbaum [1] defined that "**AI is the part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behavior ; understanding language, learning, reasoning, solving problems, and so on**."

Expert System (ES) is a computer program that emulates the behavior of human experts who are solving real-world problems associated with a particular domain of knowledge. Expert Systems technology derives from the research discipline of AI which can be illustrated as Figure 2.3 [33]. However, there are many others possible applications. The applications shown in the figure are some currently developed areas.

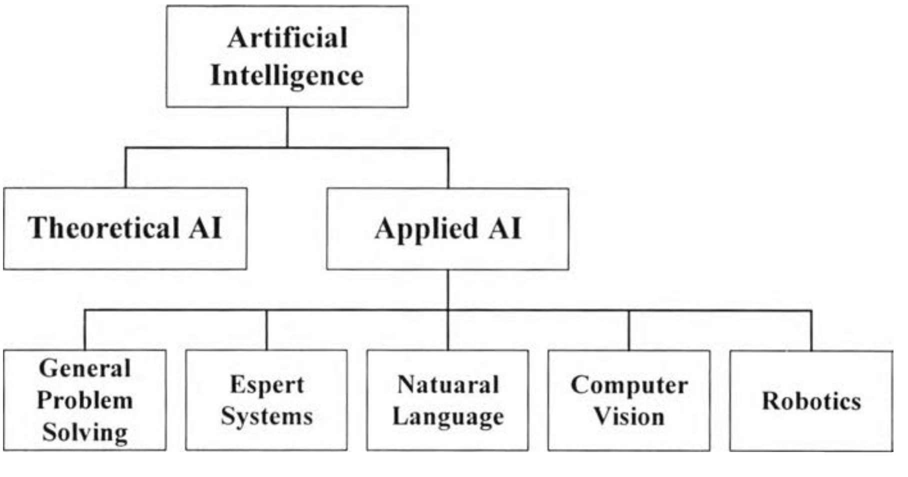

Figure 2.3 : Overall Perspective of AI

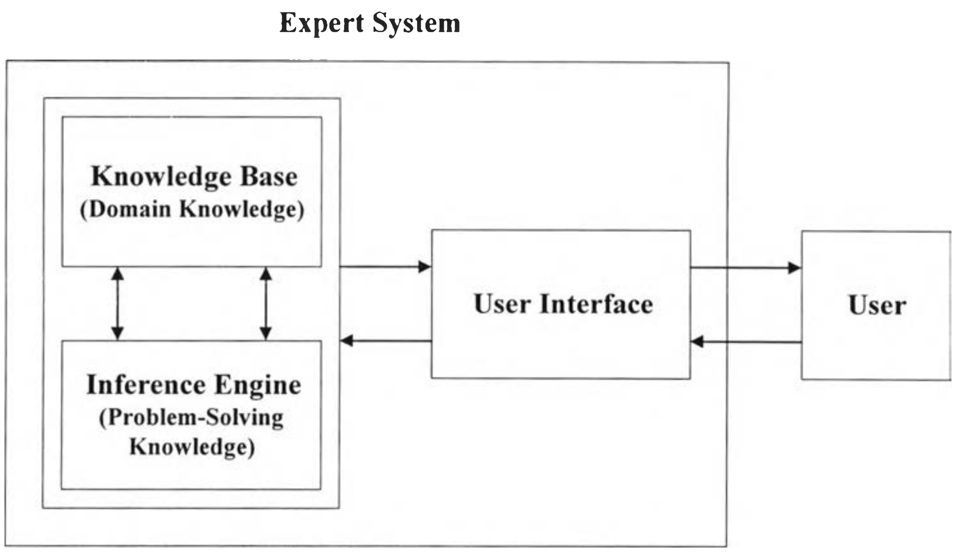

Figure 2.4 : Block Diagram of an Expert System

Expert System has three basic components: **the knowledge base, the inference engine**, and **the user interface**. Figure 2.4 shows the block diagram of an Expert System [33].

2.8.2 Classification of Expert Systems

Hayes-Roth et al. [14] classified Expert Systems, by the different kind of tasks, into ten categories which can be addressed as;

1. **Interpretation Systems** infer situation description from observations or sensor data. Typical task include signal understanding and chemical structure elucidation.
2. **Prediction Systems** infer likely consequences from situations or events. Typical tasks include weather forecasting and financial forecasting.

3. **Diagnosis Systems** infer system faults from symptom data. This category includes a broad spectrum of tasks in medical, mechanical and electronic domains.
4. **Design Systems** develop configurations of objects that satisfy certain constraints. Typical tasks include circuit design and producing optimal arrangements of machinery in a confined space.
5. **Planning Systems** generate sequences of actions that achieve stated goals. Most typical tasks are planning robot motions and route planning.
6. **Monitoring Systems** study observations of system behavior over time to guard against deviations that threaten stated goals. Typical applications involve air traffic control and monitoring of power stations.
7. **Debugging Systems** generate remedies for system faults. Typical applications involve computer-aided instruction and aids to computer programmers.
8. **Repair Systems** generate and administer remedies for system faults. Typical applications involve avionics systems and computer networks.
9. **Instruction Systems** diagnose and treat students' misconceptions concerning some domain.
10. **Control Systems** govern the behavior of a system by anticipating problems, planning solutions and monitoring the necessary actions. Typical tasks involve battle management and mission control.

The above classification has a number of drawbacks such as the overlap of some categories e.g. Planning and Design Systems, which Clancey [2], instead of directly classifying ESs in terms of the kind of problem to be solved, proposes a classification of ESs in terms of "Generic Operations".

Clancey categorizes Generic Operations into two groups, Synthetic Operations that "construct" a system and Analytic Operations that "interpret" a system. These concepts result in a hierarchical analysis of the kinds of operation, INTERPRET and CONSTRUCT operation as shown in Figure 2.5 and Figure 2.6 respectively.

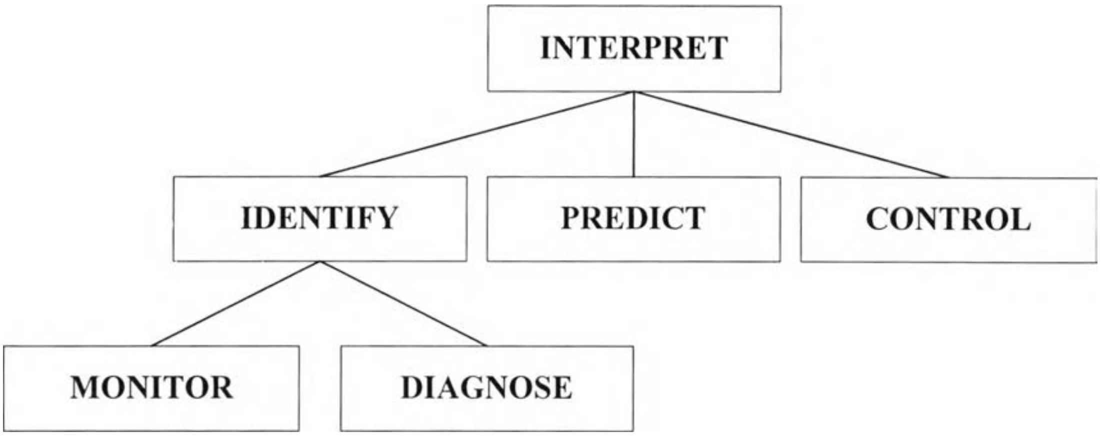

Figure 2.5 : Generic Operation for analyzing a system.

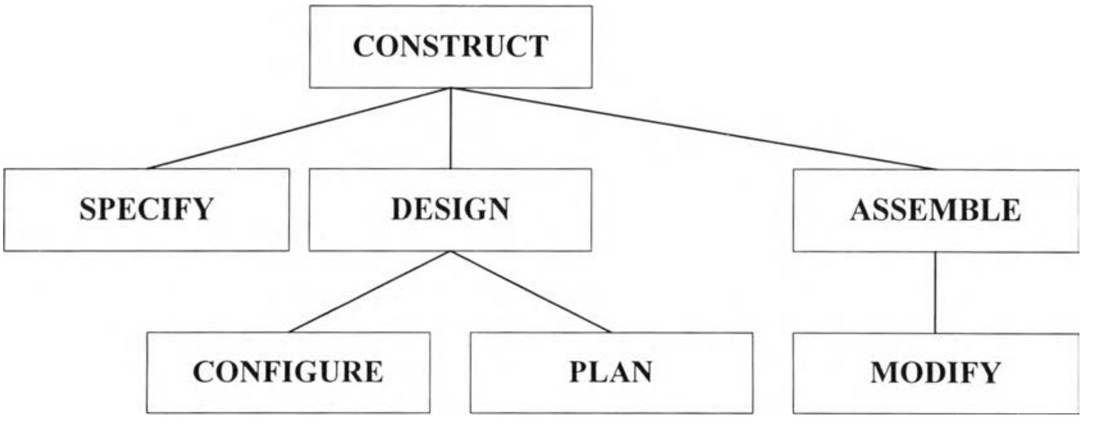

Figure 2.6 : Generic Operation for synthesizing a system.

Base on Clancey's analysis, it is clear that Hayes-Roth's classification can be adjusted as :

1. **Interpretation** is now a generic category that covers any task which involves describing a working system. Prediction and Control are now varieties of interpretation task.
2. **Monitoring** and Diagnosis are now varieties of identification task, which is itself a kind of interpretation task. Debugging is assimilated into Diagnosis, although it also includes a modification task (to put things right).
3. **Design** remains a basic category, but Instruction is assimilated into a Modify operation, as is Repair. Planning is now a specialization of Design.

2.8.3 Intelligence of Intelligent Machine

From the aforementioned definitions, it is obvious that Intelligent Machine and IMS are those kinds of Expert Systems which applied to manufacturing machines and equipment such as machining center, sensors, actuators, etc.

Hatamura et at.[11] proposed that to develop the knowledge base for IMS, there are 2 kinds of knowledge required to implement, **knowledge about manufacturing phenomena** (Physical Phenomena or Physical Model) and **knowledge about the available manufacturing processes** (Process Phenomena or Process Knowledge).

Physical Phenomena and the information produced which occurred in metal cutting are illustrated in figure 2.7. There are two conclusions about physical phenomena :

1. All constituent elements of the machine are deformed by force and heat.

2. All constituent elements emit information in the form of strain, temperature, sound, vibration, deformation, etc.

Process Phenomena are modeled by an independent analysis, and the relationship among the dominant parameters are clarified in advance.

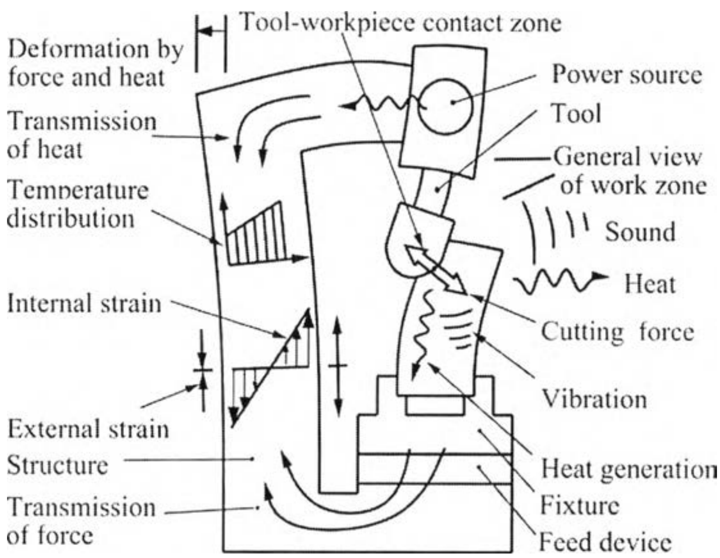

Figure 2.7 : Physical phenomena in machining

2.9 Sensors

Intelligent Systems need various kinds of sensors. Sensor is a device used for sensing system output to take in various information (before, during, and after processing) so that the system controller can detect and respond to changing conditions in its working environment. Sensors can be used to measure such variables as :

- presence or nearness of an object
- speed, acceleration, or rate of flow of an object
- force or pressure acting on an object

- temperature
- size, shape, or mass of an object
- optical properties of an object
- electrical or magnetic properties of an object

Table 2.2 shows sensors required for Intelligent Manufacturing Systems.

Type of Sensor	Performance	Example of Sensor
Force	To detect the force acting on tool	Torque-thrust-sensing tool holder, 3-directional force-sensing tool holder
	To detect the force acting on workpiece	6-axes force-sensing table, torque-sensing chuck
	To detect the force exerted by the tool on the machine	Torque-sensing spindle, thrust-sensing spindle suspension
	To detect the force exerted on the machine by workpiece	Torque-sensing coupling, thrust-sensing ball screw
Thermal	To detect the heat and temperature transferred to tool	Temperature-sensing tool holder, Temperature-sensing tip holder
	To detect the heat transferred to workpiece and its temperature	Surface temperature/heat flux-sensing table
	To detect the temperature distribution on machine structure	Temperature sensors
	To detect the unusual temperature in the whole environment	Abnormal temperature-sensing system
Deformation	To detect the deformation of machine structure	Deformation sensor
Configuration	To detect the configuration of workpiece	Configuration-measuring probe
Vision	To grasp the total situation of working environment	Vision-treating system
Sound	To grasp the total situation of working environment	Acoustic information-treating system, force sensor

Table 2.2 : Sensors required for Intelligent Manufacturing Systems

2.10 Actuators

An actuator (which does the work) is responsible for converting the information produced through knowledge into actual movement. An actuator is controlled by the controller. The actuator, in turn, changes the output of the automated process. In fact, the actuator may be several actuators, each of which provides an output that drives another in the series of actuators. Actuators required for Intelligent Manufacturing Systems are shown in Table 2.3.

Type of Actuator	Performance	Example of Actuator
Actuator for tool	To change the position and orientation of tool	Active tip holder, fine positioning tool post
Actuator for workpiece	To grip workpiece	Controllable workpiece gripper
	To change the attitude of workpiece	Fine positioning table
Actuating element	To change the dynamic characteristics of element	Active element
Actuating structure	To change the configuration of structure	Active element

Table 2.3 : Actuators required for Intelligent Manufacturing Systems

2.11 Conclusion

This chapter is the introduction to the intelligent manufacturing systems (IMSs). It has concentrated on some of the important underlying principles of the IMS and its future development. IMS is known as the autonomous or near-autonomous system that can acquire all relevant information through sensing, render decisions for its optimum operation, and implement control functions to achieve the objectives of its manufacturing tasks, including the overhead functions. However, with the expert system developer's point of view, IMS is defined as a kind of an expert system that applied to the manufacturing system. The most important sub-systems required for articulating an IMS are machines, intelligence, sensors, actuators, and technologies for integration. There are two essential knowledge bases required for implementing the IMS, knowledge about manufacturing phenomena and knowledge about the available manufacturing processes.

Finally, the characteristics of the intelligent sensors and the intelligent actuators developed at the University of Tokyo are reviewed.