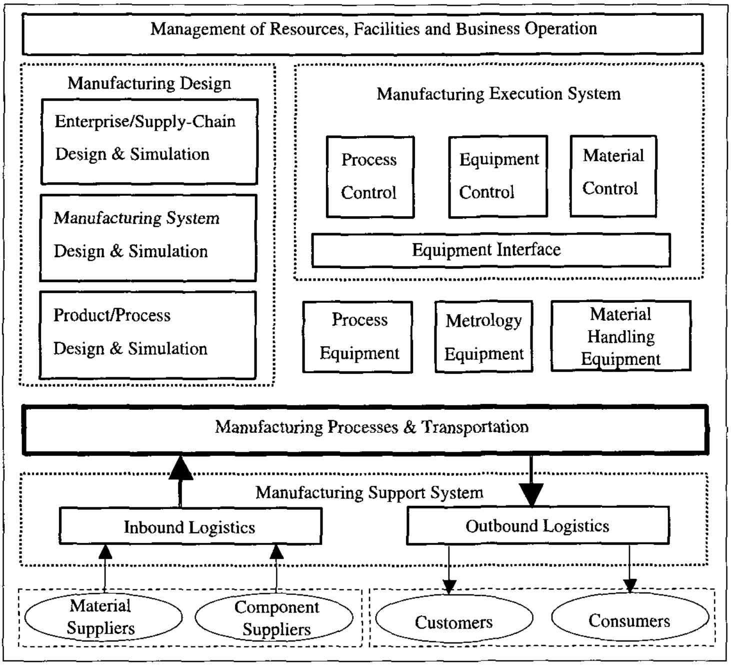

Fig. 1.2 Outline of a factory in manufacturing.

- *Manufacturing Execution System:*
  This includes process control, material flow control, equipment control and deployment of labor.
- *Manufacturing Design System:*
  This includes product design & simulation, process design & simulation and supply-chain design & simulation.
- *Enterprise Information and Management System:*
  This includes the management of resources, facilities and business operations.

1.3 Factory Automation

There are two ways to achieve high yields in manufacturing. The simplest, yet most expensive way is to increase the number of production lines. An alternative and more desirable way is to increase the rate of production in the existing production lines. It is possible to increase the production rate

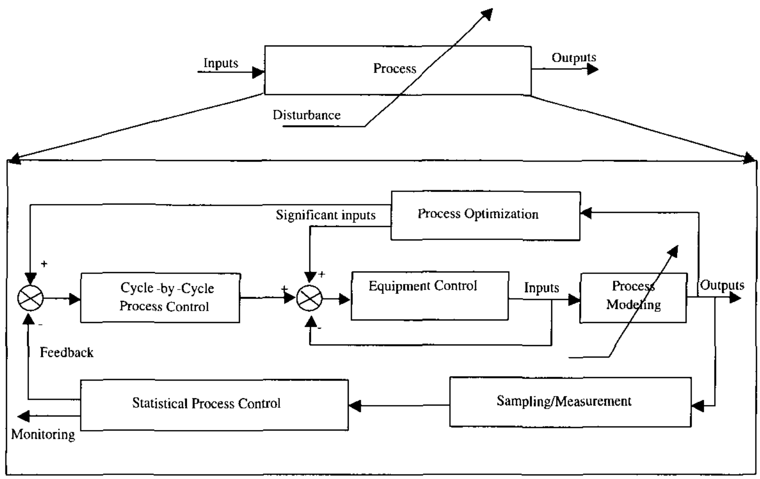

Fig. 1.3 Illustration of process optimization, process control, and equipment control in manufacturing.

by reducing the cycle time needed to produce a single part or product.

There are also two ways to reduce cycle time. The first approach is to improve the manufacturing process. The second approach is to automate the manufacturing process by using re-programmable and automatically controlled equipment.

As shown in Fig. 1.3, process optimization always starts with process modelling, which consists of establishing a mathematical description that relates a process's input $X = \{(X_1, X2, ..., X_n)\}$ to its output $Y = \{(Y_1, Y2, ..., Y_m)\}$. We can identify the subset of significant input variables by using the scientific method, called the *design of experiments*. If we regulate or control these significant input variables, the dynamics of a process can be optimized, in terms of stability, robustness, time responsiveness etc.

Therefore, one important aspect of factory automation is to automatically regulate or control the significant input variables of a process.

Refer to Fig. 1.3. Process control involves two cascaded control loops, which operate at different rates. The outer loop is the statistical process control, which aims at maximizing product quality. By definition, quality is inversely proportional to the output variation . Therefore, the quality control can be achieved by first monitoring the output variation of a process, and then automatically acting on a process's inputs for the purpose of minimizing this variation.

The inner loop, in a process control, is equipment control. As I mentioned before, the role of manufacturing equipment is to control the interaction in a process, which aims at altering in a controllable manner, the geometry, property, or appearance of the initial materials, parts, or components. Equipment control output is the direct input to a process. Therefore, the rate of equipment control depends on the dynamics of the process. In general, equipment control must operate in real-time. However, statistical-process control depends on sampling, measurement, and analysis of data. Its control cycle will be longer than that of equipment control.

1.3.1 *Automation and Robots*

As we discussed above, a manufacturing process consists of the interaction among labor, equipment, and materials, parts, or components. This interaction results in energy consumption in mechanical, thermal, chemical or electrical domains.

The aim of automation is to eliminate the direct involvement of labor in the process interaction. This is only achievable by setting up automatically-controlled equipment. In this way, the role of labor in the factory has shifted, from direct involvement to indirect programming and/or monitoring of automated equipment.

The most typical energy-driven interactions are those which convert electrical energy to mechanical energy. The manifestation of energy in the mechanical domain takes the form of motions which can be altered by using a mechanism. A mechanism is not a machine. An example of a familiar mechanism is the bicycle. A formal definition of mechanism is as follows:

Definition 1.2 A mechanism is a set of (mechanical) elements arranged in certain configurations for the purpose of transmitting motions in a pre-determined fashion.

Motion is the visible form of mechanical energy. An element which converts electrical energy into motion is called an *electric motor or actuator.* If a system includes at least one element intended for energy conversion, this system is called a *machine.* A typical example of a machine is a motorcycle or car. A formal definition of machine can be stated as follows:

Definition 1.3 A machine is a super-set of mechanism(s), and contains elements which supply energy to drive this mechanism(s).

In mathematics, motion is fully described by the parameters: position (p), velocity (v), and acceleration (a). These motion parameters (p, v, a) are important input variables for many manufacturing processes. A large family of manufacturing equipment among the variety which exists, is the one which supplies the motion required by a manufacturing process, such as: arc-welding, spray painting, assembly, cutting, polishing, deburring, milling, drilling etc. Of this class of equipment, an increasingly popular type is the industrial robot.

The English word *robot* was derived from the Czech word *robota*, meaning *forced workers*. The word *robot* became popular in 1921 because of a play named "Rossum's Universal Robots" by Czechoslovakian writer, Karel Kapek. In the play, a scientist called Rossum created human-like machines that revolted, killed their human masters, and took control of the world.

The American company, Unimation Inc., founded in 1962 by Joseph Engelberger and George Devol, was the first company to actually produce industrial robots.

From an engineering point of view, a robot is the embodiment of manipulative, perceptive, communicative, and cognitive abilities in an artificial body, which may or may not have a human shape. For example, industrial robots are merely a combination of an arm and a hand. According to the Robot Institute of America, the formal definition of industrial robot is as follows:

Definition 1.4 A robot is a programmable, multi-functional manipulator designed to move material, parts or specialized devices through variable programmed motions for the performance of a variety of tasks.

However, in view of the evolution of the robot into a sophisticated mechanical, electronic, controlling, informative, perceptive, and cognitive system, a new definition of robot is necessary:

Definition 1.5 A robot is the embodiment of manipulative, locomotive, perceptive, communicative and cognitive abilities in an artificial body, which may or may not have a human shape. It can advantageously be deployed as a tool, to *make things* in various environments.

Nowadays, the robot is not only gaining more popularity in industry, but also slowly entering society, in the form of humanoid or animal-like entertainment robots. Figs 1.4 – 1.7 show some prototypes developed by Japanese companies. Accordingly, it is necessary to concisely define the term *humanoid robot*. A formal definition of humanoid robot is as follows:

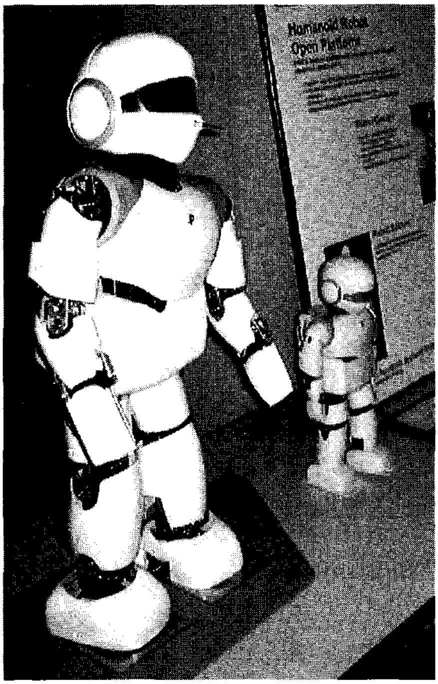

Fig. 1.4 PINO: An open development platform for a desktop humanoid robot. Photo by Author.

Definition 1.6 A *humanoid robot* is the embodiment of manipulative, locomotive, perceptive, communicative and cognitive abilities in an artificial body *similar to that of a human*, which possesses skills in executing motions with a certain degree of autonomy, and can be advantageously deployed as *agents* to *perform tasks* in various environments.

In this book, *robot* refers to both industrial and humanoid robots.

In the manufacturing industry, tasks or processes which can typically be accomplished by using robots include:

- Welding:
  This is the process of joining two work-pieces together by applying molten weld metal. For spot welding, the important motion parameter is position; for arc welding, an additional important motion parameter is the speed of travel.
- Cutting:
  This is the process of applying thermal or mechanical energy to cut a

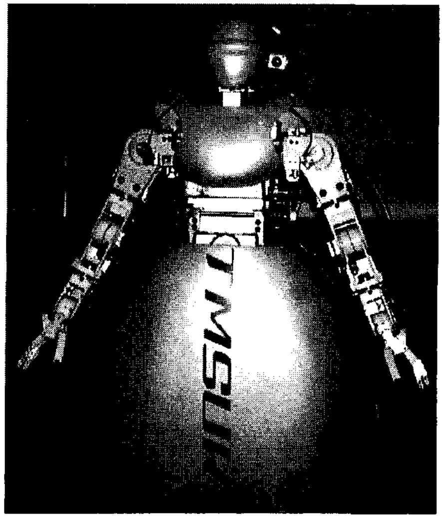

Fig. 1.5 TMSUK's humanoid robot prototype. Photo by Author.

work piece into a specific shape. In this process, the important motion parameters are position and velocity.

- Assembly:
  This is the process of either adding components to form a single entity, or affixing components to a base unit (e.g. to place components on a printed circuit board). In this process, the important motion parameter is position.
- Material Handling:
  This is the process of either packaging parts into a compartment (box) or loading/unloading parts to/from another station. In this process, position is an important motion parameter.

1.4 Impact of Industrial Robots

The industrial robot, a combination of arm and hand, can advantageously be deployed in the manufacturing industry to automate many processes, which have motion parameters as input. Obviously, automation using robots shifts the use of human labor from direct interaction with a process to various indirect interactions. These indirect interactions include process monitoring, process diagnostics, equipment setting, equipment program-