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Abstract: This paper discusses the concepts of a robotics flexible manufacturing system and the relationship between them. Definitions, applications, and social and economic aspects of robotics are summarized. Brief information about flexible manufacturing system (FMS) is summarized, and robotics as a part of FMS is discussed.

Robotics

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TERM PAPER

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1. ROBOTICS

1.1 ROBOTICS DEFINITION

Robotics is not a manufacturing system,but robots are used as a useful tool in high technology manufacturing systems.
What is robotics? Unfortunately we don't have any standardized definition for robots. Different countries and associations have different classificatins for them. Three common definitions are included here.

The definition of a robot by the Robotics Industries Association (RIA):

> "A manipulator designed to move material, parts, or specialized devices through variable programmed motions for the performance of variety of tasks." [1]

This definition and the more descriptive International Standards Organization (ISO) definition exclude special purpose hard automation equipment, manual remote manipulators, and autonomously guided vehicles (AGV) from the definition of a robot. ISO defines a robot as;

> "A machine formed by a mechanism including several degrees of freedom, often having the appearance of one or several arms ending in a wrist capable of holding a tool or a workpiece of an inspection device. In particular, its control unit must use a memorizing device and sometimes it can use sensing or adaptation appliances taking into account the environment and circumstances. These multipurpose machines are generally designed to carry out a repetitive function and can be adapted to other functions." [1]

Another classification was made for robots by the Japanese Industrial Robot Association (JIRA) according to a teaching or information input method. This classification covers a broader definition of robots than the ISO or RIA definitions. The JIRA definition includes:

1. Manual manipulators: a manipulator that is worked by an operator.
2. Fixed sequence robots: a manipulator that repetitively performs given sequential operations, and its set of information cannot be easily changed.
3. Variable sequence robots: a manipulator that repetitively performs given sequential operations and they can be easily reprogrammed.
4. Playback robots: in this classification the robot "learns" its operations. A human operator executes all of the operations and the robot "memorizes" the instructions in the same order to recall them when it is performing its function.
5. Numerical control robot: a manipulator that performs a given task by digital data.
6. Intelligent robots: a robot that is under this name has sensory devices which are used to evaluate environmental conditions, then the robot makes a decision and proceeds with its operation accordingly.

The U.S. definition does not include manual manipulators and fixed sequence robots. As stated before, there is a difference between the definition of robot in the U.S. and Japan. The definition of a robot has two important aspects. Firstly, comparisons of robot numbers between countries should be made on the same basis. Secondly, it is particularly important for the exportation of technology. A comparison of the available data shows a considerable, larger percentage of robots in Japan compared with the U.S.. Actually, robots were invented in the U.S. and the U.S. still leads in advanced research technology, but when it comes to using robots to solve practical problems on the factory floor, Japan has no equal.

Why are Japanese manufacturers very successful in the implementation of robots? Japan's success in robot production and installation can be traced to its labor relations practices [4]. Japanese workers are guaranteed lifetime employment at their company. Employees are often shifted from one job to another within a company. Since workers do not fear losing their jobs and they are not opposed to automation. In Japan, the government policy supports robot manufacturers and robot implementers. The Ministry of Trade and Industry (MITI) is following a cooperative policy rather than having adversary relations with the business of robotics.

Another reason for Japanese dominance could be said that necessity and a labor shortage forced the Japanese into the use of robots. They had to reduce their labor costs to be competitive in the world market. They had two alternatives to reduce the labor cost by allowing the immigrants to work in their factories with cheaper labor cost or to construct factories in other countries with low wages. However these solutions are not compatible with Japanese culture and their economic policy.

Japanese robot producers are not making money from the production of robots. Many Japanese firms design robots for their own use to boost competitiveness and quality, this makes the number of robots in Japan larger than any other country.

Political and technical reasons complete the circle of reasons of why the Japanese robot industry is far from the U.S.'s. The government allows accelerated depreciation for the purchase of sophisticated robots and then established their own leasing company to provide low cost robots to the private sector. These conditions make robot installation an attractive choice for robot users even though it requires high capital.

In the U.S. a companies' first application for robots is in sophisticated and complicated environments and this therefore reduces the possibility of success causing the company's management to get rid of robots from factory production altogether.[8] Overexpectation from robots or wrong tactical decisions causes the inefficient use of robots. Japanese engineers try robots first in their simple applications, then they go to more sophisticated tasks for robots. It makes the implementation success rate high because the technical staff needs time to understand the limitations of robotics.

Other reasons that make the robot penetration into the U.S. industries hard can be stated as; lack of knowledge about robots and inadequate appreciation for their potential usage.[3] Lack of standardization has also retarded the acceptance of robots. Since no organization in the robotics industry has dominated, there are not any standards in this industry.

1.2 ROBOTICS APPLICATIONS

Robots have rapidly evolved from theory to application primarily due to need for

-improved productivity

-improved quality

Applications of robots covers repetitive, dangerous, boring jobs instead of human workers. Practical and easy compatible areas for robots are;

- Machine loading and unloading
- Painting and materials finishing
- Welding
- Assembly operations.

For the initial introduction of the robots in factory, three D's or three H's work; "Dull, Dirty,Dangerous" or "Hot, Heavy, Hazardous" [1]

In all applications humans and robots have their inherent advantages over each other. A human is "cognitive, judgmental, and innovative" and On the other hand a robot can operate under all conditions including those which are repetitive and dangerous for humans. Robots are not subject to "fatigue, illness, or psychological pressures". [1]

The largest area of application for robots is in welding operations. Resistance spot welding and arc based welding processes require different machine characteristics for robotization. Both operations have unsuitable working conditions for man. During manual welding personnel safety requires workers to wear protective equipment and they have to carry heavy loads of spot welding equipment. A large determinant of the success of a robot arc-welding operation over a manual operation is the improvement in "arc on time". [3] Since most of the manual operation time is consumed to adjust the helmet, the respirator, and other protective devices. Arc on time percentages are very low for manual operations, as an average 30%. In addition the automotive industry has a shortage of highly skilled welders. But, a robot welder can increase arc time by working continuously to approximately 70%. The robots welds have consistently high quality and the result is high productivity because of minimization of nonproductive time in the welding cell.

Painting is another application for robots to ensure human safety and increase material savings. Robots remove humans from an undesirable work environment. The speed of production is also increased. The major advantages of using robots in painting are that:

1. They ensure the stability of a product quality and therefore make it possible to improve production planning and control.
2. They make it possible for a multiproduct mixed batch coating line.
3. They provide a continuous production operation and reduce the need for intermediate stocks.
4. They save on paint; and reduce the need for ventilation and reduce energy consumption.
5. They give relief from unhealthy operations.

Programming techniques used in robots are called "teaching by leading" and "teaching by showing". In these techniques a skilled human painter "leads" the robot the first time and then the robot repeats exactly same path. Material savings and improved consistency are achieved. For interior section paintings robots can be mounted on a vertical or horizontal line to reach these points. Machine loading and unloading applications have wide variety of applications, such as;

-Die casting operations

-Forging operations

-Press work operations

-Plastic molding

-Machine tool loading

-Heat treatment operations

Increased and consistent quality, shorter cycle times, increased production and productivity and safety are all advantages of using robots in the above operations.

The last and the most challenging area for the robots is assembly line operations.

1.3 SOCIAL and ECONOMIC JUSTIFICATION of ROBOTS

Robotics applications are expanding everyday. Choosing the best fitted robot for particular applications is the most important consideration for management. But first of all managers should decide the requirement of the robotics. Obviously, robots do not fit all manufacturing needs. There are some factors that should be considered by the firm before the installation of robots. Tanner summarized them as follows:

1) Complexity of operation: A robot cannot make a decision

by itself. They repeat the work that they are taught. If a job requires human judgment then robotics is not good for the application.

2) Degree of disorder: Even for the robots equipped with sensors, all robots perform their tasks in an ordered environment. If the environment is not appropriate for a robot then it should not be used.

3) Production rate and volume: For high volume production fixed automation operates with less cost; and for less output, it is better to use manual work. The technical limitations of robots and their compatibility to a company's production rate and volume should also be considered.

4) Economic justification.

5) Long term potential.

6) Acceptence of robots from top management and workers.

These are basic factors to be checked before going to implementation for future success of firms. Robotics brings labor cost savings, reduced WIP, increased throughput, and material savings if it fits into its organizational goals and structure. Management should be aware that robotics is not the only solution for better utilization and greater profitability.

Cost of Robots:

1) System purchase price: The cost of a robot itself is variable depending on its mechanical complexity, and the sophistication of its controller. Generally higher priced robots are considered cheaper to install, easier to

program, and require less special tooling.

2) Cost of special tooling: Integrating components of robots is required for full implementation. These are conveyors, feeders, or various types of end effectors.

3) Installation and engineering costs: Sometimes installation costs are included in the robot price. But in some cases factory management needs to change its layout again.

4) Programming cost: Robots could perform the job only if someone programs it. Efficient programming is the key issue for optimum use of robot and time saving.

5) Operating cost:This the cost of the power required to run the robot and other complementary equipment. This the lowest cost for consideration.

6) Maintenance cost: Like all other machinery preventive maintenance is required for robots too. But their reliabilities are considerably higher than most equipment.

7) Training cost.

These listed costs should be considered for the economic analysis. The greatest savings come from labor and material.

As in the case of other investment analysis, for robotics management is using typical evalution criteria:

1) Payback method; provides an answer to the question of the time required to recover a company's investment. At the end it gives the time in years.

2) Return on Investment: This is the approximate measure of

the value returned to the company on invested capital. Basically, it is the ratio of savings to the investment and it is measured in percentage. This computation does not account for time value of the money, nor does it account for the tax rate of the firm.

Both formulas have the same drawbacks, they are very sensitive to cost savings by displaced labor and to the cost of the operation and maintenance. It is hard to assign a certain value for them. Since these methods do not account for the time value of money, they cannot be related to profitability. As a final limitation, these methods do not account for the element of risk.

3) Internal Rate of Return and Net Present Value: These methods are utilizing the time value of money. So they need to have more accurately forecasted data. This is more suitable for profit analysis. The value of the IRR allows projects to be compared directly against the interest rates obtainable from alternative form of investments.

But both types of methods have inherent limitations for the robotics justification. These theories really apply only to situations where the nature of the operation is unchanged. In traditional manufacturing, the manufacturing process itself are unchanged. Robotics brings new benefits which are not quantifiable and consequently it changes the nature of the plant. The formulas are not capable of accounting for unquantifiable motivating reasons of employing robotics and essentials of the manufacturing industry. Much research is being focused on this issue, but suitable new methods do not exist today.

Essential error is coming because financial tools of the past consider capital equipment as an investment and labor as a cost. Modern manufacturing techology sees human capital as an asset and equipment as cost.

Another criteria for robotics implementation is performance of robots. Before purchasing of robotics there are some criteria to be checked. According to [2] these factors are;

-Operating characteristics

payload/ work envelope/ velocity/ repeatability

-Programming characteristics

control systems/ programming methods/ path control/ memory/sensors

-Robot manufacturer's checkpoints

previous installations/ evaluation of manufacturers.

As a final consideration of robotics implementation safety of robot areas could be said. Unexpected movement of robot might cause safety problems. To avoid such accidents careful robot cell design should be made. Training of people on robot functions plays an important role.

2. FLEXIBLE MANUFACTURING SYSTEMS

2.1 SCOPE of FMS

Today's competition in the manufacturing arena forces firms to produce high quality in a short life cycle and in wide variety. At the beginning of century, the market was ready to accept and buy every product. Henry Ford's statement is clearly explaining the potential consumer attitude then: "People can order any color of car as long as it is black." Obviously, this approach is not valid now. After World War II, efficiency and quality improvement concepts became the backbone of being a leader in the industry environment. Consumer needs changed toward better services, longer lived products, and after the 1970's new models of products. In the 1980's, high productivity and flexibility in manufacturing were added to the quality and efficiency concepts. Production with a wide variety and the lowest cost is required to serve today's customer needs and to survive as a competitor in the market.

To reduce cost, and improve productivity, factory management is looking for better utilization of capital equipment. "Mass production" or "hard automation" is the most suitable manufacturing system for the continuous production of limited variety to obtain higher utilization and lower cost. But as indicated before, market needs drive the firms for wider product selection. Hard automation does not allow a quick product change. Because in this system, highly specialized equipment is used and they would need hardware modifications for a product change but this takes time and big a large effort accompanied by high cost.

On the other extreme, job shop working has much more flexibility to change the design of a product than hard automation. But it lacks high volume production. Between these two extremes, mid variety/mid volume production are seen as a problem area[9]. Since a fixed automation system is not flexible enough for product variability, mid volume/ mid variety production manufacturers generate their own solutions. But, most of the time the following summarized problems, by Maleki[9], are associated with generated solutions;

a) poor utilization of machine tools,

b) increased lead time,

c) increased in-process inventories,

d) poor use of tooling,

e) insufficient use of floor space.

Production cost increases as a result of these problems. Additionally, social factors are considered advanced reason for implementation of FMS in a production line. The factory has always been an unhealthy environment for workers. People are not willing to work in such an environment unless they are paid higher wages. Worker societies forced the manufacturing managers to provide better conditions and higher wages by using legal pressures. It increased the cost and made full utilization of the workers& equipment unavoidable. All of these reasons are good motivational factors for FMS/CIM implementation in manufacturing lines as the most suitable solution for listed problems above.

Computer Integrated Manufacturing (CIM) is a coordination way among computers, material handling devices, and the flexible NC machines to meet the mid variety/ mid volume production needs. Maleki[9] categorizes CIM technology into three groups considering flexibility and production volume:

1) Special Manufacturing System: This system provides the least flexibility but the highest production rate. In this system the machines are linked together on a fixed path. The sequence of operations is dedicated to a family

of parts.

2) Manufacturing Cell: This is the most flexible division of CIM. A set of NC machines are grouped to process different part families. Parts may be randomly selected for machining.

3) Flexible Manufacturing System: This system offers variability and production rate between the two previously discussed manufacturing systems.

There are different definitions for FMS. Merchant[10] defines then as follows:

> "A flexible manufacturing system consists of an integrated assembly of work stations,such as machine tools and other equipment, together with a means for transferring components (workpieces, tooling, etc.) automatically through the system, all operating under full computer control for the purpose of carrying out manufacturing production of a mixture of parts or products with a minimum of manual attention."

Maleki[9] defines FMS as:

> "A computer controlled manufacturing system using semi independent numerically controlled (NC) machines linked together by means of a material handling network. Flexibile manufacturing systems are integrated systems which can help users to achieve the goals of increased profitability through increased productivity."

Johnson[14] underlines five basic flexibilities of manufacturing: Part mix, addition of new parts, routing, design change, and volume. Kegg[15] added to these types of flexibility, flexibility in factory systems meaninig easy accommodation of new hardware or software systems.

Integration, intelligence, immediacy are common characteristics of FMS. Integration means interdependency of system components. Intelligence is the ability to interpret given input and to produce output based on the user's expectations. Immediacy is the speed in which the system can react to changes. Comparing to other manufacturing systems, FMS is a data intensive manufacturing system. Job shop was a relatively labor intensive system and mass production was a capital intensive system.

Dunlop [10] listed the benefits of FMS as follows:

A) Short run responsiveness to the day-to-day problems on the shop floor, such as;
   1) Engineering changes
   2) Processing changes
   3) Machine availability
   4) Cutting tool failure

B) Long run accomodation to alter the system, in a cost effective manner as required to support;
   1) Changing product volumes
   2) Different part mix
   3) New product additions

For improved productivity and higher profitability the following objectives should be achieved by employing FMS.[9]

A) Reduced labor by;
   1) removing operators from the machine site,

2) eliminating dependence upon highly skilled machinists,

3) providing the "nucleus vehicle" to support unmanned operation.

B) Improved machine utilization by;

1) eliminating machine set-up,

2) utilizing automated features to replace manual intervention,

3) providing quick transfer devices to keep the machines in the cutting cycle.

C) Improved operational control by;

1) reducing the number of uncontrolled variables,

2) providing tools to recognize and react quickly to deviations from the plan,

3) reducing dependence upon human communication.

D) Reduced inventory by;

1) reducing lot sizes,

2) improving turnover,

3) providing the planning tools for "just- in- time" production.

FMS is the first major breakthrough in CIM by bringing together developments in process control, material handling, and computer technology.

2.2. FMS and RELATED TECHNOLOGIES

The planning, design, and implementation of flexible manufacturing systems involve various other concepts that need to be considered. These concepts are the technologies involved in FMS and other organizational issues. The technology components of FMS have been used in manufacturing lines, but FMS integrates them in the same unit.

Group technology, JIT inventory and production, zero defect and error traceability are the contributing concepts of FMS. Automated material handling, programmable production processing (NC machines, Computer aided process, robotics) and robotized manufacturing cells are the technologies associated with FMS. FMS uses high technology equipment such as NC machines, sophisticated handling devices and production techniques which allow the wide variety of products to be manufactured simultaneously, in varying amounts.

McGinnis [16] defines the attributes of FMS as;

a) versatile workstations, capable of processing a mix of part types with negligible change over time.

b) a material handling system capable of providing the required part routing and demand.

c) comprehensive, real-time computer control of part dispatching and routing.

For fully sized occupation of these three attributes of FMS in a system, it is required to understand the related technologies of FMS. In the simplest form, they can be set as numerically controlled machines for flexibility of tooling, change in production, and material handling systems for flexibility of path and load. A computer controlled network system is the third component of a triangle that describes the full FMS requirements.

As a first major driven factor for FMS , development of NC programmed machines can be counted. Flexibility of the system largely depends on the flexibility of the NC machining centers being used. NC machines allow the manufacturing processes to be done automatically. The need for NC machines was created by a need to find a way which was more efficient and economical for different batch sizes, and different kinds of products. Finally, automatic parts programming is the bridge for the gap between CAD and CAM. This technology aims to find relatively practical solutions for rapidly changing parts in the manufacturing environment.

The material handling system (MHS) is the backbone of FMS. The MHS delivers workpieces to the machining centers and to other modules. One function of MHS is to sustain the efficient movement of workpieces from raw material storage to the final inspection. The MHS is also responsible for picking up parts that have been processed or inspected.

There are different types of MHS equipment which allow different degrees of flexibilty. After cost, plant layout, and product considerations one of the following in installations could be implemented [9]:

-roller conveyor

-rail guide or elevated tracks

-rail guided linear transporter

-tow lines

-automatic guided vehichles

-robots

In FMS, system integration at all levels is essential. This integration is possible by the use of different processors and by the proper communication channels within hierarchical network levels. FMS hierarhical network includes [9] FMS operation level, cell operation level, individual operation level, and functional level.

Cellular manufacturing is the gathering of all machines needed to process similar parts completely. Robotized manufacturing cells are also a great tool for FMS.

3. ROBOTICS as a PART of FMS:

One of the key benefits of robots within an FMS is their versatility followed by their consistency, and high quality at work. A robot can be programmed for new tasks and with a variety of end effectors and a robot can perform new tasks to fit the needs of production lines.

From the definition of robots, a robot's features can be listed as multifunctionality, programmability, automatic working, easy handling, and task variability. Variability in task relates a robot to the flexibilty of automation. To meet changing manufacturing environmental needs its programmable characteristics gives them a powerful tool.

In short, a robot with its flexible applications has great potential for successful FMS implementations. Within the manufacturing lines, robots perform two distinct functions: value and non-value added work[zisk and palmer] welding, painting, and assembly operations are the value added operations; material handling is the non-value added operation. Both functions would be applicable in FMS.

The majority of applications are focused in the area of material handling. Robots in material handling are gaining more popularity as manufacturing cells are driven smaller. Robots drawback comes from their work envelope size. Parts that need processing should be brought to robots for operation. Therefore extra material handling system parts are required for full integration of robot. Since the robot works without any operator intervention, the parts must be in proper orientation.
Stationary or moving robots can be used by considering the requirements of the job specifications. Moving robot applications are generally seen in places where the process time at each work station is long compared to the overall handling time. For cost justification, the added robot cost, the cost of positioning, and movement of the robot should be compared.

A large part of the cost of FMS comes from robots and other material handling equipment. Therefore cost justification, before the implementation of robots, and of robot cells in the FMS system should be critically evaluated.

An advantage of choosing robots for the loading and unloading of workpieces in and out of machinery with short response time. In robot selection and implementation, proper interfacing with both material transports and machine tools must be planned and implemented.

Robots used for material handling are well suited to workplaces with limited space. When used in FMS, a robot's compatibility with other material handling systems and modules must be assured.

For welding applications, using robots with sensors makes the applications more successful. Welding robots should be implemented for the success of an FMS system. As a general rule, the simplest welding robot should be used wherever it is practical[hartley]. The use of robots increases the efficiency of welding time from 30% to 70%. If the robots can be combined with an appropriate material handling system, a cost effective FMS could be implemented. The main problem in installing robots is to provide sufficiently accurate jigs. For the best fitting every firm is trying to find an optimal solution. One alternative is to mounting the robot on turntables. Another one is that a robot with two arms.

There is a huge potential for flexible automation in assembly. Flexibible assembly involves the use of robots. Robots in assembly lines of electronics and automative industries are widespread. The main operations in assembly are pick up the workpiece, moving it, and fixing it. In addition to these routin operations, robots can perform more complex tasks in assembly lines.

Robots have many benefits if they have chosen in parallel of the organization goals and objectives. Robots are the most suitable devices for a successful application of FMS if they implemented according to factory layout and production features. At the same time, robots are decreasing the need for labor. Countries in which labor cost is cheap, robotics is not a profitable choice. Social consideration is as important as economical aspects. Integration of robots within an FMS system gives a powerful tool to management for the future competitiveness.

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