CHAPTER 2

LITERATURE REVIEW

Over the recent years, many countries have implemented robotic systems to gain competitive advantage and to build strategic capabilities of manufacturing organizations. A considerable amount of literature relating to various aspects of implementation of robotic systems has grown over the years. The contribution of these numerous individual studies exist in isolation, but taken together, they have many of the critical elements necessary for successful implementation of robotic system. Thus, a thorough analysis and understanding of various aspects of robotization is necessary for development of framework for implementation of robotic system in Indian industries. Fig. 2.1 is a complete overview of the classification of literature on various aspects of robotization.

FIG. 2.1 AN OVERVIEW OF CLASSIFICATION OF THE LITERATURE ON IMPLEMENTATION OF ROBOTIC SYSTEM
In the following sections each entry in the classification scheme in Fig.2.1 is discussed individually.

2.1 PLANNING FOR IMPLEMENTATION OF ROBOTIC SYSTEM.

Proper planning for implementation of robotic system is imperative for maintaining a strong competitive position in today's dynamic manufacturing environment. Analysis of literature suggests that planning oriented literature can be classified in two parts. 1. Technical Planning. 2. Personnel Planning.

2.1.1 Technical planning

2.1.1.1 Plant Survey and Selection of the best application.

Macci and Gemmaro C. [1] stressed the need for careful analysis of worker performed task to be given over to robots.

Nof S. Y. [2] stressed the importance of comparative study of abilities and limitations of industrial robot and human before selecting a job for robotization. He suggested that this approach will help to achieve two fold objectives.


2. To provide specification of appropriate robot for given task.

Behnumark J.A. [3] suggested seven technical and economic criteria for locating the good robot application. If the potential application satisfies these criteria, then it is considered as an attractive application for robotization.

Ottenger V.L. [4] suggested that two things must be kept in mind during a survey of plant to find robot application. First, very vivid mental image of capabilities of robot. Second, separation of task that add value from those that add none. He also stressed the need for collection of data in technical, economic and human factors areas during the plant survey.

Ottenger V.L. [5] also suggested decision tree approach for evaluating options during the development of robotic system concept. He further stressed the importance of reporting the overall development to the management.

Cris Morgan [6] suggested that scope, time spent and cost of feasibility study have direct relationship to the quality of the results and can considerably reduce the elements of uncertainty connected with decision of robotization. He proposed three phase approach for feasibility study.

Cavallaro Sal [7] emphasized the importance of planning and investigation of the process before considering robotization.

Villeneave and Laurent [8] established a knowledge_base to assist robot task identification.

of robots. He has considered following four phases: 1. Preparation, 2. Engineering, 3. Implementation, and 4. Follow up.

2.1.1.2 RTM Analysis and selection of robot

Hanify Dennis W. [10] has suggested a methodology to establish robot capabilities needed to meet job requirement and robot selection criteria.


Nof S.Y. [12] has also described a methodology to provide formal system to evaluate and optimize the robot task work prior to detailed control programming.

Kinsey and Gracne [13] emphasized that best approach to select a robot is to use a step by step process, i.e., analysing the task, environment, machine capabilities. They further stated that a robot selection criteria must include: payload analysis, positioning requirements, programming efficiency, work envelope definition and machine speed.

Roger and Mark A. [14] have suggested expert system approach for selection of correct robot for an industrial process.

Melliechamp J.M., Cassidy G., and Browne J. [15] have developed a prototype expert system ROBOSPEC for selection of robot.

2.1.1.3 Workcell design

Thomas R. [16] stressed on the need for proper co-ordination between robot and activities of the other equipments. He divided the control activities into three broad categories i.e. sequence control, operator control, and safety monitoring.

Noro K. and Okada Y. [17] have pointed out the importance of robot work-station design from ergonomic point of view.

Cris Morgan [6] has stressed the need of reviewing production planning and control system to maximize the robot utility, designing and building new jigs and fixtures, and incorporation of various safety measures while designing robot work-station.

Starrfer R.N. [18] has suggested graphic simulation approach for robot work cell design.

Groover M.P. [19] has classified the workcell design in two parts, 1. Physical design of workcell, and 2. Design of control system which will co-ordinate the activities among the various components of the cell. He has also discussed the various robot work cell layout.

2.1.2 Personnel Planning

2.1.2.1 Top management’s commitment

As is true with many complex projects/programs such as quality improvement programs,
management's commitment is a critical element necessary to decide about acquisition of robotic system.

Felting and Kathleen Shaw [20] have outlined the tactic that should be used to implement industrial robots. Its purpose is to reduce management's resistance. They have developed a technique called an educative approach and demonstrated its usefulness for large scale welding operation.

Stock Pole and Peter T. [21] consider that management still contained with factors causing human resistance to robotic installation.

Gold B. [22] found that company success in technology improvement is closely related to the reactions of managers to innovative proposals. Management policy on technology improvement is signalled to the employees through the actions of management concerning technology.

2.1.2.2 Use of process Champion

Merdith J. [23] suggested the championing process for planning new manufacturing technology. From the successful automation projects he studied, he noted that there consistently existed a champion for the project. This person usually is in upper management. The concept of process champion is closely related with the concept of management's commitment. The champion is the source of idea, salesman for idea, trouble shooter and day to day administrator of the project.

2.1.2.3 Selection and training

Carrico and Lloyd R. [24] have linked the success and failure of robotic application with the degree of knowledge and interest that management applies to the role of education and training.

Osborne and David M. [25] recommended proper training before and after robotic installation. They have elaborated the main areas of training. They have also examined the timing, curriculum, personnel selection and goal of each of these areas and outlined the program that could be implemented by user to train his personnel in the use of robot.

Hinson R. [26] divided the robotics training that should take place in a company into five categories: awareness, justification, application, operation, and maintenance and safety.

Edward M. [27] has criticized the training provided by the suppliers to the consumer companies for being superficial and inactive. His criticism is centered on the three aspects: 1. the isolation of training from application. 2. the lack of consumer company control over training content. and 3. lack of reliable methods for assessing the effectiveness of training.

Carter D.L. [28] has suggested structured programme of training for different personnel:

1. Supervisors - To improve management skills.
2. Manufacturing engineering personnel - To widen the knowledge base
for effective functioning.
3. Technical personnel - To generate a pool of multi-skill operators in order to institute advanced manufacturing systems.

Voelkel J. [29] has stressed the importance of people in a manufacturing organization by quoting that "Productivity does not just come from technology" it comes from the people who use it.

According to a survey conducted by Manji J. F. [30] training increases the productivity but also enables the operators to make better decisions, improve quality, boost morale, and results in the workers taking pride in their job.

2.2 FINANCIAL JUSTIFICATION

Any financial investment in economic activities requires justification for the purpose of committing capital. Consideration of research related to financial justification issues requires an understanding of basic economic concepts and what has been traditionally used for financial justification of robotic systems. As the Fig. 2.1 explains, literature on financial justification can be classified into five distinct themes. These themes are:

1. Traditional capital appraisal techniques and risk analysis.
2. Cost and benefit analysis.
3. Mathematical models.
4. Expert system.
5. Strategic value of intangible benefits.

2.2.1 Traditional Capital Appraisal Techniques and Risk Analysis

Traditional capital appraisal techniques have been widely used for financial justification of robotic systems, although they have been criticized for various reasons. Payback period and NPV are still the most frequently used methods by the practitioners.

Knott Kenneth [31] developed a model for economic evaluation of alternative configurations of robots. The model considers time value of money and uncertainty of time in technological development and inflation.

Fletscher G. A. [32] had classified the literature related to justification of robotic systems into three categories: those utilizing accounting methods, payback period method, and discounted cash flow method.

Stauffer R. N. [33] observed that loading and unloading operations can be justified, considering only first order effects, within a time frame of two to three years.

Van Blot and John P. [34] suggested that robotic justification is radically different from traditional financial justification and stressed the need for strategic and tactical justification of robotic systems.
Kozyrev Yu. G. and Tarasevich I.V. [35] have established a methodology for assessing economic viability while designing a industrial robot model and planning a robot assisted system.

Lewis A. [36] developed a set of economic models for investment analysis of robot application. These models consider various parameters such as capital cost involved, productivity improvement, resulting savings, Government grants, tax rates. He has also pointed out the inadequacies of traditional financial justification techniques.

Sullivan and William G. [37] have developed a software for economic justification of robot. This is accomplished through an after tax present worth assessment of cash flow difference between manual operation and robot application.

Nalin Kurilaka [38] has developed empirical simulation model for justification in robot investment, using capital asset pricing model for proper evaluation of riskiness of cash flow.

Knottel K., Bidanda B., and Pennebaker D., [39] have proposed an analytical method to carry out the economic analysis of robots. It performs

1. Economic analysis for justifying the initial investment to purchase robot.
2. Economic analysis of effect of design of the product upon the application of robot.
3. Economic analysis of the investment for providing tooling and equipment to perform specific task or operations.
4. Analysis of the effect of alternative policies on cost and price.

According to a survey conducted by Sommer T. and Gupta V.P. [40], 61% Japanese and 74% of American industries rely on Payback period method in spite of its well known drawbacks and limitations.

2.2.2 Cost and Benefit Analysis

There are many benefits of robotic system reported in the literature. Several financial justification analysis are built on costs and benefits.

Mayer Ronald J. [41] presented step by step method for economic justification of robot and automation system. He has also suggested methods for identifying and quantifying various costs and savings associated with robots.

Norman L., Naidia [42] pointed out the limitations of conventional accounting system for robot justification and suggested that cost of quality, increased capacity utilization, employee costs, and asset requirement should also be considered for realistic robot justification.

Khahorst H.T. [43] has identified 14 critical cost factors to be considered in justification of robotic system.

Primrose P.L., and Leonard R. [44] have suggested that proper identification of robot costs and benefits should be done before using any appraisal technique.
2.2.3 Mathematical Programming Models

These methods seek to determine the best course of action of a decision problem under the restriction of limited resources. If the objectives and the constraints of the problem can be expressed mathematically as a function of decision variables, a mathematical model is formed. However, these methods are basically evaluative methods and are often complex to comprehend by decision makers. Hence, there use for justification is very limited.

Nanaj Bartholomeow [45] presented mathematical model for selection and evaluation of robots. The model considers several critical factors such as maximum return on investment, objective factors such as payback value. To give a more complete cost perspective, subjective factors, such as hardware and software, vendor performance and internal adaptation, are also incorporated in the model.

2.2.4 Expert System

Use of expert system for justification of advanced manufacturing technologies, like FMS, CIM is reported in recent literature. However, very little literature is available on application of expert system for robot justification.

Parsci, Hamiel. R. losivile, and Crown Robort [46] have developed a prototype expert system for selection and justification of robot for automation project.

2.2.5 Strategic Value of Intangible Benefits

Kaplan [47] remarks that the contemporary cost accounting is based on the mass production of mature product with known characteristics and stable technology. As companies move towards automated flexible factory with its high fixed cost and low variable costs, minimum direct labour and small batch production of variety of products, the assumptions of contemporary cost accounting methods will become increasingly irrelevant. Hence, new measures that deal with non-traditional and semi-quantitative performance indicators will be required to support long term financial performance.

Frazelle E. [48] suggested AHP technique to evaluate material handling alternatives.

William G. and Sullivan P. E. [49] have also pointed out the need for upgradation of financial justification from tactical domain to strategic domain.

Hall and Geogory [50] consider that robotic justification is radically different from traditional justification methods. They have suggested that robotic justification methodology should be supplemented with three key additional factors, strategic robotic benefits, tactical manufacturing requirements and sociological requirements.

Brook and Jake [51] have discussed four strategic factors that should be included in robotic evaluation. These are: basic application fit, economic justification both obvious and strategic, non-economic justification, and organizational environment check.
2.3 ROBOT WORK-STATION SAFETY

*CISITA* [52] provides accident prevention guidelines and techniques for most of the equipment found on the factory floor, giving due consideration to the potential for human entanglement, shearing action, trapping, pinch points, molten metal ejection, electrical shock, high heat etc. and all these precautions are applicable to robotic workcells and to robot itself.

Willson Robert D. [53] suggested use of ultrasonic, infrared or microwave based personnel sensors to sense the human presence in a danger zone. He has also suggested the application of computer generated speech to warn the worker of his entry into hazardous zone when worker inadvertently or purposefully crosses a safety barrier.

John M. Howard [54] considers that there are three aspects to robot safety: protecting the curious outsiders, protecting the individuals who work with the robot and protecting the robot itself.

Sugimoto N. and Sawaguchi K. [55] made an attempt to analyze available data on accidents and near accidents to point out dangerous operations involving industrial robots and compiled a document on fundamental technology and appropriate safety measures.

Ziskovasky J.P. [56] suggested that robot safety should be a planned and continuous process. He further pointed out that safety planning can be reduced to a simple relation.

\[
\text{Robot Safety} = R^2 \quad (\text{Robot Requires Respect})
\]

John L. Cox and Brent Butter J. [57] have stressed the need for protection of workers from robots. They have divided the protection into two forms, mental protection and physical protection. They considered that if mental protection is properly installed, there will theoretically be little need for physical protections other than the painted lines, fences and kill switches.

Machine Tool Trades Association in the United Kingdom [58] has outlined and published a guide for safeguarding industrial robots and have also developed framework for risk assessment.

Jones R. And Dawson S. [59] have presented method for collection and analysis of performance data on robot use to identify problems and assess the implications of these problems on safety and reliability. They have also suggested the strategies and tactics which management and specialist personnel may adopt to deal with the problem of safety and reliability in terms of the design, implementation and use of robotic system.

Bellino J.P. [60] pointed out that majority of robotic accidents have occurred during the programming/teaching mode or during trouble shooting or maintenance mode. The cause of these accidents has been either equipment failure or human error. Keeping this in mind, he has suggested a design approach to help in preventing occurrence of accidents.
Nicolai P. [61] has suggested use of a flow chart for development of accident prevention procedure. He has also suggested the classification of data according to categories of problems. He has also presented a list of possible accident hazards associated with use of robots; their causes and pointers for solving the problem.

Parson [52] emphasized and suggested that the robot work-station safety can be enhanced through investigation of robot accidents and near accidents from ergonomic point of view.

2.4 RELIABILITY AND MAINTENANCE OF ROBOTIC SYSTEM

Perhaps no other single cost factor in manufacturing operations has been as neglected, misunderstood, and mismanaged as maintenance. [63]

Engelberger J.F. [64] suggested that manufactures should embark on a comprehensive reliability program to achieve a target availability factor of 98% or better.

Howard J.M. [54] has suggested 10 points human factors guidelines for maintenance of robotic systems.

Many of the robot manufacturers provide a list of a recommended spare parts that should be stocked by the user. Ottinger [65] suggested a budgetary estimate, for spare parts, of 10 percent of the robot base price.

Dhillon B.S. and Rayapati S.N. [66] have pointed out that in real life situation human participation is needed, hence, for realistic reliability analysis human error should also be included in reliability analysis.

Groover M.P. [19] states that robots are generally having high reliability. But the complexity of these systems causes occasional failures and requires an effective maintenance program. He stressed the need for highly skilled and trained maintenance personnel and appropriate preventive maintenance and spare parts policies.

According to Scott B. Peter [67] the reliability of robot is greatly affected by the working environment. He stressed the need for different design strategies to maintain high robot reliability under varying working environment. He also suggested that the robot should have fault tolerance and protective redundancy to provide for continuous operation of robotic system.

Bernard Hodges [68] suggested that maintenance engineer should make regular checks from basic monthly greasing checks to quarterly, half yearly and yearly checks.

Sur B.N., Shome S.N., and Jhankar Basu [69] have developed a probabilistic model of failure of a robotic system due to its subsystem failure, critical human error and common cause failure.
2.5 ORGANIZATIONAL AND SOCIAL ISSUES

Resenbreek, H.H. [70] has described the use of robot to replace unskilled, repetative human labour and associated social issues.

Laslaguec Yes [71] has discussed the social aspects of robotics such as volume of unemployment and robotics, robotics and skill, robotics and working conditions. He has also underlined the direct consequences of robot application.

Taylor John E. [72] suggested for meshing of the robotics and social aspects in order to bring about economic and technological revitalization.

Lyman John [73] has critically analysed the role of operators in robotic system.

Cris Morgan [6] states that by and large the majority of managers find a workable arrangements with their work people based on a mutual recognition of what is practical and what is not. The introduction of robot makes a change to the status quo and is therefore subject of negotiations.

Scott P.B. [67] believes that replacement of human by robots is not of itself, such a bad thing. He stressed that what must be remembered is why replacement of robot is desirable at first place, what the long term results would be, if such replacement did not take place, and why being prevented from working should be considered so awful.

Grooves M.P. [19] considers that the field of robotics will have impact beyond the immediate workforce. Society in general will be affected by this technology in the areas such as productivity, education and international economic competition.

Argot L., Goodman P.S., and Schkade D. [74] have examined worker’s reaction to introduction of robot in one factory. The study focuses on understanding workers psychology to this technology and the manner in which it was introduced.