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A Task Analysis and Projection of Future Tasks for Industrial Robot Maintenance Mechanics: With Implications for Education and Training

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Gordon Minty

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A TASK ANALYSIS AND PROJECTION OF FUTURE TASKS FOR INDUSTRIAL ROBOT MAINTENANCE MECHANICS: WITH IMPLICATIONS FOR EDUCATION AND TRAINING

By

Gordon Minty

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ABSTRACT

A TASK ANALYSIS AND PROJECTION OF FUTURE TASKS FOR INDUSTRIAL ROBOT MAINTENANCE MECHANICS: WITH IMPLICATIONS FOR EDUCATION AND TRAINING

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The following objectives served as the key purposes of the study: 1. to identify the tasks necessary to perform the job of industrial robot maintenance mechanic in Michigan, prioritized by frequency performed, criticalness, and opportunity to learn on the job; 2. to contrast tasks identified and tasks projected for 1990; 3. to identify the structural difficulties in existing job classifications for the installation, maintenance, repair and operation of robots. Implications for education and training were drawn from the objectives.

An inventory of tasks was developed by: development of task statements through review of robot operation, repair, and maintenance manuals; adding existing task statements related to skill areas identified; consolidation by teacher experts; and review by robot maintenance experts.

The data were collected by individual interview with a checklist of tasks, telephone interview, and follow-up mailed questionnaire. Because very few incumbent workers were identified, the inventory of tasks was verified and prioritized by representatives of the six manufacturers that made 97% of robot sales in the U.S. in 1980.

Identified as necessary for robot maintenance mechanics were 165 tasks. They are within six duties: Installing and Moving Robots; Performing Preventative Maintenance; Maintaining Robots; Performing Repairs; Programming; and Communicating. The actual tasks performed depends on the robots the robot maintenance mechanic is responsible for.

Few changes will occur between tasks performed today and tasks performed in 1990 because robots purchased today will still be in operation in 1990 and changes in robot design will generally require the same basic task performances.

Few robot maintenance mechanics exist in Michigan manufacturing plants for two reasons. One, most plants that have robots have too few to occupy a full-time maintenance mechanic. Two, most tasks can be performed by occupations already in the plant and unions are interested in continuing established occupations.

There are few opportunities for robot maintenance mechanics except where diagnostic abilities beyond those that presently exist in the plant are needed. Careful consideration should be given to employment opportunities for robot maintenance mechanics.

ACKNOWLEDGMENTS

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CHAPTER I

OVERVIEW OF THE STUDY

Introduction

"Ready for the robot revolution? Well, it's already begun. There are thousands of robots at work today in factories throughout the United States and abroad."[1] "There are about 3,200 robots in use in the United States and more than 10,000 in use in Japan."[2] The 1982 Robotics Industry Directory lists fifty-eight companies in the United States that are building robots.[3] The industry has grown rapidly over the last five years and projections are for accelerated growth. Robot Systems Incorporated project the industry to be a $500 million industry in 1985 and a $2,000 million industry in 1990.[4] Hunt and Hunt report:

> We expect strong growth in the utilization of industrial robots in the decade of the 1980's. By 1990 the total robot population in the U.S. will range from a minimum of 50,000 to a maximum of 100,000 units. Given our estimate of the year-end 1982 population of approximately 6,800 units, that implies an average annual growth rate of between 30 and 40 percent for the eight years of the forecast period, or roughly a seven-to-fourteen-fold increase in the total population of robots.[5]

Obruyat gave four reasons for the rapid increase in the use of robots. Previously there was insufficient return on investment, caution about accepting the new concept, stiff competition from other methods of automation, and finally technology just wasn't there for many applications.[6]

Dzengeleski and Goode, in addressing the question of growth in the robotics industry through to 1980, contended that a

> . . . significant reason for the slow growth in robotics is the lack of installation and maintenance personnel at the user level. Right now there is a shortage of these people. One result is that some companies have purchased robots but have not installed them, leaving them sitting on the loading dock.[7]

In March 1982 the Senate subcommittee on employment and productivity met. Education and Work, summed up the message from several witnesses. "Technological advances particularly in computers, robotics, and biotechnology are likely to boost U.S. productivity by the end of the century. But crucial to higher productivity is training of workers to cope with the new technologies."[8] George Arsell, Dean of the School of Engineering at Rensselaer Polytechnical Institute, testified at this meeting saying with the coming technological changes

> . . . there will be a demand for far fewer, but very highly skilled workers; those who will be able to design and build those complex manufacturing systems, and those who will be able to maintain them. To begin to address its productivity problem, the U.S. must be ready to face huge numbers of dislocated workers as well as train a new generation of engineers and technicians.[9]

Hunt and Hunt state:

> The largest single occupational group of jobs created by robotics will be robotics technicians. This is a term which is just coming into general usage: it refers

> to an individual with the training or experience to test, program, install, troubleshoot or maintain industrial robots.[10]

Brookings reports:

> Simply stated, technicians need to be trained to help design, produce, install, program, and maintain modern robots and other computer-controlled 'automated' equipment. This training must come from a combination of electronic, mechanical, and computer programming technical curricula. To prepare such a 'super' technician in the traditional two year postsecondary program may seem unlikely -but it's not impossible.[11]

Indeed, several Michigan community colleges have begun programs in robotics. Macomb County Community College and Oakland County Community College have students enrolled and Washtenaw County Community College and Schoolcraft Community College, in Livonia, have developed robotics programs. Courses were developed at the following community colleges: St. Clair County, Henry Ford, C. S. Mott, Gogebic, and Grand Rapids Junior College.

Michigan companies such as General Motors and Ford Motor Company were developing training plans for the repair and maintenance of robots.

The following study was instigated to provide trainers and educators information on the work performed and expected to be performed by robot maintenance mechanics.

Statement of the Problem

The problem of this study was to analyze the tasks performed by the industrial robot maintenance mechanic (the person who performs the installation, maintenance, repair, and operation of industrial robots) in Michigan, and project the tasks expected to be performed in this occupation in the year 1990.

With the changing technology in this industry, an attempt was made to address tasks and performances necessary not only for today but for 1990. Types of skills necessary in the future should be recognized in the education and training of these workers. From the analysis, implications for education and training were drawn.

The problem addressed, contributes to our readiness for what Chin calls the robot revolution.[12] Various authors have pointed out the need for training and retraining for the robot industry. More skills necessary for technicians and maintenance workers are specifically mentioned in the introduction. What these training needs are, and what tasks will be performed in the near future, are questions addressed in this study. The necessary training in high technology or in any other area cannot be accomplished before an analysis of the work is done and the training needs have been identified.

Objectives of the Study

The following objectives serve as the key purposes of the study.

1. To identify the tasks necessary to perform the job of industrial robot maintenance

mechanic in Michigan, prioritized by frequency performed, criticalness, and opportunity to learn on the job.

2. To contrast tasks identified for use today and tasks projected for 1990.
3. To identify the structural difficulties in existing job classifications for the installation, maintenance, repair, and operation of robots.

Implications for the education and training of persons for these occupational positions, will be drawn from the three previous objectives.

Need for the Study

The State of Michigan has a vital interest in robotics and other high technology areas. With the decline of the automotive industry, Michigan's potential in the high technology areas is being studied. In former Governor Milliken's _A Plan to Increase the High Techology Component of Michigan's Economy_ he states, "It is also proposed that special emphasis be placed on upgrading and focusing the state's training resources on key high technology areas, including robotics."[13] Lyddon points out that ". . . currently, in Michigan, there is no single comprehensive source of information on the skills of the work force."[14]

Generally, discussion on the robotics industry centers on the need for engineers and technicians, but Flanders projects, "As in the past, they [college graduates] will make little inroads in the crafts; workers in greatest demand for skilled occupations will continue to be those who have vocational training."[15] Flanders also projects

> . . . the creation of new occupations and the decline or disappearance of familiar ones are natural results of our technological development. With regard to education, we must recognize that our advancing technology will require most workers to obtain additional training throughout their careers. In some instances, complete retraining for new occupations may be necessary.[16]

Trouteaud points out:

> The industrial education community will be instrumental in the true robot revolution, for without people -- engineers, technicians and support personnel -- wide scale implementation of Industrial Revolution II cannot take place. The need to educate is immediate.[17]

Several Michigan community colleges have responded to this need to educate and train by designing programs and courses in robotics. Hunt and Hunt point out: "Given that the robotics technicians will be one of the keys to the spread of robotics technology, it is important that the Michigan community colleges ensure that their product is what employers need."[18] Analyses of tasks necessary for the occupations have not been done. A task analysis can serve as a basis for curriculum development.

No published research on the robotics industry's vocational training needs had been identified by this writer at the outset of this research project.

Background

Although literature refers to the robotics revolution the robot itself has evolved through technological advancements. Hatfield, in 1928, wrote:

> An automaton, by analogy with the human model, should consist of three parts: limbs to work with, senses to perceive what it is working with, or what result it is producing, and a brain to regulate the action of its limbs in accordance with the perceptions of its senses. Needless to say, we are striving to create, not a Frankenstein's monster, a Robot, a mechanical servant which can be set to any simple task, but thousands of different automata each specialized for a certain task. In our machines we have already developed limbs of a power and precision exceeding our own many many thousand-fold. In our instruments, we have developed senses exceeding our own, in many cases, a million-fold in sensitivity. Indeed, they are capable of receiving impressions, such as magnetism, which are qualitatively imperceptible to our natural senses. What we have still to develop is the mechanical brain, the link between instrument and tool.[19]

Hatfield provides an important link in the evolution of the robot. He refers to the Greek word automaton which means something that behaves in an automatic fashion. He suggests that the stage of technology at that time lacked a mechanical brain.

Chin reports that the term automation was used for the first time in 1935 at the General Motors Fisher Body division when D. S. Harder organized an automation engineering department in the Grand Rapids plant. The term was a combination of the words AUTOMatic and operATION.[20]

The sophisticated computer has become Hatfield's mechanical brain and is the technology which wasn't there before. The bringing together of advanced automation and computers has caused the robotics industry to grow dramatically. This has also generated demands for new skills which are necessary for the growth of the industry.

Methodology and Procedure for Data Collection

The first objective of this study, to identify tasks necessary to perform the job of industrial robot maintenance mechanic, was realized by:

A. Reviewing operating, service and installation manuals of manufacturers whose equipment will be maintained and operated during the performance of the job incumbents' duties.

B. Compiling tasks identified through the materials.

C. Adding task statements of existing occupations (for which an analysis had been done) identified as having components of the new occupation.

D. Consolidating the task statements.

E. Having the task statements reviewed by selected experts for additions, deletions, and comments.

F. Developing a questionnaire, using the task statements, to identify the frequency of the task performed, criticalness of performance of the task, and the opportunity to learn the task on the job.

G. Conducting personal interviews, using the questionnaire, with selected experts on the installation, maintenance, repair, and operation of robots in use in Michigan.

H. Sending a follow-up mailed questionnaire to the experts for input on additions and comments arising from interviews.

The second objective of this study, contrasting differences between tasks performed today and tasks projected for 1990, was realized by:

A. Adding to the questionnaire used above, a question pertaining to whether the task will still be performed in 1990.

B. Asking, during the personal interview, what additional tasks and knowledge will be necessary in 1990.

C. Adding the input from B to the follow-up mailed questionnaire to the experts for additional comments.

The third objective of this study, identifying structural difficulties in existing job classifications to the installation, maintenance, repair, and operation of robots, was realized through:

A. Interviews from Objectives One and Two.

B. Telephone solicitation of selected Michigan manufacturers and additional personal interviews with individuals on the user side.

C. Reviewing company internal literature received during interviews.

Limitations of the Study

The study was limited by the following constraints.

1. The study was limited to the State of Michigan.
2. The ability of the selected experts to analyze the tasks and make sound judgments pertaining to them.
3. The extremely limited number of experts on the installation, maintenance, repair, and operation of robots, especially on the user side.
4. The extremely limited number of employees who presently install, maintain, repair, and operate robots.

Assumptions

The following assumptions were made.

1. Experts can identify the tasks industrial robot maintenance mechanics perform and will perform on the job.

2. Given a list of tasks, the expert on industrial robot maintenance mechanics can identify the tasks performed on the job.

Definition of Terms

Duty	A large segment of work performed by an individual. It is one of the distinct major activities involved in the work performed, and is composed of several related tasks.[21]
High Technology	The integration of state-of-the-art knowledge with existing tools and equipment to increase effectiveness or productivity.
Industrial Robot Maintenance Mechanic	The employee charged with the maintenance and repair of robots.
Job Analysis	A process of determining and reporting significant worker activities, worker requirements, technical and environmental factors of a specific job through observation, interview and study.[22]
Occupational Analysis	A process which examines broad occupational areas, then classifies them according to an acceptable scheme, and

	finally identifies and describes key occupations.[23]
Robot	A reprogrammable multifunctional manipulator designed to move material, parts, tools or devices, through variable programmed motions to accomplish a variety of tasks.[24]
Task	A job activity, or a set of activities, which, if begun by one individual, is most generally completed by him. It is of such a nature that it is not generally practical . . . to further subdivide the operation so that more than one worker might specialize in doing various parts of it.[25]
Task Analysis	A process of determining the content of jobs by identifying the relative importance of tasks making up the job.
Technician	Classified occupationally the technician performs semiprofessional functions of an engineering nature, largely upon his own initiative and under general supervision of a professional engineer, he assists the engineer and supplements his work.[26]

Trade Analysis — A process of identifying the operations that make up a trade or vocation.

Preview of the Study

A review of the literature pertaining to the study is presented in Chapter II. The review is grouped around four areas: the need for robot maintenance personnel; analysis of occupations; analysis of new and emerging occupations; and the social implications of robots.

The design of the study is the focus for Chapter III. The chapter is organized around two areas: the selection of the method of analysis for the study; and the three major components of the analysis. These components are: the development of the task inventory, the selection of participants, and the collection of the information.

The findings of the study are presented in Chapter IV, as they relate to the three objectives of the study.

Chapter V is divided into four sections: the conclusions associated with the three objectives; implications of the study; recommendations; and reflections.

CHAPTER II

REVIEW OF THE LITERATURE

The review of the literature pertaining to this study is grouped around four areas. The first is the need for robot maintenance personnel. The second is literature pertaining to analysis of occupations. The third is analyzing new and emerging occupations. And the fourth is the social implications of robots.

The Need for Robot Maintenance Personnel

Robots are in operation. They are breaking down and being repaired. It is not necessary to project or conclude that robots may need to be installed, repaired, maintained, and programmed. They do need to be installed, repaired, maintained, and programmed. Robots ". . . stop, their wires get tangled, they give you all kinds of trouble, so you have to find out what's wrong, repair them and tend them. Only a human can do that," said Junkichi Kobayaski, a foreman at Nissan's Oppama Plant.[27] Sasnjara said: "Because a robot is a machine it requires someone to program it and set it up, someone to keep it running, even if only indirectly and someone to fix it when it breaks."[28]

The U.S. Department of Labor, Bureau of Labor Statistics projects that industrial machinery repairers will increase from 500,000 in 1974 to 840,000 in 1985. With a projected 12,000 replacements needed each year, an increase of 30,500 industrial machinery repairers per year is necessary.[29] Maintenance mechanics are projected to increase from 346,000 in 1978 to as much as 439,000 in 1990.[30]

The Encyclopedia of Careers and Vocational Guidance states:

> The anticipated use of more machinery and equipment such as machine tools and assembly equipment in manufacturing industries will result in continued growth in the employment of industrial machinery repairmen in the future. With widespread use of automated equipment, breakdowns will lead to greater production loss, and will make repair work more essential.[31]

Gritchlow, referring to robots and the impact on labor said: ". . . each robot can reportedly do the work equal to one and one-fourth welders. However, this labor saving is somewhat counterbalanced by the need for a larger and more highly trained maintenance crew."[32]

Dzengeleski and Goode, writing on the robot growth not being as rapid as early projections, state:

> . . . a significant reason for the slow growth in robotics is the lack of installation and maintenance personnel at the user level. Right now there is a shortage of these people. One result is that some companies have purchased robots but have not installed them, leaving them sitting on the loading dock.[33]

Brookings states:

> Simply stated, technicians need to be trained to help design, produce, install, program and maintain modern robots and other computer controlled automated equipment. This training must come from a combination of electronic, mechanical and computer programming technician curricula. To prepare such a 'super' technician in the traditional two year postsecondary program may seem unlikely - but it's not impossible.[34]

The Russians are attempting a large build-up of robot utilization but they are hindered by ". . . the lack of skilled technicians to install and service the units."[35]

If there is a demand now, will it still be there in the future and will it be in sufficient demand to have implications for training and educating? Projections are wide ranging. Centron and O'Toole give the largest forecast; they are projecting:

> The next generation of robots will be able to see, touch, hear, smell and even speak. They'll need extra loving care, which means lots of service jobs for the robot technicians. We predict there will be as many as 1.5 million robot technicians on the job in the U.S. alone in 1990.[36]

Nicholson, Fineman and Ruiz by comparing information from the U.S. Bureau of Labor Statistics, Forecasting International Ltd., and Occupational Forecasting Inc. projected employment in industrial-robot production by 1990 of 800,000. However, they do not mention specific occupations.[37]

Dzengeleski and Goode contend the ". . . only really new job that will develop as a result of robots is the robotic technician. This is an individual that learns how to install and maintain robots while attending a community college or similar institution."[38]

Vedder and Hunt do not have such glamorous predictions. Vedder sees that if ". . . even the most optimistic forecasts of sales growth materialize total employment in robotic manufacturing would not exceed 50,000 at any time in the next decade."[39] Hunt and Hunt state: "We expect 750 to 2,700 robotic technicians outside the auto industry will be created in Michigan by 1990."[40]

Industry's needs for robot maintenance mechanics will vary from industry to industry. Lustgarten reports that three industries account for 76% of robot purchases; they are: automotive, casting/foundry, light manufacturing.[41]

According to Martin, "As of 1980, roughly one-third to one-half of all robots manufactured in the United States were shipped to auto plants."[42] Heginbotham and Production Engineering report the activities robots are used for; however, they are not in full agreement. Heginbotham states that spraying and coating activities account for 22.3% of installations, machine unloading 29.6%, and spotwelding accounts for 18.3%.[43] Production Engineering reports machine loading/unloading accounts for 24%, parts handling/positioning, 19%, assembly 9%, and welding/soldering/brazing 9%.[44]

Analysis of Occupations

Need for analysis of occupations

Since the Smith-Hughes Act in 1917, vocational educators have used analysis of the occupation as a basis for their curriculum. Herschbach reports: "Analysis has long served as the primary means of deriving instructional content for occupational education curricula."[45] The first accepted authority was Allen who wrote The Instructor the Man and the

Job which was published in 1919. Allen said:

> The instructor must know just what the trainee must know, and to be able to do so he must take 'account of the stock' . . . Such a stock taking is commonly called analyzing the trade and is the first operation which the instructor must take in laying out a course of instruction.[46]

Just a few years later Selvidge said:

> In order to teach a trade successfully, we must have a clear notion of what is required of the mechanic whose trade we would teach. Every important item in the trade must be known and listed. The teacher who does not have such a list is likely to go far astray and waste much valuable time even though he is highly skilled in the trade.[47]

Frylund followed up on Selvidge's work contributing several publications on occupational analysis. In one he wrote, "In order to teach an occupation or a subject or an activity there must first be an inventory of the elements to be taught."[48] He also stated: "Most occupations in which there is human achievement can be analyzed and listed so they can be taught in an orderly and systematic way."[49] He mentioned the reason for this necessity for analysis when he stated:

> The occupational analysis technique is necessary in the training of industrial and technical training personnel. The occupational elements become habits, and habits are not noticeable to those who have them; therefore it is necessary to analyze the occupation and list the elements so the new instructor will know what to teach.[50]
>
> It is important to know that any given kind of work that is worthy and is complicated enough to make instruction necessary should be analyzed into its elements before attempting to teach it, if thorough instruction is desired.[51]

Bollinger and Weaver report the task analysis technique is the same as the technique used in scientific investigation.[52] The chemist, Bollinger and Weaver say, is able to take a container of ordinary milk and by means of tests and examinations tell you what it contains. By the same careful and scientific procedure the tradesman can examine his trade to determine what it contains.

The analysis technique should not be affected by time or technology. Frylund states:

> . . . the fact that there are technological changes in industry does not mean that the time will come when trade and job training no longer will be needed. Indeed, it is true that as technical changes do take place changes are also being made in the status of occupations. Many of them are broken up; new occupations appear but simultaneously the needs and demands for training are increased. Analysis of occupations as of today brings industrial training up to date; whereas education in general, because of its reliance on book content, lags behind in attempting to keep pace with conditions in the world outside of school. Critics of education say that education is slow in making adjustment. Industrial education, because of the trade and job analysis technique, is in a position to keep pace. There is constant seeking of up-to-date occupational teaching content.[53]

Methods used in analyzing occupations.

Analyzing work in terms of what people do and can do on the job has been called occupational analysis, job analysis, task analysis, trade analysis, and position analysis. Some writers see little or no difference in many of these terms, others see differences which have major implications for how the analysis should be conducted.

Bundy states:

> . . . when the subject of how to teach a job is mentioned, one's thoughts naturally go back to the work of Charles Allen during the First World War. His influence has been great in the development of analysis procedure and its application to teaching.[54]

Allen developed his method of analysis and teaching while supervising training courses of the Emergency Fleet Corporation during and after World War I. To Allen

> . . . analyzing the trade simply means listing out all the things that the learner must be taught if he is to be taught the complete trade. If the trade is that of a carpenter, the instructor notes down all the different jobs that a carpenter has to do. If it is plumbing, or book binding, or machine shop work, the same listing of jobs must be carried out. If in addition to the jobs themselves, there are certain special words (technical terms) whose use he must learn, or special tools whose use he must know or constructions or computations which he must be able to make or special safety precautions that he must take these must also be listed completely out.[55]

Allen looked at the trade and broke it down into jobs, technical terms, tools, computations, constructions, and safety precautions.

Selvidge considered the analysis of the job to be inappropriate.

> Very few trades can be analyzed on the basis of jobs. It is not practicable to list all the jobs that may occur in a skilled trade. Even if it were possible to do so it would be necessary to analyze each job into the processes involved in doing it, in order to teach the job. Since every conceivable job is made up of the operations of the trade, in various combinations, the simplest method of procedure is to analyze the trade for the operations involved and use this analysis as the basis of all job analysis. No job can be analyzed except in terms of the operations of the trade or vocation.[56]

Frylund, building on Selvidge's work, used the broader term occupation believing his analysis procedure can be applied not only to the trades but to any occupation requiring systematic training.[57] He considered the essential elements of the occupation should be taught. In the shop these are operations. Operations are further reduced to steps. Some steps are of a doing nature, some of a knowing nature and some are a combination of both. For the steps that require knowledge the related information should be taught.

Although Allen refers to the listing of jobs and Selvidge and Frylund to operations, Allen defined jobs differently and really concerned himself with the operations that workers performed.

Allen, Selvidge and Frylund concerned themselves with analysis for education and training only. Frylund wrote:

> While the trade and job analysis techniques can be used in analyzing other than industrial trades, it is for identifying instructional units and not assumed to be for personnel management or for production purposes.[58]

Other writers have not concerned themselves exclusively with education and training. Bundy, who recognized Allen's influence in the analysis procedure for teaching, said when discussing how to teach a job: "Since job analysis is a rather laborious process, it should be standardized as to form so that one analysis, properly and completely made would be available for all of the uses to which it can be put."[59] He recognized three other uses to which the one analysis can be put: time and motion study, for setting standards; job evaluation, for establishing job rates; and job requirements, for employment interviewing.

McCormick, using the term task analysis, believes the technique developed not with Allen and Selvidge but with the methods analysis of the industrial engineer.[60] Industrial engineering has its origin in the early work of Frank and Lillian Gilbreth during the turn of the century. Gilbreth's study of human motions led him to suggest ways of learning a trade. In Bricklaying System he lists the right and wrong operations for an apprentice bricklayer and says that the list ". . . shows what he should learn first, as well as how he should learn it."[61]

Regardless of how the analysis technique developed, the recent literature suggests three titles are used when doing an analysis of workers for educational purposes: job analysis, task analysis, and occupational analysis. Outside of the field of education job analysis is more predominant. In the Educational Resources Information Center (ERIC) Thesaurus, occupational analysis is considered synonymous with job analysis.[62] In 1980 a "scope note" was added to task analysis to clarify its difference to job analysis. Position analysis and trade analysis are not and have not been used as descriptors.

Melching and Borcher point out:

> While job analysis experts employ concepts such as task, function, responsibility, duty, etc. as though

> the distinctions among them were both obvious and fixed, this is simply not true. The curriculum designer should be warned that any attempt by him to place these terms into a reliable hierarchy may turn out to be not very rewarding.[63]

Braden and Paul report, "Most writers and researchers seem to use the terms job analysis and task analysis interchangeably."[64] The U.S. Department of Labor's Training and Reference Manual for Job Analysis states:

> Job analysis is defined as the process of determining, by observation, interview, and study, and of reporting the significant worker activities and requirements and the technical and environmental factors of a specific job. It is the identification of the tasks which comprise the job and of the skills, knowledges, abilities, and responsibilities required of the worker for successful job performance.[65]

Chenzoff and Folley define task analysis as:

> The collection of activities that are: performed by one person, bounded by two events, directed toward achieving a single objective or output, and describable by means of the method set forth so that the resulting task description conveys enough information about the task to permit the necessary training decisions to be made.[66]

Rupe's definition of a task is the definition used in this study.

> A task is defined as a job activity, or a set of activities, which, if begun by one individual, is most generally completed by him. It is of such a nature that it is not generally practical . . . to further subdivide the operation so that more than one worker might specialize in doing various parts of it.[67]

"Task analysis has come to be viewed over the last decade as a methodologically sound alternative to job and trade analysis, for years the dominant approach to instructional development in occupational education," said

Herschback in 1976.[68] He reports it is because task analysis ". . . lends validity to the content selection process, more so than was possible through trade and job analysis. Its techniques are flexible and suitable for application to a wide range of instructional situations."[69]

Occupational analysis is generally considered a broader term. Kenneke, Nystrom and Stadt state:

> Occupational analysis serves to delimit specific employment situations from the total productive arena. It examines broad occupational areas, then classifies them according to an acceptable scheme, and finally identifies and describes key occupations. The entire process sets the stage for subsequent steps of content, concept, job/trade, task and instructional analysis.[70]

The Air Force task analysis projects through 1964 have influenced the methods used for analysis by vocational educators. Originally the term position analysis was used to ". . . help select, classify and train men for Air Force positions."[71] "The Air Force method used group interviews of incumbents and conferences of technical experts in carrying out position analysis."[72]

Morsh, Madden and Christal revised the Air Force procedures for analysis to center around a task inventory for job analysis and evaluation.[73] The categories for analysis used by Morsh, Madden and Christal were the terms of duty and task. Their conclusions were based on many Air Force research projects. One by McCormick and Ammerman concluded that a task checklist was a useful procedure for obtaining task performances, length of task time, and general task difficulty.[74] Another by McCormick and Tombrink compared task elements and work action statements for consistency of job information with the use of a checklist.[75] They concluded that tasks and elements gave more consistent information than work actions for frequency of performance of the activity, time required for performance, mental difficulty, and physical difficulty. But work actions were more consistent than tasks (elements fell between the two) for the type of training received, type of training desired, and type of assistance obtained.[76]

The Center for Vocational and Technical Education at The Ohio State University developed a system of task analysis by applying the Air Force task inventory concepts. The method is described as follows:

> Developing and using task inventory involves three main phases. These phases, along with some of the goals and activities of each, are:
>
> 1. Construction of Initial Inventory of Tasks. Here the goal is to generate a comprehensive inventory of duties and tasks for a given occupational area, using various standard sources of information. With the aid of experts, statements are refined and grouped and made ready for administration to job incumbents.
>
> 2. Acquisition of Information about Each Task. In this phase, the inventory of tasks is submitted in questionnaire form to a large group of job incumbents. After each incumbent provides certain background information about himself, he checks each task in the inventory that he actually performs. Following this, he indicates the relative amount of time he spends performing this task compared with other tasks that he does on his job. On occasion, incumbents may be asked to provide other information about the tasks that they perform.

> 3. Analysis of Task Data. Once questionnaires are returned and checked for completeness, responses are tabulated and summary statistics derived. The results can then be used to guide the development or revision of training programs.[77]

In 1967 Mager and Beach published a book organized around a method of task analysis with the terms tasks and steps.[78] They directed the analysis exclusively to instruction. The tasks were to be rated in terms of frequency of performance, importance, and learning difficulty. The steps were rated by type of performance (recall, manipulative, problem solving); and learning difficulty. However, they said ". . . there are probably as many techniques for performing a task analysis as there are people doing it . . . The only large error you can make is not to use any task analysis technique at all."[79]

Sherman and Willidman came to the same conclusion as Mager and Beach. They said:

> . . . there is agreement among all the theorists on at least one point: Task analysis, at a minimum, assists the instructor or designer to understand the content to be taught. This alone is sufficient reason for recommending task analysis.[80]

The Comprehensive Dissertation Index Database indicates the shift to a task analysis approach. There are ten dissertations listed under occupational analysis, fifty-two under task analysis, three under trade analysis, and sixty-four under job analysis. Of those dissertations that relate to education and training there have been twenty task analyses since 1974, eight between 1964 and 1974, and one before 1964. There have been three occupational analyses since 1974, four were completed between 1964 and 1974 and one before 1964. There was one trade analysis before 1964 and one job analysis before 1964 (see Table 1).

TABLE I
Number of Dissertations Listed Under Task Analysis, Occupational Analysis, Trade Analysis and Job Analysis that Relate to Education and Training with Completion Dates

	Since 1974	1974-1964	Before 1964
Task	20	8	1
Occupational	3	4	1
Trade			1
Job			1

Source - Comprehensive Dissertation Online, 1982

While educators use the term task analysis more commonly, the U.S. Department of Labor has done much similar work in job analysis. The Training and Employment Service describe, in their handbook, basic techniques of job analysis. The handbook reflects the results of continued research on occupational analysis by the agency. Their techniques ". . . are flexible and adaptable to meet such objectives as job restructuring and job development."[81] Training is identified as one area that benefits from job analysis.

> Jobs should be analyzed as they exist; therefore, each completed job analysis schedule must report the job as it exists at the time of the analysis, not as it should exist, not as it has existed in the past, and not as it exists in similar establishments.[82]

The job analysis is intended for recruitment and placement, better utilization of workers, job restructuring, vocational counseling, performance evaluation, plant safety as well as training. Both the work performed and worker traits are identified.

The U.S. Department of Labor, Manpower Administration (later changed to the Employment and Training Administration) stated:

> Job analysis may be defined as any process of collecting, ordering, and evaluating work or worker-related information. It is not an end in itself but rather a means to any of several ends. The purposes for which an analysis is conducted largely determine the types of information gathered and the ways in which the information is arranged. Thus, a study whose objective is to develop jobs for the physically handicapped may use different scales, high-lighting different aspects of the task data, from one which is intended to assist in establishing a position classification system. The information may reflect job content, expressed in terms of specific work activities and procedures, or it may consist of the worker characteristics (skills, knowledge, aptitudes, tolerances, etc.) required for adequate job performance. In some instances, both job-oriented and worker-oriented information may be useful.[83]

The method used to gather information and from whom it is gathered does not seem to be influenced by the term of task, occupation or job as much as the objective for the data. Rupe's analysis of Air Force jobs was a task analysis using data collected from the workers.[84] Braden considered supervisors a better source of information on the relative importance of each task to the complete job description and the educational and vocational preparation needed to enter and progress in nuclear technician occupations.[85] Mager's technique requires ratings by the worker, the observer/interviewer, or supervisor on scales related to frequency of performance, importance, and learning difficulty.[86]

Ammerman et al. found in a survey of eight Army service schools that there ". . . was a greater tendency to obtain information from the job situation for equipment-related courses (such as maintenance instruction programs)."[87] In training for new equipment ". . . the contractor and the equipment itself were prime sources of information."[88]

Morsh gives eight methods of obtaining information: questionnaire, checklist, individual interview, observation and interview, technical conference, daily diary, work participation, and critical incident.[89]

The most popular methods of obtaining information appear to be the questionnaire and checklist. But the method of developing the questionnaire is often difficult to ascertain.

Graham's task analysis procedure was to form an advisory committee to select a list of basic processes and tasks necessary to complete the process.[90] This list of tasks was compiled as a questionnaire and mailed to selected persons. The responses were then tabulated for final presentation.

Skouby's occupational analysis of electromechanical technicians' occupations was to determine the frequency of performing selected tasks and the area of activity (electrical, mechanical, etc.) in which these tasks were performed.[91] Sixty-six supervisors of electromechanical technicians and 137 electromechanical technicians from fifty-seven industrial establishments were interviewed by twelve master's degree candidates using a questionnaire. The questionniare was developed by the degree candidates.

Sprankle, in a task analysis of electronic skills, used a mailed survey reported by 219 individuals in 82 occupations.[92]

Chenzoff concluded from his review of task analyses:

> Two basic approaches to task analysis for deriving training and training device recommendations were found.
>
> 1. The Miller (1956d) approach begins with a determination system functions and output criteria. What should the system be able to do and how well should it be able to do these things? Then the functions are allocated to men and machines and the functions to be performed by human operators are broken down into tasks and, if possible, subtasks. Both the task-relevant and the contextual variables which are anticipated to affect task performance are described. The skills and knowledges required to perform the task are analyzed according to specified rules. Eventually, after a number of such analyses, there is deemed to be sufficient data so that one can construct a curriculum and choose training equipment.
>
> 2. The Gustafson, Honsberger, and Michelson (1960) approach begins with the decisions which have to be answered before these decisions can be made. The questions which need to be answered for one system are not necessarily those which should be answered for another system. Thus each task analysis is tailor-made to gather the necessary and

> sufficient information for the training decisions associated with one particular system, although there are generalizable classes of decisions and data which will be relevant to most systems. The Gustafson, Honsberger, and Michelson approach has the obvious advantage of economy of information to be gathered. However, it has not been sufficiently refined to permit its immediate application.[93]

The Vocational-Technical Education Consortium of States (V-TECS) uses the task analysis technique. Their method begins with identifying the occupation through the Office of Education (O.E.) Code and the Directory of Occupational Titles (DOT) Code, that make up the educational program area.[94] A state-of-the-art review is then made.

> A State-of-the-Art review of all identifiable performance-based curriculum materials that are appropriate to the developmental domain of the catalog should be conducted. The State-of-the-Art study should also include a review of other related materials or information that might be used as supportive documents to the developmental process or materials. In addition, State-of-the-Art should include a review of existing V-TECS catalogs to identify task statements/performance objectives/performance guides that have potential for the development project.[95]

Development of an occupational inventory is then done. When complete it is used to survey incumbent workers. They are requested to check each task they perform on the job. Tools used by the worker are also identified.

Analyzing New and Emerging Occupations

The study of longitudinal data has been useful in identifying changes in occupations. However, Pfeiffer and Stronge suggest factors that can impair any system of data collection in identifying new and emerging occupations. "The length of time in the survey period coupled with the length of time necessary for processing the data may make some of the staffing estimates obsolete prior to the projections process."[96] They make two interesting suggestions. One is simply a study of job listings. The other they call residual studies, where during the Occupational Employment Statistics Survey employers

> . . . are asked to add descriptive information and employment data on occupations in their firms that are not included on the pre-printed O.E.S. survey form. Since the pre-printed survey form is based on occupations that are known to be characteristic of certain firms a study of these residuals may help in identifying emerging opportunities.[97]

Forgione and Kopp considered new and changing occupations as those with high employment growth, recent emergence (within ten years), arising from a new industry, or restructuring or modification of an occupation.[98] They add that it is difficult to identify new occupations because existing data sources are based on existing occupations and it is difficult to obtain data regarding future demands from employers.

Orth and Russell found six requirements for the identification of new and changing occupations. They are job descriptions and job duties, education and training requirements, employment outlook, employment environment, career outlook, and organizations knowledgeable about the particular occupation.[99]

Stembridge addresses the difficulties in analyzing tasks in new and emerging jobs. He suggests a delphi probe using experts may ". . . be used to reach agreement on possible future tasks an occupation may include."[100] His concern with the utilization of experts either through a survey or jury is a problem of identifying these experts. He suggests a task list be developed ". . . through a review of technical operating manuals and the tasks required to maintain and repair the equipment derived from the manuals."[101] He believes workers can determine the validity of the list and tasks on the list. However, the worker population for a new and emerging occupation may be hard to identify.

In a study of the biomedical equipment technician, which fits the description of a new and emerging field, it was determined that the educational program should be designed to give students skills and knowledge relevant to calibration, preventative maintenance, troubleshooting, and repair. This was based on a list of nineteen tasks and thirty-six pieces of equipment which respondents to a survey indicated that they do or do not use.[102]

The American Society for Training and Development is conducting a study to ". . . identify the training and development roles and competencies [of training directors] not only needed today but also needed in the future."[103] The method involves multiple rounds of questionnaires to experts and review by an outside group of experienced practitioners.[104]

A relatively new approach to determining curriculum content is the DACUM (Developing A CurriculUM) approach. This approach could be used to determine content in new and emerging areas. Finch and Crunkilton write:

> The development of a DACUM profile involves using a committee of ten to twelve resource persons who are experts in the particular occupation. These resource persons are nominated by employers as being skilled in the occupation and currently serving as a worker or supervisor in the area . . .
>
> The DACUM committee functions as a group with the developmental activities taking place when the members are together. Time required to complete a DACUM profile generally ranges from two to four days. A coordinator from outside the committee works with the group to facilitate the development process.[105]

There was no study identified, during the review of literature, regarding tasks performed by the robot maintenance mechanic. Konstantinov had suggested a few broad duties in his paper on on-site servicing of robots.[106] Several studies are underway and will soon be completed, but not in time to assist in the design of this study.[107]

Social Implications

There is little information on the social implications of robots. There appear to be no questions as to what level of automation is socially acceptable. Literature on robotics pre-supposes the continuing historical pattern of using advanced automation when possible.

Gold reports:

> The basic fact is that unemployment in any firm is caused primarily by a decline in its competitiveness. If it fails to adopt the technological advances utilized by competition, its employment will decline much more rapidly than if it adopts such advances even if these involve some displacement of labor.[108]

The literature suggests that though some jobs will be replaced by robots they will generate or create new jobs. The problem is in identifying the number or jobs replaced and the number of newly created jobs.

Hunt and Hunt found ". . . no existing data base to estimate the number of jobs that will be created by the robot industry in the U.S. or Michigan."[109] They said:

> Our interviews strongly supported the following conclusion about the average displacement effect of robots: one robot replaces one worker per shift. That conclusion should not be surprising. Robots are not any faster than human workers, and regardless of the protestations of some in the industry that robots should not be compared to humans, robots do in fact perform functions that were previously done by human workers.[110]

Hunt and Hunt's conclusions are similar to Behuniak's who states: "Robots, unlike other forms of automation, usually only replace humans on a one-for-one basis."[111]

Hunt and Hunt project the Michigan robot count to be between 6,500 and 12,000 by 1990, and from this conclude 13,000-24,000 jobs lost. They also conclude between 5,127 and 17,737 jobs will be created in the robot industry in Michigan. However, ". . . the occupational profile of those jobs created, is that well over half of all of these jobs require two or more years of college."[112]

The Exploratory workshop on the Social Implications of Robotics held by the Office of Technology Assessment concluded, "Any examination of the effects of robots on jobs would need to consider, at least in part, a much broader context of automation technology."[113] Gold had said at this workshop:

> More than 25 years of empirical research on the productivity, cost and other effects of major technological innovations in a wide array of industries in the U.S. and abroad have led me to draw two conclusions:
>
> First: that the actual economic effects of even major technological advances have almost invariably fallen far short of their expected effects; and
>
> Second: that such exaggerated expectations have been due to their over-concentration on only a limited sector of the complex of interactions which determine actual results.
>
> Hence, sound analysis of the prospective effects of increasing applications of robotics in domestic industries on their cost effectiveness and international competitiveness requires avoidance of such over-simplifications.[114]

Another social consideration is the quality of working environment. The Exploratory Workshop concluded:

> If robots are employed principally for jobs that are unpleasant or dangerous and if the new jobs created by robotics are better, the quality of worklife will improve. Productivity increases may also, in the longer term, result in a shorter, more flexibly scheduled workweek.[115]

Summary

A need for robot maintenance personnel for today and in the future has been identified. However, the projections as to the numbers needed are wide ranging. Centron and O'Toole predict 1.5 million robot maintenance technicians on the job in the U.S. in 1990.[116] Hunt and Hunt project as few as 750 robot maintenance technicians may be employed outside the auto industry in Michigan by 1990.[117] With the auto industry projected to use about one-half the robots, and Michigan being one of the largest states in terms of numbers of robots used, it is clear the two projections are far apart.

Analysis of occupations has long been used as a basis for curriculum by vocational educators. Several types of analysis have been used: job analysis, occupational analysis, trade analysis and task analysis are the more common types. The most common analysis since 1974 for educators has been task analysis. Herschbach believes task analysis lends greater validity to the analysis process.[118]

There are additional problems in analyzing new and emerging occupations. The first problem is in actually identifying the new and emerging occupations. Once identified, experts have to be identified for the analysis. Stembridge recommended when machines and equipment are used in the occupation, a review of operating manuals can be completed in developing a task inventory.[119] No completed analysis was identified on robot maintenance mechanics.[120]

There is little information on the social implications of robots. Some jobs will be replaced by robots and some jobs will be created by the use of robots. Information on the net gain or loss of jobs due to robots is conflicting. However, quality of the working environment is projected to improve with the use of robots.

CHAPTER III

DESIGN OF THE STUDY

In this chapter the method used to achieve the objectives of the study is presented.

The chapter is organized around two areas: the selection of the method of analysis for the study; and the three major components of the analysis. These components of the analysis are: the development of the task inventory, the selection of participants, and the collection of the information.

Selection of the Method of Analysis

Type of analysis selected.

It was seen through the review of the literature that many methods can be used in analyzing occupations. The method chosen depends on the objectives of the study. It is therefore appropriate, at this time, to restate the key purposes of the study.

1. To identify the tasks necessary to perform the job of industrial robot maintenance mechanic in Michigan, prioritized by frequency performed, criticalness and opportunity to learn on the job.

2. To contrast tasks identified for use today and tasks projected for 1990.
3. To identify the structural difficulties in existing job classifications for the installation, maintenance, repair, and operation of robots.

Given the objective of identifying common tasks necessary to perform the job of robot maintenance mechanic, the method which is generally considered the more narrow method of analysis, that of task analysis, was selected for the study. It was not the objective of the study to identify environmental factors or physical requirements of the job, or to identify similar and related jobs as job analysis and occupational analysis are often considered to do. The objective was to identify tasks and prioritize them for educational purposes.

<u>Method selected for gathering data</u>.

Morsh gives eight methods of gathering task analysis data: questionnaire, checklist, individual interview, observation and interview, technical conference, daily diary, work participation, and critical incident.[121] The method chosen depends on the objective of the study and availability and cooperation of the respondents. Objective One of the study was to prioritize the tasks in terms of frequency performed, criticalness to job performance, and opportunity to learn the task on the job. Objective Two was to contrast tasks identified and tasks projected for 1990. Objective Three, structural difficulties in existing job classification for the installation, maintenance, repair, and operation of robots, required discussion which could not be standardized on a response form and would take an estimated 30-45 minutes of response time.

The level of cooperation of the proposed participants was high, based on telephone contact. However, their availability was restricted, thus ruling out any group conference approach, such as DACUM. Multiple rounds of a questionnaire necessary for a delphi approach in addition to the interview necessary for Objective Three, could have exceeded the interest and cooperation of the participants.

The individual interview with a checklist of tasks was selected as the method which would best match the objectives and the availability and cooperation of the respondents. This method allowed for greater response and attentiveness due to the presence of the interviewer. The individual interview also allowed for one-to-one discussion necessary for Objective Three.

The Three Major Components of the Analysis

Three major components of the analysis describe the procedure for data collection. It is therefore appropriate to restate the methodology and procedure for data collection.

Methodology and procedure for data collection

The first objective of this study, to identify tasks necessary to perform the job of industrial robot maintenance mechanic, was realized by:

A. Reviewing operating, service and installation manuals of manufacturers whose equipment will be maintained and operated during the performance of the job incumbents' duties.

B. Compiling tasks identified through the materials.

C. Adding task statements of existing occupations (for which an analysis had been done) identified as having components of the new occupation.

D. Consolidating the task statements.

E. Having the task statements reviewed by selected experts for additions, deletions and comments.

F. Developing a questionnaire, using the task statements, to identify the frequency of the task performed, criticalness of performance of the task, and the opportunity to learn the task on the job.

G. Conducting personal interviews using the questionnaire, with selected experts on the installation, maintenance, repair and operation of robots in use in Michigan.

H. Sending a follow-up mailed questionnaire to the experts for input on additions and comments arising from interviews.

The second objective of this study; contrast differences between tasks performed today and tasks projected for 1990, was realized by:

A. Adding to the questionnaire used above, a question pertaining to whether the task will still be performed in 1990.

B. Asking, during the personal interview, what additional tasks and knowledge will be necessary in 1990.

C. Adding the input from B to the follow-up mailed questionnaire to the experts for additional comments.

The third objective of this study, identifying structural difficulties in existing job classifications to the installation, maintenance, repair, and operation of robots, was realized through:

A. Interviews from Objectives One and Two.

B. Telephone solicitation of selected Michigan manufacturers and additional personal interviews with individuals on the user side.

C. Reviewing company internal literature received during interviews.

The three major components of the data collection are the development of the task inventory, the selection of participants and the collection of information.

The development of the task inventory.

At the time of developing the task inventory there was no source identified as to the tasks required of robot maintenance mechanics.[122] It was therefore necessary to develop a task inventory for the checklist of tasks.

The preliminary groundwork for this research project suggested that Stembridge's concerns for the difficulties in analyzing tasks in new and emerging industries, discussed in the review of literature, were applicable to the robot maintenance mechanic - especially his concern about the difficulty in identifying the worker population from which to draw task information.[123]

An important characteristic of the robot maintenance mechanic is actual performance on the machinery or equipment. Ammerman et al. and Stembridge specifically mentioned when machinery and equipment were used during the job incumbents' work that tasks could be identified through the machinery and equipment.[124] A study of the biomedical equipment technician was done using the equipment as a basis to gather data.[125] A review of operating, repair, and maintenance manuals to develop an initial task list as suggested by Stembridge appeared feasible, based on Lustgarten's list of manufacturers of robots in the United States. Lustgarten's list (Table 2) shows total robot sales in 1980 as

$100 million. Unimation (Condec) sales were $40.0 million, Cincinnati Milacron had sales of $30.0 million and Devilbiss (Champion Spark Plug) was the third largest in sales with $9.0 million. ASEA (U.S. operation) had sales with $7.5 million, Prab Robots had sales of $6.0 million, and Autoplace (Copperweld), the sixth largest company, had sales of $4.5 million. After these six companies came Nordson with $0.7 million, Mobot with $0.7 million, Automatix with $0.4 million, and all other companies accounted for $1.2 million. The six largest companies, therefore, made up 97% of sales. It is interesting to note that ". . . foreign built robots are not a significant factor currently."[126] However, Lustgarten does consider they will be a factor in the future.

TABLE 2

Sales of Robots by U.S. Manufacturers

Company	Sales in Millions
Unimation (Condec)	40.0
Cincinnati Milacron	30.0
Devilbiss (Champion Spark Plug)	9.0
ASEA (U.S. operation)	7.5
Prab Robots	6.0
Autoplace (Copperweld)	4.5
Nordson	0.7
Mobot	0.7
Automatix	0.4
Others	1.2
Total	100.0

Source - U.S. Congress, Office of Technology assessment, Social Impact of Robotics, "Robotics and its Relationship to the Automated Factory" by Eli S. Lustgarten (Washington, D.C.: Government Printing Office, 1981), p. 128.

A review of operating, repair, and maintenance manuals was undertaken to develop an initial list of tasks. Initially a request was made to the appropriate individual at each of the six largest companies, as listed in Table 3, for manuals relating to the company's robots (Appendix A). Each company responded with at least one of its manuals.

Table 3 is a list of the six manufacturers of robots contacted and the manuals received, and the principle use for the robot described in the manual.

TABLE 3

Robot Manufacturers Contacted and Manuals Received

Company	Manual	Robot's Use
Unimation (Condec)	4030 Series equipment manual	Spot welding
Cincinnati Milacron	Pre-installation manual for T3T.M Operating/teaching manual for T3T.M Service manual for T3T.M	Machine loading/ unloading
Devilbiss (Champion Spark Plug)	TR-3500 operations manual TR-3000 maintenance manual Basic troubleshooting I	Paint spraying
ASEA (U.S. operation)	ASEA Industrial robot system maintenance ASEA Industrial robot system operation ASEA Industrial robot system description	Machine loading/ unloading
Prab	Operation programming and maintenance manual 4200/4800 series	Machine loading/ unloading
Autoplace (Copperweld)	Maintenance manual CR50 robot	Parts handling

The manuals received were reviewed to extract tasks necessary for the installation, maintenance, repair, and operation of the robot. This review produced 154 tasks.

The 154 tasks were arranged into six duties. Duty A, Installing and Moving Machines; Duty B, Performing Preventative Maintenance; Duty C, Maintaining Equipment; Duty D, Performing Repairs; Duty E, Programming; and Duty F, Communicating.

It was recognized that the review of manuals alone might not produce a complete list of tasks for the robot maintenance mechanic. The tasks identified through the robot manufacturers' manuals were in the skill areas of electronics, hydraulics, mechanics, pneumatics, programming and communication. Existing task analyses of occupations which pertain to these skill areas were sought. The areas of electronics, hydraulics, mechanics, and pneumatics yielded task statements. No task statements within the area of robot programming or communication were identified as helpful.

The publications used to make additions to the task list were:

> "An Occupational Analysis of Electromechanical Technicians Occupations with Implications for Curriculum Development" by Skouby.[127]
>
> Electronics Mechanic: A Catalog of Tasks, Performance Objectives, Performance Guides, Tools and Equipment by Skutack.[128]
>
> Maintenance Mechanic: A Catalog of Tasks, Performance Objectives, Performance Guides, Tools and Equipment by Krogstod and Dawson.[129]

These three publications produced 57 additional tasks which were not identified in the review of manufacturer manuals. They were tasks in the areas of electronics, mechanics, hydraulics and pneumatics associated with the developed duties of the robot maintenance mechanic of Installing and Moving Machines, Performing Preventative Maintenance, Maintaining Equipment, Performing Repairs, Programming and Communicating. Four additional duties appeared in this review that might be required of a robot maintenance mechanic, yet were not identified in the review of the manuals. The additional duties were: Administrating Personnel, Supervising Maintenance and Repair Function, Working Metal with Hand or Portable Tools and Working Metal with Machine Tools. These duties, however, were not central to the mechanic's job as defined.

The list of tasks now totaled 211, with four additional duty statements to consider.

Two individuals with not less than two years teaching experience in their respective areas were asked to remove and consolidate duplications of task statements. One of the teachers, in the field of electronics, reviewed the electronics tasks. The other teacher, in the field of hydraulics, mechanics and pneumatics reviewed the hydraulics, mechanics and pneumatic tasks. The reason for selecting teachers was that they were familiar with task statements and could eliminate, consolidate and rewrite duplications

(Appendix B). These teachers also verified the task area, such as: electrical or mechanical.

This reduced the number of tasks statements from 211 to 186. The four additional duty statements remained the same.

The next phase of the development of the task inventory was to request responses from experts in the robot maintenance field to the task list, with a request for additions and deletions. Six individuals were selected who were knowledgeable in the field of robot installation, maintenance, repair, and operation. It was required that they each have at least two years of experience in the area of robot installation, maintenance, repair, and operation. Two represented the robot manufacturers' view, two represented the robot users' view, and two represented the educators' view (Appendix C).

Initial contact was by telephone. The survey form was then mailed (Appendix D). The survey form contained a list of the 186 task statements and four additional duty statements which the respondent would check either yes or no to the question: Will this be performed by the robot maintenance mechanic/technician? The term technician was added because the review of the literature suggested the robot maintenance mechanic is sometimes called a technician. The cover letter requested additional comments and suggestions.

All six individuals replied by completing the checklist and giving additional comments and suggestions.

The survey form in Appendix D shows the reponses to the task statements. The additional comments and suggestions are also recorded in Appendix D.

If more than one individual responded yes to the question: Will this be performed by the robot maintenance mechanic/technician? the statement was placed on the final task analysis checklist form. The comments and suggestions were also used in developing the final task analysis checklist form.

This completed the task inventory development, reducing the number of tasks from 186 to 171, and the additional duty statements from four to three.

The procedure followed, in developing the task inventory, is illustrated in Figure 1.

Selection of participants.

It was then necessary to select experts on robots in Michigan to validate and prioritize the tasks (Objective One); identify differences between tasks necessary today and tasks necessary in 1990 (Objective Two); identify structural difficulties in existing job classifications for the installation, maintenance, repair, and operation of robots (Objective Three); and to draw implications for the education and training of persons for these occupational positions.

Incumbent workers, it was found in the review of literature, were often (but not always), used as experts.

FIGURE 1

Procedure Used in Developing Initial Task Inventory

Step 1	Development of task statements through review of robot operation, repair, and maintenance manuals.
Step 2	Development of additional task statements using selected publications relating to skill areas identified in Step 1.
Step 3	Review and consolidation of task statements by teacher experts.
Step 4	Initial task inventory prepared
Step 5	Review of initial task inventory by robot maintenance experts.
Step 6	Refinements, changes, additions and deletions as recommended by robot maintenance experts.

In this study, incumbent workers were robot maintenance mechanics. Two sources were considered for locating incumbent workers: one, the robot user plants or purchaser; two, the robot manufacturer.

In an attempt to identify expert robot maintenance mechanics in the robot user plants, forty Michigan establishments were selected from robot manufacturers' sales lists and from The Directory of Michigan Manufacturers.[130] The establishments on the robot manufacturers' sales lists were known to have purchased robots; however, not all robot manufacturers were willing to share this information. The establishments selected from the Michigan Directory of Manufacturers were selected because they were potential users of robots.

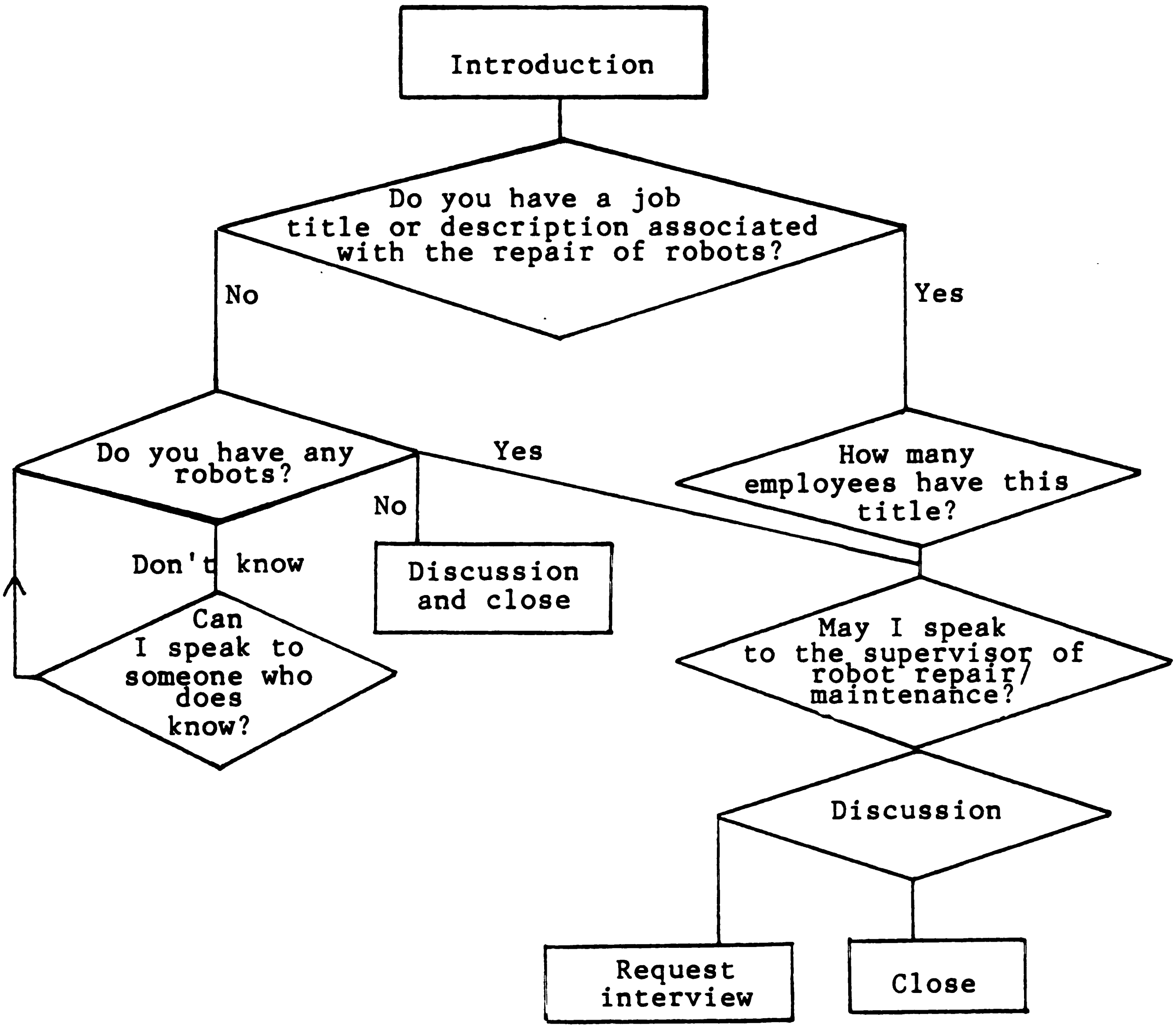
The industries using robots and the activities robots were used for, identified in the review of the literature, were considered useful in identifying the potential robot users through their Standard Industrial Classification number and their activities.[131]

The personnel departments of the forty selected establishments were contacted by telephone. The companies contacted are listed in Appendix E. The telephone procedure is shown in Figure 2.

Based on the projected need for robot maintenance mechanics it was expected that many would be identified.

FIGURE 2

Telephone Procedure Used in Attempting to Identify Robot Maintenance Mechanics in Michigan's Robot User Plants



Only one person was identified who met the requirement for completing the checklist. The requirement was that the persons have had as their major job responsibility the installation, maintenance, repair, and operation of robots for at least one year. The reason for identifying only one person is explored and discussed in Chapter IV.

In attempting to identify expert robot maintenance mechanics in robot manufacturing plants, it was decided that the experts were the manufacturers' service managers responsible for the Michigan area. All met the requirement of having as his major job responsibility the installation, maintenance, repair, and operation of robots. Through these people flows all information regarding the company's robot maintenance activities. The six manufacturers that had assisted in the review of manuals and accounted for 97% of all robots sold in the U.S. in 1980 had service managers responsible for the Michigan area. These six service managers agreed to participate in the study (Appendix F).

As previously stated, only one robot maintenance mechanic was identified, in the user plants, who met the requirement for completing the checklist. The review of literature projected a significant number of robot maintenance mechanics would be needed and that this position fitted the description of an emerging occupation. Therefore, for Objective One, the question became as much what <u>should</u> or <u>will</u> be performed as what <u>is</u> performed. Information on what should be performed and how it is performed is generated through the office of the manufacturer's service manager.

In five of the six companies the service manager participated in the completion of the checklist. In one of these cases a robot maintenance mechanic assisted in completing the checklist; in another, two robot maintenance mechanics assisted in completing the checklist. In the sixth company the service manager designated a robot service mechanic, he believed most capable of representing the company, to complete the checklist (Appendix F).

To identify the structural difficulties in existing job classifications for the installation, maintenance, repair, and operation of robots (Objective Three); and to identify implications for the education and training of persons for these occupational positions; it was necessary to interview experts from both the robot manufacturers' plants and robot users' plants.

The same representatives from the six manufacturers participating in meeting Objectives One and Two were selected to participate in meeting Objective Three.

The selection of participants from the robot user plants for Objective Three was based on the telephone procedure in Figure 2 and the subsequent telephone interviews (these interviews are discussed as findings in Chapter IV). The one person in the user plants who met the requirement for completion of the checklist for Objectives One and Two (although he did not participate in Objectives One and Two) was selected for personal interview. Four persons were selected from another plant for interview. These two plants represented opposing procedures of installation, maintenance, repair, and operation of robots. A sixth individual was selected to further explore the structural differences and training requirements of robot maintenance mechanics. The individual had responsibility of training for robot maintenance in a large automobile company. The names of the individuals interviewed appear in Appendix G.

Collection of information.

The information was collected through a checklist of tasks and interviews.

Collection of information for Objective One. The six participating manufacturers' representatives completed the checklist of tasks at the beginning of the interview. The checklist of tasks consisted of the 171 task statements and three additional duty statements in the task inventory. The task statements were grouped into the six duties identified: Duty A, Installing and Moving Machines; Duty B, Performing Preventative Maintenance; Duty C, Maintaining Equipment; Duty D, Performing Repairs; Duty E, Programming; and Duty F, Communicating. The task statements within each duty were listed alphabetically.

The three additional duty statements were then listed (Appendix H).

The interviewee was asked to respond to each statement on the checklist in terms of frequency performed, criticalness to job performance, employer expectation, and opportunity to learn the task on the job. The two questions regarding employer's expectation and opportunity to learn on the job were necessary for prioritizing the tasks by opportunity to learn on the job.

For frequency performed the interviewee was asked if the task (or one of the three duties) was performed daily, weekly, monthly, yearly or never. The appropriate box was then checked.

For criticalness to job performance the interviewee was asked the level of criticalness. He responded with a number from one for most critical to the job performance to five for least critical to job performance.

For employer expectation the interviewee was asked if the task performance was expected of a new employee, or within six months, or not expected within the first six months. The appropriate box was then checked, or left blank if the task was not expected within the first six months.

For opportunity to learn the task on the job, the interviewee was asked if the opportunity was good, average or poor. The appropriate box was then checked.

During the interview one broad question was addressed for Objective One.

> What additional tasks or duty performances not listed are required of the robot maintenance mechanic?

The individuals interviewed contributed some additions to the survey form. These additions necessitated a follow-up questionnaire so each participant could react to the suggestions (Appendix I).

Collection of information for Objective Two. The information was gathered from the six participating manufacturers' representatives through the checklist of tasks and interviews. The question, Will this task be performed in 1990? was added to the checklist of tasks (see Appendix H). The interviewee responded by checking either yes or no. Any explanation of the answer was recorded for further discussion during the interview.

During the interview a second question was asked which related to Objective Two.

> What additional task performances will be required in 1990?

Collection of information for Objective Three. The information was gathered from the six participating manufacturers' representatives through personal interviews, from telephone interviews with forty potential robot users, and through six personal interviews with persons in robot user plants.

The interviews with the six participating manufacturers' representatives were based around one question:

> What is the quality of installation, maintenance, repair, and operation in the user plants?

The procedure for the telephone interviews with forty potential users is shown in Figure 2 (page 53). The discussion section of the procedure was organized around three broad questions.

1. Who installs, maintains, repairs, and operates your plant's robots?
2. Do you experience any difficulty with the method?
3. If yes, what do you attribute this difficulty to?

Six individuals were selected for personal interview from the telephone procedure. This interview was organized around the same three questions. Exposure to the structural difficulty was obtained by attempting to complete the checklist of tasks at two plants which used opposing methods of installation, maintenance, repair, and operation of their robots.

The interviews raised a major concern in the method of repair, which necessitated an additional question being added to the follow-up questionnaire sent to the six manufacturers. The follow-up questionnaire is shown in Appendix I.

Summary

The method of analysis selected for the study was task analysis. The purposes for doing a task analysis are consistent with the key purposes of this study. The method selected for gathering data was individual interview with a checklist of tasks. This method suited the key purposes of the study and the availability and cooperation of the respondents.

The development of the task inventory proceeded through six steps: development of task statements through review of robot operation, repair, and maintenance manuals; development of additional task statements using selected publications relating to skill areas identified in step 1; review and consolidation of task statements by teacher experts; preparation of initial task inventory; review of initial task inventory by robot maintenance experts; refinements, changes, additions, and deletions as recommended by robot maintenance experts.

Information on what tasks should be performed is generated through the office of the manufacturer's service manager. Representatives of each of the six largest companies were selected to participate in identifying tasks for Objectives One and Two.

To meet Objective Three, the six participating manufacturers' representatives were interviewed, forty companies who were potential users of robots were contacted by telephone, and six people from robot user plants were interviewed.

CHAPTER IV

FINDINGS

This chapter presents the findings from the task checklist, the personal interviews, the telephone interviews, and the follow-up mailed questionnaire as they relate to the three objectives of the study.

Findings for the First Objective

The first objective was to identify the tasks necessary to perform the job of industrial robot maintenance mechanic in Michigan, prioritized by frequency performed, criticalness, and opportunity to learn on the job.

Of the 171 task statements on the final checklist it was found 158 were performed in the installation, maintenance, repair, and operation of robots. That is, at least one of the six manufacturers' representatives surveyed identified the task statement as necessary in the maintenance of his company's robots. The three additional duties on the checklist were also found to be performed in the installation, maintenance, repair, and operation of robots. The personal interviews generated an additional seven task statements and no additional duty statements. The follow-up questionnaire with the additional task statements from the personal interview increased the number of tasks performed by robot maintenance mechanics in Michigan from 158 to 165. All these tasks were within the six duties previously identified.

Thirty-five tasks were performed in the maintenance of the robots of all six manufacturers. Twenty-seven tasks were performed in the maintenance of robots of five of the six manufacturers. Thirty-two tasks were performed in the maintenance of robots of four of the six manufacturers. There were twenty-four tasks performed in the maintenance of robots of three of the six manufacturers and twenty-six tasks performed in the maintenance of robots of two of the six manufacturers. Twenty-one tasks were performed in the maintenance of only one of the six manufacturers' robots.

Table 4 shows the number of tasks common to the six robot manufacturers in the study.

TABLE 4

Number of Required Tasks that are Common to the Robot Manufacturers in the Study

Number of Manufacturers	6	5	4	3	2	1
Number of Tasks Common to the Manufacturers	35	27	32	24	26	21

The tasks necessary to perform the job of industrial robot maintenance mechanic are reported in each of the following three sets of tables: Tables 5 through 10, Tables 11 through 16 and Tables 17 through 22. Tables 5 through 10 order the tasks by frequency performed by the robot maintenance mechanic using the frequency responses from the checklist. Tables 11 through 16 order the tasks by criticalness to the job performance using the criticalness responses from the checklist. Tables 17 through 22 order the tasks by the opportunity to learn on the job using the employer expectations and opportunity to learn responses from the checklist.

Frequency of task performance

Tables 5 through 10 list the tasks performed on robots by frequency performed by the mechanic. The frequency listed in the tables is the most often checked frequency, or the mode of the responses. The number of respondents checking this frequency is also listed. The tasks are prioritized by frequency of performance selected by the modal group. The more frequent the performance the higher priority the task is given. When more than one task has the same priority they are further prioritized by the frequencies checked by the non-modal group. Any tasks which still have the same priority status are listed in the order they appear on the checklist.

The thirty-five tasks reported performed on robots of all six manufacturers are listed in Table 5. Table 6 lists the twenty-seven tasks reported performed on robots of five of the six manufacturers. Table 7 lists the thirty-two tasks reported performed on robots of four of the six manufacturers. Table 8 lists the twenty-four tasks reported performed on robots of three of the six manufacturers. Table 9 lists the twenty-six tasks reported performed on robots of two of the six manufacturers. Table 10 lists the twenty-one tasks reported performed on robots of one of the six manufacturers.

Table 5 lists the tasks performed on robots of all six manufacturers by frequency performed by the mechanic. All of the six manufacturers' representatives indicated the task was performed with their robots.

Task number D3, Locate electronic component malfunctions using fault guides, is listed as the highest priority. The most often checked frequency was daily; five of the six manufacturers who required the task indicated that the task is performed daily.

The last task to appear on the table is task number D27, Replace gear drives. The most often checked frequency was yearly; four of the six manufacturers requiring the task indicated it was performed yearly. Responses for D10, Replace bearings, were identical to D27. The task D10 appears before task D27 only because it appears first on the checklist.

TABLE 5

Tasks Performed on Robots of All Six Manufacturers Prioritized by Frequency Performed by Mechanic

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
D3	Locate electronic component malfunctions using fault guides	daily	5
F12	Communicate verbally	daily	5
E4	Enter program using teach control	daily	4
F11	Communicate using the telephone	daily	4
E5	Erase program memory	D/W/M	2
F14	Initiate maintenance activities (self starter)	D/W/M	2
D4	Remove electronic components	D/W	2
D20	Replace electrical circuit components	D/W	2
E10	Test run program	weekly	4
F13	Communicate in writing	weekly	4
E3	Edit program	weekly	3
F1	Interpret blueprints	weekly	4
D22	Replace encoders	W/Y	2
A6	Connect machine to air/ hydraulic/electrical source	monthly	3
D26	Replace fuses	monthly	3
C6	Adjust automatic gain control circuit	monthly	3
C30	Align gear drives	monthly	4
A10	Install proximity switch	monthly	4
D39	Replace indicator lamps	monthly	4
A9	Install mechanical stops for robot motion	monthly	3
D11	Replace capacitor	monthly	3

TABLE 5
(cont.)

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
D73	Solder/unsolder electronic components	monthly	3
B18	Lubricate gear drives	monthly	4
D74	Splice wires	monthly	3
B3	Clean chassis	monthly	5
B4	Clean circulation fans/ ventilators	monthly	5
D62	Replace solid state diodes	monthly	3
D67	Replace teach control	monthly	3
D6	Replace actuator	monthly	4
D57	Replace relays	yearly	3
D40	Replace integrated circuits (memory)	yearly	3
D59	Replace ribbon cables	yearly	3
D19	Replace electric motor	yearly	4
D10	Replace bearings	yearly	4
D27	Replace gear drives	yearly	4

Table 6 lists the tasks performed on robots of five of the six manufacturers by frequency performed by the mechanic. One of the six manufacturers' representatives indicated this task was not performed with their robots.

Task number F2, Interpret schematics of electronic circuitry is listed as the highest priority. The most often selected frequency was daily; three of the five manufacturers who required the task selected daily.

The next four tasks listed: C3, Adjust AC output resistance; D24, Replace faulty PC boards; E9, Reinitialize program memory; and A2, Attach safety guards, shields and covers, were the only tasks to cause an inconsistency between the objective of prioritizing by frequency performed by the robot maintenance mechanic and the method chosen to show this priority. The reason is the various responses by the five manufacturers' representatives. The responses were:

C3 Adjust AC output resistance; daily 2, weekly 3

D24 Replace faulty PC boards; daily 2, weekly 3

E9 Reinitialize program memory; daily 2, weekly 2, monthly 1

A2 Attach safety guards, shields and covers; daily 2, weekly 1, monthly 2.

Following the method of priority used they should appear in the order E9, A2, C3, and D24. It was decided to be consistent with the objective of prioritizing by frequency performed by the robot maintenance mechanic and make an exception to the method chosen to show the priority in these cases.

TABLE 6

Tasks Performed on Robots of Five of the Six Manufacturers Prioritized by Frequency Performed by Mechanic

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
F2	Interpret schematics of electronic circuitry	daily	3
C3	Adjust AC output resistance	weekly	3*
D24	Replace faulty PC boards	weekly	3*
E9	Reinitialize program memory	D/W	2*
A2	Attach safety guards, shields, and covers	D/M	2*
C7	Adjust bias network	weekly	3
E2	Copy diskette	weekly	3
C16	Adjust linkages and lever mechanisms	weekly	4
A1	Align machinery	W/M	2
E8	Produce data tape	W/M	2
A4	Complete incoming checklist	monthly	3
A5	Complete preinstallation facility checklist	monthly	2
C9	Adjust drive gear	monthly	2
B19	Lubricate linkages and lever mechanisms	monthly	3
B15	Lubricate chain and sprocket drive	monthly	4
D60	Replace servomechanisms	M/Y	2
D63	Replace solid state diodes	M/Y	2
D53	Replace pressure switch	M/Y	2
D51	Replace potentiometer	yearly	3
D64	Replace switches (lead, contact, mercurial)	yearly	
D65	Replace tachogenerator	yearly	3

TABLE 6
(cont.)

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
D52	Replace pressure line	yearly	3
A14	Position & secure machinery on foundation	yearly	3
D9	Replace air regulators	yearly	3
D16	Replace digital display segment	yearly	3
F8	Train new employees	yearly	3
D61	Replace shaft assembly	yearly	4

*Correctly prioritized by frequency performed using all responses.

Table 7 lists the tasks performed on robots of four of the six manufacturers prioritized by frequency performed by the mechanic. Two of the six manufacturers' representatives indicated this task is not performed on their robots. Task E11, Transfer program memory to cassette tape, is listed as the highest priority. The most often checked frequency was daily. Three of the four manufacturers indicated it was done daily.

The last task listed is C31, Align piston (rod) of hydraulic cylinder; three of the four manufacturers checked that it was done yearly.

TABLE 7

Tasks Performed on Robots of Four of the Six Manufacturers Prioritized by Frequency Performed by Mechanic

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
E11	Transfer program memory to cassette tape	daily	3
B21	Record meter readings	weekly	3
F3	Interpret schematics of hydraulic system	weekly	3
C23	Adjust pressure control unload valve	weekly	3
D31	Replace hydraulic gasket and seals	weekly	2
E7	Load programmable system tape	weekly	2
A3	Block and brace equipment for moving	W/M	2
E1	Complete programming chart	W/M	2
F4	Interpret schematics of pneumatic system	W/M	2
D37	Replace hydraulic system valves	weekly	2
D2	Install flexible couplings	monthly	3
D38	Replace hydraulic valves	monthly	3
C29	Align chain and sprocket drives	monthly	3
D17	Replace drive coupling	monthly	2
D32	Replace hydraulic gasket and seals	monthly	2
D58	Replace resistors	monthly	2
D69	Replace transducers	monthly	2
D71	Replace transistors	monthly	2
D75	Replace electrical clutch or brake	monthly	2
F7	Prepare safety reports	monthly	2

TABLE 7
(cont.)

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
A11	Install sensing plate	monthly	2
D36	Replace hydraulic strainer/filters	monthly	2
D41	Replace mechanical seals	monthly	2
B23	Sample hydraulic fluid	monthly	3
D48	Replace pneumatic lines and fittings	monthly	3
D54	Replace programmer	M/Y	2
D70	Replace transformers	M/Y	2
D23	Replace energy storage cells	yearly	3
A15	Prepare area for machine installation	yearly	3
A16	Raise machinery using jacks, bars, slings, etc.	yearly	3
B22	Refill hydraulic system	yearly	3
C31	Align piston (rod) of hydraulic cylinder	yearly	3

Table 8 lists the tasks performed on robots of three of the six manufacturers prioritized by frequency performed by the mechanic. Three of the six manufacturers' representatives indicated this task is not performed with their robots.

Task C25, Adjust servovalves is listed as the highest priority. The most often checked frequency was weekly.

Two of the three manufacturers indicated it was done weekly.

The last task listed is D34, Replace hydraulic pressure gauge. Two of the three manufacturers indicated it was done yearly. The last five listed tasks all have the same priority status because of identical responses. They are therefore listed in the sequence they appear in the questionnaire. The previous five responses appear before, because of the frequency checked by the third manufacturer.

TABLE 8

Tasks Performed on Robots of Three of the Six Manufacturers Prioritized by Frequency Performed by Mechanic

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
C25	Adjust servovalves	weekly	2
C32	Align shafts	D/W/M	1
C35	Calibrate timing/clock pulse	D/W/M	1
C34	Calibrate vertical amplitude	weekly	2
C38	Calibrate multi-vibrator circuit	monthly	2
C22	Adjust pneumatic rotary actuator	monthly	2
D8	Replace air filters	monthly	2
B1	Change gearbox oil	W/M/Y	1
C28	Align and adjust belt drive	W/M/Y	1
B7	Clean hydraulic strainer/ filters	monthly	3

TABLE 8
(cont.)

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
A8	Erect barricades	monthly	2
B5	Clean electrical contact points	monthly	2
D35	Replace hydraulic pump	monthly	2
F10	Write operational procedures	monthly	2
D68	Replace thermal breakers	yearly	2
F9	Translate graphic information to written	yearly	2
D28	Replace guide rollers	yearly	2
D33	Replace hydraulic motor	yearly	2
D45	Replace pneumatic clutch	yearly	2
A12	Move machine/equipment with skids or dollies	yearly	2
B10	Clean tape head	yearly	2
D21	Replace electrical relief valves	yearly	2
D29	Replace heat exchanger	yearly	2
D34	Replace hydraulic pressure gauge	yearly	2

Table 9 lists the task performed on robots of two of the six manufacturers prioritized by frequency performed by the mechanic. Four of the six manufacturers' representatives indicated this task is not performed with their robots.

Task C21, Adjust pneumatic controls is listed as the highest priority. The most often checked frequency was daily. Both manufacturers indicated it was daily.

The last task listed is D47, Replace pneumatic gauge assembly. Both manufacturers indicated it was done yearly. The last four tasks have the same priority status and are listed in the sequence they appear on the questionnaire.

TABLE 9

Tasks Performed on Robots of Two of the Six Manufacturers Prioritized by Frequency Performed by Mechanic

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
C21	Adjust pneumatic controls	daily	2
C14	Adjust hyrdraulic flow	D/W	1
C15	Adjust hydraulic pressure	D/W	1
C18	Adjust oscillator	D/W	1
E6	Load data plate	D/W	1
F5	Plan quality assessment checks	D/W	1
C8	Adjust DC generator output	D/M	1
C19	Adjust output of high frequency amplifiers	weekly	1
C24	Adjust probe calibrator signal	W/M	1
C27	Adjust thermostat	W/M	1
C36	Change direction of hydraulic pump motor	W/M	1
C37	Change rotation of electric motor	W/M	1
A7	Crate robot for transfer	W/Y	1
D25	Replace frequency converter (motor generator)	W/Y	1
B2	Clean air filters	monthly	2
B6	Clean electric motor	monthly	2

TABLE 9
(cont.)

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
B9	Clean reflector mirrors	monthly	2
D5	Replace accumulator	monthly	2
B16	Lubricate electric motor	M/Y	1
D14	Replace chain and sprocket drive	M/Y	1
D46	Replace pneumatic cushion unit	M/Y	1
D56	Replace radio frequency interface filters	M/Y	1
B17	Lubricate fans/ventilators	yearly	2
D43	Replace motor starter	yearly	2
D44	Replace motor starter transformer	yearly	2
D47	Replace pneumatic gauge assembly	yearly	2

Table 10 lists the tasks performed on robots of one of the six manufacturers prioritized by frequency performed by the mechanic. Five of the six manufacturers' representatives indicated this task is not performed with their robots.

Tasks C2, Adjust AC output resistance, C26 Adjust tape reader; C33, Calibrate P-P voltage, and D18, Replace dynamotor are all listed as the highest priority; the manufacturer indicated the task was done weekly. Task C2 appears first only because it appears first on the questionnaire. The last five tasks listed all have the same priority status. The manufacturer indicated the task was performed yearly. Task D55, Replace pulley belt, is listed last only because it appeared after the other four tasks on the questionnaire.

TASK 10

Tasks Performed on Robots of One of the Six Manufacturers Prioritized by Frequency Performed by Mechanic

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
C2	Adjust AC output resistance	weekly	1
C26	Adjust tape reader	weekly	1
C33	Calibrate P-P voltage	weekly	1
D18	Replace dynamotor	weekly	1
B8	Clean potentiometers	monthly	1
B11	Clean tape reader	monthly	1
B12	Clean tape recorder	monthly	1
B20	Lubricate tape recorder	monthly	1
C4	Adjust armature or field connection voltage	monthly	1
C11	Adjust focus control	monthly	1
C23	Adjust pressure control (relief) valve	monthly	1
D7	Replace air compressor	monthly	1
D12	Replace cathode ray tube	monthly	1
D30	Replace hydraulic accumulator bladder	monthly	1
F6	Prepare estimates of down time	monthly	1
A13	Paint machinery/equipment	yearly	1

TABLE 10
(cont.)

Task #	Task	Most Often Cited Frequency	Number Citing Most Often Cited Frequency
C12	Adjust gibs	yearly	1
C17	Adjust modulation percentage	yearly	1
D15	Adjust hydraulic pressure	yearly	1
D49	Replace pneumatic lubricator	yearly	1
D55	Replace pulley belt	yearly	1

Criticalness of task performance.

Tables 11 through 16 list the tasks performed on robots by criticalness to job performance. The respondents gave the task statement a score of one if it was considered most critical to job performance down to five for least critical. The mean score of the respondents is used to prioritize the tasks by criticalness to job performance. The mean score was determined by adding the scores and dividing by the number of respondents assigning a score to the task.

Table 11 lists the tasks performed on robots of all six manufacturers by criticalness to the job performance. All six manufacturers' representatives had indicated on the checklist that the task was performed with their robots. Task D3, Locate electronic component malfunctions using fault guides; task D4, Remove electronic components, and task D20, Replace electrical circuit components, receive the same high priority in the table because the mean criticalness of each of these tasks is 1.67. They are listed in the table in the sequence they appear on the questionnaire.

Task D39, Replace indicator lamps has the lowest priority with a mean criticalness score of 4.17.

TABLE 11

Tasks Performed on All Six Manufacturers' Robots Prioritized by Criticalness of Task to Job Performance

Task #	Task	Criticalness
D3	Locate electronic component malfunctions using fault guides	1.67
D4	Remove electronic components	1.67
D20	Replace electrical circuit components	1.67
C6	Adjust automatic gain control circuit	1.83
F11	Communicate using the telephone	1.83
F12	Communicate verbally	1.83
F14	Initiate maintenance activities (self-starter)	1.83
D22	Replace encoders	2.00
D40	Replace integrated circuits (memory)	2.00
D59	Replace ribbon cables	2.00
E4	Enter program using teach control	2.00
E10	Run test program	2.00
F13	Communicate in writing	2.00
D6	Replace actuator	2.17
D26	Replace fuses	2.17

TABLE 11
(cont.)

Task	Task	Criticalness
D27	Replace gear drives	2.17
D57	Replace relays	2.17
D62	Replace solenoids	2.17
E3	Edit program	2.17
C30	Align gear drives	2.33
D11	Replace capacitor	2.33
D73	Solder/unsolder electronic components	2.33
D74	Splice wires	2.33
F1	Interpret blueprints	2.33
A10	Align machinery	2.50
D10	Replace bearings	2.50
E5	Erase program memory	2.50
A6	Connect machine to air/hydraulic/ electrical source	2.67
B18	Lubricate gear drives	2.67
D19	Replace electric motor	2.67
A9	Install mechanical stops for robot motion	2.83
D67	Replace teach control	2.83
B3	Clean chassis	3.16
B4	Clean circulation fans/ventilators	3.50
D39	Replace indicator lamps	4.17

Table 12 lists the tasks performed on robots of five of the six manufacturers by criticalness to the job performance. One of the six manufacturers' representatives had checked that the task is never performed with their robots. Task C16, Adjust linkages and lever mechanisms, receives the highest priority in the table because the mean criticalness of the five respondents was 1.4. Tasks A5, Complete pre-installation facility checklist, and D9, Replace air regulators, receive the lowest priority with a 3.6 mean average.

TABLE 12

Tasks Performed on Five of the Six Manufacturers' Robots Prioritized by Criticalness of Task to Job Performance

Task #	Task	Criticalness
C16	Adjust linkages and lever mechanisms	1.4
D60	Replace servomechanisms	1.6
A1	Align machinery	1.8
F2	Interpret schematics of electronic circuitry	1.8
C3	Adjust amplifier gain	2.0
C7	Adjust bias network	2.0
D24	Replace faulty PC boards	2.0
A4	Complete incoming checklist	2.2
D53	Replace programmer	2.2
D64	Replace switches (lead, contact, mercurial)	2.2
D65	Replace tachogenerator	2.2
E8	Produce data tape	2.2
E9	Reinitialize program memory	2.2
A2	Attach safety guards, shields, covers	2.4
D61	Replace shaft assembly	2.4
A14	Position & secure machinery on foundation	2.6
B19	Lubricate linkages and lever mechanisms	2.6
E2	Copy diskette	2.6

TABLE 12
(Cont.)

Task #	Task	Criticalness
C9	Adjust drive gear	2.8
D63	Replace solid state diodes	2.8
B15	Lubricate chain and sprocket drive	3.0
D16	Replace digital display segment	3.0
D51	Replace potentiometer	3.0
D52	Replace pressure line filter element	3.2
F8	Train new employees	3.2
A5	Complete preinstallation facility checklist	3.6
D9	Replace air regulators	3.6

Table 13 lists the tasks performed on robots of four of the six manufacturers by criticalness to the job performance. Two of the six manufacturers' representatives had checked that this task is never performed with their robots. Tasks E11, Transfer program memory to cassette tape; E7, Load programmable system tape; and F3, Interpret schematics of hydraulic system receive the same high priority in the table because the mean criticalness of each of these tasks is 1.75. Task A15, Prepare area for machine installation has the lowest priority with a mean criticalness score of 4.5

TABLE 13

Tasks Performed on Four of the Six Manufacturers' Robots Prioritized by Criticalness of Task to Job Performance

Task #	Task	Criticalness
E11	Transfer program memory to cassette tape	1.75
E7	Load programmable system tape	1.75
F3	Interpret schematics of hydraulic system	1.75
A11	Install sensing plate	2.00
C23	Adjust pressure control unload valve	2.00
D38	Replace hydraulic valves	2.00
C31	Align piston (rod) of hydraulic cylinder	2.25
D23	Replace energy storage cells	2.25
D69	Replace transducers	2.25
D70	Replace transformers	2.25
F7	Prepare safety reports	2.25
C29	Align chain and sprocket drives	2.50
D31	Replace hydraulic gasket and seals	2.50
D32	Replace hydraulic lines/fittings	2.50
D37	Replace hydraulic system valves	2.50
D71	Replace transistors	2.50
D75	Replace electrical clutch or brake	2.50
F4	Interpret schematics of pneumatic system	2.50
B21	Record meter readings	2.75
D2	Install flexible couplings	2.75
D36	Replace hydraulic strainer/filters	2.75
D58	Replace resistors	2.75
A3	Block and brace equipment for moving	3.00
D17	Replace drive coupling	3.00
D41	Replace mechanical seals	3.00
D48	Replace pneumatic lines and fittings	3.00

TABLE 13
(cont.)

Task #	Task	Criticalness
E1	Complete programming chart	3.00
A16	Raise machinery using jacks, bars, slings, etc.	3.25
D54	Replace programmer	3.25
B23	Sample hydraulic fluid	3.50
B22	Refill hydraulic system	3.75
A15	Prepare area for machine installation	4.50

Table 14 lists the tasks performed on robots of three of the six manufacturers by criticalness to the job performance. The other three of the six manufacturers' representatives had checked that this task is never performed with their robots. Task C22, Adjust pneumatic rotary actuator has the highest priority with a mean criticalness of 1.33. Task F9, Translate graphic information to written specifications and A8, Erect barricades, have the lowest priorities with a mean criticalness score of 4.33.

TABLE 14

Tasks Performed on Three of the Six Manufacturers' Robots Prioritized by Criticalness of Task to Job Performance

Task #	Task	Criticalness
C22	Adjust pneumatic rotary actuator	1.33
C28	Align and adjust belt drive	1.67
C32	Align shafts	1.67

TABLE 14
(cont.)

Task #	Task	Criticalness
C35	Calibrate timing/clock pulse	1.67
D21	Replace electrical relief valves	1.67
C34	Calibrate vertical amplitude	2.00
C38	Calibrate multi-vibrator circuit	2.00
B5	Clean electrical contact points	2.67
D28	Replace guide rollers	2.67
D68	Replace thermal breakers	2.67
B7	Clean hydraulic strainer/filters	3.00
B10	Clean tape head	3.00
C25	Adjust servovalves	3.00
D8	Replace air filters	3.00
D29	Replace heat exchanger	3.00
D34	Replace hydraulic pressure gauge	3.00
D35	Replace hydraulic pump	3.00
B1	Change gearbox oil	3.33
D33	Replace hydraulic motor	3.33
D45	Replace pneumatic clutch	3.33
A12	Move machine/equipment with skids or dollies	3.67
F10	Write operational procedures	3.67
A8	Erect barricades	4.33
F9	Translate graphic information to written specifications	4.33

Table 15 lists the tasks performed on robots of two of the six manufacturers by criticalness to the job performance. The other four of the six manufacturers' representatives had checked that this task is never performed with their robots. Tasks C8, Adjust DC generator output; C24, Adjust probe calibrator signal; and D25, Replace frequency converter (motor generator) have the highest priority with a mean criticalness of 1.00. Task B9, Clean reflector mirrors, has the lowest priority with a mean criticalness score of 4.5

TABLE 15

Tasks Performed on Two of the Six Manufacturers' Robots Prioritized by Criticalness of Task to Job Performance

Task #	Task	Criticalness
C8	Adjust DC generator output	1.00
C24	Adjust probe calibrator signal	1.00
D25	Replace frequency converter (motor generator)	1.00
C14	Adjust hydraulic flow	1.50
C18	Adjust oscillator	1.50
C19	Adjust output of high frequency amplifiers	1.50
C21	Adjust pneumatic controls	1.50
C15	Adjust hydraulic pressure	2.00
C36	Change direction of hydraulic pump motor	2.50
C37	Change rotation of electric motor	2.50
D5	Replace accumulator	2.50
D46	Replace pneumatic cushion unit	2.50
D56	Replace radio frequency interface	2.50
E6	Load data plate	2.50
B2	Clean air filters	3.00
B16	Lubricate electric motor	3.00
C27	Adjust thermostat	3.00
D43	Replace motor starter	3.00

TABLE 15
(cont.)

Task #	Task	Criticalness
D44	Replace motor starter transformer	3.00
D47	Replace pneumatic gauge assembly	3.00
F5	Plan quality assessment checks	3.00
B6	Clean electric motor	3.50
A7	Crate robot for transfer	4.00
D14	Replace chain and sprocket drive	4.00
B17	Lubricate fans/ventilators	4.00
B9	Clean reflector mirrors	4.50

Table 16 lists the tasks performed on robots of one of the six manufacturers by criticalness to the job performance. The other five manufacturers' representatives had checked that this task is not performed with their robots. Tasks C4, Adjust armature or field connection voltage; C33, Calibrate P-P voltage; and D55, Replace pulley belt, have the highest priority with a criticalness of 1.00. Tasks C17, Adjust modulation percentage; D49, Replace pneumatic lubricator; and F6, Prepare estimates of down time all have the lowest priority with a criticalness score of 5.0.

TABLE 16

Tasks Performed on One of the Six Manufacturers' Robots Prioritized by Criticalness of Task to Job Performance

Task #	Task	Criticalness
C4	Adjust armature or field connection voltage	1.00
C33	Calibrate P-P voltage	1.00
D55	Replace pulley belt	1.00
B11	Clean tape reader	2.00
C2	Adjust AC output resistance	2.00
C23	Adjust pressure control (relief) valve	2.00
C26	Adjust tape reader	2.00
D7	Replace air compressor	2.00
D12	Replace cathode ray tube	2.00
D18	Replace dynamotor	2.00
B8	Clean potentiometers	3.00
B12	Clean tape recorder	3.00
B20	Lubricate tape recorder	3.00
C11	Adjust focus control	3.00
C12	Adjust gibs	3.00
D15	Replace deflection yoke	3.00
D30	Replace hydraulic accumulator bladder	3.00
A13	Paint machinery/equipment	4.00
C17	Adjust modulation percentage	5.00
D49	Replace pneumatic lubricator	5.00
F6	Prepare estimates of down time	5.00

Opportunity to learn the task on the job.

The responses on the checklist regarding employer expectation and opportunity to learn on the job were used to compile the priority list for opportunity to learn on the job.

It is generally considered that task competencies required of new employees take a high priority in the teaching of a trade prior to employment. And the greater the opportunity to learn the task on the job the lower the priority it should take in the teaching of the trade prior to employment. There is, however, a problem with this consideration and the actual employment situation of today for robot maintenance mechanics that was pointed out during the personal interviews. If the skills or competencies needed for the job are lacking in the job applicants and new employees, the company has to create the opportunity to learn them. Consequently, in this field, at this time, the opportunity to learn many of the tasks is good simply because employers are conducting much of the needed training.

In prioritizing the task list for opportunity to learn on the job, those task competencies required of new employees have priority because they are likely to be job hiring criteria. The larger the number of manufacturers' representatives indicating the task competency is expected of a new employee the higher the priority. The priority list is further prioritized by the opportunity to learn on the job. The manufacturer's representative had to check whether the opportunity to learn the task on the job was good, average or poor (Appendix H). Using a scale of one for good, two for average, and three for poor, a priority ranking for the opportunity to learn was established. The numbers were simply added to give a priority count. For example in Table 17, task F12, Communicate Verbally; task F13, Communicate in writing; task F11, Communicate using the telephone; and task D39, Replace indicator lamps, are the four highest priority tasks because in each case five of the six manufacturers' representatives expected this task performance by a new employee. The other tasks had less than five of the six manufacturers' representatives expecting the task performance by a new employee. The four tasks are then prioritized by the opportunity to learn the task on the job using the priority score. Tasks F12, Communicate verbally, and F13, Communicate in writing, received the highest score which was 14 so they appear highest in priority (a score of 18 would indicate every manufacturer's representative considered the opportunity learn on the job, poor). Task F11, Communicate using the telephone, received a score of 13 so it appears next. Task D39, Replace indicator lamps, received a score of six so it appears after task F11. After these tasks come those where four of the six manufacturers' representatives expected the task performance by a new employee. These tasks are then prioritized by the score for opportunity to learn on the job. After the tasks where four of the six manufacturers' representatives expected them to be performed by a new employee, are the tasks where three of the six manufacturers' representatives expected them to be performed by a new employee, prioritized by the score for opportunity to learn on the job. This procedure continues through the Table.

The lowest ranked task in Table 17 is A9, Install mechanical stops for robot motion. None of the manufacturers considered it necessary to be performed by a new employee. A score of six was given for the opportunity to learn on the job; the lower the number the better the opportunity to learn the task on the job (the score of six indicates every manufacturer gave the opportunity to learn this task on the job as good).

TABLE 17

Tasks Performed on All Six of the Manufacturers' Robots Prioritized by Number of the Manufacturers Expecting Performance by New Employee and Then by Ranking Scale of Opportunity to Learn on the Job

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
F12	Communicate verbally	5	14
F13	Communicate in writing	5	14
F11	Communicate using the telephone	5	13

TABLE 17
(cont.)

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity To Learn on the Job
D39	Replace indicator lamps	5	6
D73	Solder/unsolder electronic components	4	14
D74	Splice wires	4	12
B4	Clean circulation fans/ ventilators	4	7
B18	Lubricate gear drives	4	7
A6	Connect machine to air/ hydraulic/electric source	4	6
B3	Clean chassis	4	6
F1	Interpret blueprints	3	10
D26	Replace fuses	3	9
D57	Replace relays	2	12
D11	Replace capacitor	2	11
D59	Replace ribbon cables	2	11
F14	Initiate maintenance activity	2	10
D40	Replace integrated circuit component	2	10
D20	Replace electrical circuit components	1	14
D19	Replace electric motor	1	11
C30	Align gear drives	1	10
D10	Replace bearings	1	9
D62	Replace solenoids	1	8
D5	Erase program memory	1	8
A10	Install proximity switch	1	7
E3	Edit program	1	7
D22	Replace encoders	0	12
D3	Locate electronic component malfunctions using fault guides	0	11

TABLE 17
(cont.)

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity To Learn on the Job
D27	Replace gear drives	0	11
D4	Remove electronic components	0	10
C6	Adjust automatic gain control circuit	0	9
D6	Replace actuator	0	8
D67	Replace teach control	0	8
E10	Test run program	0	8
E4	Enter program using teach control	0	7
A9	Install mechanical stops for robot motion	0	6

Table 18 lists the tasks performed on robots of five of the six manufacturers prioritized first by the number of manufacturers requiring the task competency of a new employee and then by the priority ranking scale for the opportunity to learn the task on the job. Tasks B15, Lubricate chain and sprocket drive, and D9, Replace air regulators, receive the highest priority. Each of the five manufacturers expected these tasks to be performed by a new employee and each received a score of six for the opportunity to learn on the job (a score of five would indicate every manufacturer considered the opportunity to learn the task on the job as good). Task B19, Lubricate linkages and mechanisms ranked lower, though each of the five manufacturers expect the task to be performed by a new employee, because the task received a score of five for the opportunity to learn on the job (indicating all five manufacturers considered there was good opportunity to learn the task on the job).

TABLE 18

Tasks Performed on Five of the Six Manufacturers' Robots Prioritized by Number of the Manufacturers Expecting Performance by New Employee and Then by Ranking Scale of Opportunity to Learn on the Job

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
B15	Lucricate chain and sprocket drive	5	6
D9	Replace air regulators	5	6
B19	Lubricate linkages and lever mechanisms	5	5
A2	Attach safety guards, shields, and covers	4	5
D16	Replace digital display segment	3	9
A14	Position & secure machinery on foundation	3	7
D52	Replace pressure line filter	3	6
D63	Replace solid state diodes	2	12
F2	Interpret schematics of electronic circuitry	2	10
D51	Replace potentiometer	2	9
D53	Replace pressure switch	2	7

TABLE 18
(Cont.)

Task	Task	Number of Manufacturers Expecting Performance By New Employees	Ranking Scale of Opportunity to Learn on the Job
D60	Replace servomechanisms	1	10
D64	Replace switches (lead, contact, mercurial)	1	9
D65	Replace tachogenerator	1	9
E2	Copy diskette	1	7
A4	Complete incoming checklist	1	5
A5	Complete preinstallation facility checklist	1	5
D24	Replace faulty PC boards	0	10
D61	Replace shaft assembly	0	10
C7	Adjust bias network	0	9
C9	Adjust drive gear	0	9
E8	Produce data tape	0	8
E9	Reinitialize program memory	0	8
F8	Train new employees	0	7
A1	Align machinery	0	6
C3	Adjust amplifier gain	0	6
C16	Adjust linkages and lever mechanisms	0	6

Table 19 lists the tasks performed on robots of four of the six manufacturers prioritized first by the number of manufacturers requiring the task competency of a new employee and then by the priority ranking scale for the opportunity to learn on the job. Task A15, Prepare area for machine installation receives the highest priority.

Each of the four manufacturers expected this task to be performed by a new employee. The score for the opportunity to learn on the job is five (four would indicate each manufacturer considered the opportunity to learn the task on the job as good). Tasks All, Install sensing plate; D31, Replace hydraulic gasket and seals; and Ell, Transfer program memory to cassette tape are ranked lowest. None of the manufacturers expected this task competency of a new employee and the score on the opportunity to learn the task on the job was six.

TABLE 19

Tasks Performed by Four of the Six Manufacturers' Robots Prioritized by Number of the Manufacturers Expecting Performance by New Employee and Then by Ranking Scale of Opportunity to Learn on the Job

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
A15	Prepare area for machine installation	4	5
A3	Block and brace equipment for moving	3	4
D48	Replace pneumatic lines and fittings	3	4
D54	Replace programmer	2	7
D58	Replace resistors	2	7
D71	Replace transistors	2	7
B21	Record meter readings	2	6
D23	Replace energy storage cells	2	6

TABLE 19
(cont.)

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
D32	Replace hydraulic lines/ fittings	2	6
A16	Raise machinery using jacks, bars, slings, etc.	2	5
B22	Refill hydraulic system	2	5
D36	Replace hydraulic strainer/filters	2	4
D41	Replace mechanical seals	2	4
D37	Replace hydraulic system valves	2	4
D70	Replace transformers	1	9
F3	Interpret schematics of hydraulic system	1	9
C29	Align and adjust belt drive	1	7
C23	Adjust pressure control unload valve	1	6
B23	Sample hydraulic fluid	1	6
D69	Replace transducers	1	6
D38	Replace hydraulic valves	1	5
D75	Replace electrical clutch or brake	1	5
F7	Prepare safety reports	1	5
C31	Align piston (rod) of hydraulic cylinder	0	9
F4	Interpret schematics of pneumatic system	0	8
D2	Install flexible couplings	0	7
D17	Replace drive coupling	0	7
E1	Complete programming chart	0	7
E7	Load programmable system tape	0	7

TABLE 19
(cont.)

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
A11	Install sensing plate	0	6
D31	Replace hydraulic gasket and seals	0	6
E11	Transfer program memory to cassette tape	0	6

Table 20 lists the tasks performed on robots of three of the six manufacturers prioritized first by the number of manufacturers requiring the task competency of a new employee and then by the priority ranking scale for the opportunity to learn the task on the job. Tasks A8, Erect barricades, and A12, Move machine/equipment with skids or dollies receive the highest priority. Each of the three manufacturers expect the task competencies of a new employee. The score of five for opportunity to learn the task on the job was the same for the two tasks. The last ranked task is F9, Transfer graphic information to written specifications. None of the manufacturers expect the task competency of a new employee and the opportunity to learn the task on the job is five (average). Task F9 is at the same priority level as tasks C34, C35 and D53 and appears last only because it was last of these four tasks to appear on the questionnaire.

TABLE 20

Tasks Performed on Three of the Six Manufacturers' Robots Prioritized by Number of the Manufacturers Expecting Performance by New Employee and Then by Ranking Scale of Opportinity to Learn on the Job

Task	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
A8	Erect barricades	3	5
A12	Move machine/equipment with skids or dollies	3	5
B7	Clean hydraulic strainer/ filters	3	3
D21	Replace electrical relief valves	2	5
B1	Change gearbox oil	2	4
C38	Calibrate multi-vibrator circuit	2	4
D68	Replace thermal breakers	2	4
D8	Replace air filters	2	3
C32	Align shafts	1	7
C28	Align and adjust belt drive	1	6
D29	Replace heat exchanger	1	6
D34	Replace hydraulic pressure gauge	1	4
B5	Clean electrical contact points	1	3
B10	Clean tape head	1	3
C22	Adjust pneumatic rotary actuator	1	3
C25	Adjust servovalves	0	6
D28	Replace guide rollers	0	6
D35	Replace hydraulic pump	0	6
F10	Write operational procedures	0	6
C34	Calibrate vertical amplitude	0	5

TABLE 20
(cont.)

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
C35	Calibrate timing/clock pulse	0	5
D33	Replace hydraulic motor	0	5
D45	Replace pneumatic motor	0	5
F9	Translate graphic information to written specification	0	5

Table 21 lists the tasks performed on robots of two of the six manufacturers prioritized first by the number of manufacturers requiring the task competency of a new employee and then by the priority ranking scale for the opportunity to learn the task on the job. Task A7, Crate robot for transfer, receives the highest priority. Each of the two manufacturers expected the task competency of a new employee. The score of four for the opportunity to learn the task on the job indicates average opportunity.

TABLE 21

Tasks Performed on Two of the Six Manufacturers' Robots Prioritized by Number of the Manufacturers Expecting Performance by New Employee and Then by Ranking Scale of Opportunity to Learn on the Job

Task	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
A7	Crate robot for transfer	2	4
B17	Lubricate fans/ ventilators	2	3
B2	Clean air filters	2	2
B9	Clean reflector mirrors	2	2
C21	Adjust pneumatic controls	2	2
D47	Replace pneumatic gauge assembly	2	2
C15	Adjust hydraulic pressure	1	4
C24	Adjust probe calibrator signal	1	4
C27	Adjust thermostat	1	4
D25	Replace frequency con-verter(motor generator)	1	4
C18	Adjust oscillator	1	3
C19	Adjust output of high frequency amplifiers	1	3
C36	Change direction of hydraulic pump motor	1	3
C37	Change rotation of electric motor	1	3
B6	Clean electric motor	1	2
B16	Lubricate electric motor	1	2
C8	Adjust DC generator output	0	5
C14	Adjust hydraulic flow	0	4

TABLE 21
(cont.)

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
E6	Load data plate	0	4
D5	Replace accumulator	0	3
D14	Replace chain and sprocket	0	3
D43	Replace motor starter	0	3
D44	Replace motor starter transformer	0	3
D56	Replace radio frequency	0	3
F5	Plan quality assessment	0	3
D46	Replace pneumatic cushion unit	0	2

Table 22 lists the tasks performed on robots of one of the six manufacturers prioritized first by the number of manufacturers requiring the task competency of a new employee and then by the priority ranking scale for the opportunity to learn the task on the job. Task B20, Lubricate tape recorder receives the highest priority. The manufacturer expected the new employee to have the task competency and, the task offered only average opportunity to learn on the job.

TABLE 22

Tasks Performed on One of the Six Manufacturers' Robots Prioritized by Number of the Manufacturers Expecting Performance by New Employee and Then by Ranking Scale of Opportunity to Learn on the Job

Task #	Task	Number of Manufacturers Expecting Performance By New Employee	Ranking Scale of Opportunity to Learn on the Job
B20	Lubricate tape recorder	1	2
A13	Paint machinery/equipment	1	1
B8	Clean potentiometers	1	1
D49	Replace pneumatic lubricator	1	1
C2	Adjust AC output resistance	0	3
C26	Adjust tape reader	0	3
C33	Calibrate P-P voltage	0	3
D12	Replace cathode ray tube	0	3
D15	Replace deflection yoke	0	3
C11	Adjust focus control	0	2
D7	Replace air compressor	0	2
D18	Replace dynamotor	0	2
F6	Prepare estimates of down time	0	2
B11	Clean tape reader	0	1
B12	Clean tape recorder	0	1
C4	Adjust armature or field connection voltage	0	1
C12	Adjust gibs	0	1
C17	Adjust modulation percentage	0	1
C23	Adjust pressure control (relief) valve	0	1
D30	Replace hydraulic accumulator bladder	0	1
D55	Replace pulley belt	0	1

Three additional duties.

There were three additional duties on the checklist. Although they were not considered central to the robot mechanic's job as defined, data on these duties were considered useful. The Duty of administering personnel was indicated done by three of the six manufacturers. The most common frequency was weekly and the task had a criticalness level of 2.67. No employer expected this task to be done within the first six months of employment. The Duty of supervising maintenance and repair function was done by all six manufacturers. The most common frequency was weekly and the task had a criticalness level of 1.67. No employer expected the task to be done within the first six months of employment. And the Duty of working metal with hand or portable tools was expected by five of the six manufacturers. The most common frequency was monthly and the task had a criticalness level of 2.4. Three of the five employers expected this duty to be done by a new employee.

Review of the tasks.

Tables 5 through 22 list the tasks performed on robots of the six manufacturers in terms of frequency performed, criticalness, and opportunity to learn on the job. Some tasks are performed on robots of all six manufacturers, some on the robots of five of the six manufacturers, some on four of the six manufacturers, some on three, some on two, and some are performed on the robots of only one of the manufacturers.

The essential tasks for an individual robot maintenance mechanic will vary depending on the robots for which he is responsible. However, the more manufacturers requiring the task performance the more likely an individual is to be required to perform the task. For this reason, more concern should be given to tasks expected of all six manufacturers than of five manufacturers and more concern given to tasks expected of five manufacturers than of four manufacturers and so on.

The selection of tasks from the tables will vary according to the needs and preferences of the selector. Herschbach says a great number of combinations of selection factors exist and while some procedures help quantify the decision-making as to what should be taught, they do not eliminate the need to make judgments.[132] The weight one puts on frequency of performance compared to criticalness of performance will influence any overall priority order of tasks; as will the weight one puts on criticalness of performance compared to opportunity to learn on the job.

The objective of this study was to identify tasks, prioritized by frequency, criticalness, and opportunity to learn on the job. The educational designer can then make the necessary judgments as to what to teach from the tables.

This writer has made some selections. It is acknowledged they contain a level of judgment. The selections are presented and discussed in Chapter V.

Findings for the Second Objective

The second objective of the study was to contrast tasks identified for use today and tasks projected for 1990. The procedure used in identifying these differences is discussed in Chapter III.

No task is eliminated from the present list of tasks when projected to tasks necessary in 1990. No specific tasks were identified as being necessary in 1990 which are not now being performed, although some general and broad areas were suggested. These general and broad areas included camera repair work for robots with vision. Two respondents mentioned an increased use of pneumatics. One respondent mentioned a decreased use of pneumatics. Robots with self-diagnostic qualities were also mentioned.

It was reasoned by the respondents that most robots purchased today will be in operation in seven years time. Changes in robot design will be in the form of additions and improvements, such as vision, which will have little effect on the basic task competencies required. For these two reasons the respondents see little change in actual task requirements from today when looking to 1990.

There are a few changes in the number of manufacturers who will require the task be completed. Table 23 is a list of the projected differences between the tasks performed today and expected in 1990 by the manufacturers.

For all but two of the tasks listed, the number of manufacturers requiring the task to be performed in 1990 will drop by one (-1) from the number of manufacturers who presently require the task performance. In the case of task C28, Align and adjust belt drive, the number of manufacturers requiring the task will drop by two (-2) from three to one.

The only task which increases is C21, Adjust pneumatic controls. Two respondents considered a line of robots being developed with more advanced pneumatic capabilities will require adjustment of controls which are not now necessary. One respondent considered this task to be unnecessary in 1990. This gives the task a gain of one in the number of manufacturers requiring the task.

TABLE 23

Projected Differences Between the Tasks Performed Today and Those Expected to be Performed in 1990

Task	Task	Number of Manufacturers Requiring Task Now	Change in Number of Manufacturers Requiring Task in 1990
A8	Erect barricades	3	-1
B5	Clean electrical contact points	3	-1

TABLE 23
(cont.)

Task #	Task	Number of Manufacturers Requiring Task Now	Change in Number of Manufacturers Requiring Task in 1990
B10	Clean tape head	3	-1
B11	Clean tape reader	1	-1
B12	Clean tape recorder	1	-1
B16	Lubricate electric motor	2	-1
B17	Lubricate fans/ ventilators	2	-1
C9	Adjust drive gear	5	-1
C28	Align and adjust belt drive	3	-2
C29	Align chain and sprocket drives	4	-1
C30	Align gear drives	6	-1
D38	Replace hydraulic valves	4	-1
C21	Adjust pneumatic controls	2	+1

Findings for the Third Objective

The third objective of the study was to identify the structural difficulties in existing job classifications for the installation, maintenance, repair, and operation of robots.

In verifying the tasks performed by robot maintenance mechanics, contact with mechanics who worked for the manufacturers and mechanics who worked for the robot user companies was attempted. It was soon found, however, that despite the projections for robot maintenance mechanics in the future very few of them were, at the time, working in the robot user plants. This was consistent with literature identified in Chapter II of this study. Telephone contact with forty Michigan plants and subsequent personal interviews with six individuals associated with the use of robots in their plants, clearly demonstrated that a problem exists between projections and the situation of today.

The selection of the forty Michigan plants contacted was discussed in Chapter III. Of the forty plants surveyed seventeen used robots. In fourteen plants robots were repaired and maintained by personnel with previously existing job titles.

At the Budd Company in Detroit, electricians were responsible for the plant's two robots.

Whirlpool Corporation in St. Joseph had several robots which were maintained and repaired by their millwrights, electricians, and machine maintenance personnel.

Mueller Brass Company in Port Huron had their electricians and machine maintenance personnel repair every problem with the plant's robots except once, when the problem was covered by the manufacturer's warranty.

The Personnel Manager of Tecumseh Products said his company saw no need for robot maintenance mechanics because skills necessary to maintain and repair them existed within present job classifications. Any new job classification would not be covered by the union-management agreement. The union had an interest in identifying any skills necessary as being part of an existing job.

Similar comments were made by the head of the Master Mechanics Department at General Motors Pontiac Plant. He said robots were just another piece of equipment on an automated assembly line. Consequently the equipment was maintained and repaired with the skills already present in the existing job classifications: electricians for electrical problems, machine maintenance for mechanical and hydraulic problems, pipefitters for pneumatic problems. In addition, millwrights were responsible for installation and the lubrication department was responsible for lubrication. He pointed out that unions had made clear their interest in keeping with these job classifications and their lines of demarcation. The unions believe this will shelter the jobs of current union members and allow them to learn new skills relating to their jobs. Otherwise, they fear, a new job could be created requiring new employees, reducing the jobs of existing employees.

Ford Motor Company was developing robot maintenance training within existing job classifications. Specifications for a Technical Training Program on Industrial Robot Maintenance states:

> Since Ford has a variety of trade classifications which may require robot training, the equipment shall be subdivided into the following groups: electrical, mechanical, fluid power. . . The included audience of this program is the Industrial Electrician, Hydraulic Repairmen or Machine Repairman (depending on task concerned) at Ford Motor Company.[133]

This program has the support of the union.

It appeared that for many Michigan manufacturers a robot maintenance mechanic is considered unnecessary. The skills needed or expected to be needed to install, maintain, repair, and operate the robots exist within current jobs.

The companies that had created robot related positions had developed different job titles. At Steelcase in Grand Rapids, the recent purchase of robots required two new job titles, a Robotic Mig Welder and a Robotic Arc Welding Technician. The Mig Welder "Observes operation of robot to detect any control malfunctions and performs minor corrective action. Reports any major malfunctions to the Robotic Mig Welding Technician or Supervisor. sic"[134] The primary function of the Robotic Arc Welding Technician was written, "Program and select appropriate modes of operation for the automatic arc welding robots. Troubleshoots equipment malfunction. sic"[135] The immediate supervisor for both jobs was the foreman.

At Bendix Corporation's Hydraulics Division in St. Joseph, a person with the title of Robot Engineer was responsible for maintaining, repairing, and programming the plant's robots.

At Detroit Plastic Molding Company one person, the Supervisor for Maintenance, had assumed the responsibility for the installation, maintenance, repair, and operation of all robots in the plant, doing most of the work personally. It was noted that the involvement with robots of Detroit Plastics Molding Company was more than most other companies contacted. Yet the installation, maintenance, repair, and operation of robots were not the only responsibilities of the Supervisor's job. To further explore this concern, an additional question was added to the follow-up mailed questionnaire sent to the manufacturers of robots (Appendix I) which asked: In the robot user plant, how many robots do you think it would take for a person (assuming he has all the necessary skills and the robots are of average complexity) to work full-time in the maintenance and repair of robots? The mean average response was eleven robots. This suggested that until a plant had at least eleven robots there was not enough work to keep a robot maintenance mechanic employed full-time at that job. Considering this and the fact that Hunt and Hunt reported there were 6,800 robots in use in the United States in 1982, the number of full-time robot maintenance mechanics in the U.S. would be (if every plant that had robots had eleven or a multiple of eleven) a maximum of approximately 618.[136]

Of the seventeen plants identified who had robots, only four had eleven or more. Therefore, in many instances, the number of robots a plant had in operation was below the number of robots necessary to require a full-time position for robot installation, maintenance, repair, and operation.

It appeared that there were two reasons for the lack of robot maintenance mechanics in the plants using robots. One reason was that most plants had too few robots to require a full-time position of robot maintenance mechanic. And the other reason was that a robot maintenance mechanic was considered unnecessary in most Michigan plants because the skills needed to install, maintain, repair, and operate the robots already existed in other positions in the plants.

The question then became, how will industry get from very few robot maintenance mechanics today to the large numbers projected for 1990?

The projection of future robot use is one reason for the increase in robot maintenance mechanics. With the projected growth in numbers of robots there will be more plants with enough robots to have a full-time robot maintenance mechanic. This would be the case at companies which have taken the maintenance route of Detroit Plastics Molding, Bendix, and Steelcase.

The other reason for lack of robot maintenance mechanics today, that of the skills already existing in the plant, should not be overlooked when projecting for the future. However, the subdividing of these mechanics into specialized skill areas within their trade should not be overlooked either.

At Massey Ferguson, the Maintenance Supervisor reported that their electricians repaired and maintained the robots. However, they were the electricians who went through the robot manufacturer's training program and they will be expected to work on any new robots.

Each of the robot manufacturers participating in this study offered training programs in the installation, maintenance, repair, and operation of the robots sold. The people who attended the training programs were the mechanics who would be responsible for the maintenance and repair of the robots.

At Ford Motor Company the planned training program was designed for trades people to assume the duties of maintenance and repair of the robots.[137] The program covered Unimation, Prab, ASEA and Cincinnati Milacron robots. The maintenance personnel with the specialized skills of maintenance and repair of robots obtained through training were the individuals expected to maintain and repair them.

As the number of robots grows in the plants, the individuals with knowledge of the robots will spend more time on robot maintenance and less on their other duties. A person may therefore spend all his time on the maintenance and repair of robots but still have the job title of electrician or machine maintenance mechanic. This, according to the Service Manager at ASEA in Detroit, is what happened in Sweden's Volvo Plant where he worked for twelve years before working for ASEA. Electricians there, worked with machine maintenance mechanics to maintain and repair the robots. The lines of demarcation between jobs were less clearly defined and they cooperated in their assigned duties of maintenance and repair of the robots.

This had not come about in the companies contacted. The unions were very interested in maintaining clearly defined lines of demarcation. At General Motors Pontiac Plant the attempt to complete the task checklist questionnaire required a machine maintenance mechanic, an electrician, a pipefitter, a millwright, a person from the lubrication department and an industrial engineer. This required going to different parts of the plant for each segment of the interview. The electrician would work on electrical problems and the machine maintenance mechanic would work on mechanical problems. Thus, it could take several people to take a turn working on a problem with a robot.

ASEA's Service Manager pointed out that his service people were usually sent to a plant when the problem was not clearly electrical or mechanical, or when such things as electrical malfunctions caused a mechanical malfunction. He did not understand how (based on his experience at Volvo) ASEA's customers were willing to wait a day with no production, for the ASEA service mechanic, because they did not have people who knew the machine completely enough to fix it.

The Maintenance Supervisor at Detroit Plastics Molding observed that when robot service mechanics were called in, they did not know any more about electricity and electronics or mechanics or hydraulics or pneumatics; they just knew more about robots.

An Industrial Engineer at Pontiac Motors believed the maintenance personnel needed to know more about robotics and not just the parts of robots that related to the person's trade. This would, however, lead to crossing established lines of demarcation in unionized plants such as his.

The interviews with the six manufacturers' representatives, six individuals on the user side, and telephone interviews, generated two views on the maintenance and repair of robots. One view was that skills necessary for the maintenance and repair of robots existed in the plant. The other view was that the necessary skills were not the only consideration; efficiency in the installation, maintenance, repair, and operation was necessary and specialists in the maintenance and repair of robots would be more efficient.

Summary

For the first objective it was found that 165 tasks were performed by robot maintenance mechanics in Michigan. These tasks are presented in three sets of tables. The first set orders the tasks by frequency performed, the second set orders the tasks by criticalness to the job and the third set orders them by the opportunity to learn the task on the job. The essential tasks for an individual robot maintenance mechanic will vary depending on the robots for which he is responsible.

For the second objective it was found that task competencies required of robot maintenance mechanics will change very little between 1983 and 1990.

For the third objective it was found that despite the projections for robot maintenance mechanics in the future, there were very few of them. There were two reasons for this: most plants had too few robots to require a full-time position of robot maintenance; and a robot maintenance mechanic was considered unnecessary in most plants because many of the skills needed already exist in other positions in the plant.

There were two views on the maintenance of robots. One view was that skills necessary for the maintenance and repair of robots existed in the plant. The other view was that the necessary skills were not the only consideration; efficiency was necessary and specialists in the maintenance and repair of robots would be more efficient.

CHAPTER V

CONCLUSIONS, IMPLICATIONS AND RECOMMENDATIONS

This chapter is divided into four sections. The first section contains the conclusions associated with the three objectives. The second section contains implications of the study. The third section contains recommendations. The fourth section contains reflections by the researcher.

Conclusions

Conclusions for the First Objective.

The first objective was to identify tasks necessary to perform the job of industrial robot maintenance mechanic in Michigan, prioritized by frequency performed, criticalness, and opportunity to learn on the job.

There are 165 task competencies necessary for robot maintenance mechanics. These tasks are within six duties. Sixteen of the tasks are within the duty of installing and moving robots. Twenty-one of the tasks are within the duty of performing preventative maintenance. There are thirty-four tasks within the duty of maintaining robots. Sixty-nine tasks are within the duty of performing repairs on robots. Eleven tasks are in the duty of programming the robots and there are fourteen tasks in the duty of communicating.

Although not central to the job of the robot maintenance mechanic as defined, there are three additional duties that the robot maintenance mechanic can be expected to perform. These duties are: administering personnel, supervising maintenance and repair functions, and working metal with hand or portable tools.

Because the robots are built differently the exact number of tasks an individual robot maintenance mechanic will perform will depend on the manufacture and type of robots the robot mechanic is responsible for. Of the 165 task competencies necessary for robot maintenance mechanics, thirty-five are expected to be performed on the robots of all six of the six largest manufacturers of robots in the United States (the six largest manufacturers produced 97% of robot sales in the United States in 1980). Twenty-seven of the tasks are expected to be performed by five of the six largest manufacturers of robots. Thirty-two are expected to be performed by four of the six largest manufacturers. Twenty-four are expected to be performed by three of the six manufacturers. Twenty-six are expected by two of the manufacturers and twenty-one by just one of the six manufacturers.

Of the 165 task competencies necessary, 109 encompass traditional areas of electrical, mechanical, hydraulic, and pneumatic skills. Fifty-five of the tasks can be considered electrical, twenty-six can be considered mechanical, nineteen can be considered hydraulic, and nine can be considered pneumatic. Some of the other fifty-six tasks could fall within the requirements of any of these trade areas depending on how clearly defined the lines of demarcation between the jobs are, as for example, task A6, Connect machine to air/hydraulic/electrical source. Some tasks are difficult to classify such as B8, Clean reflector mirrors. Programming tasks are not encompassed by other trade areas.

The tasks vary in frequency of performance from daily to yearly or less. They vary in criticalness to job performance from a level of 1.00 indicating critical to job performance to 5.00 indicating not very important to job performance. The tasks also vary in the opportunity to learn the tasks on the job and the number of manufacturers expecting the task performance by a new employee. No task competency was expected of a new employee by all six manufacturers. There were six task competencies expected of a new employee by five of the six manufacturers. These competencies were B15, D9, F11, F12, and F13. These task competencies could be considered important as job entry requirements and therefore could have implications for education and training.

Any attempt to prioritize tasks based on all information gathered, that is, the number of manufacturers requiring the task performance, the frequency of the task performance, the criticalness to job performance, and the opportunity to learn the task on the job is judgmental. An overall prioritizing of the tasks will vary according to the needs and purpose of those doing the selecting. For training to work with specific robots, only those task competencies necessary for those specific robots need be considered. The value one puts on the various areas will influence any overall priority order of tasks.

A demonstration.

For purposes of demonstration the writer of this study has developed an overall priority list as an educational designer might do for a hypothetical, general, pre-employment program or curriculum for robot maintenance. Considerations are the rank order positions of the tasks and number of the manufacturers requiring the task to be done. Judgment is used in weighing frequency against criticalness and all other combinations of factors such as the worth of a task performed daily over a task performed weekly, or a criticalness to job performance of 1.4 over that of 1.83.

There were twenty-four tasks that appeared, to this writer, to be more prominent than the other 141. Of these twenty-four, the top ten are discussed in priority order to illustrate the factors involved in the judgment process. All twenty-four are presented in Table 24.

No. 1 D3, Locate electronic component malfunctions using fault guides.

All six manufacturers required this task to be done. Five of the six manufacturers said it was performed daily. In terms of the frequency ranking, this task had the joint highest priority. This task had the highest criticalness priority with the six manufacturers with a criticalness level of 1.67 on a scale of 1-5. No manufacturer expected a new employee to perform the task. It had an average learning opportunity on the job.

No. 2 D20, Replace electrical circuit components.

All six of the manufacturers required this task to be done. Four manufacturers expected this task to be performed daily, placing it fifth in priority of the six manufacturers in terms of frequency performed. The task had a criticalness level of 1.83 which placed it fourth in criticalness priority. One of the six manufacturers expected this task performance of a new employee.

No. 3 D4, Remove electronic components.

All six manufacturers required this task to be done. Two manufacturers expected this to be done daily and two expected it to be done weekly, placing it seventh in priority of six manufacturers in terms of frequency performed. The task has a criticalness level of 1.67 which puts it at the highest priority. Although no manufacturer expected a new employee to perform the task, it has an average learning opportunity on the job.

No. 4 F12, Communicate verbally.

All six manufacturers required this task to be done. Five of the six manufacturers said it was performed daily. This task had joint highest priority in terms of frequency. The task had a criticalness level of 1.83 which placed it fourth in priority. Five of the six manufacturers expected this task performance of a new employee. It was considered quite difficult to learn on the job, placing it highest in terms of lack of opportunity to learn on the job.

No. 5 F11, Communicate using the telephone.

All six manufacturers required this task to be done. Four manufacturers expected this task to be performed daily, placing it fifth in priority of six manufacturers in terms of frequency performed. The task had a criticalness level of 1.83 which placed it fourth in priority. Five of the six manufacturers expected this task performance of a new employee.

No. 6 C16, Adjust linkages and lever mechanisms.

Five of the six manufacturers required this task to be done. Four of the five manufacturers said it was done weekly. This task had the highest criticalness level of all tasks. The five manufacturers gave it a criticalness level of 1.40. No manufacturer expected this task to be performed by a new employee.

No. 7 F2, Interpret schematics of electronic circuitry.

Five of the six manufacturers required this task to be performed. Three of the five expected it to be done daily. The task was given a criticalness level of 1.8 by the five manufacturers, placing it joint third in priority in criticalness for five manufacturers. Two of the five manufacturers expected this task to be performed by a new employee and the opportunity to learn it on the job was average.

No. 8 F14, Initiate maintenance activities (self-starter).

All six manufacturers required this task to be done. Two of the manufacturers said it is done daily, two weekly, and two monthly. The task had a criticalness level of 1.83 which placed it joint fourth in priority of those tasks required by all six manufacturers. Two of the six manufacturers expected this task to be completed by a new employee. The opportunity to learn this task on the job was a little better than average.

No. 9 F13, <u>Communicate in writing</u>.

All six manufacturers required this task to be done. Four of the six manufacturers said it was done weekly. The task had a criticalness level of 2.00, which placed it joint eighth in priority of those tasks required by all six manufacturers. Five of the six manufacturers expected this task to be completed by a new employee. The opportunity to learn this task on the job was poor, placing it joint highest in terms of lack of opportunity to learn on the job.

No. 10 E4, <u>Enter program using teach control</u>.

All six of the manufacturers required this task to be performed. Four of the six manufacturers said it was done daily. The criticalness level was 2.00, placing it joint eighth in priority of those tasks required by all six manufacturers. No manufacturer expected a new employee to perform this task on the job and there was a good opportunity to learn this task on the job.

Twenty-four tasks appear, to this writer, more prominent for the teaching of a hypothetical, general pre-employment program or curriculum for robot maintenance. These tasks are listed in the order they appeared on the questionnaire. No attempt has been made to prioritize them; varying objectives for prioritizing would result in a different priority order. The task is listed with the number of manufacturers requiring the task, the most commonly selected

TABLE 24

The Twenty-four Tasks That Were More Prominent in Terms of Number of Manufacturers, Frequency, Criticalness, and Employer Expectations

Duty	Task #	Task	Number of Manufacturers Expecting Task Competency	Frequency	Criticalness	Number of Manufacturers Expecting Task of New Employees
Installing	A1	Align machinery	5	W/M	1.80	0
	A2	Attach safety guards, shields and covers	5	D/M	2.40	4
Maintaining equipment	C3	Adjust amplifier gain	5	weekly	2.00	0
	C6	Adjust automatic gain control circuit	6	monthly	1.83	0
	C7	Adjust bias network	5	weekly	2.00	0
	C16	Adjust linkages and lever mechanisms	5	weekly	1.40	0
	C32	Align shafts	3	D/W/M	1.67	1
	C35	Calibrate timing/clock pulse	3	D/W/M	1.67	0
	C39	Adjust pressure control unload valve	4	weekly	2.00	1
Performing repairs	D3	Locate electronic component malfunctions using fault guides	6	daily	1.67	0
	D4	Remove electronic components	6	D/W	1.67	0
	D20	Replace electrical circuit components	6	D/W	1.67	1
	D24	Replace faulty PC boards	5	weekly	2.00	0

TABLE 24
(cont.)

Duty	Task	Task	Number of Manufacturers Expecting Task Competency	Frequency	Criticalness	Number of Manufacturers Expecting Task of New Employees
Programming	E4	Enter program using teach	6	daily	2.00	0
	E5	Erase program memory	6	D/W/M	2.50	1
	E7	Load programmable system tape	4	weekly	1.75	0
	E9	Reinitialize program memory	5	D/W	2.20	0
	E10	Test run program	6	weekly	2.00	0
	E11	Transfer program memory to cassette tape	4	daily	1.75	0
Communicating information	F2	Interpret schematics of electronic circuitry	5	daily	1.80	2
	F3	Interpet schematics of hydraulic system	4	weekly	1.75	1
	F11	Communicate using the telephone	6	daily	1.83	5
	F12	Communicate verbally	6	daily	1.83	5
	F13	Communicate in writing	6	weekly	2.00	5
	F14	Initiate maintenance activities (self-starter)	6	D/W/M	1.83	2

frequency, the criticalness level, and the number of manufacturers expecting the task to be performed by a new employee. Two notable omissions are tasks B15 and D9. Although five of six employers considered them job entry requirements, in this writer's judgment they ranked too low in all other areas.

Conclusions for the Second Objective.

The second objective contrasts tasks identified for use today and tasks projected for 1990.

Task competencies required of robot maintenance mechanics will change very little between 1983 and 1990. There are two major reasons for this. The first is, robots purchased today are expected to still be in operation in 1990. The second reason is that changes in robot design will be in the form of additions and improvements. These changes will have little effect on the basic task competencies required. Improvements in vision, touch, and self diagnostics will generally require the use of tasks already identified. Some new tasks may be expected due to technological developments such as cameras for vision. New, specific task requirements arising from technological developments proceed from the development.

As the average age of robots increase in a plant, some tasks will be performed more frequently than when the machines were newer. Robot maintenance mechanics may not perform as many major repairs in the early years of a robot's life as in the later years, so task performances may shift in a given plant.

Conclusions for the Third Objective

The third objective identifies structural difficulties in job classification associated with robots. There are, at present, few robot maintenance mechanics in Michigan manufacturing plants. There are two reasons:

1. Most Michigan plants have too few robots to require a full-time position of robot maintenance mechanic. It takes an average of eleven average complexity robots to require one full-time position of robot maintenance mechanic.

2. A robot maintenance mechanic is unnecessary in most Michigan plants because many of the task competencies necessary to install, maintain, repair, and operate the robots already exist in other job positions in the plant. Of the 165 tasks necessary, 109 can be considered the domain of the electrician, machine maintenance, hydraulic repairman or pipefitter. In some plants the millwrights would be responsible for the complete duty of installing and moving the robot. The Lubrication Department (as identified in one large company) can be responsible for all tasks associated with the lubrication of robots. Some of the remaining tasks are common to more than one trade area, further increasing the number of tasks in the domain of existing job positions.

The fact that many of the skills exist in the plants is cause for one view on the installation, maintenance, repair and operation of robots. This view is: since skills already exist in the plant it is unnecessary to have specialized full-time robot maintenance mechanics. Unions are subscribing to this view because they have a particular interest in maintaining the present jobs of their members.

Another view is, that having the necessary skills is not the only consideration. Efficiency in the installation, maintenance, repair, and operation is necessary; and specialists in the installation, maintenance, repair, and operation of robots would be more efficient. This requires a specialized full-time robot maintenance mechanic; a person knowledgeable of the type of problems associated with robots and who can identify them quickly.

One view on the installation, maintenance, repair and operation of robots is supported out of the desire to maintain existing job classifications, the other view is supported out of the desire for efficiency in diagnosis of problems.

In this study the respondents to the checklist of tasks were robot manufacturers' representatives. They had no concern with the maintenance of job classifications in the robot user plants. This writer selected and ranked, for demonstration purposes, ten tasks which were judged to be the most prominent for a hypothetical pre-employment program in Conclusions for the First Objective. Of these ten tasks, little knowledge of any skill area is required of four of them; they are: F12, Communicate verbally; F13, Communicate in writing; F11, Communicate using the telephone; and F14, Initiate maintenance activities (self starter). All are skills necessary for diagnosticians to communicate their findings. Task D3, Locate electronic component malfunctions using fault guides and task F2, Interpret schematics of electronic circuitry, are also in this hypothetical top ten and are necessary task competencies for diagnoses of robot problems.

The task list shows the importance of diagnoses of problems, the interviews at Detroit Plastics Molding Company and ASEA illustrate problems associated with failure to diagnose correctly.

For those mechanics who are not able to diagnose a problem, the ability to communicate with the diagnostician is still a high priority.

It was not the purpose of this study to find which method of maintenance is best. However, the level of efficiency attained will have a direct bearing on the number of jobs associated with the installation, maintenance, repair, and operation of robots. And the decisions by companies regarding how their maintenance is to be done will have a direct bearing on the number of robot maintenance mechanics in the future. Thus structural problems with existing job classifications will affect the number of robot maintenance mechanics employed. The single most important factor regarding the structural problems is the position unions in the robot user plants take regarding the job classification of robot maintenance mechanics.

Implications

During interviews with the six robot manufacturers' representatives, the telephone interviews with the forty users, and personal interviews with the six users, two broad questions were asked, to assist in identifying implications:

1. What is the educational background of those who install, maintain, repair, and operate robots?
2. What is the desired educational background for those who install, maintain, repair, and operate robots?

In Objective One, task competencies necessary in the installation, maintenance, repair, and operation of robots were identified. In Objective Two, few differences between the task competencies necessary today and those projected to be necessary in 1990 were identified. In Objective Three, problems with the existing job classifications for the installation, maintenance, repair, and operation of robots were identified. All of these findings have implications for the education and training of robot maintenance mechanics.

Many tasks identified in Objective One can be divided into the skill areas of electrical, mechanical, hydraulic, pneumatic, programming, and communicating. These areas are an integral part of the robot mechanic's work and will have to be learned by the mechanic. It can be seen in Tables 5 through 22 that some tasks are performed more frequently than others, some are more critical than others, there is a greater opportunity to learn some on the job than others, and some are required of more manufacturers of robots than others. In terms of being expected of a new employee the most prominent of these tasks are three of the communication tasks. Tasks F12, Communicate verbally, F13, Communicate in writing, and F11, Communicate using the telephone, are expected of a new employee by five of the six manufacturers and they are considered difficult to learn on the job. Task F12, Communicate verbally, is expected to be performed daily by five of the six manufacturers. Task F11, Communicate using the telephone, is expected to be performed daily by four of the six manufacturers. Task F13, Communicate in writing, is expected to be performed weekly by four of the six manufacturers. These three tasks also rank high in terms of criticalness to the job. Tasks F11 and F12 have a criticalness level of 1.83 and F13 has a criticalness level of 2.00. These levels indicate it is critical to job performance. Communication skills in education and training programs should take a high priority.

Several electrical tasks take a high priority in frequency and criticalness, but they are reported less likely to be required by a new employee. D3, Locate electronic component malfunctions using fault guides, is expected to be done daily by five of the six manufacturers requiring the task. D4, Remove electronic components and D20, Replace electrical circuit components are expected to be performed daily/weekly. All three of these electrical tasks have a criticalness level of 1.67. These tasks are not expected of new employees but they are expected within six months of employment. Any education or training program must therefore provide the necessary background for the new employee to be able to learn and perform the task within six months. Almost all task competencies recorded are expected by the new employee either immediately or within six months of employment. Education and training programs must provide the necessary background in electrical, mechanical, hydraulic, pneumatic, communicating, and programming areas so the student can perform the task within six months of employment.

The ability to not only avoid and correct problems but also to diagnose problems should be taught. For those mechanics who are not taught to diagnose problems the ability to communicate with the diagnostician is essential.

The task competencies expected in 1990 compared with today will have changed little. Students educated and trained for repair and maintenance of robots today will possess the necessary task competencies to maintain and repair the industrial robots in the plants in 1990. Any additional competencies necessary will likely require minimal updating of the employee.

The major implications for education and training are derived from Objective Three, the structural problems.

If a large proportion of the plants using robots continue to use existing skill areas for the maintenance and repair of robots, most education and training should be directed towards these existing skill areas. Electricians, machine mechanics, hydraulic repairmen, pipefitters, and industrial engineers should be prepared for the operation of robots. Tasks associated with robots which fit the skill area should be taught if the student could reasonably be expected to work on robots.

If a large proportion of plants using robots move to the specialized skills of robot maintenance mechanics for the repair and maintenance of robots, education and training programs can provide the necessary competencies required through training on the tasks identified in Objective One. However, very few plants presently have enough robots to occupy, full time, a robot maintenance mechanic.

The community colleges in Michigan that have robot programs should consider the employment opportunities of robot program graduates carefully. The Technical Training and Contracts Supervisor of the Management and Technical Training Department at the Ford North American Training Center, sees no opportunity for these graduates at Ford for two reasons. The first is, the company is interested in task competencies not course credits; the second is that the company draws from skilled trades for training in these task competencies. The Supervisor of Maintenance at Detroit Plastics Molding sees a need for the graduates of these programs, robot maintenance mechanics, able to maintain and repair a variety of manufacturers' robots. The robot manufacturers generally consider the two-year community college robotics program beneficial. In fact, several of the interviewees were on advisory boards to community college programs. Several of the manufacturers' robot maintenance mechanics have been enrolled in the robotics programs. The robot manufacturers consider the community college degree the appropriate educational requirement for the job. The unfortunate point is that at present, outside of the robot manufacturers, few companies have a robot maintenance mechanic, few companies are looking to hire robot maintenance mechanics, and few companies have enough robots to employ a full-time, robot maintenance mechanic.

The high school vocational programs in Michigan should consider robotics education carefully, also. The literature generally projects that robot maintenance mechanics will be graduates of two-year degree programs. The manufacturers in this study generally consider the two-year college program the appropriate educational medium and level. The robot user plants generally consider skilled trades training as the appropriate medium. While a robotics program may well be sufficient motivation to learn basic electronics, mechanics, hydraulics, pneumatics, communicating, and robot operating skills it is unlikely that any significant number of placements as robot maintenance mechanics (or trainees) will occur. On the one side, manufacturers consider the two-year degree appropriate. On the other side, the robot user plants are unlikely to hire any significant number of personnel for the robot maintenance mechanic positions.

It was stated in Chapter I that robots have evolved. Robots are not a result of a revolution as much as an evolution; as such, the move to this type of machine has been gradual. Recognition of this by educators and trainers has important implications for their programs. There are other machines that have similar characteristics in terms of electrical, mechanical, hydraulic, and pneumatic workings. These machines include: numerical controlled machines, computer numerical controlled machines, computer aided manufacturing machines, and machining centers. A broader program which addresses all these areas, such as an electro-mechanical program, could broaden the employability of students.

One view on the installation, maintenance, repair and operation of robots is supported out of the desire to maintain existing job classifications. If the ability to diagnose problems is hindered by this (the evidence suggests it will), then opportunities will exist for people who can diagnose robot problems either with robot manufacturers or independent contractors. These individuals will require education and training. The number of individuals required will be determined by the number of robots in operation, the rate at which problems arise and the ability of the non-diagnosticians to identify the problems themselves.

Recommendations

Recommendations Relating to Education and Training

There are seven recommendations relating to education and training.

1. The schools and colleges in Michigan should carefully consider employment opportunities for robot program

graduates. Few companies, outside of the manufacturers, have robot maintenance mechanics and few companies are looking to hire robot maintenance mechanics.

In plants that have robots, increased knowledge and task competencies relating to robots is expected of employees, but whether this will lead to any significant number of jobs for robot maintenance mechanics is doubtful. Much of the increased knowledge and task competence is acquired through robot manufacturers' training programs on operation and maintenance.

2. Educators and trainers should consider that robot maintenance may well be performed by electricians, or machine maintenance or some other trade already existing in the plant. The application of these trade areas to the installation, maintenance, repair, and operation of robots is required by labor management agreements in many of the plants presently using robots. It follows that it would be appropriate to teach the task competencies necessary for robot installation, maintenance, repair, and operation along trade lines.

3. Educators should seriously consider electro-mechanical programs. The increased use of numerical controlled machinery, computer assisted design (CAD), and computer assisted manufacturing (CAM) demonstrate robots are not the only machines developed with electrical and mechanical components. A broader program thrust such as

electro-mechanical could improve the marketability of the students' skills.

4. The educational program should bring the student to a point where all task competencies will be acquired within at least six months of employment. Almost all task competencies are expected of a person within six months of employment. The student must have the necessary background to be able to acquire the competencies within this time.

5. Development of the ability to communicate orally, on the telephone, and in writing should be a high priority in the educational and training programs. These competencies are expected upon employment and are difficult to learn on the job.

6. Educators and trainers should be concerned with the teaching of diagnostic skills.

7. Today's education and training programs should be carefully developed because they will not have to be changed significantly due to changes in robot design by 1990. Changes in robot design will have little effect on the task competencies necessary for installation, maintenance, repair, and operation by 1990.

Recommendations for Further Research

There are four recommendations for further study.

1. Different occupational titles were identified in the robotics area. An occupational analysis in robotics

could identify the different occupations both present and emerging in this field.

2. A comprehensive follow-up study of robotics maintenance program graduates is essential to identify the demand for robot maintenance mechanic graduates.

3. Research on the acquisition of basic task competencies in electronics, machine maintenance, hydraulics, pneumatics, and communication in high school vocational robotics programs would indicate whether the study of robotics generates greater interest than the traditional program areas for these subjects.

4. Three duties were identified which, although not central to the job of robot maintenance mechanic as defined, could be expected of them. The tasks within these duties should be identified.

Reflections

When this writer set out to do this study, the literature indicated robot use was extensive and would grow rapidly, the position of robot maintenance mechanic/technician was in demand and would grow rapidly. It seemed essential for educators and trainers to allocate resources to meet the training demands and the anticipated demands of what many people considered the robot revolution.

A task analysis of robot maintenance mechanics was envisioned where a jury of incumbent robot maintenance mechanics would develop an initial list of tasks and more incumbent mechanics would validate them. It was soon found that the robot population was smaller than initial literature generally indicated. It was a surprise to find a robot maintenance mechanic was an extremely rare person in a robot user plant. It was necessary, therefore, to follow the sequence described in Chapter III to develop the initial task inventory, rather than the sequence envisioned.

In developing the task lists a significant problem arose: six companies were responsible for 97% of robot sales. Task competencies necessary to maintain a robot varied with the manufacturer of the robot. Consideration had to be given to this because a task competency considered essential by three manufacturers' representatives for their robots may not be necessary for the other three, the task competency is either essential or not necessary depending on what robots the mechanic works on. For education and training, is the task competency essential or not necessary? The problem was addressed by presenting a series of task tables. This led to another question: should the larger of the six companies be recognized by weighting responses? The answer was no.

There are clear indications that it is easier, when diagnosing robot problems, for the mechanic to know the whole system rather than only some parts such as electrical or mechanical. As most robot user plants have unions which are generally against a new classification of robot maintenance mechanic, opportunities may develop for persons who can diagnose robot problems and for those who train them. A robot user company may have three different manufacturers' robots in its plant. If a robot problem develops which cannot be corrected by in-plant personnel, the manufacturer's representative may be called in. A different representative for each manufacturer traveling from a home office which would likely require considerable travel time to an unfamiliar plant. Robot user companies may find it more economical in terms of down-time and travel expense to contract with local companies specializing in robot maintenance.

It was found in the study that one full-time mechanic can maintain eleven robots. Many companies will not have eleven robots. It may be more economical for them to contract with a local company specializing in robot maintenance also.

There is a void that needs to be filled. Either it can be filled as discussed, or robot user plants can upgrade employees' skills to fill this void. Manufacturers' training programs are offered which can assist. However a plant which has robots manufactured by three different manufacturers may need the employees to attend three different programs. It was found in this study that robot manufacturers consider the community college degree program appropriate for their mechanics. Their mechanics are the trainers in the training programs offered to robot purchasers. It appears to this writer that the community college is the only potential supplier of training which: has the flexibility to customize training and upgrading for more than one manufacturers' robots; and have the expertise to do it.

FOOTNOTES

FOOTNOTES TO CHAPTER I

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APPENDICES

Appendix A

Letter Requesting Operating/Service Manuals From the Six Largest Manufacturers of Robots in the U.S.

Appendix A

Letter Requesting Operating/Service Manuals From the Six Largest Manufacturers of Robots in the U.S.

Dear

Dzengeliski and Goode have said "A significant reason for the slow growth in robotics in the United States is the lack of installation and maintenance personnel at the user level. Right now there is a shortage of these people." While you may or may not agree with this statement, many potential robot users perceive this to be true.

The burden of training for the use of a company's product is usually on the manufacturer. But educators can prepare students in the basic skills and knowledge of tools and mechanisims so the user company have employees capable of benefiting from company training programs. In the field of robotics, educators have not sufficiently documented what these basic skills should be.

With the cooperation of several manufacturers and users, I am researching the tasks performed by robot installation and repair mechanics. From these lists of tasks, curriculum can be developed to teach students the necessary basic skills.

One of the most effective methods of drafting an initial list of tasks is through analyzing operating and service manuals. It is for this reason I turn to you. Your company, as one of the largest U.S. producers of robots, should be represented when reviewing the manuals for the knowledge and skills required to interpret and apply solutions in robot maintenance.

I am requesting the loan of a couple of robot operating and/or service manuals so a draft of the tasks required can be made. The manuals can be returned within a couple of weeks.

A final report will be available, upon request, which could assist in your own company's training courses.

I thank you in advance for your cooperation.

Sincerely,

Appendix B

Persons Consolidating Initial Task Statements

Appendix B

Persons Consolidating Initial Task Statements

Lyndol Aumiller	Power and Mechanics Instructor University of Maryland College Park Campus
Delbert Carson	Electricity/Electronics Instructor University of Maryland College Park Campus

Appendix C

Experts Responding to Initial Task Inventory

Appendix C

Experts Responding to Initial Task Inventory

Robot Manufacturers

P. J. Rosato
Director
Technical Training/Pbls.
Unimation Inc.
Shelter Rock Lane
Danbury, Conn. 06810

William Weisel
Director, Education
Prab Robots
6589 Donjoy Drive
Cincinnati, OH 45242

Robot Users

Don Dunn
Operations Manager
United Iron & Metal Co., Inc.
2545 Wilkens Ave.
Baltimore, MD 21223

Vince Shannon
Supervisor Shaft Seal
Koppers Co.
P.O. Box 626
Baltimore, MD 21203

Educators

John Lawson
President
Feedback Inc.
620 Springfield Ave.
Berkeley Heights,
N.J. 07922

Nigel Wright
Engineering Ed. Executive
Feedback Inc.
620 Springfield Ave.
Berkeley Heights,
N.J. 07922

Appendix D

Response to Initial Task Inventory

Appendix D

Response to Initial Task Inventory

Dear

Here is the checklist of tasks for robot maintenance mechanics/technicians as discussed over the telephone.

Please check the appropriate box for each task statement.

Comments, suggested changes or additions to the checklist will be appreciated. Please write them wherever you feel it appropriate.

Sincerely,

Appendix D
(cont.)

	DUTY A Installing and Moving Machines TASK	Will this be performed by the robot technician? YES	 NO
A1	Align machinery	3	3
A2	Attach safety guards, shields and covers	4	2
A3	Block and brace equipment for moving	2	4
A4	Complete incoming checklist	3	2
A5	Complete preinstallation facility checklist	3	3
A6	Connect machine to air/hydraulic/electrical source	4	2
A7	Crate robot for transfer	2	4
A8	Erect barricades	2	4
A9	Install mechanical stops for robot motion	4	2
A10	Move machine/equipment with skids or dollies	2	4
A11	Operate power hoist	0	6
A12	Operate fork lift	0	6
A13	Operate overhead crane	0	6
A14	Paint machinery/equipment	2	4
A15	Position & secure machinery on foundation	2	4
A16	Pour concrete (for foundation)	0	6
A17	Prepare area for machine installation	2	4
A18	Raise machinery using jacks, bars, slings etc.	2	4

Appendix D
(cont.)

	DUTY B Performing Preventative Maintenance TASK	Will this be performed by the robot technician? YES	NO
B1	Change gearbox oil	6	0
B2	Clean air filters	5	0
B3	Clean chassis	5	1
B4	Clean circulation fans/ventilators	6	0
B5	Clean electrical contact points	6	0
B6	Clean electric motor	6	0
B7	Clean hydraulic strainer/filters	6	0
B8	Clean potentiometers	5	0
B9	Clean reflector mirrors	5	0
B10	Clean tape head	6	0
B11	Clean tape reader	5	0
B12	Clean tape recorder	5	0
B13	Clean tuner	4	0
B14	Lubricate air compressor	5	0
B15	Lubricate chain and sprocket drive	6	0
B16	Lubricate electric motor	5	0
B17	Lubricate fans/ventilators	5	0
B18	Lubricate gear drives	6	0
B19	Lubricate linkages and lever mechanisms	6	0
B20	Lubricate tape recorder	5	0
B21	Record meter readings	6	0
B22	Refill hydraulic system	6	0
B23	Sample hydraulic fluid	5	1

Appendix D
(cont.)

	DUTY C Maintaining Equipment TASK	Will this be performed by the robot technician? YES	NO
C1	Adjust AC generator output	4	1
C2	Adjust AC output resistance	3	1
C3	Adjust amplifier gain	6	0
C4	Adjust armature or field connection voltage	5	1
C5	Adjust audio intensities	4	1
C6	Adjust automatic gain control circuit	5	0
C7	Adjust bias network	5	0
C8	Adjust DC generator output	6	0
C9	Adjust drive gear	6	0
C10	Adjust fluid capacitance	2	2
C11	Adjust focus control	5	0
C12	Adjust gibs	4	0
C13	Adjust humidistats	3	3
C14	Adjust hydraulic flow	6	0
C15	Adjust hydraulic pressure	6	0
C16	Adjust linkages and lever mechanisms	6	0
C17	Adjust modulation percentage	3	2
C18	Adjust oscillator	5	0
C19	Adjust output of high frequency amplifiers	3	2
C20	Adjust piezoelectric devices	3	2
C21	Adjust pneumatic controls	6	0
C22	Adjust pneumatic rotary actuator	5	0
C23	Adjust pressure control (relief) valve	5	1
C24	Adjust probe calibrator signal	5	0
C25	Adjust servovalves	6	0

Appendix D
(cont.)

	DUTY C Maintaining Equipment TASK	Will this be performed by the robot technician? YES	NO
C26	Adjust tape reader	5	0
C27	Adjust thermostat	5	0
C28	Align and adjust belt drive	6	0
C29	Align chain and sprocket drives	6	0
C30	Align gear drives	6	0
C31	Align piston (rod) of hydraulic cylinder	6	0
C32	Align shafts	6	0
C33	Align T.R.F.	1	3
C34	Calibrate multi-vibrator circuit	2	0
C35	Calibrate P-P voltage	4	1
C36	Calibrate vertical amplitude	4	1
C37	Calibrate timing/clock pulse	5	0
C38	Change direction of hydraulic pump motor	4	0
C39	Change rotation of electric motor	4	0

Appendix D
(cont.)

	DUTY D Performing Repairs TASK	Will this be performed by the robot technician? YES	NO
D1	Bleed hydraulic system	5	0
D2	Construct belt joints	1	4
D3	Disassemble/reassemble air compressor	2	3
D4	Install flexible couplings	6	0
D5	Locate electronic component malfunctions using fault location guides	6	0
D6	Remove electronic components	6	0
D7	Repair centrifugal clutch	4	1
D8	Repair drive couplings	5	1
D9	Replace accumulator	6	0
D10	Replace actuator	6	0
D11	Replace air compressor	5	0
D12	Replace air filters	6	0
D13	Replace air regulators	6	0
D14	Replace bearings	6	0
D15	Replace capacitor	5	0
D16	Replace cathode ray tube	5	1
D17	Replace chain and sprocket drive	6	0
D18	Replace deflection yoke	5	0
D19	Replace digital display segment	5	1
D20	Replace dynamotor	4	1
D21	Replace electric motor	6	0
D22	Replace electrical circuit components	6	2
D23	Replace electrical relief valves	4	1
D24	Replace encoders	6	0
D25	Replace energy storage cells	6	0

Appendix D
(cont.)

	DUTY D Performing Repairs TASK	Will this be performed by the robot technician? YES	NO
D26	Replace faulty PC boards	6	0
D27	Replace frequency converter (motor generator)	3	1
D28	Replace fuses	6	0
D29	Replace gear drives	6	0
D30	Replace guide rollers	6	0
D31	Replace heat exchanger	5	1
D32	Replace hydraulic accumulator bladder	3	2
D33	Replace hydraulic gasket and seals	6	1
D34	Replace hydraulic lines/fittings	6	0
D35	Replace hydraulic motor	6	0
D36	Replace hydraulic pressure gauge	6	0
D37	Replace hydraulic pump	6	0
D38	Replace hydraulic strainer/filters	6	0
D39	Replace hydraulic system valves	6	0
D40	Replace hydraulic valves	6	0
D41	Replace indicator lamps	6	0
D42	Replace integrated circuits (memory)	5	1
D43	Replace klystron	0	4
D44	Replace magnetron	1	4
D45	Replace mechanical seals	4	0
D46	Replace microphone	2	2
D47	Replace motor starter	5	1
D48	Replace motor starter transformer	5	1
D49	Replace pneumatic clutch and brake	5	0
D50	Replace pneumatic cushion unit	4	1

Appendix D
(cont.)

	DUTY D Performing Repairs TASK	Will this be performed by the robot technician? YES	NO
D51	Replace pneumatic gauge assembly	6	0
D52	Replace pneumatic lines and fittings	6	0
D53	Replace pneumatic lubricator	6	0
D54	Replace pneumatic transfer block seal	6	0
D55	Replace potentiometer	6	0
D56	Replace pressure line filter element	6	0
D57	Replace pressure switch	6	0
D58	Replace programmer	6	0
D59	Replace pulley belt	6	0
D60	Replace radio frequency interface filters	3	2
D61	Replace relays	6	0
D62	Replace resistors	5	0
D63	Replace ribbon cables	4	1
D64	Replace servomechanisms	5	0
D65	Replace shaft assembly	6	0
D66	Replace solenoids	6	0
D67	Replace solid state diodes	4	1
D68	Replace switches (lead, contact, mercurial)	6	0
D69	Replace tacho generator	6	0
D70	Replace tape head	3	2
D71	Replace teach control	6	0
D72	Replace thermal breakers	6	0
D73	Replace transducers	6	0
D74	Replace transformers	6	0
D75	Replace transistors	5	0

Appendix D
(cont.)

	DUTY D Performing Repairs TASK	Will this be performed by the robot technician? YES	NO
D76	Replace tubes	2	4
D77	Solder/unsolder electronic components	5	0
D78	Splice wires	5	0

Appendix D
(cont.)

	DUTY E Programming TASK	Will this be performed by the robot technician? YES	NO
E1	Complete programming chart	3	3
E2	Copy diskette	3	3
E3	Edit program	3	3
E4	Enter program using teach control	6	0
E5	Erase program memory	5	0
E6	Install proximity switch	5	0
E7	Install sensing plate	5	0
E8	Load data plate	3	0
E9	Load programmable system tape	6	0
E10	Produce data tape	6	0
E11	Reinitialize program memory	5	0
E12	Test run program	6	0
E13	Transfer program memory to cassette tape	4	1

Appendix D
(cont.)

	DUTY F Communicating Information TASK	Will this be performed by the robot technician? YES	NO
F1	Design support hardware	1	4
F2	Draw schematic of electronic circuitry	1	4
F3	Draw schematic of hydraulic system	1	4
F4	Draw schematic of pneumatic system	1	4
F5	Interpret blueprints	6	0
F6	Interpret schematics of electronic circuitry	6	0
F7	Interpret schematics of hydraulic system	6	0
F8	Interpret schematics of pneumatic system	6	0
F9	Plan quality assessment checks	4	2
F10	Prepare estimates of down time	4	2
F11	Prepare estimates of production time	1	3
F12	Prepare safety reports	4	2
F13	Train new employees	3	2
F14	Translate graphic information to written specifications	2	3
F15	Write operational procedures	4	2

Appendix D
(cont.)

	OTHER DUTIES TASK	Will this be performed by the robot technician? YES	NO
	Duty of administering personnel	3	2
	Duty of supervising maintenance & repair function	5	1
	Duty of working metal with hand or portable tools	3	3
	Duty of working metal with machine tools	1	5

Appendix D
(cont.)

Comments

A9 May be done before robot arrives.

A14 Maybe touch-up scratches.

B16 Usually sealed.

B17 Usually sealed.

C38 Why?

C39 Why?

D7 Replace but not repair.

D8 Replace but not repair.

D46 Never seen one.

D76 Who uses tubes in 1983?
Don't believe any modern robot uses them.

D77 Limited use.

D78 Limited use.

E6 Why under programming duty? (2)

E7 Why under programming duty? (2)

F13 Depends on company practices.
OJT, after formal education and training.

Duty A Many of the tasks here have conflicting responsibilities in union shops.

There may be restrictions that prevent the technicians from doing the task and may or may not prevent the technician to direct others in doing the work.

Often works with specialized skilled trades.
Coordinates and checks but may not do this duty.

Appendix D
(cont.)

Comments (cont.)

Duty C The influence of unions may place each of these tasks under a different group of workers---electrical, mechanical, set-up, etc.

Duty of supervising maintenance & repair function
In union shop.

Duty of working metal with machine tools
Small, non-union installations only.

Manufacturers normally design for major component replacement not discrete parts.

Many of these tasks will be done by the electrical technician, mechanical technician and plumber in union shops.

I have not attempted to fill in everything that probably should be listed because I am not familiar with all types of robots presently being used in industry-(suggested several other robot manufacturers to provide information).

Additions

Have ability to effectively communicate both verbally and in writing.

Have well above average ability for good interpersonal relationships.

Capable of solving problems and making decisions (often independently).

Self-starter.

Appendix E

Plants Contacted in Telephone Survey of Forty Michigan Potential Robot Users

Appendix E

BENDIX CORP.
Hydraulics Div.
3737 Red Arrow Hwy.
St. Joseph, MI 49085
Telephone 429-3221
SIC 3714-Motor Vehicle Parts & Accessories

BUDD CO., THE
12141 Charlevoix
Detroit, MI 48215
Telephone 823-9100
SIC 3714-Motor Vehicle Parts & Accessories
3465-Stampings, Automotive

CHRYSLER CORP.
Warren Stamping Plant
22800 Mound Rd.
Warren, MI 48092
Telephone 497-1000
SIC 3465-Stamping, Automotive

CHRYSLER CORP.
Warren Truck Assembly Plant
21500 Mound Rd.
Warren, MI 48091
Telephone 497-1000
SIC 3711-Motor Vehicles & Car Bodies

CLARK EQUIPMENT CO.
Transmission Div.
1300 Falahee Rd.
Jackson, MI 49204
Telephone 764-6000
SIC 3714-Motor Vehicle Parts & Accessories
3566-Speed Changers, Drives, Gears

Appendix E
(cont.)

DANA CORP.
Industrial Group Div.
23577 Hoover Rd.
Warren, MI 48090
Telephone 758-5000
SIC 3566-Speed Changers, Drives, Gears

DART CONTAINER CORP.
432 Hogsback Rd.
Mason, MI 48854
Telephone 676-3800
SIC 3079-Plastic Products - Misc.

DETROIT PLASTIC MOLDING CO.
6600 15 Mile Rd.
Sterling Heights, MI 48077
Telephone 979-5000
SIC 3079-Plastic Products - Misc.

DOW CHEMICAL U.S.A.
Div. The Dow Chemical Co.
Dow Center
Midland, MI 48640
Telephone 636-1000
SIC 2869-Chemical, Industrial Organic - Misc.

EAST JORDAN IRON WORKS, INC.
301 Spring
East Jordan, MI 49727
Telephone 586-2261
SIC 3321-Foundries, Gray Iron

Appendix E
(cont.)

EVART PRODUCTS CO.
Sub. American Motors Corp.
601 W. 7th St.
Evart, MI 49631
Telephone 734-5522
SIC 3079-Plastic Products - Misc.

FEDERAL-MOGUL CORP.
310 E. Steel
St. Johns, MI 48879
Telephone 224-3221
SIC 3469-Metal Stampings - Misc.

FORD
Wixom Assembly Plant
50000 Grand River Freeway
Wixom, MI 48196
Telephone 344-5000
SIC 3711-Motor Vehicles & Car Bodies

FORD
Dearborn Assembly Plant
3001 Miller Rd.
Dearborn, MI 48121
Telephone 322-3000
SIC 3711-Motor Vehicles & Car Bodies

GENERAL MOTORS CORP.
Hydra-Matic Div
Willow Run
Ypsilanti, MI 48197
Telephone 485-5000
SIC 3714-Motor Vehicle Parts & Accessories

Appendix E
(cont.)

GENERAL MOTORS CORP.
Pontiac Motor Div.
One Pontiac Plaza
Pontiac, MI 48053
Telephone
SIC 3711-Motor Vehicles & Car Bodies

GENERAL MOTORS CORP.
GMC Truck & Coach Div.
660 E. South Blvd.
Pontiac, MI 48053
Telephone 857-5000
SIC 3711-Motor Vehicles & Car Bodies

GOODYEAR TIRE RUBBER CO.
Jackson Plant
2219 Chapin St.
Jackson, MI 49204
Telephone 782-8181
SIC 3011-Tires & Tubes

GREAT LAKES CASTING CORP.
800 N. Washington Ave.
Ludington, MI 49431
Telephone 49431
SIC 3321-Foundries, Gray Iron

HAMILL MFG. CO.
Div. Firestone Tire & Rubber, Akron, OH
61166 VanDyke
Washington, MI 48094
Telephone 755-7700
SIC 3714-Motor Vehicle Parts & Accessories

Appendix E
(cont.)

HAYES-ALBION CORP.
1999 Wildwood Ave.
Jackson, MI 49202
Telephone 782-9421
SIC 3465-Stampings, Automotive
3322-Foundries, Malleable Iron
3451-Screw Machine Products
3369-Castings, Nonferrous - Misc.
3321-Foundries, Gray Iron
and Others

HOOVER UNIVERSAL INC.

Ann Arbor, MI 48104
Telephone 665-1500
SIC 2891
3079-Plastic Products - Mis.
and Others

JACKSON DROP FORGE CO.
2001 Wellworth
Jackson, MI 49203
Telephone 787-5800
SIC 3462-Forging, Iron, Steel

KASLE STEEL CORP.
4343 Wyoming
Dearborn, MI 48126
Telephone 943-2500
SIC 3316-Steel - Cold Rolled Sheet, Strip, Bar

KELSEY-HAYES CO.
Div. of Fruehauf Corp., Detroit, MI
38481 Huron River Drive
Romulus, MI 48174
Telephone 941-2000
SIC 3714-Motor Vehicle Parts & Accessories
3728-Aircraft Parts & Equipment - Misc.

Appendix E
(cont.)

LA-Z-BOY CHAIR CO.
1284 N. Telegraph
Monroe, MI 48161
Telephone 242-1444
SIC 2512-Furniture, Household - Wood, Upholstered

MASCO CORP.
21001 VanBorn Rd.
Taylor, MI 48180
Telehpone 274-7400
SIC 3432-Plumbing Fixtures - Brass
3471-Electroplating, Polishing, Anodizing
3564-Blowers & Fans

MASSEY-FERGUSON INC.
Massey-Ferguson Ltd., Toronto, Ontario
12601 Southfield Rd.
Detroit, MI 48223
Telephone 493-7125
SIC 3523-Farm Machinery & Equipment
3537-Industrial Trucks, Tractors, Trailer, Stackers

McDONALD MFG.
36870 Green St.
New Baltimore, MI 48047
Telephone 725-2111
SIC 3079-Plastic Products - Misc.

MIDWEST FOUNDRY CO.
Div. of the Marmon Group Inc.
77 Hooker St.
Coldwater, MI 49036
Telephone 278-2331
SIC 3321-Foundries, Gray Iron

Appendix E
(cont.)

MITCHELL CORP.
123 N. Chipman St.
Owosso, MI 48867
Telephone 725-2171
SIC 3714-Motor Vehicle Parts & Accessories

MOTOR WHEEL CORP.
Sub. Goodyear Tire & Rubber Co,
1600 N. Larch St.
Lansing, MI 48909
Telephone 487-4000
SIC 3714-Motor Vehicle Parts & Accessories

MUELLER BRASS CO.
Sub. of U V Industries, Inc.
1925 Lapeer Ave.
Port Huron, MI 48060
Telephone 987-4000
SIC 3351-Copper, Brass, Bronze-Rolling, Drawing, Extruding
and Others

NATIONAL TWIST DRILL & TOOL DIV.
6841 N. Rochester Rd.
Rochester, MI 48063
Telephone 651-9531
SIC 3545-Machine Tool Accessories

ROCKWELL INTERNATIONAL
2135 W. Maple Rd.
Troy, MI 48084
Telephone 435-1000
SIC 3714-Motor Vehicle Parts & Accessories
3079-Plastic Products - Misc.
3321-Foundries, Gray Iron
and Others

Appendix E
(cont.)

STEELCASE, INC.
1120 36th St. S.E.
Grand Rapids, MI 49508
Telephone 247-2710
SIC 2522-Furniture, Office - Metal
2521-Furniture, Office - Wood

STURGIS MOLDED PRODUCTS CO.
70343 Clark St.
Sturgis, MI 49091
Telephone 651-9381
SIC 3079-Plastic Products - Misc.

TECUMSEH PRODUCTS CO.
Patterson St.
Tecumseh, MI 49286
Telephone 423-8411
SIC 3585-Air Conditioning, Refrigeration

TRW MICHIGAN INC.
Div. TRW, Inc.
34201 VanDyke
Sterling Heights, MI 48077
Telephone 977-1000
SIC 3714-Motor Vehicle Parts & Accessories

WHIRLPOOL CORP.
St. Joseph Div.
Upton Dr.,
St. Joseph, MI 49085
Telephone 926-5000
SIC 3633-Laundry Equipment, Household

Appendix F

Manufacturers Representatives Participating in the Study

Appendix F

Manufacturers Representatives Participating in the Study

ASEA Robots
Larse Peterson
Regional Service Mg.
1176 E. Big Beaver Rd.
Troy, MI 48084

DeVilbiss
John Edelhauser
Field Service Technician
300 Phillips Avenue
P.O. Box 913
Toledo, OH 43692

Cincinnati Milacron
Tom Macknosky
Regional Service Mgr.
Industrial Robot Div.
28500 Southfield Rd.
Lathrup Village, MI

Prab Robots
F. P. "Woody"Leipold
Mgr. Customer Services
Joe Messer
Field Service Technician
6007 Sprinkle Rd.
Kalamazoo, MI 49003

Copperweld Robotics Inc.
Peter Malega
Field Service Mgr.
Steve Svoboda
Service Technician
Michael Nieman
Service Technician
1401 E. Fourteen Mile Rd.
Troy, MI 48084

Unimation
Brian Hansen
Regional Service Mgr.
23400 Industrial Park Ct.
Farmington Hills, MI 48084

Appendix G

Six Individuals Interviewed in Robot User Plants

Appendix G

Six Individuals Interviewed in Robot User Plants

Dick Socks
Maintenance Supervisor
North American Plastics Co.
6600 E. 15 Mile Rd.
Sterling Heights, MI 48077

J. R. Durfee
Master Mechanics Supervisor
Pontiac Motor Div.
Pontiac, MI 48023

Bob Johnson
Industrial Engineer
Pontiac Motor Div.
Pontiac, MI 48023

Tom Hopper
Electrician
Pontiac Motor Div.
Pontiac, MI 48023

Bob Trent
Machine Mechanic
Pontiac Motor Div.
Pontiac, MI 48023

Dick Hartshorn
Technical Training & Contracts Supervisor
Management & Tech. Training Dept.
Ford North American Training Center
2201 Elm Dale
Dearborn, MI 48121

Appendix H

Questionnaire Used

Appendix H Questionnaire Used

	#	TASK	FREQUENCY					CRITICALNESS	EXPECTATION		OPPORTUNITY			FUTURE
			This is done					This is	This is expected to be performed		Chance to learn this on the job			Will this still be done in 1990?
			Daily	Weekly	Monthly	Yearly	NEVER	Most critical 1 2 3 4 Least critical 5	By a new employee	Within six months of employment	Good	Avg.	Poor	
A	1	Align machinery												
A	2	Attach safety guards, shields and covers												
A	3	Block and brace equipment for moving												
A	4	Complete incoming checklist												
A	5	Complete preinstallation facility checklist												
A	6	Connect machine to air/ hydraulic/electrical source												
A	7	Crate robot for transfer												
A	8	Erect barricades												
A	9	Install mechanical stops for robot motion												
A	10	Install proximity switch												
A	11	Install sensing plate												
A	12	Move machine/equipment with skids or dollies												
A	13	Paint machinery/equipment												
A	14	Position & secure machinery on foundation												
A	15	Prepare area for machine installation												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
A	16	Raise machinery using jacks, bars, slings etc.												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1 2 3 4 5 Least critical	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
B	1	Change gearbox oil												
B	2	Clean air filters												
B	3	Clean chassis												
B	4	Clean circulation fans/ ventilators												
B	5	Clean electrical contact points												
B	6	Clean electric motor												
B	7	Clean hydraulic strainer/ filters												
B	8	Clean potentiometers												
B	9	Clean reflector mirrors												
B	10	Clean tape head												
B	11	Clean tape reader												
B	12	Clean tape recorder												
B	13	Clean tuner												
B	14	Lubricate air compressor												
B	15	Lubricate chain and sprocket drive												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1 2 3 4 Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
B	16	Lubricate electric motor												
B	17	Lubricate fans/ventilators												
B	18	Lubricate gear drives												
B	19	Lubricate linkages and lever mechanisms												
B	20	Lubricate tape recorder												
B	21	Record meter readings												
B	22	Refill hydraulic system												
B	23	Sample hydraulic fluid												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
C	1	Adjust AC generator output												
C	2	Adjust AC output resistance												
C	3	Adjust amplifier gain												
C	4	Adjust armature or field connection voltage												
C	5	Adjust audio intensities												
C	6	Adjust automatic gain control circuit												
C	7	Adjust bias network												
C	8	Adjust DC generator output												
C	9	Adjust drive gear												
C	10	Adjust fluid capacitance												
C	11	Adjust focus control												
C	12	Adjust gibs												
C	13	Adjust humidistats												
C	14	Adjust hydraulic flow												
C	15	Adjust hydraulic pressure												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
C	16	Adjust linkages and lever mechanisms												
C	17	Adjust modulation percentage												
C	18	Adjust oscillator												
C	19	Adjust output of high frequency amplifiers												
C	20	Adjust piezoelectric devices												
C	21	Adjust pneumatic controls												
C	22	Adjust pneumatic rotary actuator												
C	23	Adjust pressure control (relief) valve												
C	24	Adjust probe calibrator signal												
C	25	Adjust servovalves												
C	26	Adjust tape reader												
C	27	Adjust thermostat												
C	28	Align and adjust belt drive												
C	29	Align chain and sprocket drives												
C	30	Align gear drives												

Appendix H (cont.)

	#	TASK	FREQUENCY This is done: Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS This is Most critical 1 2 3 4 Least critical 5	EXPECTATION This is expected to be performed: By a new employee	Within six months of employment	OPPORTUNITY Chance to learn this on the job: Good	Avg.	Poor	FUTURE Will this still be done in 1990?
C	31	Align piston (rod) of hydraulic cylinder												
C	32	Align shafts												
C	33	Calibrate P-P voltage												
C	34	Calibrate vertical amplitude												
C	35	Calibrate timing/clock pulse												
C	36	Change direction of hydraulic pump motor												
C	37	Change rotation of electric motor												

Appendix H (cont.)

	#	TASK	FREQUENCY This is done					CRITICALNESS This is	EXPECTATION This is expected to be performed		OPPORTUNITY Chance to learn this on the job			FUTURE
			Daily	Weekly	Monthly	Yearly	NEVER	Most critical 1 2 3 4 Least critical 5	By a new employee	Within six months of employment	Good	Avg.	Poor	Will this still be done in 1990?
D	1	Bleed hydraulic system												
D	2	Install flexible couplings												
D	3	Locate electronic component malfunctions using fault guides												
D	4	Remove electronic components												
D	5	Replace accumulator												
D	6	Replace actuator												
D	7	Replace air compressor												
D	8	Replace air filters												
D	9	Replace air regulators												
D	10	Replace bearings												
D	11	Replace capacitor												
D	12	Replace cathode ray tube												
D	13	Replace centrifugal clutch												
D	14	Replace chain and sprocket drive												
D	15	Replace deflection yoke												

Appendix H (cont.)

	#	TASK	FREQUENCY This is done					CRITICALNESS This is	EXPECTATION This is expected to be performed		OPPORTUNITY Chance to learn this on the job			FUTURE
			Daily	Weekly	Monthly	Yearly	NEVER	Most critical 1 2 3 4 Least critical 5	By a new employee	Within six months of employment	Good	Avg.	Poor	Will this still be done in 1990?
D	16	Replace digital display segment												
D	17	Replace drive coupling												
D	18	Replace dynamotor												
D	19	Replace electric motor												
D	20	Replace electrical circuit components												
D	21	Replace electrical relief valves												
D	22	Replace encoders												
D	23	Replace energy storage cells												
D	24	Replace faulty PC boards												
D	25	Replace frequency converter (motor generator)												
D	26	Replace fuses												
D	27	Replace gear drives												
D	28	Replace guide rollers												
D	29	Replace heat exchanger												
D	30	Replace hydraulic accumulator bladder												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
D	31	Replace hydraulic gasket and seals												
D	32	Replace hydraulic lines/ fittings												
D	33	Replace hydraulic motor												
D	34	Replace hydraulic pressure guage												
D	35	Replace hydraulic pump												
D	36	Replace hydraulic strainer/filters												
D	37	Replace hydraulic system valves												
D	38	Replace hydraulic valves												
D	39	Replace indicator lamps												
D	40	Replace integrated circuits (memory)												
D	41	Replace mechanical seals												
D	42	Replace microphone												
D	43	Replace motor starter												
D	44	Replace motor starter transformer												
D	45	Replace pneumatic clutch and brake												

Appendix H (cont.)

	#	TASK	FREQUENCY This is done: Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS This is: Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION This is expected to be performed: By a new employee	Within six months of employment	OPPORTUNITY Chance to learn this on the job: Good	Avg.	Poor	FUTURE Will this still be done in 1990?
D	46	Replace pneumatic cushion unit												
D	47	Replace pneumatic gauge assembly												
D	48	Replace pneumatic lines and fittings												
D	49	Replace pneumatic lubricator												
D	50	Replace pneumatic transfer block seal												
D	51	Replace potentiometer												
D	52	Replace pressure line filter element												
D	53	Replace pressure switch												
D	54	Replace programmer												
D	55	Replace pulley belt												
D	56	Replace radio frequency interface filters												
D	57	Replace relays												
D	58	Replace resistors												
D	59	Replace ribbon cables												
D	60	Replace servomechanisms												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is (Most critical 1, 2, 3, 4, 5 Least critical)	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
D	61	Replace shaft assembly												
D	62	Replace solenoids												
D	63	Replace solid state diodes												
D	64	Replace switches (lead, contact, mercurial)												
D	65	Replace tachogenerator												
D	66	Replace tape head												
D	67	Replace teach control												
D	68	Replace thermal breakers												
D	69	Replace transducers												
D	70	Replace transformers												
D	71	Replace transistors												
D	72	Replace tubes												
D	73	Solder/unsolder electronic components												
D	74	Splice wires												

Appendix H (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
E	1	Complete programming chart												
E	2	Copy diskette												
E	3	Edit program												
E	4	Enter program using teach control												
E	5	Erase program memory												
E	6	Load data plate												
E	7	Load programmable system tape												
E	8	Produce data tape												
E	9	Reinitialize program memory												
E	10	Test run program												
E	11	Transfer program memory to cassette tape												

Appendix H (cont.)

	#	TASK	FREQUENCY This is done Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS This is Most critical 1 2 3 4 Least critical 5	EXPECTATION This is expected to be performed By a new employee	Within six months of employment	OPPORTUNITY Chance to learn this on the job Good	Avg.	Poor	FUTURE Will this still be done in 1990?
F	1	Interpret blueprints												
F	2	Interpret schematics of electronic circuitry												
F	3	Interpret schematics of hydraulic system												
F	4	Interpret schematics of pneumatic system												
F	5	Plan quality assessment checks												
F	6	Prepare estimates of down time												
F	7	Prepare safety reports												
F	8	Train new employees												
F	9	Translate graphic information to written specifications												
F	10	Write operational procedures												

Appendix H (cont.)

#	TASK	FREQUENCY This is done Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS This is Most critical 1 2 3 4 Least critical 5	EXPECTATION This is expected to be performed By a new employee	Within six months of employment	OPPORTUNITY Chance to learn this on the job Good	Avg.	Poor	FUTURE Will this still be done in 1990?
	Duty of administering personnel												
	Duty of supervising maintenance & repair function												
	Duty of working metal with hand or portable tools												

Appendix I

Follow-up Mailed Questionnaire and Letter

Appendix I

Follow-up Mailed Questionnaire and Letter

Dear Mr.

Thank-you for your assistance in the analysis of tasks necessary for robot maintenance mechanics. The time and expertise you supplied was a valuable contribution to this project.

During my discussions several additions were suggested. Could you please spend a few moments to indicate your opinion on these additions.

Again thank-you for your assistance.

Sincerely,

Appendix I (cont.)

	#	TASK	FREQUENCY: This is done — Daily	Weekly	Monthly	Yearly	NEVER	CRITICALNESS: This is — Most critical 1, 2, 3, 4, Least critical 5	EXPECTATION: This is expected to be performed — By a new employee	Within six months of employment	OPPORTUNITY: Chance to learn this on the job — Good	Avg.	Poor	FUTURE: Will this still be done in 1990?
A	17	Install external mechanical stops for robot motion												
C	38	Calibrate multi-vibrator circuit												
C	39	Adjust pressure control unload valve												
D	75	Replace electrical clutch or brake												
F	11	Communicate using the telephone												
F	12	Communicate verbally												
F	13	Communicate in writing												
F	14	Initiate maintenance activities (self-starter)												

In the robot user plant, <u>how many robots</u> do you think it would take for a person (assuming he has all the <u>necessary skills</u> and the robots are of average complexity) to work full time in the maintenance and repair of robots? Check below.

1 3 6 9 12 15 18 21 24 27 30 robots

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SELECTED BIBLIOGRAPHY

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