DEERE & COMPANY

MANUFACTURING ENGINEERING

JD/IBM JOINT ROBOTIC ASSEMBLY STUDY

FINAL REPORT

JOHN DEERE

JD/IBM JOINT

ROBOTIC ASSEMBLY STUDY

FINAL REPORT

SYNOPSIS

The JD/IBM joint study evaluated the potential of assembling John Deere parts with an IBM robot. This report is a summary of all activities during the project. Additional documentation is outlined in the Appendix.

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R. Jerz

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PROJECT OVERVIEW AND SUMMARY

In February 1979, IBM proposed a joint study in robotic assembly with John Deere. IBM had developed an assembly robot for internal use and wanted to assess the robot's capabilities in outisde industries to survey its sales potential. John Deere was chosen as a representative for the heavy manufacturing industry.

John Deere units were surveyed for their interest to participate in the project and for potential assembly applications. IBM desired to place the robot in an assembly environment.

In November 1979, Deere & Company and IBM entered into the joint agreement to evaluate the feasibility of assembling John Deere parts with an IBM developmental robot and signed a formal contract that outlined the scope of the project and established confidentiality for a three year period. The participating units were the Component Works and Horicon Works.

The system supplied by IBM consisted of a robot (manipulator), hydraulic power supply, Series I computer, keyboard typewriter, cathode ray tube (CRT), and interfacing supplies. IBM supported this equipment throughout the project and provided application development personnel.

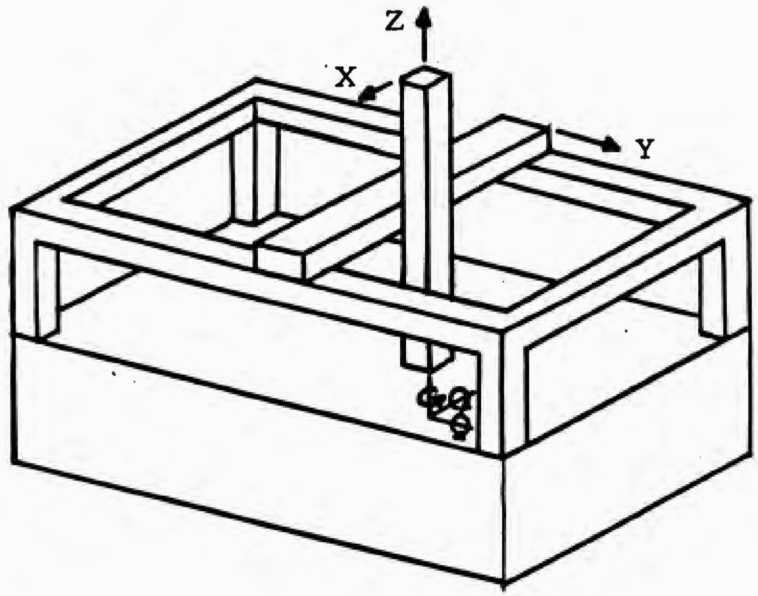
The joint agreement consisted of a three-phase study scheduled for completion in February 1981. Phase I involved the application selection process. This process consisted of reviewing the assemblies of the Component Works and Horicon Works to evaluate their adaptability to robotic assembly. Phase II was intended to gain experience with fixtures and feeders. Phase III consisted of simulated production runs with the most promising assemblies.

The study provided exposure to the new industry of robotic assembly, stimulated John Deere units into analyzing current assembly methods and efficiencies, and focused our attention to the requirements to make robotic assembly successful.

The robot is one piece of the total assembly system. Part orientation devices are extremely important, part redesigns may be necessary, and maximum benefits may be realized when a "systems" approach to assembly is taken. High production volumes are still necessary to automate and obtain an acceptable return on investment; but robots will assist us in automating part families that together represent high production volumes or in automating production volumes that are impractical for conventional dedicated assembly machines. Depending on the application, a sophisticated robot may or may not be needed.

Decisions were made at both the Component Works and Horicon Works not to purchase an IBM assembly robot due to its current price-performance characteristics. All John Deere units have indicated that they will continue to monitor the robotic assembly industry and trends within their own units to take advantage of this technology when economic benefits can be realized.

IBM PROTOTYPE ROBOT SPECIFICATIONS



COORDINATE SYSTEM: RECTILINEAR

AXES: X, Y, Z, YAW, ROLL, PITCH, GRIP

WORK RANGE: X = 19", Y = 59", Z = 19"

WT. CARRYING CAPACITY: 5 LBS.

REPEATABILITY: ± .005 INCHES

SPEED: 40 INCHES/SECOND MAX.

CONTROL SYSTEM: SERIES 1 MINICOMPUTER

MEMORY SIZE: 128K TOTAL, APPROX. 64K FOR USER

LANGUAGE: AML - "A MACHINE LANGUAGE"

PROGRAMMING MODES: TEACH PENDANT AND CRT (OFF-LINE)

SENSORS: TACTILE (FORCE) & VISION (LED IN GRIPPER - ON-OFF)

ESTIMATED COST: $100,000

OVERVIEW OF PHASE I

Phase I involved the identification of assemblies adaptable to robotic assembly. An assessment of technical and ecomonical feasibility of robotic assembly was made. The assemblies with greatest potential for success were selected for further development in Phases II and III.

Physical planning for the installation was completed and the prototype robot was installed at the Engine Works North. Prior to the installation of the robot, IBM provided training in programming the computer that controlled the robot.

The Phase I Management Review Meeting was held in Waterloo, Iowa on 28 May 1980, attended by representatives from Deere & Company, Component Works, John Deere PEC, Horicon Works, John Deere Technical Center, and IBM.

APPLICATION SELECTION PROCESS

Technical feasibility consisted of identifying potential assembly applictions that were compatible with the limitations of the IBM robot. A methodology for identifying potential robotic assemblies evolved at each unit.

The John Deere Component Works developed a list of robot capabilities to establish a set of constraints for evaluating potential applications. Eleven constraints were developed based on part weight, part size, difficulty of assembly, fixturing, tooling, and the requirements for auxiliary tools (see appendix 1).

A list of possible applications were compiled using parts data base information and brainstorming sessions. There were 4,500 assemblies at the Component Works. Given the size and weight constraints of the robot, 1,760 assemblies would comply with these two constraints. There are 300 assemblies within the 1,760 that had a labor cost of $2,000 or more per year.

The final evaluation involved the selection of ten assemblies for extensive evaluation. These ten assemblies were identified by using a matrix analysis that compared the robot constraints to three categories of feasibility; promising, least promising, and not practical. From these ten assemblies, three were chosen for Phase II development. These three were: guide assembly, pressure control valve, and hi-lo blocker sub-assembly. These assemblies are shown in appendix 2.

Two application selection procedures were performed at the Horicon Works. The first procedure involved a parts catalog search for potential applications complying to robot constraints including size, weight, type of parts, and complexity of assembly. The parts chosen from this search were then observed in the assembly shops to verify compatibility with robotics. Nine assemblies were identified as having the most potential for success and worthy of further study.

The nine assemblies included six which were basically a family of parts wheels, pulleys, and metal straps. The assembly procedure involved stacking and nut running. The remaining three assemblies had special assembly requirements such as close fits and special tools. An extensive evalution of these nine parts was made and three assemblies were selected for Phase II development. These three were the gage wheel, circle welder assemblies and steering gear case (shown in appendix 3).

An approach to analyze the machine load for each assembly department in an attempt to identify operation costs per assembly did not provide adequate information.

A statistical analysis of Horicon Works parts in terms of potential for robotic assembly was accomplished by a bench analysis. The assembly benches in six departments were visited and seventy-two assemblies were observed, evaluated, and ranked in terms of suitability to assembly by the IBM robot. The purpose was to develop a base of information using Horicon Works as a typical manufacturing plant to measure of the robot's capability for automated assembly and to suggest modifications required to increase the range of robot applicability. The summary of this study is shown in appendix 4.

Economical feasibility involved the computation of potential ROI's and a sensitivity analysis to identify and quantify factors affecting ROI computation.

The Componente Works performed a preliminary analysis of economic potential for the three selected assemblies that were to be developed during Phase II. The assumptions for this analysis is shown in appendix 5.

For each assembly, savings in labor was based on 75% of manual direct labor plus fringe. This was derived from the assumption that all labor would not be eliminated and that 1/4 of a man would be required to tend the robot. Each assembly application was charged capital cost for the robot in proportion to the estimated time that assembly utilized the robot.

The three assemblies chosen for further study were analyzed in detail. For example, the guide assembly (a simple stacking assembly) would utilize the machine an estimated 7.4% of the time, estimated tooling costs including fixtures and feeders was $5,000. Manual assembly time was 20 seconds compared to 15 seconds for robot assembly. With a capital cost of $100,000, the ROI was 20%. The graph below illustrated the ROI sensitivity with capital cost. This sensitivity analysis gave an indication what we could afford to spend for the robot and gave IBM an idea of what they could charge for the robot.

A similar analysis was performed for the pressure control valve and the hi-lo blocker. Their ROI's were 15% for each.

The Horicon Works focused their preliminary economic analysis on investigating the sensitivity of the analysis to changes in various input factors including speed of the robot, amount of labor required to support the robot, and project life. Their assumptions for the cash flow analyses are shown in appendix 6.

A summary of the DCF Analysis for the three selected assemblies is presented below.

DCF ANALYSIS - SELECTED THREE ASSEMBLIES

Assembly	Yearly Requirement	Expense Cost	Capitalized Cost Robot	Capitalized Cost Tooling	Yearly Savings	% ROI	Years Payback
Gage Wheel	109,000	$8,485	$18,070	$17,500	$ 9,750	4.5	5
Circle Welder 22 Weldments	600,910	$25,800	$85,000	$66,000	$43,265	10.0	5
Gear Case	41,275	$10,320	$31,950	$20,000	$17,255	11.7	5

From these economic studies, several conclusions were derived to guide application selection. There must be a reasonable labor savings potential and expenditures for fixtures and feeding must be in proportion to savings. The man time to support a robot must be minimized and machine speed optimized. The discounted cash flow is also sensitive to project life.

ASSESSMENT OF THE ROBOTIC SYSTEM

During the Phase I study period, several physical and operational concerns were identified based on the background and experience of the John Deere study team members.

The size of the robot work space and the framework supporting the robot arm presented specific restrictions to the size and number of parts that could be presented to the work space. Accessibility to the work space with parts feeders was a concern during the set up of the Phase I demonstration assemblies. The robot construction was judged too light for continued plant floor durability. Also, cleaning and lubrication was a concern since the plant assembly areas are semi-clean with contaminants in the plant environment. Expected maintenance of the robot moving parts needed to be determined.

Operational concerns involved the placement of assembly robots on the plant floor. In-house expertise should be developed in depth to enable correct selection of robot applications for successful production operations. There is the long term need to begin to design the product for automated assembly. Robot programming and manufacturing engineering skills in tooling, fixtures, and feeders must also be developed.

Fixtures, tracks, and feeders are expensive. This leads to the judgement that manpower will be required to support robotic automation. There is a point for each assembly at which expenditures for these sophisticated and complex items must be limited and replaced with affordable manpower. Therefore, there is need to define man/machine interface for robotic assembly.

Production installation of assembly robots will require the identification of families of parts to develop maximum utilization of the robot and minimize feeder and fixture costs. There are many small runs which do not justify automation, but combined with common feeders these small runs can accumulate into profitable production runs. The robot up time must be evaluated for simulated production runs.

The appraisal of the software was generally very positive. First impressions by the JD programmers were that the software was too sophisticated and required training and experience to become proficient with AML. However, as the programmers developed expertise the sophistication was not only desirable but necessary.

There were two major software disadvantages identified. A program could not be keyed while the robot was operating and the on-line memory available to the user was insufficient.

The robot had adequate accuracy and repeatability. Flexibility is the most advantageous aspect of this system. Several suggestions were presented to IBM as the development of the assembly robot continues. Industrialize the robot providing more sturdy construction, provide industrial electrical enclosures, shield wiring, and provide protection from contaminants for the moving parts. Improve the accessibility to the robot work space by removing unnecessary interferences or enlarging the work space.

Another problem that occurred was the interchange of gripper fingers. For each assembly application a unique gripper finger is required. Set-up time between assembly runs was difficult due to the small size of screws and the stripping of threads. An improved method of fastening fingers to the grippers was recommended.

The robot system must be prepared to last in the plant environment. The computer driving the robot should be enclosed in an environment designed to maintain the integrity of the circuitry. The space required for the robot, computer, and power source should be designed for compactness to efficiently utilize floor space.

Technical assistance by IBM staff was most helpful and, more importantly, available when desired.

PHASE I MANAGEMENT REVIEW MEETING

The Phase I Review Meeting was held in Waterloo, Iowa, on 28 May 1980. The results and conclusions of the first of the three phases were reviewed and the remaining phases outlined. Representatives from IBM, Deere & Company, John Deere Component Works, Horicon Works, and John Deere Product Engineering Center attended the meeting.

The prototype assembly robot installed at the Engine Works North was demonstrated. An assembly was selected by each unit to develop into a demonstration operation. The Component Works chose a brake boot assembly and the Horicon Works chose the gage wheel assembly. The demonstrations were programmed by JD personnel. The fixtures, tooling, and parts feeders were designed and build by JD. The demonstration assemblies were presented to management at the Phase I briefing. These demonstrations were also videotaped and are available for viewing.

CONCLUSIONS AND RECOMMENDATIONS FROM PHASE I

The IBM robot is capable of assembling selected JD parts.

Robot constraints limit the number of assembly candidates.

The IBM robot provides flexibility.

Automated parts presentation is expensive and small runs are marginal.

Design robot assemblies for operator assistance providing incentive opportunity.

Information developed in this study is directly transferable to other JD units.

We are developing the knowledge to become astute shoppers for robots.

A methodology to quickly appraise robotic assembly feasibility at a plant needs more thought and development.

Expand the study team to include Industrial Engineering, Industrial Relations, and Product Engineering.

Approximately 35% of the bench assemblies at the Horicon Works can possibly be made with an IBM robot.

The return on investment for a few applications was lower than expected.

Continue into Phase II.

OVERVIEW OF PHASE II

Several assemblies were identified in Phase I as having a high potential of success for robotic automation. Phase II involved conceptualizing the robotic assembly operation, developing fixture and part feeding mechanisms, estimating assembly standards, and evaluating the economics.

The Component Works chose the hi-lo blocker assembly for detailed analysis since it required a sophisticated robot and the Horicon Works chose the circle welder application since it had shown the highest economic potential.

The Phase II Management Review Meeting was held at the Horicon Works on 2 December 1980.

APPLICATIONS DEVELOPMENT

COMPONENT WORKS

The Component Works conceptualized the methods to robotic assembly the component parts of the three assemblies chosen in Phase I; guide valve assembly, pressure control valve, and hi-lo blocker. During the conceptual stage some of the robot assembly methods developed were tested. The methods tested were those that lacked confidence in the equipment and concept. Simple locating and holding fixtures were used in conjunction with the robot in these tests. An example of the assembly concept for the hi-lo blocker is shown in appendix 7.

The concepts developed showed that the pressure control valve and guide valve assemblies would require a robot with only three degrees of freedom to assemble, and the hi-lo blocker a robot with six degrees of freedom. Based on this data the hi-lo blocker was determined to lend itself best to testing the capabilities of the IBM robot in Phase III.

The majority of the time was then spent on developing the tooling concepts and costs for the hi-lo blocker assembly. An economic feasibility study was run on the hi-lo blocker. This study consisted of computation of R.O.I. and a sensitivity analysis to identify factors affecting R.O.I.

Four economic analysis were evaluated under different situations. The best return on investment was 10.5% if the hi-lo blocker robot cost was proportional to its robot utiliziation and the robot could be utilized for other assemblies. The calculations for the analysis are shown in appendix 8.

The conclusions of the sensitivity analysis were:

1. As the schedule limit increased the R.O.I. increased. At 100% utilization the R.O.I. was 16%.
2. As robot cost went down and tooling cost remained constant, R.O.I. increased. When robot cost was $0.0 the R.O.I. was 21% (Tooling cost equaled $21,700).
3. As tooling cost went down and robot cost remained constant, R.O.I. increased. At $0.00 tooling cost the R.O.I. was 29% (Robot cost charged to hi-lo blocker equaled $15,965).

These sensitivity analyses are shown graphically in appendix 9.

Results obtained from the prototyping and testing of concepts were the major items used for assessing the robot software and hardware. Tests were also run on the repeatability of the robot. The results were analyzed by Quality Engineering to determine if the robot could be used for inspection applications. This analysis determined that the repeatability was not accurate enough for the majority of the inspection applications.

Also included in Phase II were a part weight study to determine a weight profile of component parts and a Product Engineering study to determine the feasibility of robotic assembly of a new valve being designed at the Product Engineering Center.

HORICON

During Phase II the Horicon Works concentrated on showing how the machine would interface with the circle welder. The intent was to use the robot to load the fixtures on the index table of the circle welder. The welding was to be done by the circle welder, not the robot.

Twelve circle welded parts were studied during Phase II. The evaluation criteria included looking at part revisions required, weld fixtures, part presentation, assembly procedure, part fit-up, part flow (where the parts came from and where they went), and timing estimates for both man and machine. The information obtained in the investigation was used for economic analysis of the automatic assembly system.

The Horicon Works investigated two types of tooling-"hard" and "soft". The difference was how adaptable the tooling was to a family of parts ("hard" tooling implied not very adaptable to a variety of parts).

Some of the advantages of hard tooling are: accomplishing part orientation with bowl feeders and sensing devices, faster robot move times, and reduced manual input for parts handling. The tooling cost per assembly is reduced as the quantity of the assemblies is increased. Some disadvantages are: higher costs, longer set-up times, and feeding problems caused by part inconsistency.

The total cost of the tooling consisted of part dependent tooling and utility tooling which increased with the number of different parts run on the welder.

To calculate the savings for the circle welder it was necessary to estimate the time it would take to load the tracks and shuttles. These estimates were made by the I.E. Department. These timing estimates were then compared to the present incentive standards to calculate labor savings.

The hard tooling requirements and costs for each of the 12 parts were determined. Weld fixtures were designed and drawn, part presentation tracks and shuttle fixtures were designed and costs for each part was estimated. The return on investment with these costs and savings was 12.8%.

After it became clear that a robot assembly system could not be economically justified with hard tooling, IBM came up with a "soft" tooling approach that used plastic pallets with special inserts to hold parts. The pallets would be shuttled in and out of the robot station in containers. The containers could be transported from point to point using an automatic guidance vehicle system. This tooling could handle a variety of parts.

Some of the advantages of soft tooling are: lower cost, reduced changeover time, orientation for the next assembly station can be maintained, the same pallet and insert may be used on other robots, and there is great flexibility of holding parts in pallets. Pallet inserts could be made to kit parts, holding all the components needed. The inserts could be made from many materials.

Some of the disadvantages of soft tooling are: longer distance traveled from pick-up point to place point, parts require manual loading into the pallet insert, and high volume does not reduce tooling cost per part proportionately.

An assembly system was conceptualized integrating the elements of the soft tooling approach. This assembly system and components are shown in appendix 10.

The economic analysis for the assembly machine using soft tooling was done in the same way that it was done for hard tooling. The tooling cost for the soft tooling system was much less than that of the hard tooling (see appendix 11 for comparison). This reduction in tooling cost was a result of replacing the expensive feeding tracks and shuttles with inexpensive pallets. The cost of the weld fixtures and the utility equipment remained about the same.

Labor savings were calculated as the difference between estimated new cost of running the circle welder versus the present cost.

The return on investment obtained under the soft tooling approach was 24.5%.

ASSESSMENT OF THE ROBOTIC SYSTEM

An additional arm on the robot would allow it to more closely simulate a human worker. The advantage of a multi-arm robot is the reduction in floor to floor cycle time. Vision sensing would be very helpful to locate loosely oriented parts.

The addition of a new software aid (called TRIBE) helped in trying out applications. The software was relatively easy to use but some syntax was difficult especially in data processing. The subrouting capabilities allowed the AML language unlimited capabilities, but higher level subroutines were needed in certain areas. The syntax needs to be simplified to make it easier to remember.

Background in programming is still necessary to understand the logic of structuring a program, but a computer programmer would not be recommended. The best candidate to program the robot would be an engineer with a background in programming who enjoys working with a computer.

Several mechanical problems such as wires on motors breaking while the manipulator was moving, oil leaks, and easily damaged strain gages were encountered. IBM did service and update the equipment as needed.

PHASE II MANAGEMENT REVIEW MEETING

The Phase II Management Review Meeting was held at the Horicon Works on 2 December 1980. In attendance were representatives from the Component Works, Horicon Works, John Deere Foundry, Deere & Co., and IBM. The meeting included presentations by the Component Works, Horicon Works and IBM.

CONCLUSIONS AND RECOMMENDATIONS - PHASE II

The John Deere Component Works concluded the following:

Prototyping of portions of the three applications determined that the IBM robot was capable of assembling selected J.D.C.W. parts.

Lower technology robots could assembly two of the applications.

The economic feasibility study of the hi-lo blocker assembly determined that tooling cost is a large contributer to the R.O.I. results.

They recommended the following:

Discontinuation of the project based on: the low R.O.I.'s obtained through the economic analysis performed; the low assembly hours required for the applications chosen; and the majority of the goals set had been completed.

Robotic or automatic assembly of new products will continue to be investigated.

A specification to aid in designing new products for possible automatic assembly of the components should be developed by Deere & Co.

The Horicon Works concluded that the pallet concept of handling parts had promise especially with small quantities and batch orders, and that the total system was economically justifiable. They recommended proceeding into Phase III with the circle welder application.

PHASE III OVERVIEW

At the end of Phase II, the Component Works recommended not to continue into Phase III. Subsequently, the robot and peripheral equipment was moved to the Horicon Works.

The goal in Phase III was to run production parts, test the pallet concept, and gather data to verify the assemptions in Phase II. This involved building all the necessary peripheral equipment, interfacing the robot to the circle welder, writing the computer program, and running parts with an operator.

The Phase III Management Review Meeting was held at the Horicon Works on 23 April 1981.

PHASE III ACTIVITIES

The circle welder application was picked for Phase III since it showed the highest economical potential and that it would simulate the robotic loading of parts into a fixture. The pallet concept of handling parts was demonstrated.

The total system included standard pallets used to transport all parts, pallet inserts to hold and orient specific parts (inserted inside the pallet), a conveyor system to move the pallet into the robot work area, robot grippers, circle welder fixtures, a computer program to control the operation, and interfacing supplies.

Initially, IBM indicated that they would supply the standard pallets and conveyor as part of the system, however, this was not completed during Phase III. Consequently, the Horicon Works designed and built all the final equipment for the operation giving them excellent experience with designing the total application.

The pallets were built out of plywood. The inserts were made from vacuum formed plastic and designed to hold enough parts for ten assemblies. Quick change grippers were made to hold a variety of parts. (See appendix 12 for examples of pallets, inserts, and grippers). Punched holes were added to some parts to enable the robot to grasp the parts. The fixturing was designed to locate the parts and break the part from the fixturing if weld splatter got on the part or fixture. The pallet handling system was designed from angle iron and simulated the loading concept. The total installation is pictured below.

A general computer program was written to load all parts. It controlled the sequence of operation, collected run data, and printed error messages when necessary.

The overall operation was as follows:

Operator loads pallet of parts into the robot work envelope on the conveyor.

Robot loads parts into welding fixture #1.

Circle welder rotates table and presents finished welded assembly to robot.

Robot removes finished welded assembly from welding fixture #2 and drops it into an exit shoot while the circle welder is welding parts in fixture #1.

Robot repeats load/unload cycles.

Robot stops when pallet is empty.

Cycle times and operator input was determined from the production runs. The return on investment calculations included calculations of costs and savings. A cost breakdown is shown in appendix 13. The robot operation direct labor cost included estimates for loading parts into the pallets, cleaning circle welder nozzles, and a parts washing operation. The robotic operation was fully loaded, three shifts.

The return on investment result was 6.6% with a nine year payback.

A ROI sensitivity analysis was performed by changing robot cost, robot speed, and labor input (see appendix 14). At best a 25% to 30% ROI could be obtained with a much faster, lower cost robot and less labor input. IBM did not indicate that a lower priced and faster robot would be offered in the near future.

ASSESSMENT OF THE ROBOTIC SYSTEM

The "AML" language was easy to learn and to work with. Subrouting capabilities were excellent. The use of user originated commands made the language very powerful. A potential problem with this type of system was that the program would be unreadable to those not familiar with the special user originated commands. Though the language was easy to understand, implementation was not always easy. One problem that should be worked on is how data points are entered into a program or data set. It would have been more convenient and accurate if the robot's arm could be placed in position and the data points for the arm's position placed into the memory of the computer. A full screen editor would be beneficial. Computer memory availability was limited at times.

The system of interfacing the robot to the outside world was easy to understand and worked very well. The use of multi arms on the robot may be necessary to get production speed up fast enough to compete with a two-armed operator. Multiple arms on a robot could be used together on a common assembly or could work separately on individual assemblies within the same robot frame.

Due to the hydraulic motor design and operating pressures, small oil leaks may go undetected and cause cleanliness problems. The hydraulic pump was very noisy.

PHASE III MANAGEMENT REVIEW MEETING

The Phase III Management Review Meeting was held at the Horicon Works. In attendance were representatives from Deere & Co., IBM, and the Horicon Works. The Phase III results were presented. IBM gave a presentation on their newest assembly robot.

CONCLUSIONS AND RECOMMENDATIONS - PHASE III

As a result of the Phase III study, a robot for the circle welder application will not be purchased and installed in the near future. This conclusion is primarily based on the expected 6.6% R.O.I.

The low R.O.I. does not appear to be the result of any single factor but is to some degree a result of the following:

1. Cost of the robot (now @$105,000).
2. Performance of throughput (presently at about 1/2 the speed of a man).
3. Labor savings with the pallet system.
4. Maintenance cost estimated at 12% of the robot cost per year.

The following conclusions reflect the Horicon Works thoughts on robotic assembly only and should not be interpreted as their conclusions for all robotic applications.

1. The soft tooling approach for part presentation fits well with low to medium volumes of production.
2. The flexibility provided by a computer controlled robot is advantageous in robotic assembly.
3. Part presentation is the largest problem facing the installation of assembly robotics.
4. One armed robots are not as fast as a man with two arms. A second arm added to the IBM robot would help throughput.
5. End of arm tooling design is critical to provide the needed dexterity for assembly operations.
6. Part cleanlines is critical.
7. The assembly fixtures must be square to the robots coordinate system.

PROJECT SUMMARY

The goals and objectives of the JD/IBM Joint Robotics Assembly were:

Gain knowledge in use of robots in assembly.

Determine potential for automation for JD assemblies.

Gain knowledge of feeders, special fixtures, and part oritentation techniques.

Increase understanding of special assembly robots.

Develop knowledge necessary to determine product design techniques to enhance automation potential.

These goals and objectives have been obtained. All Deere units have shown interest in the project and robotic assembly. It has been demonstrated that the IBM robot can assemble selected assemblies.

The study showed that the robot is only part of the total robotic assembly system. Part orientation equipment, assembly fixtures, and interfacing supplies make up another significant portion of the complete system. The robot must be easy to program and maintain in order to reduce engineering support required.

Part redesign may be necessary for robotic assembly. New products should be designed for automated assembly. Part consistency will remain important. In essence, the whole assembly process may have to be investigated in order to maximize productivity gains.

The decision not to purchase IBM's robot was the result of its price-performance characteristics and not its construction or reliability. IBM has made changes to their latest robot which does incorporate many of the changes that were suggested by Deere throughout the project. The IBM robot does represent the state-of-the-art in computer controlled robots. The weight carrying capacity of five pounds may present problems to us with medium sized assemblies. A sophisticated robot is helpful in some applications but a hinderance in others. At times, using the robot's intelligence to sense parts presence instead of simple sensors slowed down the overall speed of the system, affecting capacity and reducing the ROI. The relationships between price, speed, and labor input of the system must be improved upon.

Some of the general problems associated with manual versus robotic assembly are: operators are faster than robots in assembling our small assemblies due to the operator's efficiency of handling our parts, few fixtures are required in manual assembly (operator's hands), and operators have complete sensory feedback. In the electronics industry robots may be used effectively and efficently for assembling small diodes, capacitors, or other electronic components into circuit boards where operators tend to make errors due to the repetitive and monotonous nature of the work.

Robotic assembly will not be the answer to all assembly operations. An investigation should consider all alternatives from "hard" automation to manual assembly. Part volumes and parts families will be an important consideration. In low volume operations, part associated costs for grippers, part orientation devices, and fixtures must be reduced.

As a result of this study, we are now in a very good position to evaluate other manufacturers equipment. We have developed a data base of information and can compare alternatives much better. If we believed that robotic assembly would play a role in our future factories (which we did) it would have taken time and man-effort to develop this data base. The IBM project presented an opportunity to develop this data base ahead of our competition and without any capital expenditure.

The future is promising. We anticipate several new manufacturers to soon market assembly robots. Already, General Electric is selling a multi-armed assembly robot with better price-performance characteristics than the IBM equipment. We will certainly continue our interest in IBM's progress. Internally, we will need to consider robotic assembly when designing parts and establishing the manufacturing process. We should continue our interest in robotic assembly.

COMPONENT WORKS

LICATIONS -- DETAIL CRITERIA EVALUATIONS

APPLICATION	CRITERIA 1	2	3	4	5	6	7	8	9	10	11	12	K$
1. Valve, selective control	4	3	3	1	3	3	2	2	3	2	3	1	655
2. Valve, seat control	4	3	2	1	3	3	2	3	4	2	3	1	196
3. Control Support	4	4	3	4	3	4	1	2	4	3	3	1	381
4. Pump, Steering Metering	4	2	3	1	3	3	2	2	4	2	3	1	175
5. Pump, Hydraulic	4	4	3	2	3	3	2	2	4	3	3	1	324
6. Valve, Brake	3	2	2	1	2	3	2	2	3	2	3	1	126
7. Valve, New Steering	3	3	1	1	3	1	2	3	3	2	3	1	143
8. Cylinder, Remote	4	3	3	2	3	1	2	2	4	2	3	1	130
9. Instrument Panel	4	2	2	2	2	1	1	2	4	3	3	1	73
10. Housing, Clutch Op Piston	4	4	3	2	3	4	2	2	3	3	3	1	97
11. Lever (arm)	1	1	1	1	2	3	2	1	4	1	2	1	96
12. Valve, stroke control	4	3	3	1	2	1	2	4	3	2	3	1	102
13. Rockshaft	4	4	3	4	3	3	2	4	4	3	3	1	251
14. Clutch Assembly	4	4	3	2	3	3	1	2	4	2	3	1	121
15. Valve, Dual Selective	3	4	3	3	3	1	1	2	4	3	2	1	45
16. Housing, Pump w valves	1	3	1	3	2	3	2	2	3	1	3	1	90
17. Accumulator, brake	3	2	3	1	2	3	1	1	3	3	3	1	60
18. Body with gears (strg pump	not elvaluated					0							
19. Rockshaft control valve	4	4	3	2	3	3	2	3	4	3	3	1	156
20. Shaft with gear	1	4	1	1	3	3	2	1	1	2	3	2	49
21. Clutch ,quad range	4	4	3	2	3	3	1	2	4	2	3	2	31
22. Housing, trans control	4	1	3	1	3	3	2	2	4	2	3	1	63
23. Valve, old steering	4	4	3	3	3	3	2	2	4	3	3	2	28
24. Cylinder, draft sensing	3	4	3	1	3	3	2	3	4	3	3	2	28
25. Housing, sel control	1	3	1	1	2	3	2	1	3	1	3	2	28
26. Tube, steering column	1	1	1	1	2	3	2	1	4	1	3	2	27
27. Valve, differential lock	3	3	1	1	3	3	2	3	3	2	3	2	26
28. Body, load control valve	2	1	1	1	1	3	2	1	1	2	3	2	26
29. Transmission Planetary	3	3	3	2	3	3	2	1	3	2	2	1	108
30. Gear, diff. drive	1	3	1	1	2	3	2	1	3	1	3	2	31
31. Clutch, Hi lo	4	3	3	2	2	3	2	2	3	2	3	2	32
32. Housing, Clutch valve	4	1	2	1	2	3	2	2	4	2	3	1	70
33. Body, steering w valve	not evaluated												0
34. Valve, presure control	2	1	1	1	1	3	2	1	1	1	2	2	35
35. Differential assembly	4	4	4	2	3	4	2	2	4	3	3	2	42
36. Carrier, Planet pinion	4	3	2	2	3	3	2	2	3	2	3	1	55
37. Drive Shaft	3	3	2	1	2	1	2	2	3	2	2	2	20
38. Lever, tilt strg	1	1	1	1	3	3	2	1	1	1	2	2	16
39. Pinion shaft assembly	1	3	2	1	2	1	2	1	3	2	2	2	29
40. Cylinder, lift assist	2	3	2	2	2	3	2	3	3	2	3	2	15

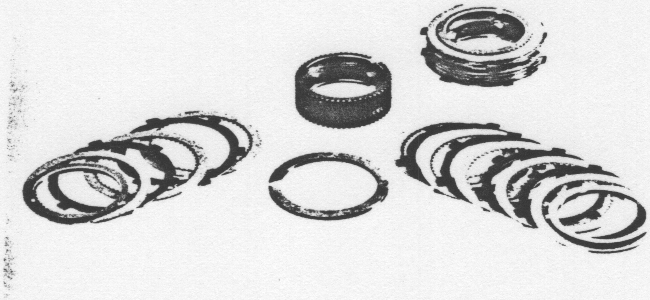
COMPONENT WORKS

TERLCC TRACTOR WORKS - APPLICATION SELECTION CRITERIA

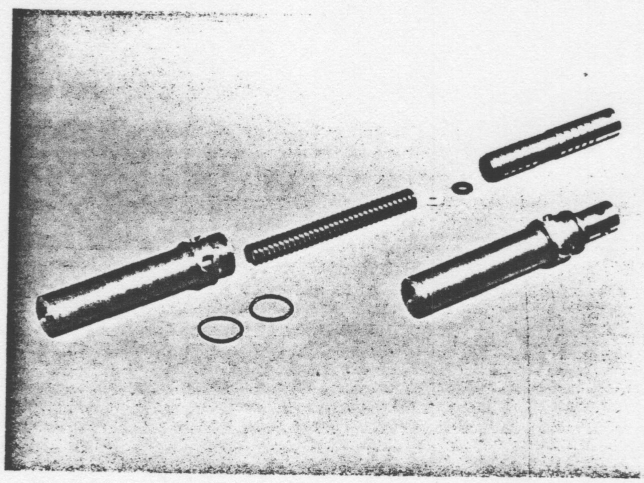
CRITERIA	1	2	3	4
1. # OF UNIQUE PARTS	· 1-5	6-10	11-20	21 +
2. PART WEIGHT	All < 5#	2= >5# 1st/last	2->5# 1/1 man.	>2 or can't be 1 or last
3. GRIPPER SIZE	less 3.0"	.25 " or > 3.0 "	under .25 > 3.0 "	or > 3.0 or thinner dime
4. ASSEMBLY SIZE	< .5 cubic feet	.5 to 1.5 cubic feet	.5 to 1.5 cubic feet	> 1.5 cubic feet
5. ASSEMBLY METHOD	Stacking Top	Slide/Push Together	Combination	Force Fits
6. PART FIT	All slip in or on	Slight Force < 10#	Force Fit w/fixture	Force Fit no fixture
7. ACCURACY	None less Than .005	Some < .005 Program can Handle	Some < .005 Tooling will Handle	Some < .005 Tooling will Not Handle
8. FASTENERS	Self lock Snap Fit	Snap on or Thread Feed and Install Standard Devices	Threaded Feed and Install Special Tools	Snap on or threaded Requires Expensive Fixturing Feeding
9. PART FEEDING	All parts Fed with Known Device < 1 k $	Parts not Easily fed with std. 1 - 5 k $	First/last Part Manual feed 5 - 10 k $	Expensive or New design for feed > 10 k $
10. TOOLING	Gripper Only 0 k $	Auxiliary Tool Req'd With Gripp 1 - 2 k $	Auxiliary Tool Req'd + Revision to Robot 2 - 5 k $	Multiple Tool Chg. or New Tool Design > 5 k $
11. FIXTURES	Locating Pins Only < 1 k $	Single Nest Fixture 1- 10 k $	Complex or Multi-Stage > 10 k $	Not Possible or Practical
12. ASSEMBLY COST	> 50 k $	10 - 50 k $	2 - 10 k $	< 2k $

COMPONENT WORKS

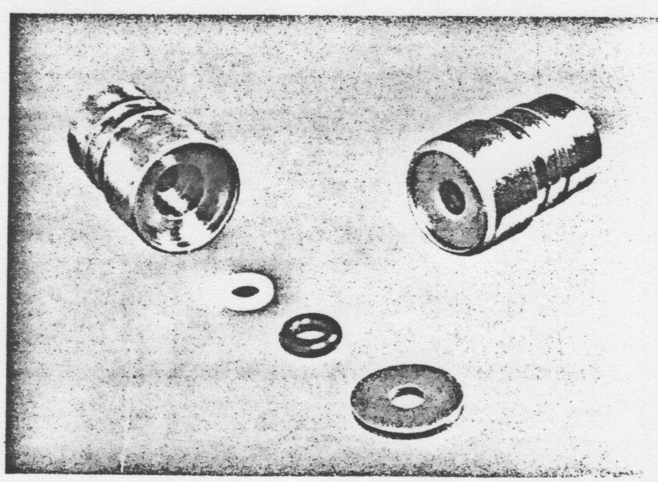
Selected Assemblies



BLOCKER HI-LOW



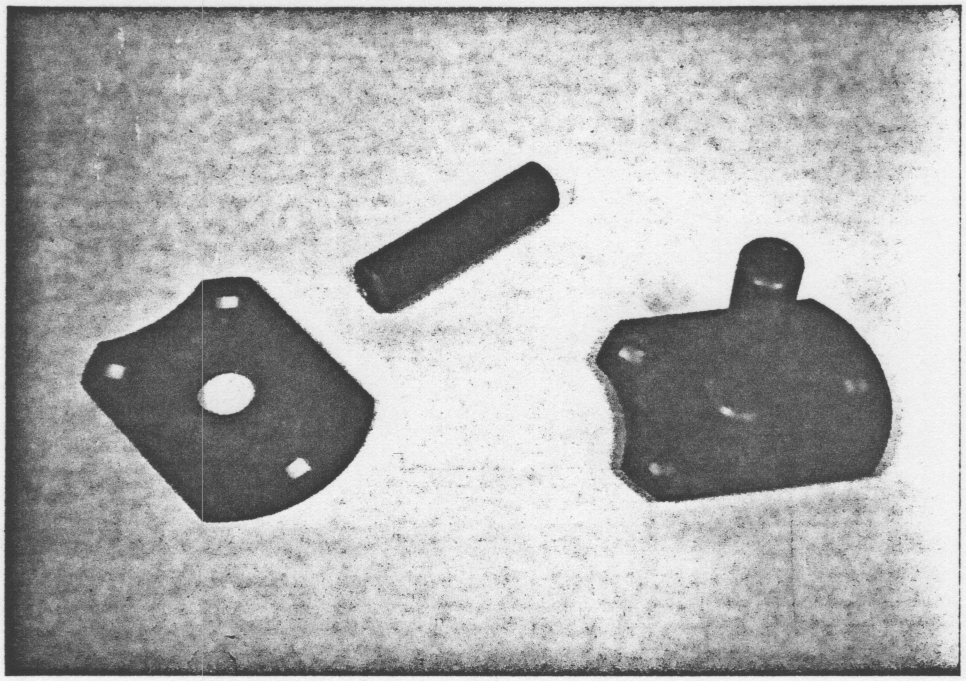
VALVE, PRESSURE CONTROL



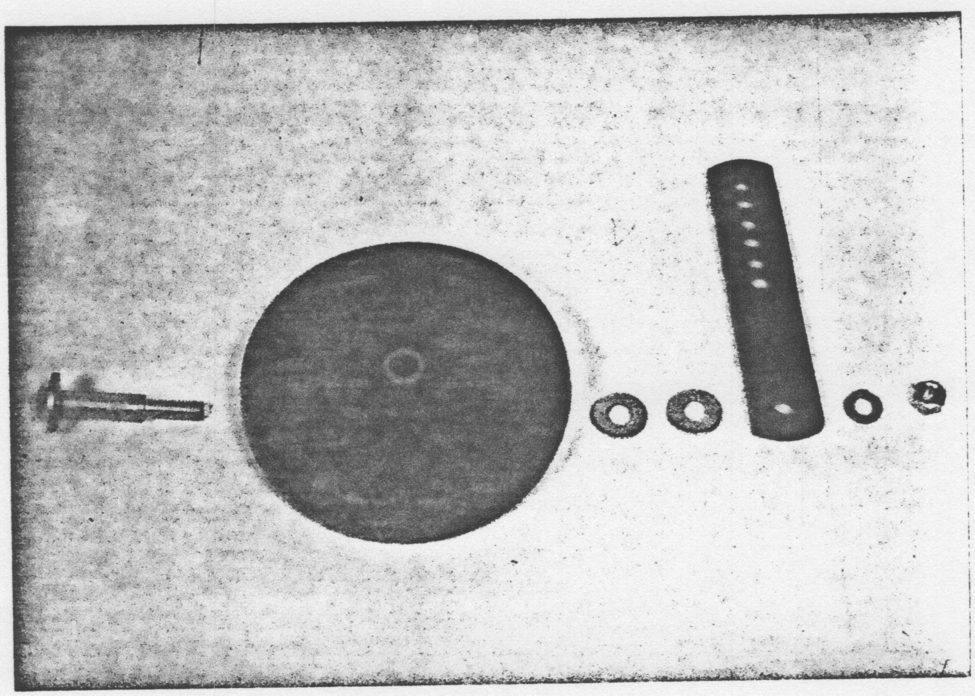
GUIDE ASSEMBLY

HORICON WORKS

Selected Assemblies



Circle Welded Part



Gage Wheel

HORICON WORKS

STATISTICAL ANALYSIS OF ROBOTIC ASSEMBLY APPLICATIONS

SUMMARY OF RESULTS				
Rank*	# of Assemblies	% of Assemblies	Annual Cost To Produce	% of Total Annual Cost Represented
2	21	29%	$126,421	5.6%
3	21	29%	654,295	28.9%
4	30	42%	1,482,135	65.5%

* Rank 1 Directly applicable to robot
Rank 2 Auxiliary tools required
Rank 3 Modification of robot required
Rank 4 Not practical

COMPONENT WORKS

Phase I

The economic analysis is based on the following assumptions:

Estimated robot cost	$75,000
Software lease cost	$4,800/year, first four years
Maintenance	$6,000/year
Training and technical assistance	$3,000/year
Startup	$3,000
Shipping and installation	$5,000
Full machine load	20.4 hours

HORICON WORKS

PHASE I

The assumptions derived for the cash flow analyses were:

1/4 man to stock up and attend one job

The robot is as fast as a man

Feeding mechanisms are 50% adaptable to jobs within a family grouping

Robot and computer cost is $80,000

Robot cost is applied in proportion to time used

Maintenance cost is $6,000/year

Salvage value is 20% of first cost

No escalation on labor cost

COMPONENT WORKS

Hi-Lo Blocker

Robot Assembly Concept

Component Parts (See Example 12 for Detail DWGS.)

2 - Retainers

1 - Blocker Synchronizer

6 - Synchronizer plates

8 - Disks

Glue

Parts Feeding

- Retainer manually loaded in horizontal position and located in holding fixture.
- Retainer holding fixture located in robot work area manually.
- Blocker synchronizer loaded in chute and located on slot manually. Blocker escaped in horizontal position.
- Synchronizer plates manually loaded horizontal position in holding fixture.
- Plates holding fixture located in robot work area manually.
- Disks manually loaded in horizontal position and located by teeth in holding fixture.
- Disk holding fixture located in robot work area manually.

Assembly of Parts by Robot (See Example 4 for Detail Layout)

- Robot moves to blocker synchronizer; grasps O.D. of blocker and lifts out chute.
- Robot moves to assembly fixture and places blocker in fixture.
- Fixture clamps I.D. of blocker and rotates it to locate a tooth on the O.D. (See Example 5 for Detail Layout)

- Robot moves to disks; grasps disk on I.D. teeth with (3) pins on end of fingers. Disk is lifted up off of stack.
- Robot moves to blocker with disk tilts gripper 5° and lowers disk to blocker. After teeth of disk contact teeth of blocker disk is dropped onto blocker.
- Robot moves to synchronizer plates; grasps plates on I.D. with (3) pins on end of fingers. Plate is lifted up off of the stack.
- Robot moves to blocker with plate; lowers plate over blocker and releases plate.
- After stacking of disks and plates, robot moves to glue applicator, picks up glue pen and moves to blocker.
- At blocker robot locates glue pin above and perpendicular to blocker face.
- Robot rotates gripper 360° applying glue on face of blocker with pen.
- Robot moves to glue applicator station and places pen back in location.
- Robot moves to retainers; grasps edge of retainer and removes from fixture.
- Robot moves to blocker with retainer, and places on face of blocker.
- Press swings over blocker; presses retainer into location and stakes it in place.
- After press swings aside robot, moves to blocker; grasps both faces, lifts blocker up turns it over and places it back in assembly fixture.
- Placing of disks, plates, glue and retainer is then accomplished on this side as already described.
- After completion of assembly robot grasps both faces, removes assembly from fixture and asides it to completed assemblies area.

Possible Problem Areas

1. Applying glue to the blockers face.
2. Moving disks at a high speed with robot without loosing them from the robots grippers.
3. Disks not falling correctly when being installed on blocker, causing disks to hang up and not fall flat.

Comments

1. This concept would require the technology and capabilities of a high technology robot such as the IBM robot.
2. Manual loading of locating fixtures is required because:
   - Bonded facing on disks needs to be inspected for presence of grooves.
   - Hole in plate needs to be checked visually for location.
   - Anti-rotational ear needs to be located for placing on blocker and inspection for flaws is required.

COMPONENT WORKS

ROI ANALYSIS AND CALCULATIONS

Standard Data Used in Each Analysis

Capital

Robot Cost = $75,000

Salvage Value = $15,000

Shipping & Installation = $5,000

Fixtures = $21,700

Expense

Maintenance Cost:

Hardware = $6,000/year

Software = $4,800/year

Total = $10,800 First 4 years

Last 6 years hardware & software maintenance cost = $6,000/year

Misc. Data

Project Life = 10 Years

Depreciation = 8 Years

Investment Tax Credit = 10% of Capital

Machine Utilization Limit = 65% x 24 Hrs/Day = 15.6 hours
(Based on Computer Controlled Machines at J.D.C.W. Historical Data)

Analysis #2

Time required for robotic assembly/day =

88 assemblies/day x 2.00 min/assy ÷ 60 min/hr =

2.93 hours/day

% machine utilized by this assembly = 2.93/15.6 hours =

18.8%

Capital:

Robot + Ship. & Inst. = 18.8% x $80,000 =

$15,965

Fixtures = $21,700

Salvage Value = 18.8% x $15,000 = $2,817

Expense Items:

Maintenance = 10,800 x 18.8% = $2,028

6,000 x 18.8% = $1,127

Training & Tech Assistance = $3,000 x 18.8% = $563

Sales Tax = ($2,400 x 18.8%) + $650 (Fixt. Tax) = $1,100
Mach. Tax

Savings:

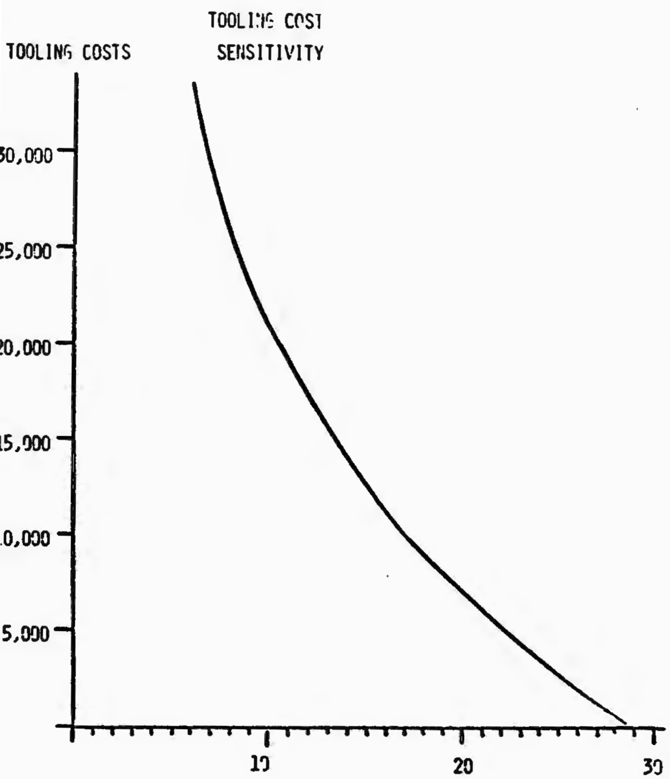
Same as Analysis #1

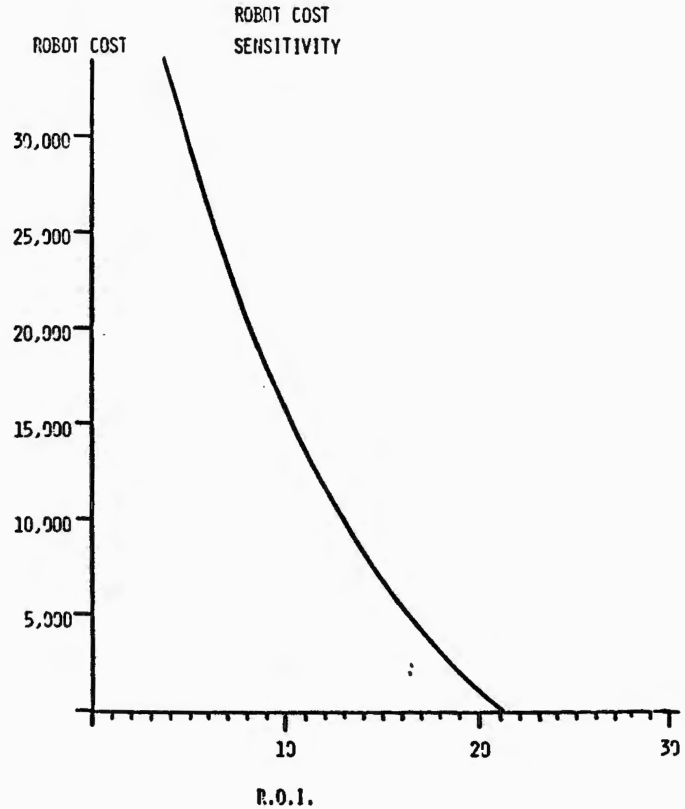
= $7,638/year

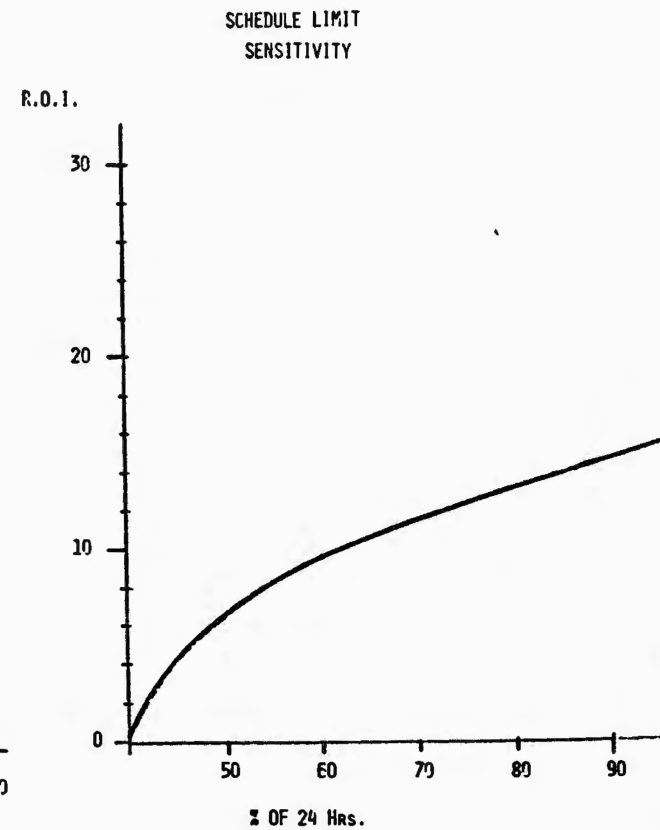
R.O.I. = 10.5%

Payback = 7 years

COMPONENT WORKS
ROI SENSITIVITY ANALYSIS

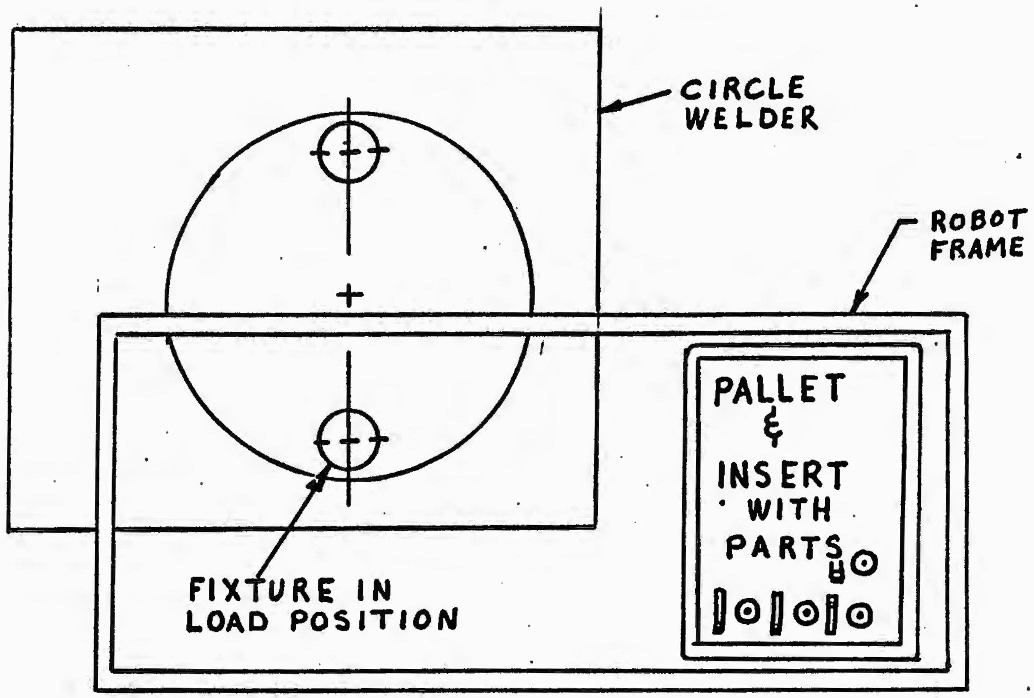




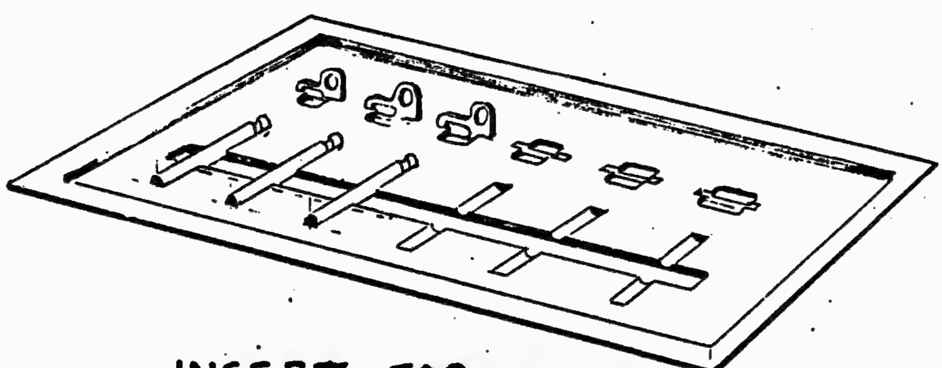


HORICON WORKS

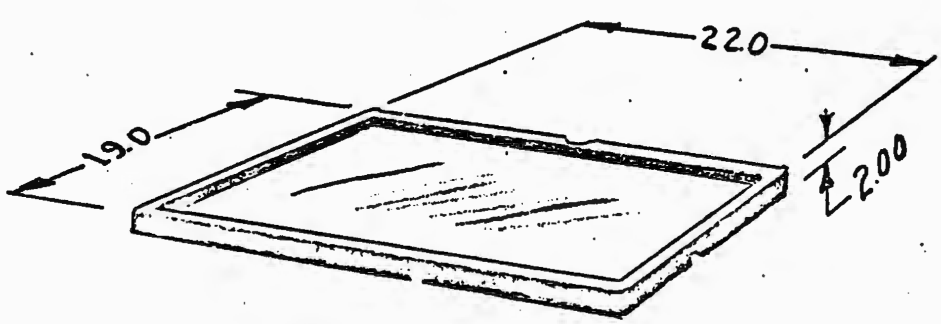
Assembly System - Components



CIRCLE WELDER
FLOOR PLAN



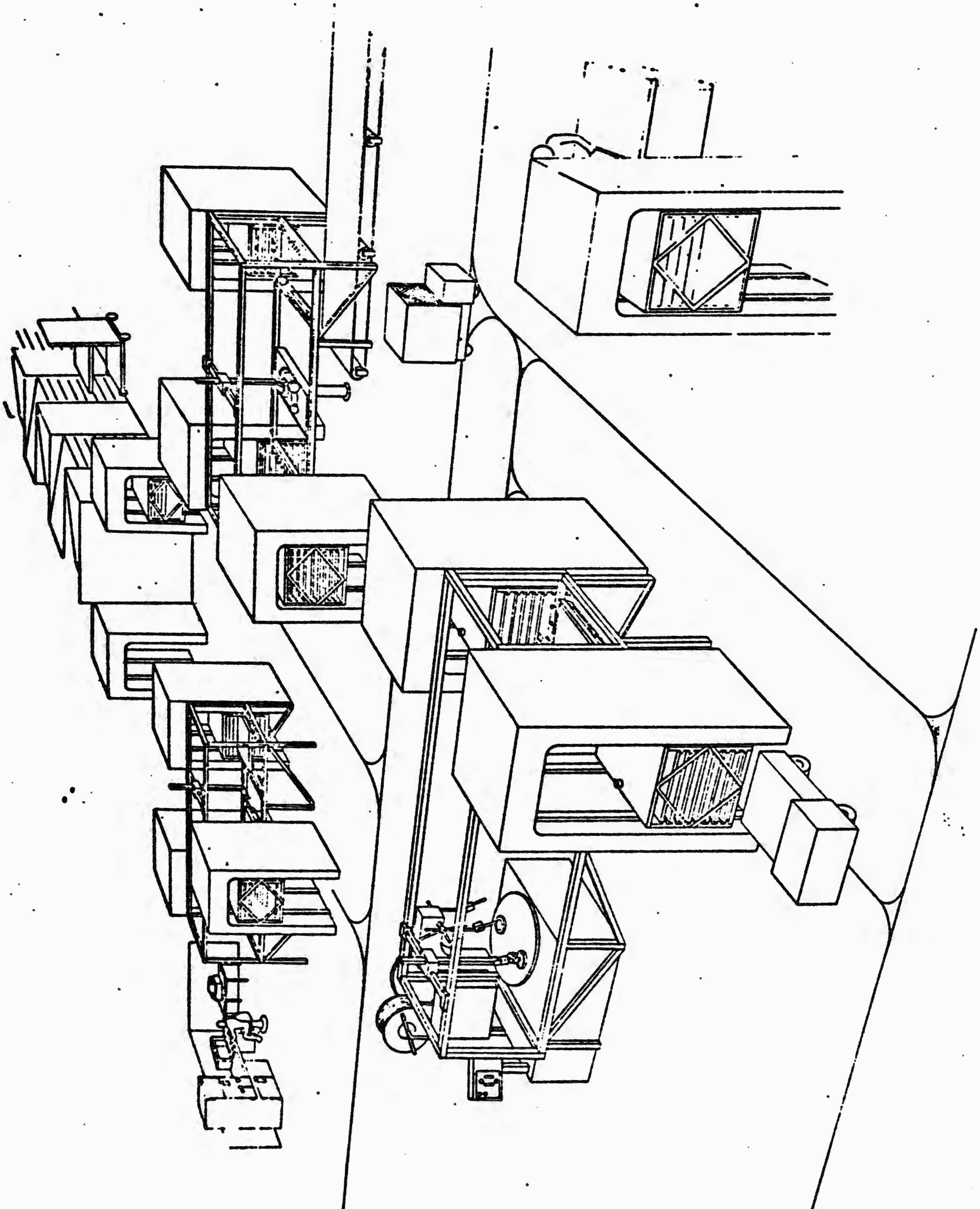
INSERT FOR PALLET



PALLET

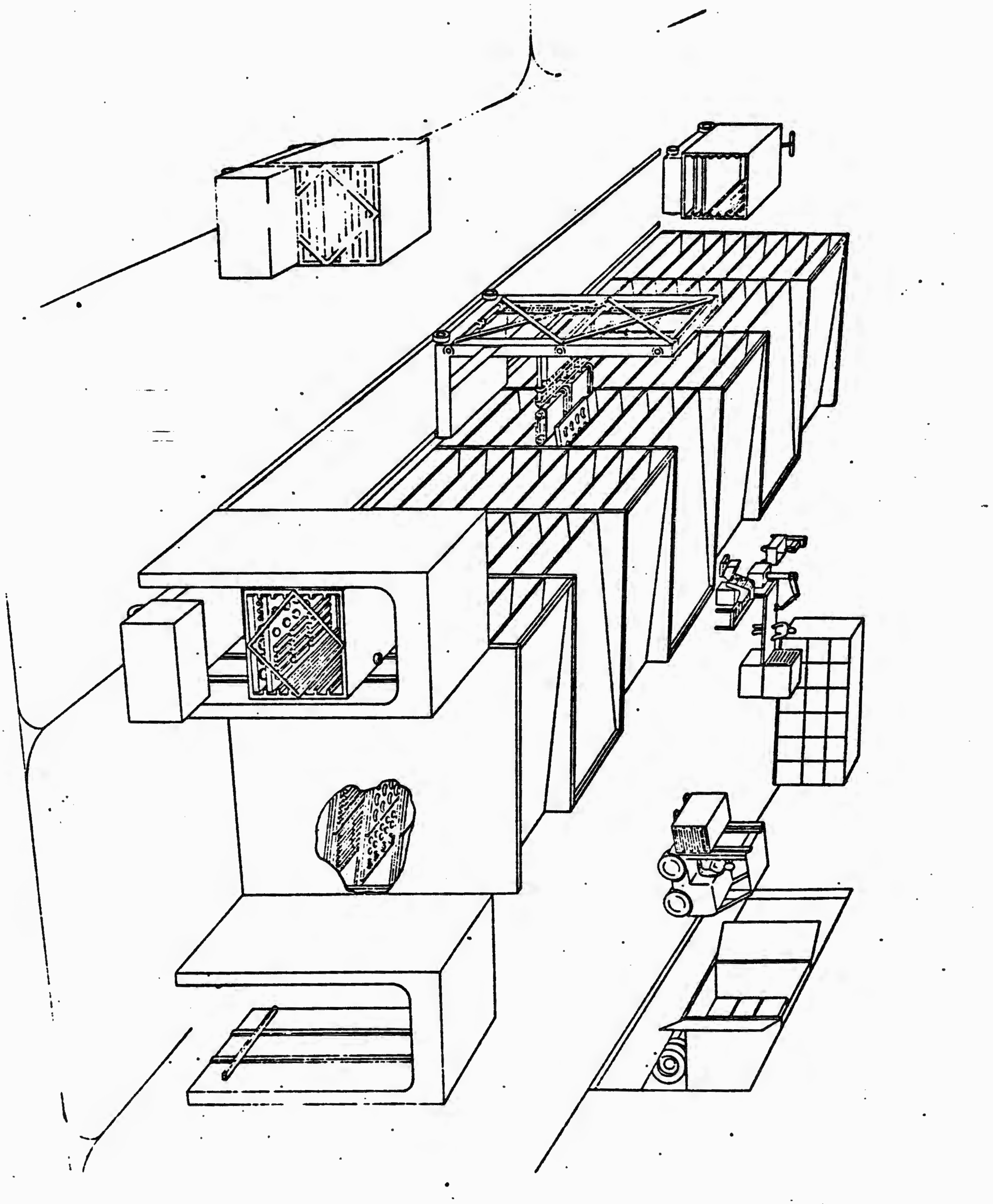
HORICON WORKS

Concept For Automated Assembly Departments



HORICON WORKS

Storage System Concept For Automated Assembly Department



HORICON WORKS

CIRCLE WELDER HARD TOOLING COSTS

Chart #1

	Weld Fixture F50-10-( )	Feed Track F45-24-( )	Stack & Shuttle F45-24-( )	Incline Belt Feeder	Eject System	Base Plate F45-24-17007	Discharge Chute	Vibratory Bowl	Total	
TY				15,400	4,275	590	60		20,325	
59 W/ 10	(17086) 800	(17001) (17005) 400	(17002) (17003) (17004) 5,450	*	*	*	*		6,650	
39	(01205) 00	(17024) (17025) 1,200	0	*	*	*	*		1,200	
42	(17089) 495	(17015) 300	(17014) 1,650	*	*	*	*		2,445	
37	(17025) 495	(17035) 450	(17036) 1,800		*	*	*		2,745	
74	(00436) 00	(17008) (17009) 825	0		*	*	*		825	
44	(17090) 450	(17018) (17019) 1,330	0	*	*	*	*		1,780	29885 Non Utility Cost
64	(17088) 700	(17011) (17012) 950	0	*	*	*	*		1,650	
41	(17094) 750	(17032) 1,550	(17033) 475	*	*	*	*		2,775	
63	(17092) 400	(17027) (17009) 725	0		*	*	*		1,125	
83	(17091) 290	(17021) (17022) 2,300	0		*	*	*	3,000	5,590	
11	(17093) 500	(17029) (17030) 2,600	0	*	*	*	*		3,100	
	4,880	12,630	9,375	15,400	4,275	590	60	3,000	50,210	

HORICON WORKS

CIRCLE WELDER - SOFT TOOLING

Chart #10

	F50-10-17086 Weld Fix. AM35139	F45-24-17006 Temp.Stor. Sub-Weld	Eject System	Pallet Feed System	Pallet for System @ 20/Pallet-Tooled	F50-10-01205 Wels Fix. for AM37995	F50-10-17089 Weld Fix. for AM37642	F50-10-17095 Weld Fix. for AM33337	F50-10-00436 Weld Fix. for AM31374	F50-10-17090 Fix. for AM37644	F50-10-17088 Weld Fix. for AM37664	F50-10-17094 Weld Fix. for AM35141	F50-10-17092 Weld Fix. for AM31163	F50-10-17091 Weld Fix. for AM34983	F50-10-17093 Fix. for Weld AM35411	TOTAL
Utility			4275	15K	687 con't											19,962
Misc.			X	X												
AM35139 w/ AM38410	800	275	X	X	200											1,275
AM37999			X	X	200	00										200
AM37642			X	X	200		495									695
AM33337			X	X	200			495								695
AM31374			X	X	200				00							200
AM37644			X	X	200					00						200
AM37664			X	X	200						700					900
AM35141			X	X	200							750				950
AM31163			X	X	200								400			600
AM34983			X	X	200									290		490
AM35411			X	X	200										500	700
TOTAL	800	275	4275	15K	2889	00	495	495	00	00	700	750	400	290	500	26867

$\frac{\text{2894 hrs. total}}{\text{2016 one shift hrs}} = \frac{6897}{X}$ Tot. Non-Utility Cost

X = 4804

$4804 is proportional total of parts shown on sheet, but for one shift only

Tooling Cost for One Shift
$4804 + $19962 = $24766

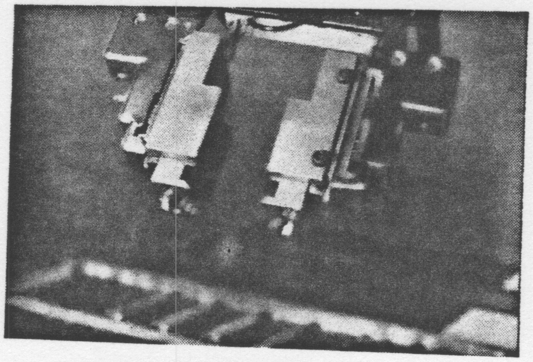
Non-Utility Cost (rows Misc. through AM35411)

$\frac{\text{\$6897 Non Utility}}{\text{12 Part Nos.}}$ = Ave. Part No. Cost $575 $575 x 70 Parts = $40250 $40250 + $19962 = $60212

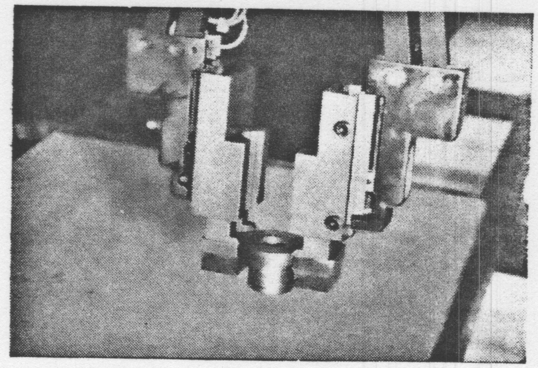
(Total No. of Parts on Circle Welder)

HORICON WORKS

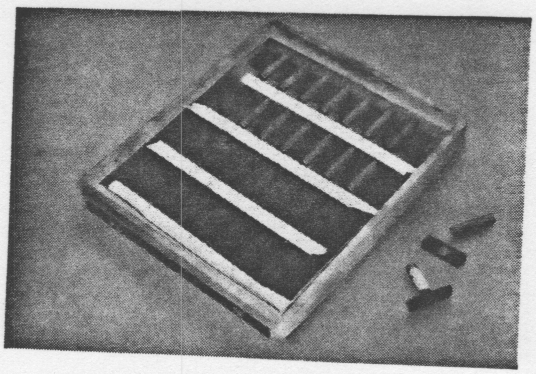
Application Components



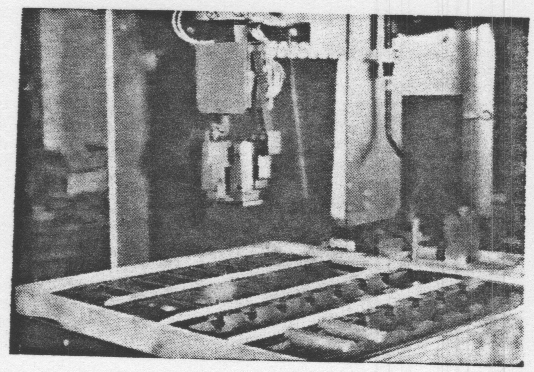
Robot Grippers



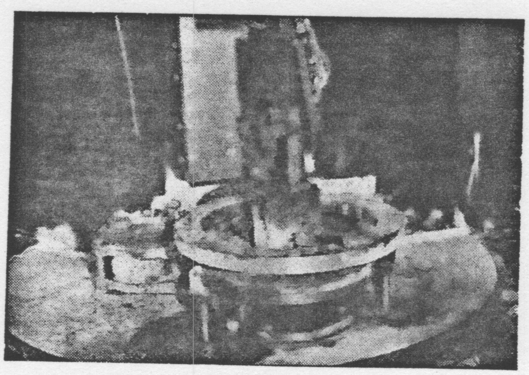
Grippers Holding Part



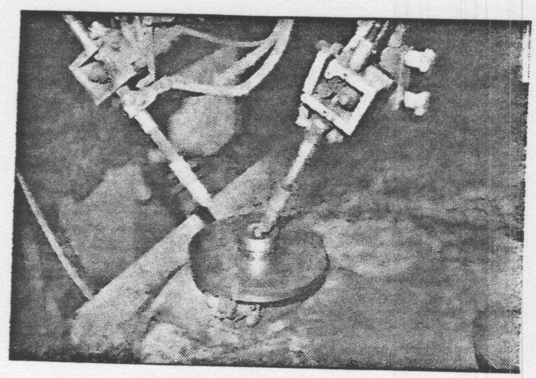
Pallet with parts



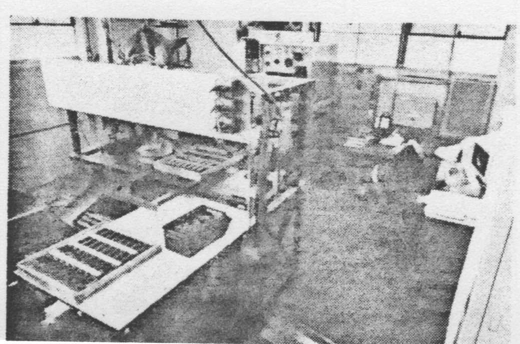
Robot unloading Pallet



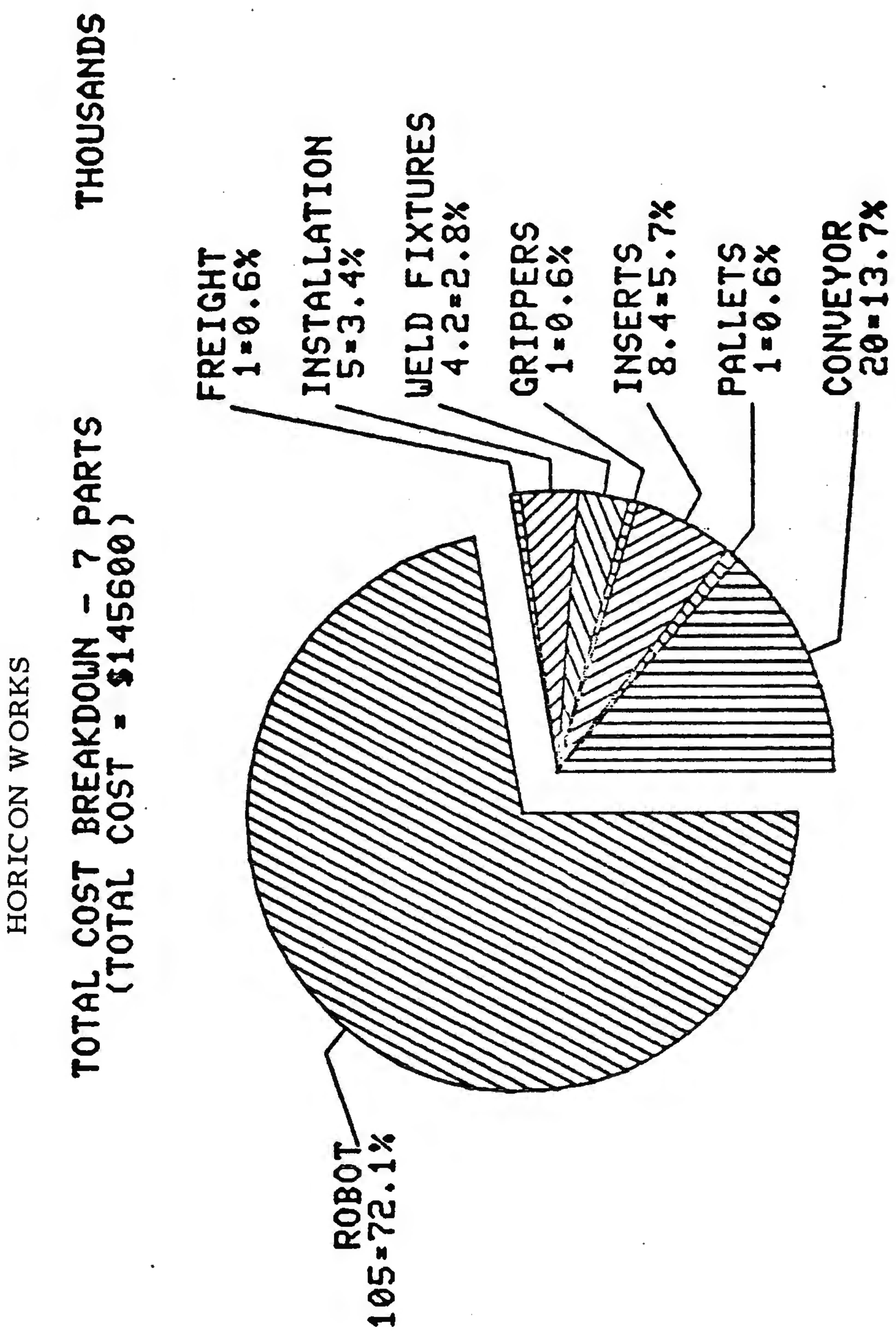
Robot loading weld fixture



Weld fixture

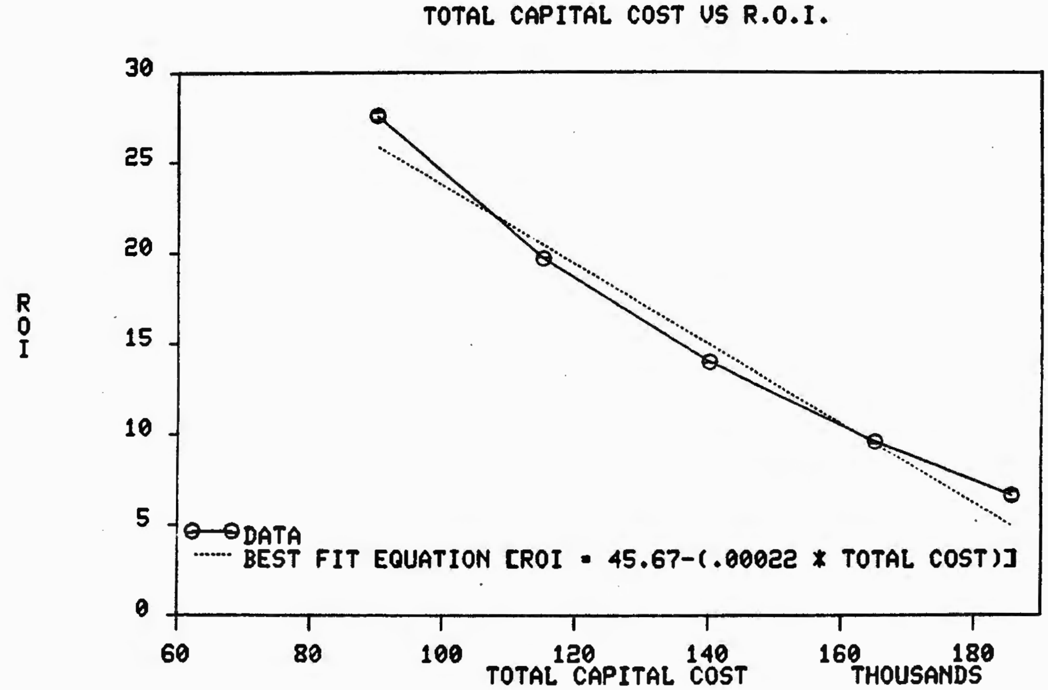


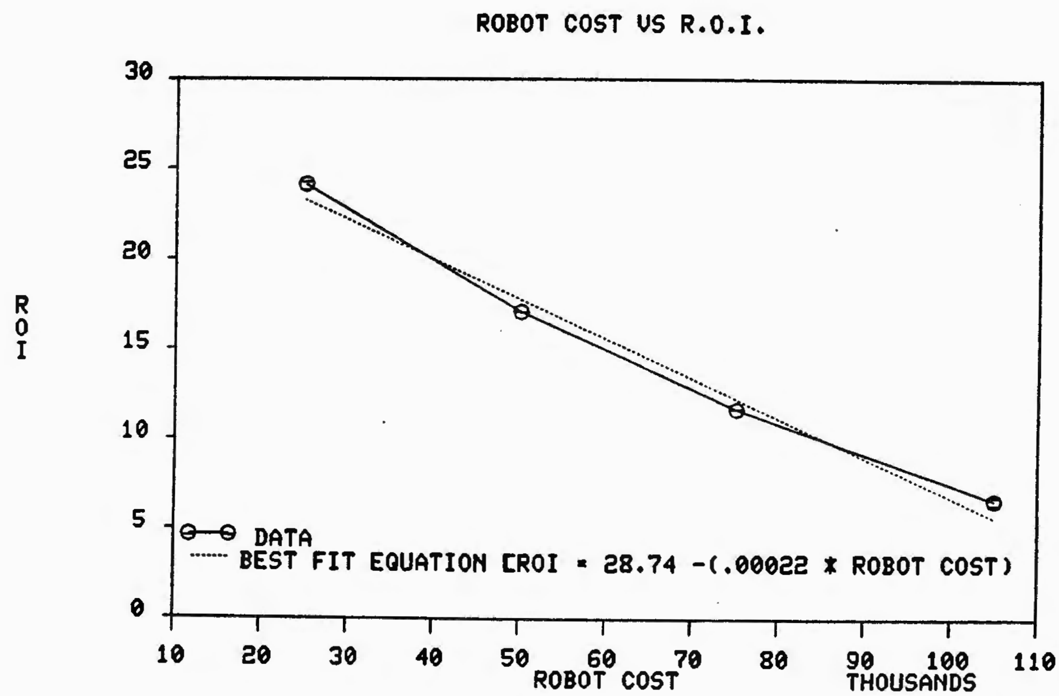
System Installation


HORICON WORKS
TOTAL COST BREAKDOWN - 7 PARTS
(TOTAL COST = $145600)
THOUSANDS
FREIGHT
1=0.6%
INSTALLATION
5=3.4%
WELD FIXTURES
4.2=2.8%
GRIPPERS
1=0.6%
INSERTS
8.4=5.7%
PALLETS
1=0.6%
CONVEYOR
20=13.7%
ROBOT
105=72.1%

HORICON WORKS

Sensitivity Analysis

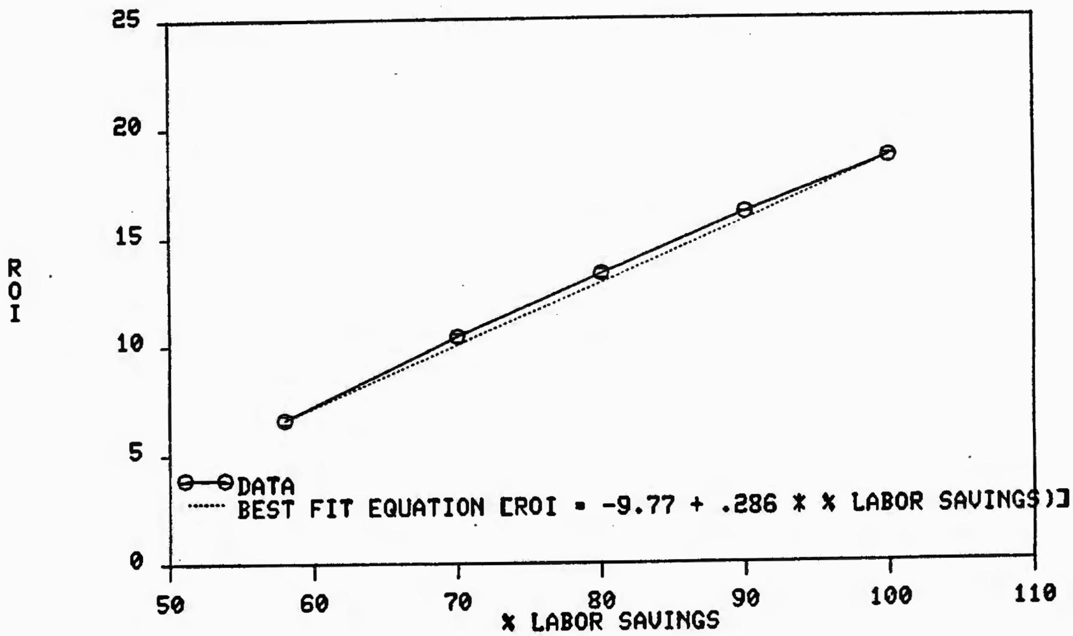




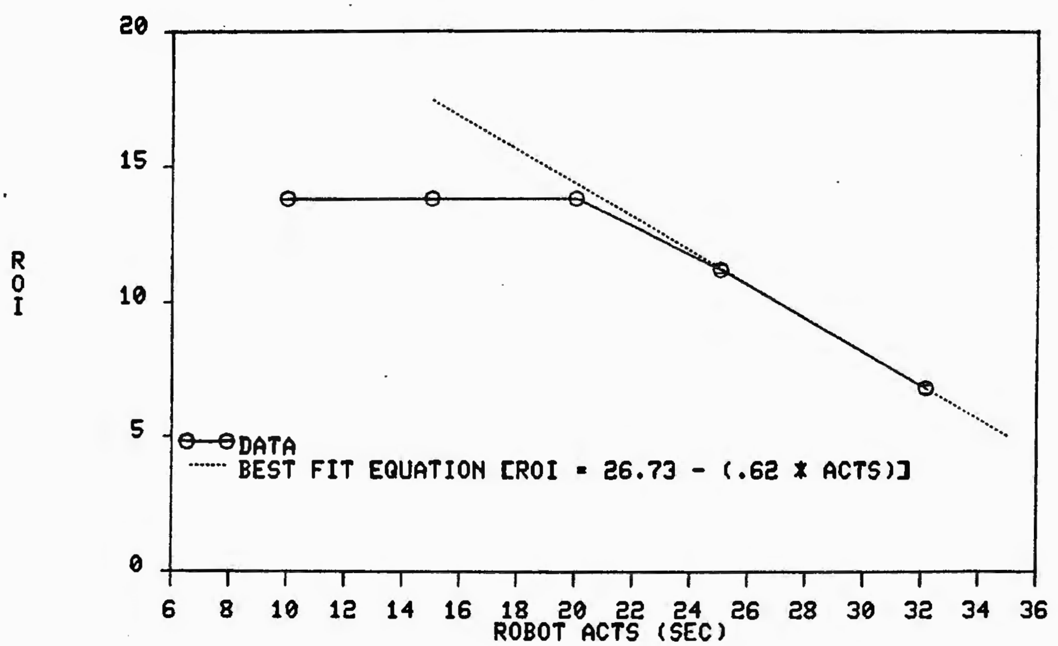
HORICON WORKS

Sensitivity Analysis

PERCENT LABOR SAVINGS VS.R.O.I.



ROBOT PERFORMANCE VS R.O.I.



STUDY TEAM MEMBERS

PHASE I

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Dawn Goldberg

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Jim Dreager

PROJECT DOCUMENTATION AND RESOURCES

(Available from Manufacturing Research and Development - Deere & Co.)

Reports

Phase I Management Overview

Phase I Technical Report

Phase II Report - Horicon Works

Phase II Report - Component Works

Parts Flow Study - Horicon Works

Plow/Planter Potential Robotic Assembly Applications

Phase III Report - Horicon Works

Final Report - Deere & Company

Design for Assembly Handbook - P. Andrews

Documentation

Phase I Back-up Information

Phase II Back-up Information, Vol. I & Vol. II

Phase III Back-up Information

Slides

Miscellaneous Project Slides

Videotapes

Brake Boot Assembly - Component Works

Gage Wheel Assembly - Horicon Works

Gage Wheel Assembly - Experimentation

Introduction to TRIBE/Rocker Arm Assembly - Dubuque Works

Circle Welder Application - Horicon Works