

Program Prospectus for the Simulation, Design and Implementation of a Flexible Assembly and Inspection Cell

by

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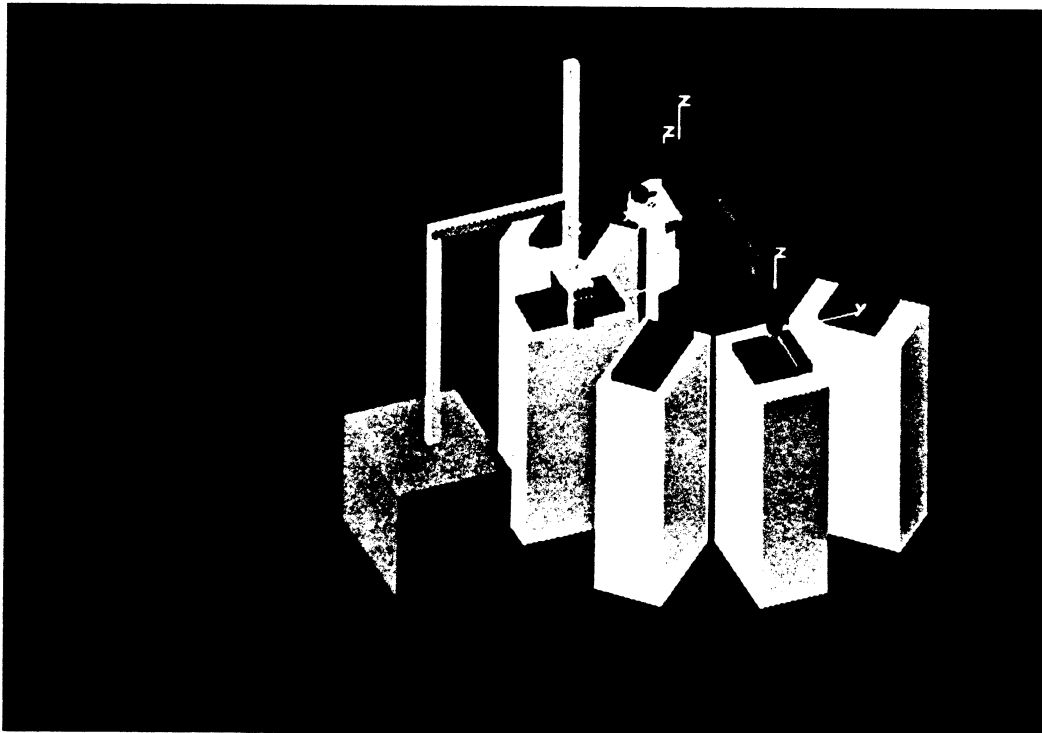


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PART I: SUMMARY OF THE MAJOR GOALS

The *short term goal* is to simulate, using ROBCAD (a parallel process simulation and solid model animation system), to design and implement a "generic" robotized assembly and inspection cell, consisting of an industrial robot and peripheral devices, designed and/or integrated by us to achieve extremely high flexibility, manufacturing quality and productivity levels.

The core of the concept is to develop an "*intelligent*", *generic assembly and inspection cell*, capable of changing parts, tools (i.e. robot hands), changing flexible component feeding and orientating devices using a direct access material handling system (e.g. an AGV), as well as capable of communicating with the outside world via standard data communication networks, such as MAP and/or other LANs.

Having successfully demonstrated the development of the cell, the idea in *the long term* is to duplicate the device and by linking several together demonstrate the way such cells could be used as building blocks for highly productive, mixed production flexible assembly/inspection systems.

The potential user's major financial benefits of this concept is that by developing an "*intelligent and generic*" cell one can save the cost of individual, customized developments which in most cases are redundant and result in rigid systems, which are not capable of reacting to the variation of different batch sizes of different product families, nor to the requirement of producing products

in a mixed mode. Such a system represents an advance in the state-of-the-art, and should be regarded as an investment for a future competitive edge.

On the research side, the proposed research work on our recently acquired ROBCAD/SILICON GRAPHICS solid model simulation system and the flexible assembly/inspection cell will enable us to

- *Formulate design rules for a knowledge based, expert assembly and inspection system,*
- *Provide access to different automatically, semi-automatically and manually generated assembly strategies and more accurate "know how" on how to design for flexible automation,*
- *Design, simulate and implement robotized assembly fully integrated with a powerful CAD/CAM design, simulation and operation control system,*
- *Write and execute task level robot assembly and inspection programs generated off-line, demonstrating a highly integrated, but still modular and flexible system design approach,*
- *Design and implement "intelligent" robot tools and grippers, which have the automatic recoupling facility between the robot tool and the wrist both electronically and pneumatically and provide "on-board" computing power for real-time decision making,*
- *Design and implement a Programmable Remote Center Compliance RCC table, which can accommodate palletized parts, loaded by AGVs - Automated Guided Vehicles - to the assembly/inspection area,*
- *Redesign - as necessary - and integrate modular, flexible fixturing systems into the cell, which can be automatically assembled by a robot,*
- *Integrate a variety of different contact and non-contact sensors into the system in order to increase its "learning" capability and to decrease its positioning and orientation errors in 3D,*
- *Enable us to test different production control rules and rule based scheduling strategies and to demonstrate the results to students,*

visitors and partners of this project.

To *summarize*, our task is to simulate different strategies, system design concepts and when implemented, demonstrate the way the above outlined design and integration problems can be overcome and rules can be formulated for an expert system running in the background of the CAD/CAM facility assisting the designer as well as the production control staff.

PART II: DESIGN CRITERIA AND GENERAL CONSIDERATIONS

The goal of designing flexible assembly and inspection systems is to enable the production facilities of the company to accommodate required changes in product design and to react to the market needs without necessitating large and time consuming investment programs.

In order to achieve the desired high productivity levels and the shortest throughput time at minimum cost, flexible assembly and inspection systems should be part of an overall CIM (Computer Integrated Manufacturing) concept, integrating all the business related, the CAD, the CAM and the flexible production facilities and activities of the "factory of the future"

It is important to realize that the Computer Integrated Manufacturing Technology has a common base of knowledge, principles and rules which can be applied to a wide range of different processes, including flexible assembly and inspection. The awareness of these important principles should be the common interest of all parties involved in designing and implementing flexible production

facilities.

In general flexible assembly and inspection systems deal with high level distributed data processing and automated material flow using computer controlled robots, material handling, feeding and part orientating devices, contact and non-contact sensors (e.g. image processing, or machine vision systems) linked together in a modular way. Through such integrated modularity, such flexible systems can produce goods adaptively and economically, and their control, programming, recovery and integration into larger systems is greatly simplified.

When designing flexible assembly and inspection systems, or other manufacturing systems, one must begin with the analysis and very often with the redesign of the parts to be assembled. Design for assembly, inspection and in general for manufacturing is of crucial importance. In this area CAD/CAM systems need to work with expert systems and should become increasingly "better informed" about "*What is possible?*" and at "*What cost?*" on the shop floor.

The best solution would be to avoid assembly entirely, but in many cases this is not possible, because of functional constraints, because different materials must be used (e.g. rubber, plastic and steel in the same subassembly), because of maintenance, the required mobility of components, or a combination of the above reasons.

If assembly cannot be avoided, the part, or the subassembly should be made suitable for flexible, robotized assembly. In general this can be assured by:

- **Shape** one-dimensional assembly sequencing ("z-stacking"), common electrical, etc. feedthroughs;

- **Mechanical fasteners** eliminate and/or simplify;
- **Weight**, elimination of excess weight through careful design and stress analysis;
- **Material**, use of substitute materials (plastics, HSLA steels, composites, etc.) to reduce weight, and enhance quality;
- **Mechanical interface** designing the way the part can be gripped for manipulation purposes - use of Group Technology principles in design, so products can be assembled with standard, modular fixturing;
- **Manufacturing accuracy requirements**, designing tolerances to be as loose as possible consistent with product performances, assembly process equipment accuracy/repeatability, and with assembly problems due to tolerance buildup (stacking); and
- **Part orientation**, by designing parts that can have a consistent and stable orientation.

To *summarize*, in order to be able to design and operate flexible assembly systems built of cells capable of communicating with each other both in terms of material handling and data, one should provide:

- **A suitable modular product design**, preferably using solid modeling CAD/CAM systems in order to create a solid model data base containing all the design and manufacturing data and rules related to the particular product, which can also be accessed by other CIM subsystems
- **Appropriate dimensional accuracy** of the components to be assembled
- **Assembly without the need for adjustments** and in-process inspection of certain dimensional values or performance characteristics
- **Full computer supervision**, control and report generation of the assembled components

- **Material quality control and comprehensive, real-time process control**
- **The possibility of individual product and mixed batch assembly** in order to accommodate a variety of different orders and assembly sequences as well as dynamic changes in the system.

The *individual cell* of a flexible assembly and inspection system, generally consists of:

- **The robot arm** (or arms, with its controller);
- **The necessary grippers and/or robot tools** (preferably in a tool magazine enabling automated robot hand changing);
- **The part feeding mechanism;**
- **Palletized part docking** (if required), part locating devices;
- **Part orientating devices** (if required);
- **Other electronic and sensory based** (vision, force, torque sensing, position calibration, etc.) devices which are interfaced with it and are used for guidance, safety or generating feedback data in real-time.

The key issue is that the robot controller should be a powerful micro or mini-computer, configured for executing operation control, diagnosis and communications tasks in real time. It should be able to handle and support ([2]):

- **Multi axis control, motion control, acceleration control, dynamic compensation, etc.**
- **Digital and analogue interfaces,**
- **Standard communications interfaces** to remote controllers and computers linked to LANs (Local Area Networks),
- **Standard peripherals,** such as teach pendant, disk, display, keyboard, operator's panel (important devices if the cell is a standalone

device, programmed and operated as a single and separate unit. In most cases when more cells are linked together peripherals such as the keyboard, or the display are used only in "panic" situations, during debugging and maintenance).

- **Tool changing devices and tool magazine data management**
- **Part docking and part identification tasks** (for parts typically arriving on standard size pallets - i.e. standard size within a particular system)
- **Safety devices and diagnostic software**, including interlocks, built-in error detection sensors, leak detection sensors, in the case of hydraulic robots, power interruption control, extra power sources for sensors, or tools requiring separate power supply, etc.,

The cell controller should also run the *system software*, typically consisting of the *operating system*, the *manipulator specific modules* and the *programming language interpreter or compiler* and the *communication programs* keeping in touch with the "outside world". Intelligent software (e.g., Lisp or Prolog-based) for expert systems or self-diagnostics requires particularly power computing resources.

1. Cell Programming, System Programming

Cell programming should be done preferably off-line, using robot and/or robot language independent, task oriented, interactive and user friendly languages, or language generators making use of graphics and AI techniques and generating robot dependent code which needs only minor changes if any, when executed on the cell.

When programming the flexible assembly and inspection system one should enable the *dynamic operation scheduling system* (working together with the

capacity checking and balancing programs and communicating with the CIM data bases) to select from different alternative assembly and/or inspection sequences.

Typically, assuming an "intelligent system", inspection operations should be automatically requested and executed if required by any of the cell controllers, independently of whether or not they have been pre-planned.

Similarly, assembly sequences and their possible alternatives should be generated preferably automatically, or with minor human assistance, making good use of the previously mentioned solid model based CAD/CAM data base and the expert systems imbedded in the CIM architecture.

2. Cell Tooling and Tool Transportation in the System

As we have emphasized before, automated robot hand changing, or in general *tool changing at cell level is of extreme importance* in order to provide the needed flexibility and the short tool changing times for the system as a whole.

This problem occurs at the system level too, but in a different form. Here there is a need to carry and change entire tool magazine contents, and/or to partly update tool magazines according to the actual needs, described in each part program and in the current schedule. This task can be economically solved by using the AGV based part transportation system, if the AGV is capable of picking up entire tool (i.e. robot hand) magazines and the cell is capable of docking them. Often the cell robot itself takes care of replacing the contents of the magazine. This might be an economic solution, even if valuable production time

is spent on this activity.

If the industrial robot could change its end-effectors like a human operator when using different tools, then it would become *more versatile* and allow automated assembly of small batch sizes, or individual products arriving in a mix, where dedicated machinery is uneconomic. It would also use few robots, since robots would rather change tools (i.e. hands) than distribute the workload on many different dedicated devices.

On the negative side, changing grippers and robot tools takes valuable time, so by increasing the versatility of the robotized assembly and inspection cell the cycle time is also increased. On average, the time taken to drive the arm to the gripper magazine is a few seconds. The robot arm has then to move to the part feeding station, which can take a few seconds more. Having finished the job with one tool, it must be changed again, which can cause another 2 to 4 seconds delay in the cycle time.

There are different solutions for changing tools fast on industrial robots.

Methods include:

- **Storing self powered tools in a rack system**, and have standard mechanical interface, so that the robot can easily pick any of them up in any order.
- **Arranging tools around a pneumatically indexing disk**, or if there are only two or three tools on one head, at 30-90 degrees from each other. This solution is *very productive*, since the tool or finger changing time can be as low as 0.5 - 1 second. On the other hand *the major problem is that they often become too large*, thus preventing certain operations from being carried out by the robot. In such cases fingers, or tools must be changed individually.

- **Using an automated hand changing system** for recoupling an entire wrist, or powered tool.

When designing and/or selecting automated robot hand changing systems, the following important aspects should be considered:

- **Weight** should be light enough not to decrease loading capacity.
- **Longitudinal and axial sizes** should be small enough not to limit operations which would otherwise be feasible to carry out.
- **Torque transfer capacity** job dependent, but generally should be high.
- **Coupling stiffness** job dependent, must be adequate to prevent the need for compensating the overall deflection of the arm.
- **The number of possible pneumatic connection lines.**
- **The number of possible electronic connection lines** crucial if a large number of sensors are utilized in the hand. In such cases as much data processing should be done at the hand as possible, via a microprocessor, to reduce the amount of data linkages between the hand and the robot controller.
- **Easy adaptation to different robot wrists** and end-of-arm flanges to provide interchangeability, and thus allow low cost tooling for many different robots.

To *summarize*, one must realize that since the robot arm itself is incapable of doing much alone, the peripheral devices, such as the end-effectors and special purpose tooling, part orientation, part storage and part feeding devices, safety and guarding devices and their communication with the robotized cell controller, are of crucial importance and must be considered carefully when designing such cells.

In order to cut down setup times and switchover times, parts and components to be assembled and/or inspected should arrive to the cell and be located at the cell in a known orientation and location, enabling the robot to handle them properly. *Furthermore*, parts and components involved in the assembly and/or inspection should be able to be loaded and unloaded and transported between cells using preferably direct access material handling devices (e.g. AGVs).

Fixturing of parts on pallets should be done by using modular and flexible, sometimes programmable devices. Since the cost of the pallets can be high because of the dimensional accuracy and rigidity requirements in assembly systems pallets are often made of plastic.

Pallet identification at cell level can usually be solved by employing non-contact sensors, like bar code readers, or in hostile environments using mechanically coded rings or pins.

The latest solutions include memory chips mounted inside pallets, capable of maintaining a data communications link with the control architecture of the system, employing non-contact data transmission media, such as infrared light. This later solution can be very useful partly for checking current status information of each part and component to be assembled, as well as when recovering of a cell or system breakdown.

3. Cell Buffering, Part Transportation and Storage in the System

The materials handling system *links together the different islands of automation* both at cell as well as system level from the transportation point of view. *Serial access, or sequential systems* such as a conveyor line provide low flexibility, and low reliability, since the cells are chained together in a rigid way with a single transportation facility. *On the other hand, random access, or direct material handling systems*, such as AGVs offer the possibility to transport parts, tools, finished components, etc. from any cell to any cell and are more reliable too, because there can be many of them in a system, taking each-other's job as required.

Materials handling systems in general need to consider:

- **Part and component transportation** (preferably in an oriented way and using standard size pallets)
- **Raw material, final product and in-process transportation of parts**
- **Tool and robot hand transportation and storage**
- **Fixture and clamping device transportation and storage**
- **Storage and transportation of empty pallets, auxiliary materials, wastes and spare parts**
- *A well designed transportation facility* should be direct access and should be capable of handling all above listed types of items using standard pallets in the FMS.

4. Dynamic Operation Control

Dynamic operation control in a flexible manufacturing system means that decisions concerning what workpiece is manufactured next on which cell, are

made close to the end of the operation currently being performed by the particular cell. In other words, the schedule for the flexible assembly and inspection system is not made in advance like on transfer systems, or dedicated lines, because it must be capable of responding to real-time decisions and changes, such as an "urgent order", a "cell break down", a scheduled "cell maintenance", etc.

Operation control for robotized assembly and inspection systems can be designed and/or analyzed basically at three different levels, these being:

- **The factory level**, or business level handled by the *business data processing system of CIM*
- **The FMS off-line level**, representing simulation and optimization activities prior to loading a batch or a single component on the FMS, handled sometimes by the FMS part programming computer, sometimes by the CAM system
- **The real-time controlled level**, taken care of by the FMS operation control system, representing a situation where the parts are physically as well as logically in the process controlled environment.

In order to satisfy the demand generated by the business system modules of CIM (i.e. the MRP and the MPS programs) the first major task is the selection of the appropriate part mix for a defined period of time, which can be as short as a few hours, a shift, a day or a week, but usually no longer than a few weeks. *Note that this period of time will depend very much on how random and organized is the part arrival to the system entry point.*

If there are sufficient number of different batches of components and the time span allows, (i.e. due dates are not too close) it is worth while doing batch size analysis. *In general, batch size analysis is less important in FMS compared*

to conventional methods, because the aim is single component, rather than batch production, the setup and downtimes are low anyway, and because the entire production is better organized.

Balancing can also be useful in particular if there are many operations to be done on the part (like in the case of most assembly operations), and if the resources allow different operations to be performed in a random order at no additional cost (e.g. robots have an adequate selection of tools in their tool racks, if they can change parts automatically, and if the material handling system is a *direct* one).

To avoid unrealistic planning, capacity planning and capacity checking are important too.

Loading sequencing or FMS off-line scheduling is a simulation, or optimization method aiming to establish the best order in which parts should be processed by the system in a relatively short period of time, e.g. a shift.

If parts arrive at the FMS in a random order, in very small batches, or as single components and if they must be executed (i.e. manufactured) as soon as they arrive, there is not much point in selecting the appropriate part mix, nor in establishing an optimum loading sequence, because there is simply no time for that. *However in the case that most FMS parts arrive in a fairly well planned order*, there is time to load sequence and then it is essential not only for utilizing the system at a level *close to 100%*, but also processing the parts without delay.

6. Cell and System Diagnosis and Maintenance

As has been stressed already, cell controllers and assembly systems should give maximum safeguards against faulty operation. This can be achieved by *high level of local and distributed intelligence* and by using *Adaptive Control (AC)* techniques with distributed sensory feedback systems on the controlled equipment.

High level of local intelligence is particularly useful at the following times:

- **When debugging robot programs**
- **When cells break down**
- **When loading new hands into a robot tool magazine**
- **When editing robot programs on site**
- **When sensory input data is important for the cell**
- **Generally in "panic" situations** when quick and safe error recovery is very important

Most up-to-date cell controllers incorporate troubleshooting features, including:

- **On board diagnostics**, allowing efficient and logical testing of the controller by displaying the status of the built-in diagnostic switches and indicators on the printed circuit boards;
- **I/O monitoring, status checks, simulation mode** to test robot and inspection machine programs without generating any motion commands;
- **Emergency stop and error recovery routines;**

- **Power failure protection**, non-volatile storage for part programs;
- **Automatic recovery routines** with animation and graphics enabling the simulation of the completion procedure of interrupted programs.

PART III. COMPARISON OF DEDICATED VERSUS FLEXIBLE AND INSPECTION SYSTEMS

1. Introduction

Conventional or Dedicated Assembly (and Inspection) Systems are designed for *a known part, or a family of known parts*. They are optimized both in terms of cycle time, operation distribution between assembly/inspection heads and/or robots as well as for cost. The cycle time in these systems is precalculated, because all parts and all operations to be performed on these parts *are known before the system is designed*. Dedicated systems, even when utilizing robots working along a serial access material handling system, are neither designed for product changes, nor for cycle time alterations. They are *rigid in this sense*.

On the contrary, parts to be assembled and/or inspected on a *truly flexible system* (FAS = Flexible Assembly System) are *not necessarily known (at least not all of them)* prior to designing the manufacturing system. Certain limitations in terms of size, weight, material, tolerances, etc. are known, but the FAS is "*opened from the design point of view, thus a generic approach can be followed*".

This is an important, often overlooked, difference between dedicated systems and the FAS, resulting in

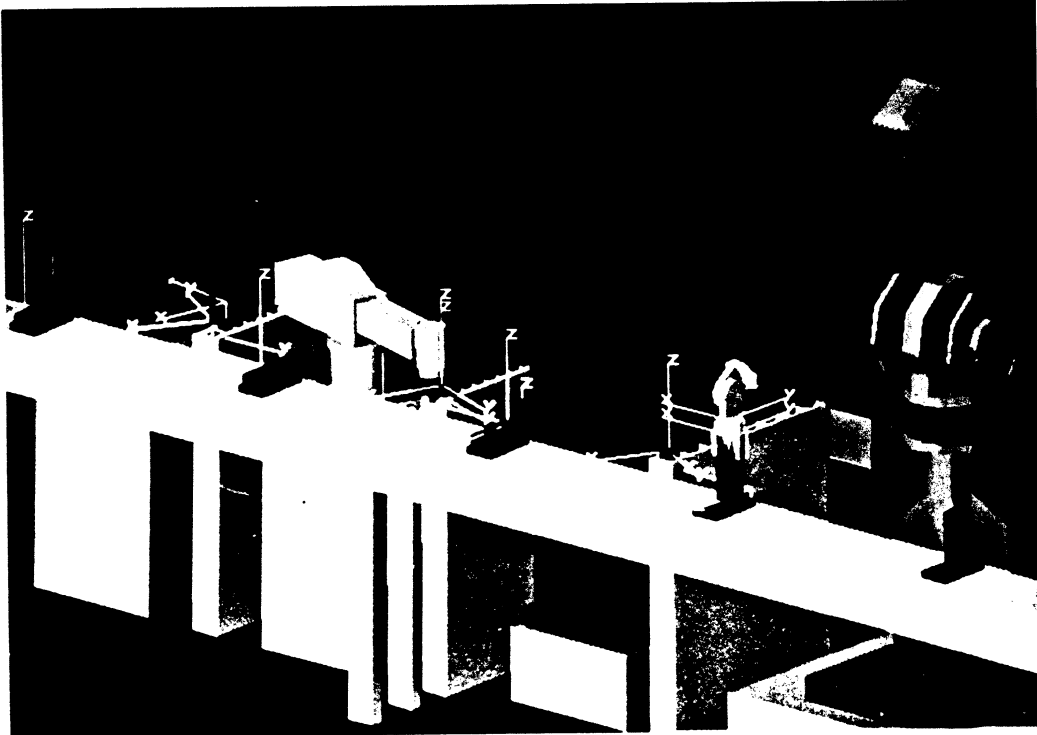
- *much higher flexibility,*
- *reduced development cost of new assembly systems,*
- *reasonably shorter changeover time,*
- *the possibility of making goods on order in a mixed mode, rather than economically sized large batches for stock,*
- *and higher overall system reliability and system efficiency.*

If one considers only one factor of the above list, e.g. the reduced development cost of new assembly systems, than one should realize that the development cost of manufacturing systems in general is as high as 50 to 70% of the total cost. Saving most of this cost is substantial when designing the second, third, etc. system. The other listed factors, e.g. *high reliability and efficiency should not be ignored too, because these are very important issues from the manufacturing management point of view.*

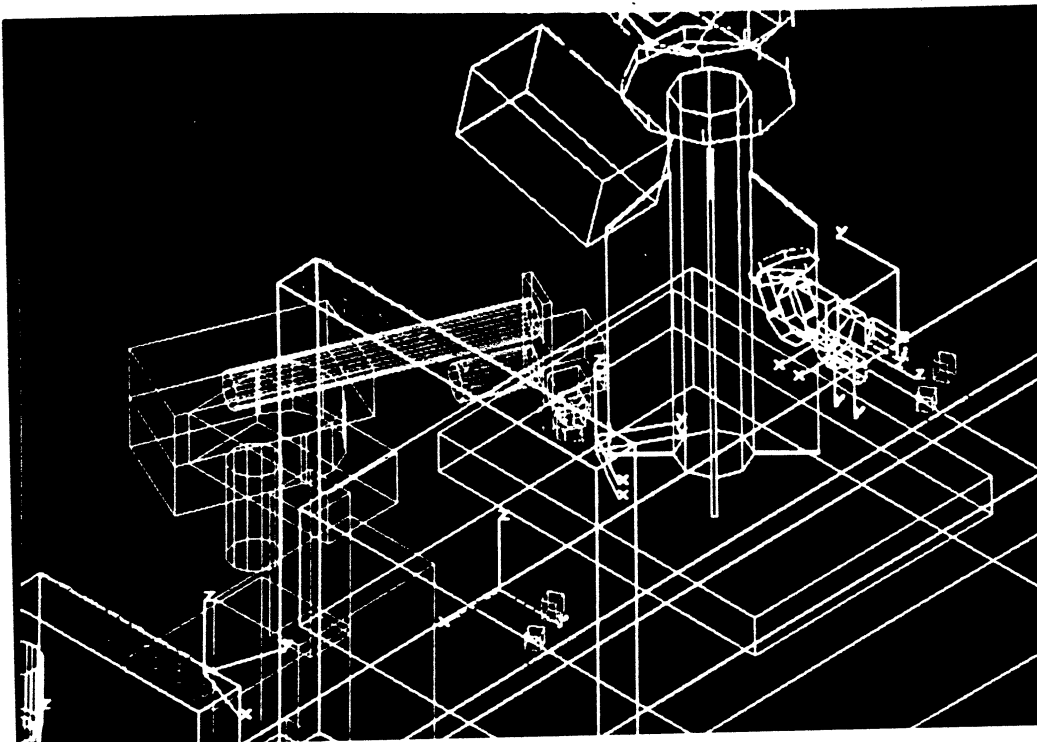
The proposed FAS compared to the previous systems is flexible and “generic”, because:

- It can change tools and parts under a few seconds in random order, resulting in that more operations can be concentrated on each assembly cell (rather than one operation per each assembly head) and that each cell can accommodate large amounts of different parts.
- The data communication links provide real time control, maintenance and close to 100% cell efficiency level. (Note that because of reliability problems as well as transportation problems dedicated systems operate usually at only 60 to 75% efficiency)
- The FAS is more reliable than any dedicated system, because intelligent cells are linked into a data processing network, and because all parts, part feeding devices, robot tools, etc. arrive and leave each cell

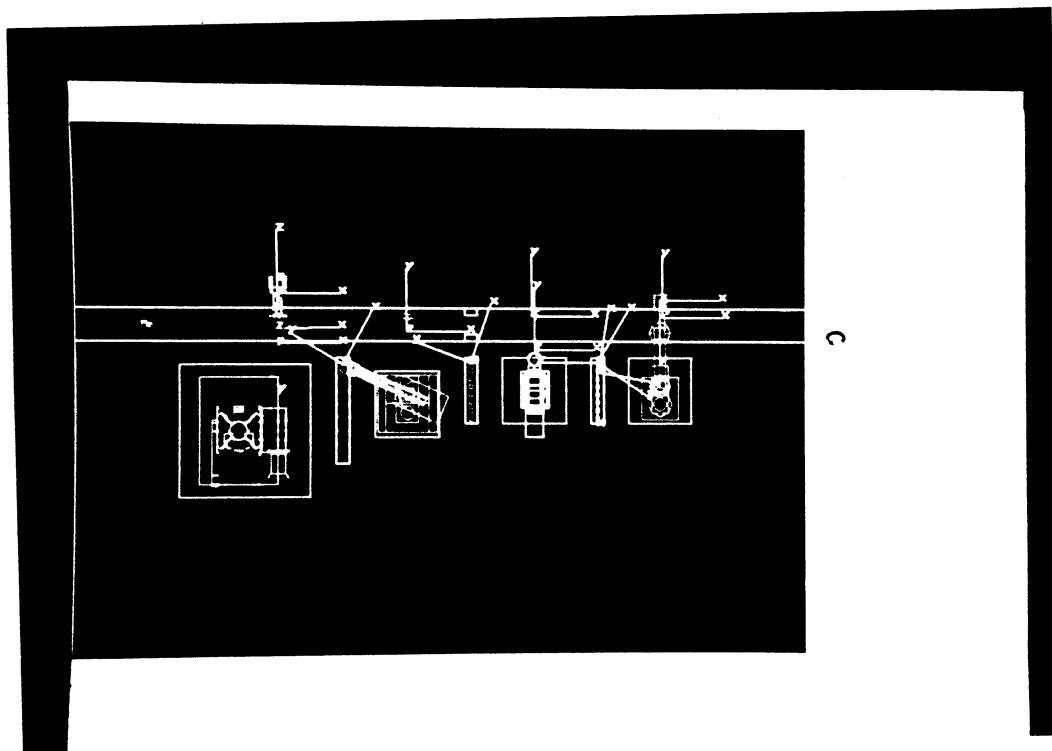
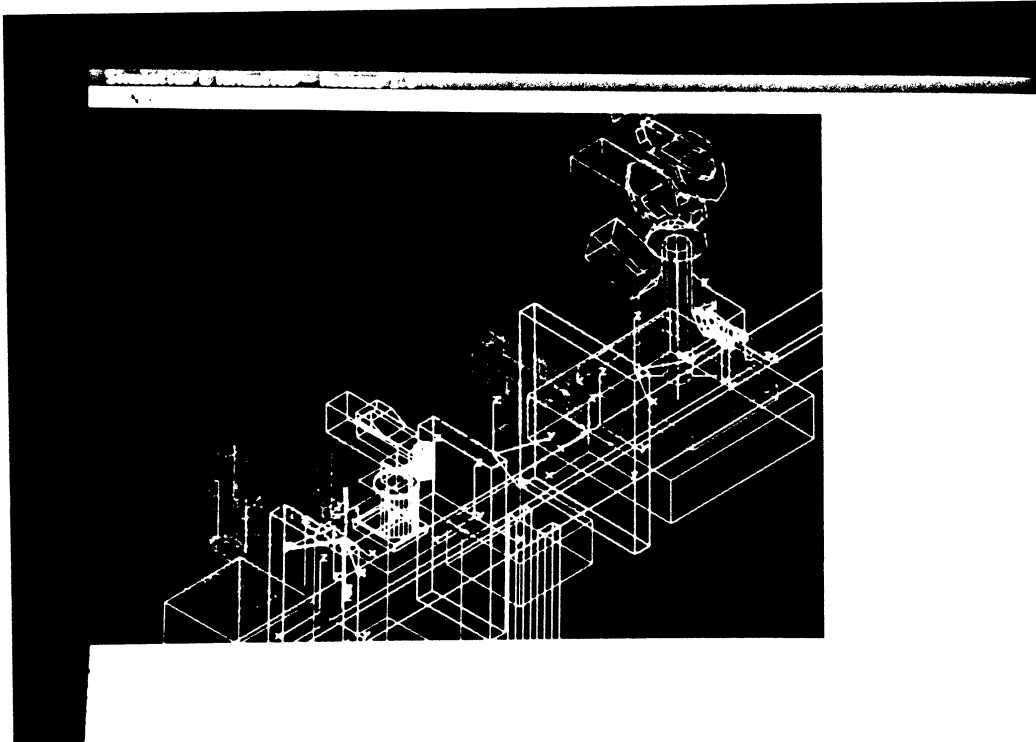
(and the system) by means of a direct access material handling system.



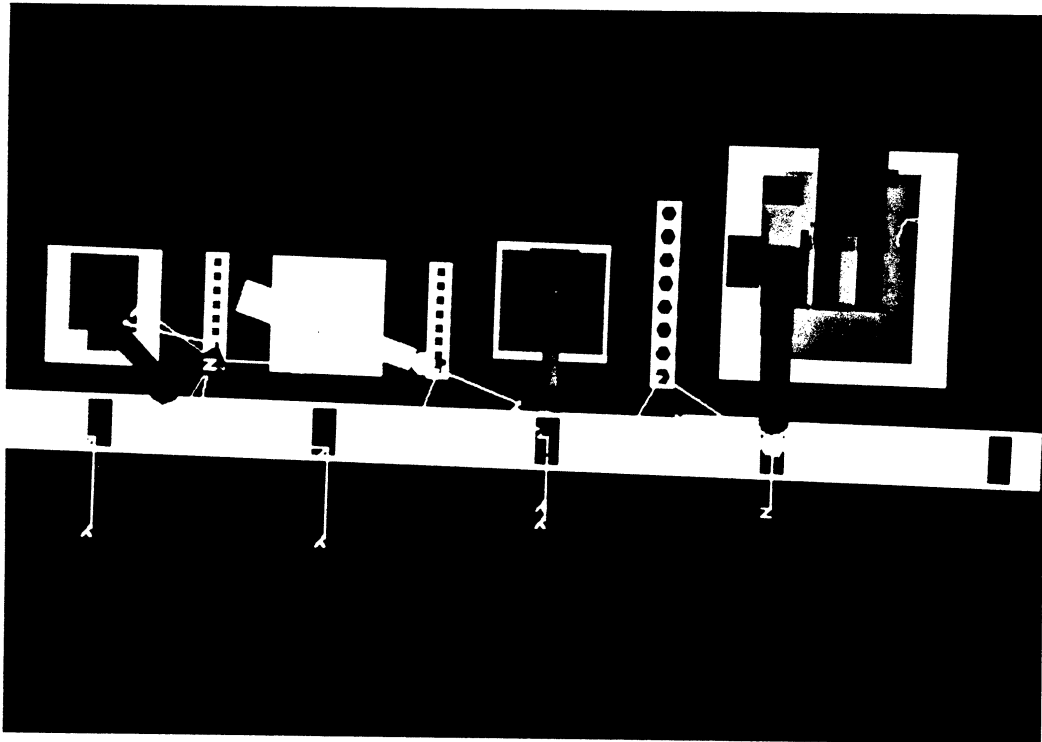
Solid model animation of the dedicated assembly line.



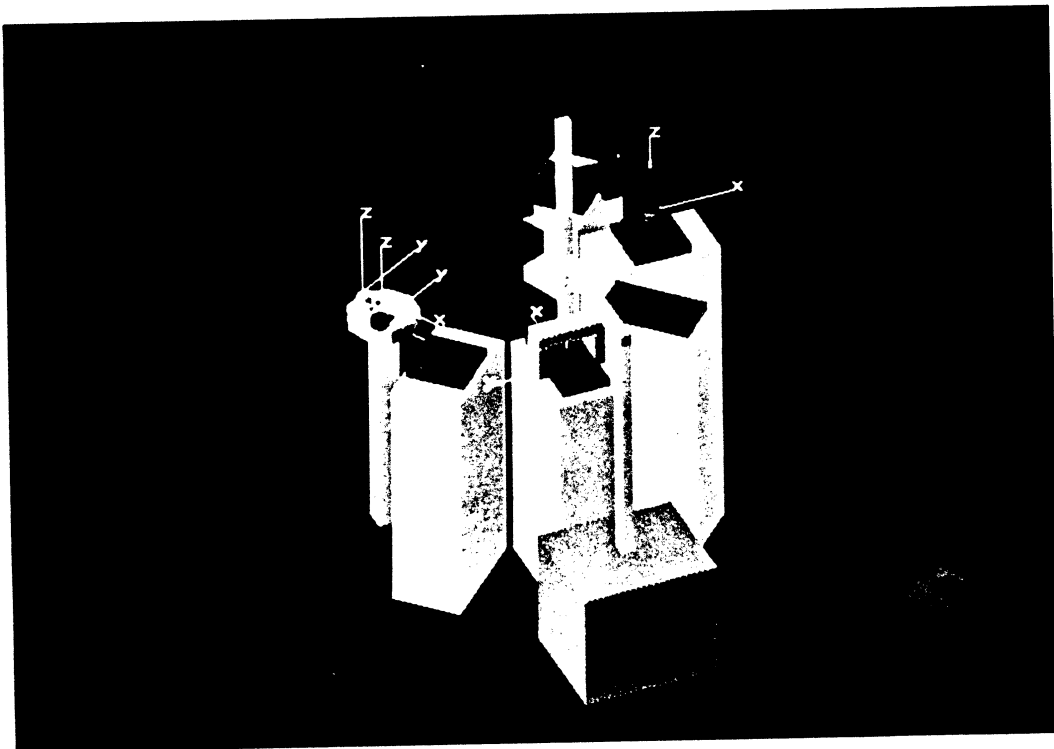
The wire frame model of the dedicated assembly line.

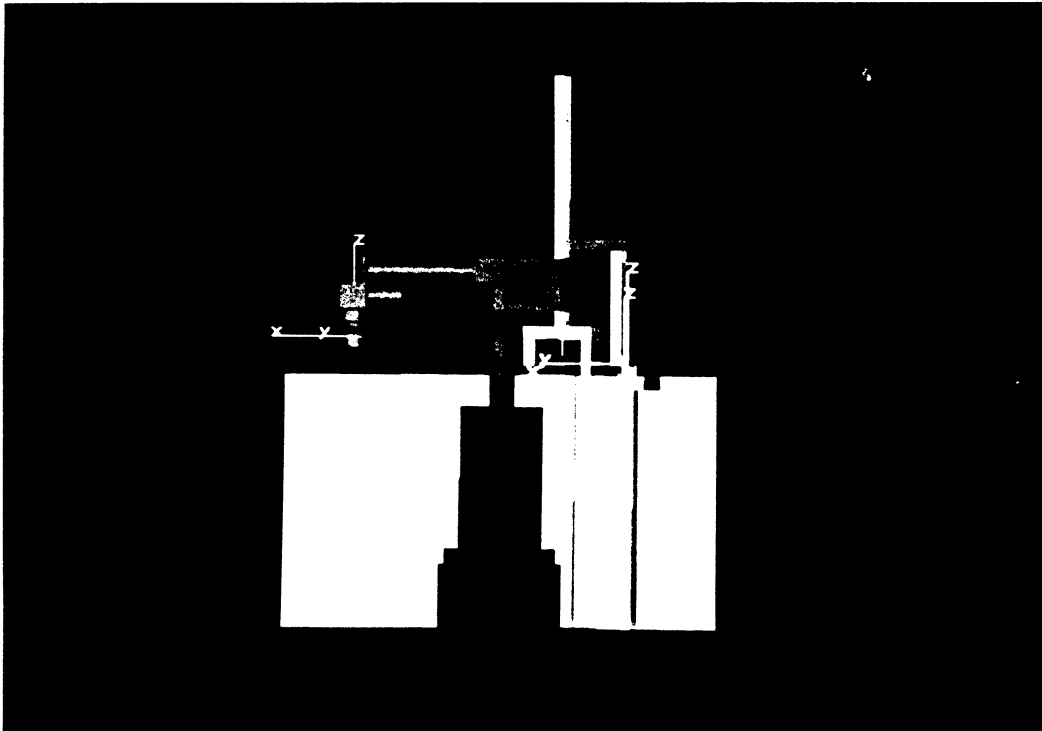


The top view of the dedicated assembly line.



The solid model of the truly flexible assembly/inspection cell, capable of reacting to random events. By multiplying this cell, flexible and modular assembly/inspection systems can be built.





The layout design of the flexible cell, showing the AGV docking stations, the working robot, the tool magazine with three tools (i.e. robot hand positions) and the AGV itself prior to pallet unload operation.

2. Comparison List of Unique Features - Dedicated Versus Flexible Systems

1. Changeover Time and Cost

- Typically takes several hours to several days and is often impossible in the case of dedicated, or conventional systems.
- Changeover time can be as short as a few seconds to a few minutes in the case of flexible systems as long as the "new" product(s) fall into some limitations discussed in Part IV.

2. Product Mix

- In the case of the dedicated systems the product mix (if there is any) must be preplanned and predesigned, prior to implementing the assembly/inspection system.
- New parts can be added, mixed in a random mode on the flexible system as long as the appropriate robot tools (i.e. robot hands) are available and certain limitations of the parts, such as weight, size, material, tolerances, etc. are not violated. (Note that these limitations normally allow a large range of known and unknown products to be planned for, and typically mean that for example a flexible assembly system designed for assembling/inspecting display terminals cannot be used in a mixed mode for car component assembly for example. On the other hand because of the "generic approach of the flexible concept" the operation control software, the layout, tool changing, part changing and the material handling principles can be the same for both otherwise extremely different jobs.)

3. Part Presentation

- Typically parts must be kitted and /or fed using a variety of incompatible, special purpose feeding, loading, orienting, etc. devices in the case of dedicated systems. In such systems part orientation errors can cause major breakdowns, because misfed parts intend to jam. If such an error occurs, the entire dedicated system must be stopped and production is at halt until the jammed part is removed.

- Flexible systems do not need, but can accept kitting, but known (i.e. oriented) part presentation must be provided, preferably using standard, interchangeable pallets. Vibratory bowl feeders, generic and non-generic feeding devices are not excluded as a possibility but should be avoided if possible. (In other words parts must arrive in a known orientation to each cell of the flexible system. This criteria does not represent a major restriction of flexibility if we consider that most products (i.e. approx. an estimated 99% of manufactured i.e. machined, tested, assembled, etc. goods) are fabricated in a known orientation, but unfortunately this known orientation is lost when such parts are thrown into a bin, for example. This is common practice even in the case of "most advanced" manufacturers.
- The only remaining solution then is to use human operators, expensive vision systems and robots, or vibratory bowl feeders to reestablish the previously known orientation of parts. This is a waste, unfortunately not realized by most manufacturers. Obviously, if most parts would be manufactured on flexible cells, this would not represent a problem, but would save a lot of money for all manufacturers.

4. Cycle Time

- Dedicated systems have a fixed cycle time and cycle time alterations are resolved by providing relatively high work-in-progress values (i.e. 3-12 components typically).
- Flexible systems are not sensitive for cycle time changes. One could say that in the case of flexible systems the cycle times can and/or are different for each product and that the cycle times can be changed dynamically during production without causing any interruptions to the system. Work-in-progress in flexible systems can be reduced virtually to zero, in practice typically to one.

5. Sensitivity Towards Dynamic Changes

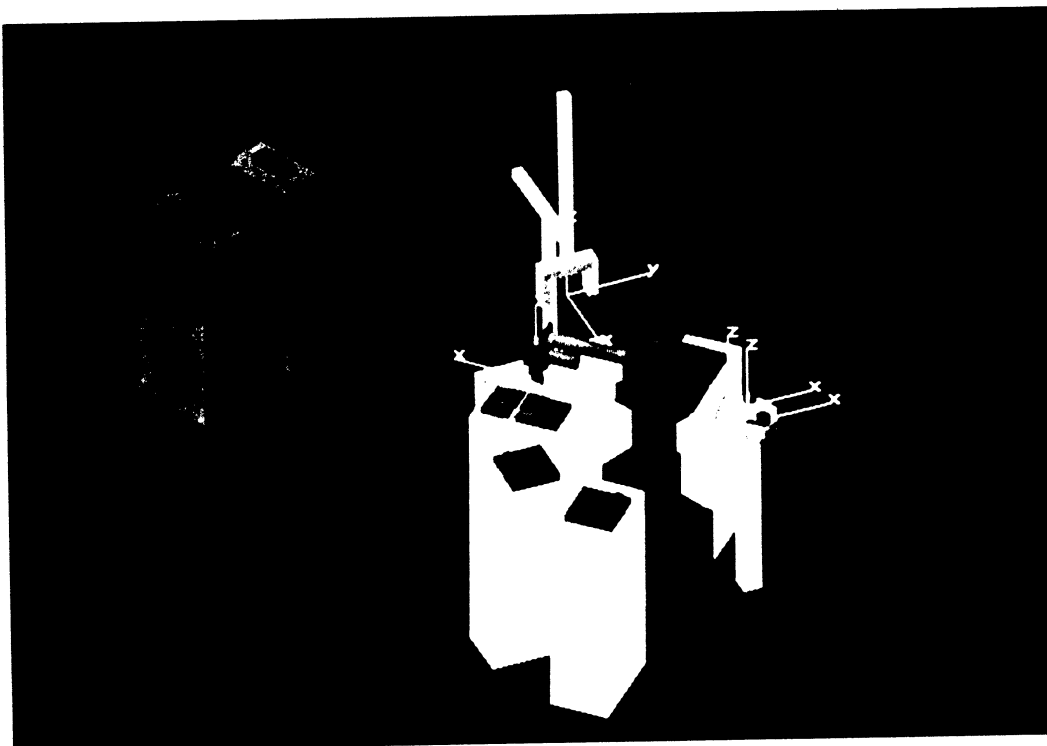
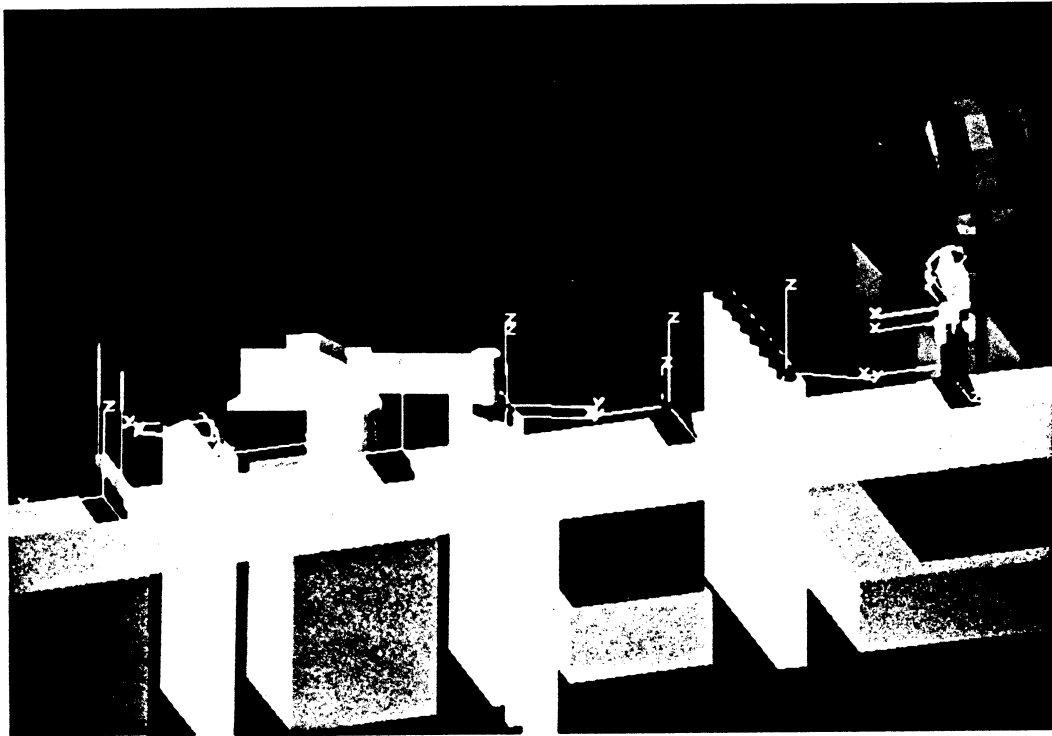
- Dedicated systems are very sensitive for any changes.
- Flexible systems are not sensitive for changes, thus are ideal for extreme requests like prototype assembly/inspection during regular *production time, testing new product assemblies and learning from the results* using "closed loop" CAD/CAM/FAS systems.

6. Expandability

- Dedicated systems are hard or often impossible to expand. The high cost factors should not be overlooked too, when changing virtually *anything* on dedicated systems.
- Flexible systems consisting of “well designed” cells are easy to expand. They are designed for dynamic changes both in terms of product mixes, as well as product quantities.

7. Assembly Head, Assembly System Utilization

- Dedicated systems cannot achieve 100% utilization. Their utilization level is typically 50-75% at system level, consisting of 25-30 assembly/inspection heads minimum.
- Flexible systems can achieve 98% efficiency, since they are more reliable and are not sensitive for changes. (For example, scheduled preventive maintenance can be performed on any redundant cell while the rest of the system is producing parts.)



PART IV: SIMULATION RESULTS USING "THE FMS SOFTWARE

LIBRARY" AND SOLID MODEL PARALLEL ANIMATION TECHNIQUES ROBCAD"

In order to demonstrate the concept outlined above three wire frame and three solid model based animation and simulation programs have been developed and parts of them have been video taped for You. These models represent the first step in our cell design and simulation efforts.

We have acquired the ROBCAD system running on the Silicon Graphics Workstation, and have allocated a significant amount of resources to developing simulation software and case studies of different assembly cells and systems for potential users and researchers of this field.

We believe that we have all the necessary expertise in developing new concepts, rule based scheduling and real-time assembly system control and simulation software, new system design tools as well as the flexible cells discussed in this proposal and the video tape.

We are also linking this simulation and cell design system to the Robot Evaluation and Test Program at the Industrial Technology Institute in order to be able to use the most accurate data in our simulation models.

We would like to invite you to join us in supporting our efforts.

As mentioned before, a sample run of each of the simulation programs have been video taped.

It consists of the following different assembly/inspection system simulation models:

- **1.** A "*conventional assembly line*" employing several different robots along a conveyer line showing what most manufacturers design and implement today, calling them "*flexible assembly systems*". As it can be seen in our terminology, such systems are *not flexible at all* and robots in these systems are *not utilized properly*, because they become dedicated devices along a rigid material handling system. (The simulation shows real-time parallel action, using solid modelling).

- **2.** The second program demonstrates the "*truly flexible assembly cell design*" outlined in this proposal. The concept is demonstrated using a robot, accessing six AGV docking stations and an End of Arm Tool changing system (Robot Hand Changing System). The cell is shown in real-time parallel simulation fashion working on randomly loaded/unloaded and palletized parts.

The simulation programs and the video tape compare the outlined "conventional/dedicated" and the truly "flexible" systems and demonstrate the drawbacks of the dedicated versus flexible system design as well as showing the unique features of the proposed flexible and generic assembly and inspection system for a wide audience.

Summary

The proposed project will provide a pilot implementation of a simulation system as well as a generic assembly and inspection cell and system both for student projects and courses at The University of Michigan (e.g. Design, Robotics, FMS, CIM, etc. courses) as well as for contract work and research for industry at the Industrial Technology Institute (ITI) and The University of Michigan.

By integrating this proposed system with the ROBCAD real-time graphics simulation and design tool, as well as by further developing the ROBCAD system (i.e. incorporating robot test results into the robot database and some modules of the FMS Software Library) a nationally, as well as internationally unique pilot system can be offered to the faculty, students, ITI, and industry for research and education.

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