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Final Report: A Workshop on the Application of Virtual Reality to Manufacturing

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U.S. DEPARTMENT OF COMMERCE
Ronald H. Brown, Secretary

TECHNOLOGY ADMINISTRATION
Mary L. Good, Under Secretary for Technology

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AND TECHNOLOGY
Arati Prabhakar, Director

FINAL REPORT

A WORKSHOP
ON THE
APPLICATION OF VIRTUAL REALITY TO MANUFACTURING

Intelligent Systems Division
(formerly Robot Systems Division)
Bldg. 220, Room B140
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Gaithersburg, Maryland 20899

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1.0 PURPOSE

The Intelligent Systems Division (ISD) of the Manufacturing Engineering Laboratory (MEL) at the National Institute of Standards and Technology (NIST) is committed to the standardization of protocols for the application of information and interface technology for the virtual and distributed manufacturing of discrete parts. As part of this effort, ISD is developing an initiative in human interfaces in manufacturing, emphasizing the integration of human factors, virtual reality, and manufacturing systems technologies. A one-day workshop, sponsored by ISD, was held on 9 August 1994 to examine the application of information and interface technology for the virtual and distributed manufacturing of discrete parts.

The purpose of this report is to document the workshop, including presentations, participant discussions, and the results of working group deliberations. A videotape of the workshop is available at NIST.

2.0 BACKGROUND

Manufacturing technology is currently a focus of national initiatives sponsored by numerous government organizations and industrial consortia. It is supported by programs in the Department of Commerce (Advanced Technology Program [ATP]), Department of Defense (Technology Reinvestment Program [TRP]), as well as the Department of Energy, NASA, and other Federal and state agencies. All of these programs address the necessity of boosting US manufacturing capabilities.

In this regard NIST has been given an expanded role in standardizing technological infrastructures and applications in such programs as:

* Manufacturing Research Technology Centers (METCs), which have become major regional technology resources

* The Automated Manufacturing Research Facility (AMRF), an open architecture testbed for the automated manufacture of discrete parts

* The PDES-STEP (Product Data Exchange using STEP - Standard for the Exchange of Product Model Data) Program for standardizing manufacturing data representations.

2.1 Virtual Reality

Virtual reality (VR) is rapidly becoming technically and economically feasible. VR has many definitions and formats. At the ambitious end of the spectrum, VR allows a user to have the illusion that he is immersed in a synthetic or remote environment. He experiences sensory information, such as three-dimensional vision and binaural sound, that is generated by a computer or originates from remote sensors (or a combination of the two sources). He interacts kinesthetically with computer-generated or teleoperated objects. At the less ambitious end of the spectrum, VR allows a user to operate in a text-based interactive mode (i.e., on-line *Dungeons and Dragons*) or a graphics-based mode to manipulate objects, or to interact with an environment, as displayed in two dimensions on a monitor (computer or workstation) or on a head-mounted-display. For manufacturing applications, the modest or ambitious versions of VR are appropriate.

The Intelligent Systems Division and the Factory Automation Systems Division (FASD) of the Manufacturing Engineering Laboratory at NIST are concerned with standardizing information protocols and interface technologies and techniques for manufacturing technology. ISD is examining the human factors involved in interfaces for appropriate information interactions. NIST is interested in exploring virtual and distributed manufacturing with initial testbed efforts in the production of discrete parts. Primary target areas include: Engineering Design, Product Planning, Process Planning, Factory Simulation, Monitoring and Control.

ISD is working with users and developers to coordinate standard information protocols and interfaces, which will eventually be reflected in the integration of virtual reality in a manufacturing framework. This human factors initiative will have a major impact in: information content for each user; presentation bandwidth and fidelity; presentation modality (real time or non-real time and mixes of text, graphics, pictures, videos, and other sensory modalities).

Virtual reality may be able to integrate intelligent manufacturing systems: products, processes, and enterprises. The potential impact of virtual reality may be dramatic, but it will be defining itself from the user pull and the technology push over the next several years. VR has several common threads:

* Virtual reality provides new worlds for one or more users. Related terminology is: artificial worlds, virtual environments, and synthetic environments.

* Some VR systems attempt to give the user a sense of telepresence by immersive sensation (vision, sound, tactile [pressure], haptile [force]). Virtual reality may apply to single sites with human/machine interfaces to co-located computers, or to interconnected, distributed systems at distant sites linked through communications networks.

* Virtual reality establishes a framework which will ultimately

integrate many areas of technology: human factors, computer hardware and software, and communications.

* Virtual reality permits each user to participate in a collective effort.

Virtual reality is supported by enabling technology programs in the following areas:

* Communications: the National Information Infrastructure (NII)

* High performance computation: High Performance Computing and Communications (HPCC)

* Data and interface standards: PDES-STEP

* Hardware including head mounted displays (HMDs), body suits, exoskeletons, data gloves, large screens

* Human factors studies.

VR to date has been focused primarily in four application areas:

(1) Simulation - which yields new views and perspectives which are unattainable by current methods.

(2) Teleconferencing participation - for "meeting at a distance," with a sense of telepresence, in a collaborative, immersive environment for joint activities, including discussions, interviews, planning, and training

(3) Training and Education, including:

* Integration of training for personnel at distributed sites with distributed elements

* Using simulations or synthetic environments to achieve cost savings by not using "real" elements; when "real" elements are unavailable; and to protect personnel in training for hazardous operations and environments, e.g., nuclear environments, toxic contamination, or live-fire conditions

* Students using educational virtual reality toolsets to build their own virtual worlds, to immerse themselves, and to interact in "what if?" situations

* Students can learn by interacting with unavailable and out-of-size components and environments, such as observing a real-time manufacturing process through a magnifying glass

(4) Mutual participation in shared activities in a synthetic

environment. The most striking current participatory applications of virtual reality are for: Entertainment (several theme parks have simulator rides and other are currently being design as entire virtual reality theme parks); and Military (to test new technology or tactics, and to train personnel at distributed sites in synthetic environments).

2.2 Survey

A survey was conducted prior to the workshop to examine the human factors aspects of information and interfaces needed to integrate virtual reality technologies into the virtual and distributed manufacturing of discrete parts. The respondents, who were experts in human factors, virtual reality, and manufacturing, were asked to address: (1) a definition of the requisite information and interfaces for virtual and distributed manufacturing applications; (2) human factors approaches in information and interface technologies; and (3) leveraging of efforts in specific topical areas. The results of the enquiry will assist the ISD in determining the needed standards and protocols for information and interfaces.

The Survey Form was included as part of the workshop invitation package, although some respondents did not attend the workshop. The invitation package, reproduced in **Appendix I**, includes: the agenda, workshop objectives, breakout session topics, registration form, direction and map to the Gaithersburg Hilton, background information for the survey, and the enquiry form (*Application of Information and Interface Technology for Virtual and Distributed Manufacturing of Discrete Parts*).

The results of the survey was delivered to the ISD as a report on *Activities Preliminary To Convening A Workshop On The Application Of Virtual Reality To Manufacturing: Results Of A Survey*, dated August 94. This report is reproduced in its entirety in **Appendix II**, including the list of survey respondents, which is located in Appendix B (of the report in Appendix II). The workshop attendees are listed in **Appendix III**.

3.0 A PRECIS OF THE WORKSHOP

The following description of the Workshop paraphrases the various presenters and participants in an attempt to summarize the key issues discussed.

3.1 Dr. Ernie Kent

Dr. Ernie Kent of the Intelligent Systems Division of NIST, welcomed the attendees at the Workshop and addressed several issues, as shown in the charts in **Appendix IV**. He noted that the attendees probably have the following questions: (1) Why are we doing this? (2) Why are we here? and (3) What's in it for me?

Why are we doing this? NIST is sponsoring this workshop in an attempt to identify some of the issues in a program concerning operator interfaces to virtual distributed manufacturing systems. This is part of a larger NIST program. Essentially we see a developing interest in the intersection of new technologies for display, for human interaction with traditional kinds of manufacturing methods. We want to maintain competence and assist industry in this area. Also, this is part of the traditional NIST role. In order to do this, we are seeking the guidance of experts in the technology and in the industry to try and learn to best fulfill that mission. That is essentially why we are running the workshop.

Why are we here? We basically tried to identify the overlap of three different significant areas of expertise: (1) **virtual reality** technology: what technology is available today, what technology will be available in the near-term future that we can apply to operator interfaces; (2) **human factors** technology: what are the human factors involved in the interface display, and how do we: make it most effective; maximize the bandwidth to the human operator; and present information with whatever technologies we have; and finally, of course, (3) **manufacturing** technology: we need input from the manufacturing experts to know what kinds of data should come across the interface. This is not an obvious question because it is not clear that the expert who runs something today (when he is physically present) really knows, or can tell us, exactly the kind of information he needs or how he gets it. We need to pursue this in order to understand what we are doing. The objective is to bring together a group of fairly disparate people from different disciplines. I think we have a very interesting group today, with true experts in all of the areas of interest. All of you can contribute to a dialogue out of which we hope to identify an intersection of all of the relevant technologies.

What's in it for all of us? We can learn something from one another. Perhaps we can form a community of interest to guide NIST, in this program, into the future. We want to get to know you, we want to ask questions, to learn from you, and, we hope, to have you communicate with one another as this field develops. We want you to steer NIST to your benefit. We are here to help you, but, in order to help, we need to understand the industry pull in order to understand what we ought to be doing. There are many NIST programs which can be of benefit to many different kinds of organizations and industries, and it would be useful to maintain cognizance of those.

Let me tell you, briefly, how we view the program at this point, so it will give you a basis for telling us how to change it. We perceive a variety of industry needs when we begin to look at semi-automated manufacturing systems, at manufacturing systems that are real, but distributed. We see opportunities in: product design, process planning, remote supervision, simulated "what if" decisions, discussions among remote experts, training remotely, and remote trouble shooting.

If we look at what is going to be required to meet those needs, we are currently thinking of something that looks approximately like this [please see the diagram in **Appendix IV**]. We need some kind of real-time operator interface for a control database and a simulation database. These interfaces, we believe, will come in two "flavors." One will be a high-tech, single-use interface - the very flashy kind of VR - with fine graphics and perhaps goggles, gloves, and the like. But this is an expensive solution, at least in the near-term, and will be limited to a fairly small number of specialized, but some very important, areas. We need to explore this. So we will be building, at NIST, a testbed where we can try out ideas with this kind of interface.

A second type of interface would be a multi-user, shared-data environment interface, where we will have many people in different parts of the world (perhaps a factory manager in Hong Kong, a production executive in New York, a consultant in Cleveland, and a shop floor supervisor in Baltimore). All of them probably have some low-tech terminals, but they need to look into these databases together, to navigate through them, to manipulate them, to discuss them, and to do things in real-time, and probably with some kind of natural language interface (because we can't rely on them being highly trained in the use of these interfaces). These are the two kinds of virtual reality that we are looking at - one is probably what we would call today *graphics-based* virtual reality and the other is probably what we would call *text-based* VR.

One of the NIST roles will be to investigate the best possible standards for presenting information in either of these modes. Another will be to try to define standard interfaces for communicating information between databases representing manufacturing systems and operator interfaces.

So these are some of our thoughts today. They may not be perfect or complete thoughts, but this workshop begins our effort to bring together people who can tell us how that picture can be changed. That is really what we would like to focus on today.

The objectives for the workshop are to: (1) identify industry pull in order to identify what we should be doing; (2) identify technology push in order to learn what technology can do for us today and over the next 5 years, and (3) target meaningful opportunities in the overlap of these pulls and pushes in order to learn where NIST can make a difference. This workshop is the means to bring together experts who can help us learn.

From NIST's perspective, there are three principal issues, what we would like to have answers for at the end of the day:

(1) What kinds of data should we focus on? What things ought to come across the interface for the shop floor supervisor, the remote consultant, the factory manager, and all of the different kinds of people who really need data? What kinds of things should we bring to the operation through the operator interface?

(2) What about the human factors issue, such as the best formats for presenting this information? There are ways of optimizing how information is presented to people, and we need to understand, in the context of manufacturing data, what these formats are.

(3) Finally, we need to find the best technologies to deliver the information to the user. After we understand what we want to present and how, optimally, we want to present it, we need to look at the technical issue of how it can be done, where do we have to drive the technology in order to do it, what research is required.

We will try to arrive at a consensus solution, or at least how to proceed toward a solution. To get underway, I would like to introduce Dr. Mark Luce, who will give us a broader perspective of this program.

3.2 **DR. MARK LUCE**

The larger NIST program, under which this workshop is a part, concerns systems integration for manufacturing applications. The NIST program is supporting the National Information Infrastructure (NII) and the government initiative for High Performance Computing and Communications (HPCC).

The overall **focus** of the program is to address the problems of integrating manufacturing applications, including design, planning, and production. The SIMA (Systems Integration for Manufacturing Applications) Program was established in 1994. The HPCC application for advanced manufacturing was then included in the program.

The overall **objective** is to support the application of high performance computing into various areas, including: education for life-long learning, energy management, advanced manufacturing, and others. Some of the research areas are addressed by other government laboratories. NIST is addressing: (1) concurrent engineering; (2) systems integration; (3) protocol for electronic data exchange; and (4) virtual design technologies. The NIST **role** is to support the development of standards, with an emphasis on the application of information exchange. The NIST role is to:

* Produce new methodologies for developing standards for integrating systems using HPCC technology.

* Develop, demonstrate, and recommend prototype standards.

* Lead national and international standards experts.

* Produce testing methods and services for information exchange standards.

* Perform basic and applied research.

The SIMA Program **goal** is to:

* Provide, in five years (by means of a collaborative work environment) an integrated strategy, methods, and standards for integrating a set of commercial software applications which support manufacturing.

* Target such applications as design, planning, production control, and simulation.

* Target industry domains, with an emphasis on the discrete parts and mechanical parts manufacturing industry, process plants, and apparel manufacturing.

SIMA Program **environments** include: the Manufacturing Systems Environment (**MSE**), which concerns the research and development of integration strategies, methods, and systems; the Standards Development Environment (**SDE**), which concerns the development of tools and methodologies for information exchange standards; and the **AMSANT** (Advanced Manufacturing Systems and Networking Testbed) Environment, which concerns the development of an internal testbed and facilitating access to the information highway.

Within the SIMA Program environment, the objective of the **MSE** is to:

* Develop, test, and implement solutions to achieve a manufacturing data exchange across engineering applications.
* Design, plan, and produce.
* Develop information models for manufacturing processes and resources.
* Develop interface specifications between applications.
* Define system the architecture for the data exchange of products and processes.

The emphasis on **MSE** applications is to determine how different applications share and exchange information, and how information is represented. The objective of the **SDE** is to develop and assist industry with the implementation of an information exchange standard. The objective of the **AMSANT** is to develop a NIST-wide testbed. Part of the testbed will be a VR room. We hope to get the testbed implemented by 1 October 1994.

In FY 94 we have been scoping the problems. In FY 95 we will define solutions, in which this workshop is part of the process. In FY 96-97 we will develop new integration capabilities, and in FY 98 we will integrate, test, and refine the system.

There will be a number of workshops dealing with a wide range of issues. Contact me, Mark Luce, to be included on the invitation list.

[The question (Q) and answer (A) session for Dr. Luce included the following].

Q: Is one of your goals to develop a reference model document for the standards?
A: Yes.

Q: Will industry and academia have access to testbed?
A: Yes. We expect to use it as a place for collaboration, such as with CRADAS (Cooperative Research and Development Agreements).

Q: Can multiple laboratories collaborate over networks with NIST?
A: Yes.

3.3 **DR. ERNIE KENT**

Thank you Dr. Luce.

We would like the users to let us know what we should have in our VR testbed. We can have whatever network people want, including lower speed network teleconferencing; remote operations will be included in the testbed. As for the construction of the VR testbed by Oct 1994: the walls may be in place, but not the equipment.

3.4 **DR. BOWEN LOFTIN**

My purpose here is to walk you through a survey of the technology of Virtual Reality [please see the Charts in **Appendix V**].

VR is known by many names (chart 2); all mean the same thing, or different things, depending on who is doing the defining. My definition is a very broad one (chart 3). If we can make an individual or group believe they are somewhere else, then, as far as I am concerned, that is virtual reality. A video game can be virtual reality because one can become fairly immersed in that environment. A good novel can even be virtual reality in that sense. This is a very broad definition because I do not think we should exclude particular features or flavors of technologies that can provide this kind of immersive experience because they all can be useful to us, depending on the application.

I have a list (chart 4) of what I think are important applications, but it is not a complete list. The human/machine interaction is a key application. For thousands of years we have built machines and we have adapted ourselves to our machines - maybe we are finally at the point where we can have a machine adapt to us. A computer keyboard is not a natural interface. We have to force ourselves to adapt to our machines. The empowerment of disabled humans is another very important application. Or to empower researchers by "enlarging" or "shrinking" objects or environments of interest (such as allowing researchers to move around molecules). The underlined applications (in chart 4) are those I work in, with my largest effort in training and education applications.

Beginning the formal overview (chart 5): these technologies, when brought to bear in some combination, will provide what we call virtual reality. Not all are required - a couple may be enough.

Many VR applications (chart 7) can be accomplished on desktop PC's, such as Amigas. I tend to work in the middle of the computer spectrum, on workstations. In terms of the key elements, those are lots of problems in producing good graphics. Parallel processing is a growing method. The bottom line is speed and cost, and the two are interrelated. High speed usually implies high cost.

The heart of a graphics application (chart 8) has to be a way to render it - the graphics software. Normally, the environments consist of polygons. To make a curved surface, we need lots of polygons. The polygon count is usually the measure of how fast you can render a particular scene. The best workstations today can usually render tens of thousands of polygons in real time (about 30 frames/second). We commonly work with 40-60 thousand polygons systems and render them at rates around 25 frames/second. But filling in the polygons with colored pixels also requires effort, time, and hardware. Texture mapping is something which has been used widely and makes attractive environments, but texture maps are just pixels which are turned off and on; you have no way of using these pencils for object collision detection. So polygon count is the way we determine interactions. High resolution interactions (to determine where two objects interact) require many polygons.

There are many books written about ray tracing. Realistic environments require ray tracing and lighting models.

There are many machines using multiple processing; but we do not know yet how to use them appropriately.

One of our goals is to develop accessible tools to enable almost anyone to build and alter complete virtual environments. We shouldn't be held captive by a few people who know how to build VR environments because this will lead to high cost and frustration. The tools will allow VR applications to become widespread.

The two basic divisions in displays (chart 9) are the non-head mounted vs. head-mounted approaches. The military has been using projected dome systems for years. They are common in military training environments, but they are extraordinarily expensive. They require big facilities and high performance systems costing millions of dollars But the day of the big projection dome is about gone. There is a limited market. They are dinosaurs. The cost of cave technology, however, is coming down rapidly.

I tend to work with head-mounted displays because we are interested in providing people with good mobility in virtual environments, and the focus is on individual use, as opposed to group use. (In a cave with five people, one person controls the viewpoint for the other four people).

There are two major types of head-mounted displays. One type is based on CRT technology, and another type is based on LCD technology. There are several CRT-type displays. Direct displays are fairly common. There are some very expensive piped displays consisting of fiber optics bundles (costing as much as $3 million for a helmet). Direct displays will improve even as their cost decreases.

The LCD displays are popular because they're lighter than CRT displays and have lower power requirements (less volts on your head). Ongoing ARPA projects can lead to higher resolution, lower cost LCD displays. Within a year or two there will be very good LCD systems on the market at fairly low cost. The retinal display (a developmental technique) uses a low power base to paint the image directly on the retina, just like an electron beam on a CRT. It provides a wide field of view and high resolution.

The issues are resolution and field of view (FOV). You want both, but may get neither. Resolution has always been a problem, especially in the LCD system. Only in the past year or two has there been significant improvement. Generally, you trade-off resolution for field of view, or vice versa.

About a 60-degree field of view is minimum for immersion in the environment. In the future we should be able to get high FOV and high resolution at reasonable cost.

Q: Has anyone tried to do fovial-peripheral kinds of things, with variable resolution?
A: Yes. Early in the dome-based approach, there was high resolution in the direction in which you were looking and lower resolution around that. It is complicated computationally, however. This has been pretty well solved in dome systems, but it has not been well-addressed in helmet-mounted systems. It is a very good approach because once you move a few degrees outside your fovial view, the resolution required is low. The blending of the field is difficult.

Q: What about eye-tracking?
A: Some approaches have used eye-tracking, but it is still a tough problem. We haven't been able to build a system with good eye-tracking and good displays. There is a whole issue of eye-tracking related to helmets.

Q: What about boom systems?
A: I haven't mentioned them, but they have been around for awhile. The boom system can offer fairly high resolution and field of view. It is usually a CRT-based system. The head doesn't get tired because it doesn't have to support the weight of the system. There is a company offering a commercial system able to support about 20 pounds. They cost about $150K and up, so they are not very cheap.

Q: Can you discuss VR sickness?
A: This is a topic in itself which I won't address in detail. There are all kinds of problems, but we think they fall in a few categories. Nausea tends to come from conflicting sensory cues, primarily when the vestibular and visual cues don't match. If you don't have the correct interocular distance in your display, your eyes will adapt. But when you remove the system, you will have ocular motor problems, eye strain, headache, etc. You need to transition the user back into the world - before they drive a car or fly a plane, for example, to avoid accidents. Someday, someone is going to get sued after a car wreck. In car applications, nausea is rare, but ocular motor problems are common.

Most of our VR sessions run 45 minutes to an hour. In a compelling VR environment, people may stay longer than they should and can suffer eye strain or other adverse affects. In our lab a training session might last 25 minutes.

All of our ears are different, so to provide good 3-D localization, you need a model of each individual's ear (chart 10). The main problem is not localization in azimuth, but in elevation, which depends more on the shape of the ear.

There are various technologies to provide the user with a sense of touch (chart 11). The electrorheological glove is an experimental system involving a fluid enclosed in a double layer glove which can change viscosity based on the application of electrical fields, becoming stiff or soft. The available technology is interesting, but crude.

There is only one company building a thermal system. This provides a very high fidelity temperature change. For example, you can grasp a virtual glass of iced tea and it will feel cold to the touch. But we need to integrate these systems to allow two or three properties at one time, such as tactile, force, and thermal.

Olfactory displays (chart 12) have been around for awhile, and they can be important in some applications. For virtual surgery, the smell of the opened human body can be important to the surgeon. In other applications it might be important to smell hot oil or insulation burning, for example. There are no real examples of taste displays, but there are some interesting possibilities.

Eventually, there may be some way to use our brains directly as displays. This is the ultimate computer - between our ears - if we could stimulate high resolution at will, we will have an excellent approach to VR.

Tracking devices (chart 13) are necessary, but very frustrating things to work with. You have to head-track to be able to follow changing scenery, to move your head around. You have to be able to track hands and other body parts if you want to replicate motion. This is accomplished today mostly using magnetic tracking devices. Magnetic tracking has limited range and resolution. Acoustic trackers also have limited range, as well as interference problems. Optical trackers are not bad, but they are not easy to emplace without permanence - they represent a big investment in the workplace. There's lots of work needed to improve tracking technology for the manufacturing community, as well as other applications.

Input devices (chart 14) have been used for many years. The VPL Dataglove originated in work done at the NASA Ames Research Center. The Cyberglove is more precise and robust than the

Dataglove. Video capture has worked very well for a number of applications. Eye tracking is still difficult. Voice input is a given - people are used to talking to communicate. Myoelectric involves using the electrical impulses generated by muscle action, but there is much work to be done. The 3-D mouse is not nearly as useful as the 2-D mouse. We cannot simply extrapolate a 2-D interface to the 3-D environment. Computer scientists and human factors researchers must work together to develop suitable interfaces for 3-D applications. We should not have to adapt to the machine - the machine should adapt to us.

There is lots of work going on in shared work environments (chart 15). There are 2 predominant ways of doing shared work environments today. In the first way, everyone has their local database and graphics generator ability. Then all I need do is send you data as I change the state of my world. This is how we've done it for years with SIMNET. This is a low bandwidth technique - about 25 kbits/sec is usually sufficient. But everyone needs similar hardware and systems in order to participate. In the second way, graphics are produced at one site and transmitted to other sites. Therefore, multiple sites can have low-cost equipment. But there is a high bandwidth requirement. This is technique is the ultimate solution.

We have, in our lab, an equipment-rich environment by most standards today (chart 16). These are the objectives of our lab (chart 17).

Here are the research issues that I believe stand before us (chart 18). I have mentioned a few previously. We need to prove that training is actually accomplished - or doable - using VR technology. Our first effort to do this on a large scale was the Hubble Telescope mission last year where we trained a hundred people using virtual environments. Everyone who has trained felt that training was very useful. This conclusion is not the result of a scientific study, but it is an indication of the usefulness of the technology for training purposes. But the integration issues are high. The registration issue is knowing, in augmented reality, where to put the graphics representing real objects (and their actual locations) in the environment. It is doable, if you can control your environment and place appropriate sensors in the environment (for example, superimposing graphics onto pegboard to show where to string a wiring harness).

Among many applications for VR (charts 19-33), virtual reality can be used to navigate and understand many large databases, which is significant if we are to make sense of a terrabyte/hour of data about the state of the earth. We are working with people in biology and biochemistry to look at virtual representations of data from electron microscopy and x-ray processes showing the structure of proteins, viruses and cells. We are working with chemists looking at molecular docking mechanisms for designer drug development. The area of navigation and exploration for large digital libraries is very essential, but not much as been published because some of the best and brightest doing VR work have been going into the financial industry, never to be heard from again. Large institutions that make money by moving money around have learned that there may be ways of looking at their massive data sets using virtual environments - there is lots of work going on, but not much has been published.

Multisensory perception or immersion for discovery is my personal favorite (chart 21). The human bandwidth is one that we have to worry about. Most of us think in terms of vision only. But think about how many variables you can perceive visually at one time. Research suggest maybe 7-9 variables, using color and everything else you can think of. If I can add two or three more variables using auditory techniques, and two more variables with optic techniques, etc., I might be able to almost double my bandwidth. Certain patterns, such as temporal patterns, may be detected better auditorally, than visually. There is much work to be done to explore multisensory perception and how to optimize the performance of our senses to perceive problems in data.

Q: What are new directions for presenting data that is now in the form of graphics and charts (the kind of data used in manufacturing as well as the financial community)?

A: I'm convinced that we can find ways to display data non-visually. The trick is to find what works. All of our lives we work with visual data, ignoring other possibilities. We can talk with artists who use sound or music. We need to find out the proper modality between the data and the way the human being wants to model it, and find the right transduction between the data and the human. We need to systematically explore what is possible in using senses other than visual for the perception of data. There are bits and pieces of programs in data manipulation, but no major programs out of ARPA or other government agencies. Nobody has seriously tackled this problem in a systematic way yet. NIST may be the place to base this kind of research.

[Dr. Lofton then showed a video illustrating the VR work at his laboratory].

Q: Won't auditory systems will have a problem in the manufacturing environment, which is noisy? Even the postal service has a high percentage of hearing impaired. Assumptions in the research would might not be relevant in the industrial environment.

A: Headsets can isolate the worker from the noisy environment. For hearing impaired people, we could use visual or haptic interfaces. We would use other sensory modalities to supplement what a person might be deprived of in a given situation.

Q: Data representation seems to be drowning in polygons. Is there any work to use true solid representations in VR?

A: There's technology and products in the CAD world that uses true mathematical solid representation. There is other work to take real images and place them directly into the VR environment. Standardization in this area is very poor.

Q: How would you characterize the financial size of the VR industry currently?

A: There are two kinds of VR companies. One kind has VR as one product among many. The other kind is totally specialized in VR, but these companies are not generally long-lived.

[Audience comment]: One number is that VR industry revenues, in 1994, are about $250 million. Caveats for this estimate are that: (1) this represents equipment packaged solely for VR and not shared across other applications; (2) it does not include location-based entertainment; (3) it does not include government expenditures. So everything else is $250 million, give or take $100 million. And this is world-wide. The Europeans and Japanese are investing in VR, so the majority of this revenue probably is not in the U.S.

3.5 **DR. ERNIE KENT**

Our next researcher is from ATR, Inc., which has been working on simulation and control for the Post Office, which bears a striking resemblance to the discrete parts manufacturing industry. Clyde Findley is the manager of the Control Simulation division of ATR (Advanced Technology and Research Corporation). He is a systems engineer with over 15 years of experience in the design and development of control systems control languages, and video graphics applications.

3.6 **DR. CLYDE FINDLEY**

A new mail processing center for the Sacramento, California area was completed in September 1992 (please see the accompanying charts and a related paper in **Appendix VI**). ATR was asked to use its prototype software called the Control and Simulation Analysis Tool (CSAT) to analyze the West Sacramento tray transport and staging system. This would help to identify key problem areas and develop ways to modify the system to enhance its performance. The goal of our analysis was to examine several possible ways that the tray transport and staging system could be improved and to validate the accuracy of the CSAT software against realistic performance data wherever possible.

The CSAT is a prototype software system that was designed to support the development of real-time control software in a simulated environment. It is based on the NIST Real-time Control System (RCS) methodology. The RCS employs a task decomposition technique to create a hierarchy of well-defined software modules such that each performs small sets of tasks. These modules are designed so that the lowest modules correspond exactly to the actual hardware devices that are being simulated. If these devices are physically connected to the CSAT computer, they can be controlled directly, thereby enabling an operator to use the tool not only for simulation and analysis, but for direct management and control of an actual facility.

While the CSAT control and simulation modules are executing, a parallel user interface module monitors the state of the simulated environment and extracts the object and physical data in order to display an interactive, 3-dimensional view of the environment. The user is able to watch and, to a limited extent, interact with the control and simulation systems while they are running.

What we need now are standard interface protocols which will allow user interface software to communicate effectively with real-time control systems and device-level simulation systems. New developments on both sides of the interface, including virtual reality techniques and advances in human factors engineering, will help drive the requirements for these protocols and enable the development and use of generic tools to support the design of more sophisticated systems.

3.7 **DR. ERNIE KENT**

The next presentation is by Dr. James Geiwitz. He has a Ph.D. in cognitive psychology from the University of Michigan. He taught at Stanford and the University of California at Santa Barbara. He is currently a Principal Research Scientist at the Carnegie Mellon Research Institute, and he is President of Advanced Scientific Concepts. He is the author of 13 books on psychology and human factors. His current research is on knowledge acquisition technologies and meta-cognitive skills for problem solving.

3.8 **DR. JIM GEIWITZ**

Dr. Geiwitz's charts are given in **Appendix VII**. In addition, post workshop comments by Dr. Geiwitz can be found in **Appendix VIII**.

I would like to list some of the human factors issues - some of which have been raised and discussed in preparation for the breakout sessions this afternoon. The chief meta-cognitive skill is to define a problem in some representation that affords a solution.

The first charts show a restatement of the workshop's objectives so that I can orient myself to what we are doing here.

We have a standardization challenge here. One of the issues I think is the role of reference models in this kind of standardization. We are also looking at information technology. How do you get the advice of the expert into the system you are building? The virtual reality is the focus of the workshop, but it also has a distributed objective. We want to look at shared synthetic environments and cooperative learning and work in that environment. The participants may be in different locations across the country.

In this workshop we are really talking about the design of a product consisting of some kind of virtual reality workstation that would be useful in conjunction with some kind of manufacturing system. The vision is to integrate the three areas in which we are working in.

As a psychologist, my view of VR is that it is an hallucination. Virtual reality exists in a continuum of definitions along some direction, which we will talk about. But a good working definition is: occupying an environment other than the physical environment of the moment. One dimension for VR might be the ambitious vs. not ambitious ends of the VR spectrum. The dimension might have something to do with the degree of similarity of the virtual world to the real world. The number of modes (such as sensory) also has something to do with the level of ambition of VR.

A definition, which I think is from NASA Ames, is: "Virtual Reality is the true-to-form representation of objects in the real-world and their interactions." Television and telerobotics, by their definition, is a presentation of the real world, not a representation of the real world. And artificial worlds are not necessarily constrained by real world limitations (such as the laws of physics).

Comment (from audience): Text-based VR may be a major practical form of VR for machine shops.

The primary human factor issue is: what does the user need to know; when does he need to know it; and in what form is it most conducive for effective performance. Who needs virtual reality? What is it good for? Some applications can get by with something less ambitious and considerably less costly.

Comment (from audience): One dimension of VR might be the degree to which the user is required to use his imagination (as in reading a novel versus looking at graphics). The use of the imagination might be stimulating to some, but it might detract or distract from the task at hand (e.g. manufacturing a part effectively and efficiently).

An example of an unusual form of VR is an acoustic VR system being developed by Dr. Roberta Klatzky (of Carnegie Mellon University and who is the wife of Dr. Geiwitz) and Dr. Reginald Golledge (University of California at Santa Barbara). It is a prototype GPS-based navigation system for the blind which announces the location of objects through stereo headphones ("bench here, bench here"). The system, connected to a computer in a backpack, creates a virtual landscape for the blind user.

We offer a definition of manufacturing systems, along with a diagram of manufacturing as a feedback system (in **Appendix VII**). The human factors issues depend on the task. As we said, the basic human factors issues are (1) What does the user need to know to perform the task; (2) when does he need the knowledge; and (3) in what form is the knowledge most conducive to effective use.

3.9 **LUNCH BREAK: VIDEOS**

[The lunch break included the showing of VR-related videotapes. Sandia videotapes included: *Visualization Facility Walk Through*; *VR/Hypermedia for Training* (demonstrating full body representation); *Enhanced Telepresence Interactive Modeling*; *Determining Wheelchair Access*; and *Assembly of Parts Visualization*. A videotape from Boeing showed *Virtual Reality Research at Boeing*, where VR is permitting the production of aircraft with full physical work-ups during the design process (the designer can walk inside the VR model of the aircraft), as well as providing augmented reality for laying out wiring harnesses. A videotape from United Technologies Research Center showed a VR conference room as a testbed.]

3.10 **DR. JIM GEIWITZ** [continued after lunch]

There have been few relevant research studies on the issues we're concerned with. If these systems do not work, it's costly. They had better be effective or they are not going to be used. The chart (**Appendix VII**) summarizes a few relevant studies and their key findings. But there have been no major field studies of automated manufacturing (and the last major field study of any kind of manufacturing was in 1935). In this team session, we should consider the various target tasks and the various human factors issues which are listed in the chart (**Appendix VII**).

Knowledge acquisition is important. In the knowledge acquisition guidebook are described 55 different knowledge acquisition techniques (KAT), along with the circumstances in which they are identified or contradicted. Psychologists generally distinguish between semantics and procedural knowledge. The former is knowing what an object is, and the latter is knowing how to perform some task. KATs are needed because experts may not be able to articulate procedural knowledge.

We need many more models of the manufacturing process -- we have been deficient in this area. The application of VR to training is much more admired than the VR applications to manufacturing. And part of the reason is that we don't have as good models for the manufacturing process that we have for the training process. In particular, we need models of autonomous interactive agents, such as are in SIMNET.

3.11 DR. HAROLD VAN COTT

Like many new fields of technology, virtual reality has developed in a haphazard, sporadic fashion. It tends to be applications oriented. A lot of the generic, cross-cutting issues that are fundamental to the development of the field and its proper exploitation and commercialization dropped through the cracks -- basic questions don't get answered. So two years ago I initiated a budget at the National Research Council on virtual reality in conjunction with the Committee on Human Factors and the Board on Computer Science and Telecommunications. They are looking at the broad field of virtual reality - what the state of the technology is, what the burning issues are, and, in particular, they are looking to devise an agenda for cross cutting research. The project is nearing completion.

The report (about 750 pages) should be published in October 1994. The study was funded by 12 different government agencies, such as NASA, ARPA, NSA, Coast Guard, and several others. The report will be available from the National Academy Press.

3.12 DR. ERNIE KENT

The plenary session will break into small groups to get some good one-on-one discussions and interactions, and then it will return for another plenary session to discuss the results of those groups. The charge to the groups will be for each group to put together its vision of where VR in manufacturing could go in the next five years. What things are possible? What things must be done? What are the means we have to bring to bear? What are the questions we have to ask? Take some guesses and try to project yourself into the future. In particular, those in the manufacturing community should try and put some demands on us. Tell us that this is the kind of information you need. These are the kinds of things you need to look at. I would like the human factors people to put demands on us, and the VR people to say "we can't do that for a hundred years."

The moderator assigned to each group will summarize what the groups came up with. Then we will have a plenary discussion where everybody can voice their opinions on what the other groups came up with and arrive at a summary conclusion of what VR for manufacturing will look like over the next five years.

[Three groups were formed, each with a mix of human factors, virtual reality, and manufacturing experts. They deliberated and returned to the plenary sessions, where Dr. Kent continued.]

Now that the group meetings are completed, we will have three summary statements from the groups.

3.13 WORKING GROUP 1: BAILY BUNCH

One of the things we discussed was that it was hard to describe the nature of manufacturing. And a cost/benefit analysis would require a definition of manufacturing. We agreed that manufacturing encompasses processes, planning, materials, controls, scheduling, resources (people and equipment), testing, integration (assembly), maintenance, training, and other things.

We noted that three or four things that are peculiar to manufacturing contribute to a goodness in VR. From a VR point of view, you can break manufacturing into operations (or processes), maintenance, and an aspect of training. We took those three items and asked what they mean from a VR point of view.

For operations, there is a goodness in VR for process/factory integration; optimization; situational awareness (monitoring); safety; real-time processes; and achieving agile manufacturing and just in time (JIT) distribution.

Relating to the maintenance part of the manufacturing process, we came up with these terms: teleoperation, remote, integration of maintenance and operations, repair, skills, safety, and tools. Teleoperation and remote control of maintenance, in particular, we may want to operate with VR.

We looked at training, and the pervasiveness of training jumped out all over the place. We listed benefits, mistakes/identification, cost, reconfiguration, 3D, training technology, worker safety, and process feedback.

We felt it more important to talk about a description of things that would go into the national testbed than to try to respond to the questions directly.

3.14 WORKING GROUP 2: GEIWITZ GROUP

We found that the whole company can use VR in design, manufacturing, finance, sales, and training. We need more generalists in VR, and fewer specialists. The integration of domain models is a major problem. By using VR for designing and testing (simulation), we can prevent errors in manufacturing.

We decided that standards and protocols were needed to interact with databases in VR. Protocols are required to connect CAD with process planning, to connect process planning with simulation and scheduling. Reference models are needed as well; there are perhaps seven hierarchical control layers between the Information Superhighway and the manufacturing process.

We agreed that graphics are basic to VR to visualize a problem and for knowledge acquisition. We need VR in the tools and the various system development phases. But we need to understand the domain before we understand the application of VR. We need to understand the manufacturing requirements before we decide that VR is an appropriate technology and where it should be applied. We struggled with this in the breakfast session.

3.15 WORKING GROUP 3: FINDLEY'S FLOCK

We decided that the problem is all about information management and how best to represent the knowledge we may or may not have about the manufacturing processes. We need to know how to manage large databases, and how to view information from different perspectives.

VR to be used to monitor real-time processes is much more difficult than other applications, due, in large part, to the need for new sensor technology.

VR must support changing information structures and models. With standard representations of requirements and designs, VR can help create alliances of companies - a virtual manufacturing system.

VR can be used to represent conceptual patterns of reality. It can be used effectively to support design and what-if analysis in a simulated world, as for physics-based models or task-based control systems.

3.16 DR. ERNIE KENT

We will be establishing a process of workshops at NIST on this topic. In conclusion:

* This group should:
  - stay in contact
  - share in information and insights
  - establish lines of communication
* NIST will be investigating these issues and providing facilities so that others can investigate these issues as well
* NIST is inviting you to use our resources
* Eventually, we will issue recommendations for standards (for interfaces, human factors, etc.)

* The ATP program cognizant of this program
* You will receive a physical copy of the workshop report
* In future meetings, we want to bring in software suppliers

This has been a long, hard day, but I think a productive one. I would like to give you all my personal thanks for being here today. I think it certainly has been very useful for us and I hope that we're all going to be able to remain in contact. I think we've developed some good associations here, and I hope they will be as profitable for you as I believe they are going to be for us. Thank you very much for attending [applause].

APPENDIX I

INVITATION PACKAGE

Agenda

Workshop Objectives

Breakout Session Topics

Registration Form

Direction & Map To Gaithersburg Hilton

Background Information For The Survey

Enquiry Form

TO:
Designated Respondent

FROM: Dr. Joe Iseman
(301)-983-2465 - VOICE
(301)-983-2509 - FAX

DATE: 27 July 1994

Cover + 6 Pages

****

Subject: NIST Workshop - *APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS* - 9 August 1994

(1) The Intelligent Systems Division (ISD) of the Manufacturing Engineering Laboratory (MEL) at the National Institute of Standards and Technology (NIST) is at the forefront of a commitment in the area of standardization of protocols for the application of information and interface technology for virtual and distributed manufacturing of discrete parts. As part of this effort, ISD is currently developing an initiative in human interfaces into manufacturing, emphasizing integration of human factors, virtual reality, and manufacturing systems technologies. One of the ISD priority items is a one-day workshop on Tuesday, 9 August 1994, with registration starting at 8:00 am.

(2) The workshop will be at the Gaithersburg Hilton, 620 Perry Parkway, Gaithersburg, Maryland. A large scale map and directions are attached.

(3) The purpose of this workshop will be to determine a vision for human factors in information and interfaces needed to integrate virtual reality technologies into the virtual and distributed manufacturing of discrete parts.

(4) As we discussed in our telephone conversation today, as a leader in the fields of Human Factors, Virtual Reality, or Manufacturing, you are invited to attend and participate (or to designate a participant) in this workshop. Each invited participant will interact in general and breakout sessions to address: (1) a definition of the requisite information and

interfaces for virtual and distributed manufacturing applications, (2) human factors approaches in information and interface technologies, and (3) leveraging of efforts in specific topical areas. Robotic Technology Inc. is working on this workshop under contract to NIST.

(5) You are provided with brief background information describing human factors and virtual reality (VR) interfaces for manufacturing. Please familiarize yourself with this material. You probably also have been asked to fill out the attached questionnaire - if you have not, we now request you to do so. Please answer the questions using your expert judgment and opinion.

(6) If you have any questions or comments on the questionnaire, or if you wish to suggest additional respondents or participants, please call: Dr. Joe Iseman, Robotic Technology Inc., (301)-983-2465.

(7) **ACCOMMODATIONS**

For your convenience a block of rooms has been set aside at the Gaithersburg Hilton for the night of Monday, 8 August at a (single or double) rate of $75.00. Please contact the Hilton directly at (301)-977-8900 to reserve a room.

(8) **POINTS OF CONTACT**

Cathy Kilmer (NIST, (301)-975-2858, voice and (301)-948-2067, fax) or Dr. Joe Iseman (Robotic Technology, Inc.- (301)-983-2465, voice and (301)-983-2509, fax) are additional points of contact.

(9) **ACTIONS ITEMS**

*	REGISTRATION -	Please fax the registration form for your participation in the workshop, as soon as possible to (301)-983-2509.
*	QUESTIONNAIRE -	Please fax only the completed form (not the background information), as soon as possible, to (301)-983-2509.

Thank you so very much!

ENCLOSURES:
- Draft Agenda
- Objectives of the Workshop
- Breakout Sessions for the Workshop
- Registration Form
- Directions and Map to Gaithersburg Hilton
- Background Information (for questionnaire)
- Enquiry Form - *Application of Information and Interface Technology for Virtual and Distributed Manufacturing of Discrete Parts*

AGENDA
WORKSHOP ON
APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PRESENTED BY
INTELLIGENT SYSTEMS DIVISION
MANUFACTURING ENGINEERING LABORATORY
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

GAITHERSBURG HILTON
GAITHERSBURG, MARYLAND

9 AUGUST 1994

0800-0830 REGISTRATION (Rockville-Potomac Suites)

0830-0900 WELCOME - DR. ERNEST KENT, NIST.

0900-0915 *OVERVIEW OF SIMA (SYSTEM INTEGRATION FOR MANUFACTURING) PROBLEM* - MARK LUCE, NIST.

0915-1015 *OVERVIEW OF VIRTUAL REALITY: A NEW TOOL FOR MANUFACTURING* - DR. R. BOWEN LOFTIN, NASA JSC.

1015-1030 MORNING BREAK

1030-1100 VIDEO: *A US POSTAL SERVICE APPLICATION: CONTROL, SIMULATION, AND ANALYSIS OF A VIRTUAL MAIL PROCESSING FACILITY* - CLYDE FINDLEY, ATR.

1100-1200 *HUMAN FACTORS ISSUES IN VR INTERFACE DESIGN* - DR. JAMES GEIWITZ, CARNEGIE-MELLON UNIVERSITY.

1200-1300 WORKING LUNCH: VIDEO PRESENTATIONS: *VIRTUAL REALITY DEVELOPMENTS*

- STANSFIELD, SANDIA NATIONAL LABS
- BAILEY, BOEING DEFENSE AND SPACE GROUP
- EDWARDS, UNITED TECHNOLOGIES RESEARCH CENTER

1300-1315 *A FRAMEWORK FOR SUCCESSFUL BREAKOUT SESSIONS* - DR. ERNEST KENT, NIST.

1315-1445 BREAKOUT SESSIONS - GROUP 1 - GEIWITZ, CMU
GROUP 2 - FINDLEY, ATR
GROUP 3 - BAILEY, BOEING

1445-1500 AFTERNOON BREAK

1500-1600 REPORTS BY BREAKOUT SESSION CHAIRPERSONS

1600-1700 PLENARY DISCUSSION DEFINING NIST DIRECTION, DR. ERNEST KENT, NIST

1700 ADJOURNMENT

OBJECTIVES OF THE WORKSHOP

(1) Define a vision of information and interfaces for virtual and distributed manufacturing systems:

* the human role in manufacturing systems
* human factors viewpoints for information and interfaces in virtual and distributed interactions
* types of data which should be presented by virtual and distributed multimedia (textual and graphical)
* technologies available for virtual and distributed interactive (visual, auditory, and tactile) interfaces (work station monitors, head-mounted displays, data gloves) and to support immersion (viewpoint, movement)
* technology transfer from current and developmental entertainment and military applications systems
* communications support requirements for expected local and wide area networks.

(2) Explore human factors for future information interfaces in virtual and distributed manufacturing systems:

* pulls or objectives: what are the user needs?
* pushes or drivers: what are current and expected technologies from the developers?
* short and long term objectives and drivers
* most effective formats for manufacturing information
* requirements for natural language interfaces
* requirements for graphical interfaces
* requirements for other sensor interfaces.

(3) Realistic leveraging in specific topical areas:

* value added (potential payoffs of new approaches for information and interfaces for virtual and distributed manufacturing, particularly in terms of a competitive edge in the global marketplace)
* shortfalls
* potential insertion rates for virtual and distributed manufacturing.

(4) Needed standards and protocols:

* standards for human interface technologies
* interface standards between display technologies and manufacturing data bases.

BREAKOUT SESSIONS FOR THE WORKSHOP

Topics to be considered in each breakout session include:

HUMAN FACTORS APPROACHES TO INFORMATION AND INTERFACES IN VIRTUAL AND DISTRIBUTED MANUFACTURING SYSTEMS

* Types and levels of information content
* Human Factors Considerations
  - Information detail - bandwidth, resolution, and fidelity
  - Interaction approaches - visual, auditory, tactile, and haptile
* Individual interactions
  - The shop floor - shop floor supervisors, shop floor personnel (machine operators, inspectors, material handlers, and personnel Involved with maintenance and repair, the supply room, and the tool room)
  - The designer and planners - CAD-CAM designers, design engineers, process planning engineers, manufacturing consultants
  - The business and management personnel - plant managers, schedulers, accountants, management information systems personnel, and business consultants
  - The external environment
* Collaborative participation
  - Across one company
  - Among companies
  - The enterprise.

EXAMPLE APPLICATION 1: VIRTUAL CORPORATIONS

* Distributed entities and integrating functions
* Working together in a synthetic environment
* Teleconferencing for "meeting at a distance;" telepresence in a collaborative, immersive environment for joint activities, including discussions, interviews, planning, and training.

EXAMPLE APPLICATION 2: VIRTUAL AND DISTRIBUTED MANUFACTURING - THE FACILITIES, PROCESSES, AND PRODUCTS

* Virtual and distributed design - facilities, processes, and products
* Simulation: new views and perspectives unattainable by current methods
* Virtual and distributed planning - facilities, processes, and products.
* Simulation and development

EXAMPLE APPLICATION 3: VIRTUAL AND DISTRIBUTED TRAINING

* Integration of training for personnel at distributed sites with distributed elements
* Simulations or synthetic environments (cost savings, hazardous environments, unavailable real items)
* Distance learning and instruction
* Students interacting with unavailable and out-of-size components and environments

REGISTRATION FORM

for the

WORKSHOP ON
APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PRESENTED BY
INTELLIGENT SYSTEMS DIVISION
MANUFACTURING ENGINEERING LABORATORY
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY

GAITHERSBURG HILTON
GAITHERSBURG, MARYLAND

9 AUGUST 1994

Please fax this completed form as soon as possible to
Dr. Joe Iseman
Robotic Technology Inc.
(301)-983-2509 (FAX)
(301)-983-2465 (VOICE)

Please Mark One: I Will [ ] I Will Not [ ] attend this workshop on *INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING*

YOUR NAME____
Last First

POSITION or TITLE________________________________

ORGANIZATION/AGENCY______________________________

ADDRESS____

____

____

PHONE____

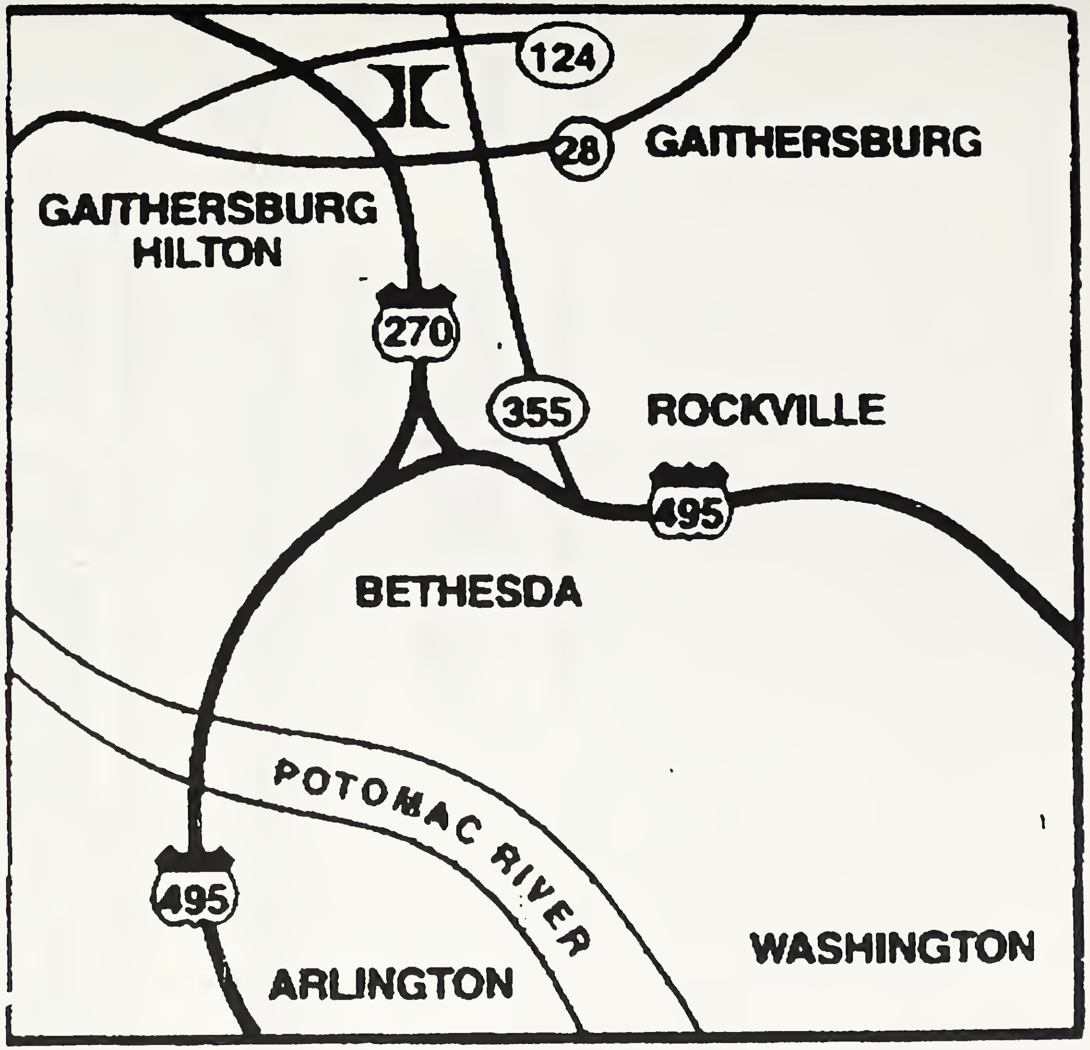
FAX____

E-Mail____

IF YOU ARE DRIVING

SOUTHBOUND:
I-95 South to I-495 West (Silver Spring). Follow I-495 West 9 miles to Exit 35 (I-270 North to Frederick). Follow I-270 15 Miles to Montgomery Village Avenue (Exit 11). Take Montgomery Village Avenue to Second Light and Turn Right on Frederick Avenue (Rte. 355 South). Turn Right at Next Light onto Perry Parkway. Hotel is Just Down the Street.

NORTHBOUND:
I-95 North to I-495 West (Fairfax/Frederick) Follow I-495 15 Miles. Take Exit 38 to I-270 North to Frederick. Follow I-270 to Montgomery Village Avenue (Exit 11). Take Montgomery Village Avenue to Second Light and Turn Right on Frederick Avenue (Rte. 355 South). Turn Right at Next Light onto Perry Parkway. Hotel is Just Down the Street.



Gaithersburg
Hilton

620 Perry Parkway • Gaithersburg, MD 20877
(301) 977-8900 • (800) 599-5111
Fax (301) 869-8597

TO:

Designated Respondent

FROM: Dr. Joe Iseman
(301)-983-2465 - Voice
(301)-983-2509 - FAX

DATE: 27 July 1994

Subject Questionnaire On *Application of Information and Interface Technology for Virtual and Distributed Manufacturing of Discrete Parts*

Cover + 13 Pages

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(1) The purpose of this questionnaire is to determine a vision for human factors in information and interfaces needed to integrate virtual reality technologies into the virtual and distributed manufacturing of discrete parts. You are asked to address: (a) a definition of the requisite information and interfaces for virtual and distributed manufacturing applications, (b) human factors approaches in information and interface technologies, and (c) leveraging of efforts in specific topical areas. The results of this questionnaire will allow the Intelligent Systems Division (ISD) and the Manufacturing Engineering Laboratory (MEL) of the National Institute of Standards and Technology (NIST) to determine needed standards and protocols for information and interfaces. Robotic Technology Inc. is working on this questionnaire under contract to NIST.

(2) You are provided with brief background information describing potential intersections of human factors and virtual reality (VR) for manufacturing. Please familiarize yourself with this material before answering the questions using your expert judgment and opinion.

(3) Please **fax** only this completed form (not the background information), as soon as possible, to (301)-983-2509.

(4) If you have any questions or comments, or if you wish to suggest additional respondents, please call: Dr. Joe Iseman, Robotic Technology Inc., (301)-983-2465.

(5) *Thank you so very much*

BACKGROUND INFORMATION:
APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PURPOSE

The National Institute of Standards and Technology (NIST) is supporting new initiatives in manufacturing technology which promise to have a major impact on the national economy. The Intelligent Systems Division (ISD) of NIST is exploring the potential applications of human information and interface technology for virtual and distributed manufacturing. The purpose of the enclosed enquiry is to determine some of the issues in human factors and virtual reality (VR) for manufacturing from the user's perspective and to build a new vision for manufacturing systems.

Key questions relate to the attributes of human information interactions through IO interfaces and their impact on potential leveraging of manufacturing technology. Who needs to look at information? What kinds of information are appropriate for each user to support real-time, collaborative decision-making? What differences are there in information needed for different users - individually or in new collaborative process within a "virtual" presentation environment? What are the important issues in how users choose to view information - both text or graphics? What human factors issues and design considerations should be included in a VR computer-interface? How can the information content and presentation best be approached with VR computer-interface technologies?

NEW INITIATIVES

Manufacturing technology is currently a focus of national initiatives sponsored by numerous government organizations and industrial consortia. There is a commitment of funding by programs in the Department of Commerce (Advanced Technology Program [ATP]), Department of Defense (Technology Reinvestment Program [TRP]), as well as the Department of Energy, NASA, and other Federal and state agencies. All of these programs address the necessity of boosting US manufacturing capabilities.

In this regard NIST has been given an expanded role in standardizing technological infrastructures and applications in such programs as:

* Manufacturing Research Technology Centers (METCs), which have become major regional technology resources
* The Automated Manufacturing Research Facility (AMRF), an open architecture test-bed for the automated manufacture of discrete parts
* The PDES-STEP (Product Data Exchange using STEP - Standard for the Exchange of Product Model Data) Program for standardizing manufacturing data representations.

Virtual Reality

Virtual reality is rapidly becoming technically and economically feasible. VR has many definitions and formats. At the ambitious end of the spectrum, VR allows a user to have the illusion that he is immersed in a synthetic or remote environment. He experiences sensory information, such as three-dimensional vision and binaural sound, that is generated by a computer or originates from remote sensors (or is a combination of the two sources). He interacts kinesthetically with computer generated or teleoperated objects. At the less ambitious end of the spectrum, VR allows a user to operate in a text-based interactive modes (i.e., on-line dungeons and dragons) or a graphics-based mode to manipulate objects, or interact with an environment, as displayed in two dimensions on a monitor (computer or workstation) or on a head-mounted-display. For the purposes of manufacturing applications, the more modest version of VR is acceptable along with the more ambitious version.

ISD Initiative in Information and Interfaces for Manufacturing

The Intelligent Systems Division (ISD) and the Factory Automation Systems Division (FASD) of the Manufacturing Engineering Laboratory (MEL) at NIST are concerned with standardizing information protocols and interface technologies and techniques for manufacturing technology. ISD is examining the human factors involved in interfaces for appropriate information interactions. NIST is interested in exploring virtual and distributed manufacturing with initial testbed efforts in the production of discrete parts. Primary target areas include: Engineering Design, Product Planning, Process Planning, Factory Simulation, Monitoring and Control.

ISD is working with users and developers to coordinate standard information protocols and interfaces, which will eventually be reflected in the integration of virtual reality in a manufacturing framework. This human factors initiative will have a major impact in: information content for each user; presentation bandwidth and fidelity; presentation modality - real time or non-real time and mixes of text, graphics, pictures, videos, and other sensory modalities.

VR Threads

Virtual reality may be able to integrate intelligent manufacturing systems: products, processes, and enterprises. The potential impact of virtual reality may be dramatic. VR, which will be defining itself from the user pull and the technology push over the next several years, has several common threads:
* Virtual reality provides new worlds for one or more users. Related terminology is: artificial worlds, virtual environments, and synthetic environments.

* Some VR systems attempt to give the user a sense of telepresence by immersive sensation (vision, sound, tactile (pressure), haptile (force). Virtual reality may apply to single sites with human/machine interfaces to co-located computers, or to interconnected, distributed systems at distant sites linked through communications networks.
* Virtual reality establishes a framework which will ultimately integrate many areas of technology: human factors, computer hardware and software, and communications.
* Virtual reality permits each user to participate in a collective effort.

Virtual reality is supported by enabling technology programs in the following areas:
* Communications: the National Information Infrastructure (NII)
* High performance computation: High Performance Computing and Communications (HPCC)
* Data and interface standards: PDES-STEP
* Hardware including head mounted displays (HMDs), body suits, exoskeletons, data gloves, large screens
* Human factors studies.

VR to date has been focused primarily in four application areas:

(1) Simulation - which yields new views and perspectives which are unattainable by current methods.
(2) Teleconferencing participation - for "meeting at a distance," with a sense of telepresence, in a collaborative, immersive environment for joint activities, including discussions, interviews, planning, and training
(3) Training and Education, including:
* Integration of training for personnel at distributed sites with distributed elements
* Using simulations or synthetic environments to achieve cost savings by not using "real elements; when "real" elements are unavailable; and to protect personnel in training for hazardous operations and environments, e.g., nuclear environments, toxic contamination, or live-fire conditions
* Students using educational virtual reality toolsets to build their own virtual worlds, to immerse themselves, and to interact in "what if?" situations
* Students can learn by interacting with unavailable and out-of-size components and environments, such as observing a real-time manufacturing process through a magnifying glass.
(4) Mutual participation in shared activities in a synthetic environment. The most striking current participatory applications of virtual reality are for: Entertainment (several theme parks have simulator rides and other are currently being design as entire virtual reality theme parks); Military (to test new technology or tactics, and to train personnel at distributed sites in synthetic environments).

HUMAN FACTORS IN VR INTERFACES FOR MANUFACTURING

ENQUIRY FORM: APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PURPOSE

The purpose of this questionnaire is to determine a vision for human factors in information and interfaces needed to integrate virtual reality technologies into the virtual and distributed manufacturing of discrete parts. You are asked to address: (1) a definition of the requisite information and interfaces for virtual and distributed manufacturing applications, (2) human factors approaches in information and interface technologies, and (3) leveraging of efforts in specific topical areas. The results of this questionnaire will allow the Intelligent Systems Division (ISD) and the Manufacturing Engineering Laboratory (MEL) of the National Institute of Standards and Technology (NIST) to determine needed standards and protocols for information and interfaces. Robotic Technology Inc. is working on this questionnaire under contract to NIST.

PROCEDURE

You have been provided with brief background information describing human factors and virtual reality for manufacturing. Please familiarize yourself with this material before answering the questions using your expert judgment and opinion.

Please fax only this completed form (not the background information), as soon as possible, to (301)-983-2509. If you have any questions or comments, please call: Dr. Joe Iseman, Robotic Technology Inc., (301)-983-2465. *Thank you for your participation and cooperation.*

YOUR NAME______________________________________

Last First

POSITION or TITLE______________________________

ORGANIZATION/AGENCY____________________________

ADDRESS____

____

____

PHONE____

FAX____

E-Mail____

1. With respect to VR, are you a potential: (Please check one)

(a) Developer [ ] (b) User [ ] (c) Researcher [ ]

Comments (if any):______________________________________

____

2. How much do you know about virtual reality? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Don't Know Much                     Very Knowledgeable
```

Comments (if any):______________________________________

____

3. How would you best characterize the field of "Virtual Reality"? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Figment of Imagination                         Realistic
```

Comments (if any):______________________________________

____

4. How much do you know about human factors/ergonomics for defining information presentations with computer-interface technology and techniques? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Don't Know Much                     Very Knowledgeable
```

Comments (if any):______________________________________

____

5. How would you best characterize the areas of human factors/ ergonomics for defining information presentations with computer-interface technology and techniques? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Inadequate                                 Well Developed
```

Comments (if any): ____

____

6. Are information presentations currently adequately embedded in the manufacturing process? (Check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any): ____

____

7. For the kinds of manufacturing activities with which you are familiar, what kinds of information would typical users require to perform their job remotely: (Please comment on as many activities as you wish)

7a. Shop floor supervisors ______________________________________

____

7b. Machine operators ____

____

7c. Inspectors ____

____

7d. Material handlers ____

____

7e. Maintenance and repair personnel ___________________________

____

7f. Supply room personnel ______________________________________

____

7g. Tool room personnel ____________________

7h. CAD-CAM designers ____________________

7i. Design engineers ____________________

7j. Process planning engineers ____________________

7k. Manufacturing consultants ____________________

7l. Plant managers ____________________

7m. Schedulers ____________________

7n. Schedulers ____________________

7o. Accountants ____________________

7p. Management information systems personnel ____________________

7q. Business consultants ____________________

7r. External environment personnel ____________________

7s. Other (please specify) ____________________

8. Are you familiar with interactive text-based virtual reality information presentations (i.e., on-line dungeons and dragons games)? (Check one)

(a) Yes [ ] (b) No [ ] (c) Somewhat [ ]

Comments (if any):______________________________________

____

9. When will text-based information presentations using VR-computer-interface technology first be used in manufacturing? (Please indicate with an "x" on the scale):

```
     /------------/------------/------------/------------
    1995         2005         2015         2025        >2025
```

Comments (if any):______________________________________

____

10. Are you familiar with interactive graphics-based virtual reality information presentations (head-mounted displays, small or large screens in entertainment)? (Check one)

(a) Yes [ ] (b) No [ ] (c) Somewhat [ ]

Comments (if any):______________________________________

____

11. When will graphics-based information presentations on VR-computer-interface technology first be of used in manufacturing? (Please indicate with an "x" on the scale):

```
     /------------/------------/------------/------------
    1995         2005         2015         2025        >2025
```

Comments (if any):______________________________________

____

12. What do you believe are the most important features of information presentations with VR computer-interface technology for manufacturing?

____

____

13. With respect to VR graphic presentations, which features are most important to you: (Please prioritize: Most important = 1)

(a) Visual quality [ ] (b) Refresh speed [ ] (c) Seamless [ ]
(d) Tactile interactions [ ] (e) Other (specify below) [ ]

Comments (if any):____

____

14. What do you think of the likelihood that information structures and VR user interfaces, customized to support specific users will be useful and valuable in manufacturing:

```
     /---------/----------/----------/----------/---------/
P=   0        .2         .4         .6         .8        1.0
     Low                 Moderate              High      Certain
     Probability         Probability           Probability
```

Comments (if any):____

____

15. What would be the value added by customized information presentations on VR computer-interface technology for manufacturing? (Please indicate with an "x" on the scale):

```
     /---------/----------/----------/----------/---------/
     0         1          2          3          4         5
     None                   Moderate                   High
```

Comments (if any):____

____

16. Who will drive information presentations and VR computer-interface technology for manufacturing? (Check one)

(a) Developers [ ] (b) Users [ ] (c) Both [ ]

Comments (if any):____

____

17. Who will be primary funding sources for information presentations with VR computer-interface technology for manufacturing? (Check one)

(a) Developers [ ] (b) Users [ ] (c) Government [ ]

Comments (if any):____

____

18. Which technologies do you believe must be exploited to make information presentations with VR computer-interface technology for manufacturing workable and affordable to users?

____

____

19. Which industries or types of processes do you feel can benefit first from information presentations with VR computer-interface technology for manufacturing applications?

____

____

20. How would you rank the <u>necessary</u> growth of the following technological factors for the integration of information presentations on VR computer-interface technology into manufacturing? (Please indicate with an "x" on the scales for each factor):

```
20a. Computer hardware?        /-----/-----/-----/-----/-----/
                               0     1     2     3     4     5
                               None                A Great Deal

20b. Communications systems?   /-----/-----/-----/-----/-----/
                               0     1     2     3     4     5
                               None                A Great Deal

20c. Software?                 /-----/-----/-----/-----/-----/
                               0     1     2     3     4     5
                               None                A Great Deal

20d. Human Factors?            /-----/-----/-----/-----/-----/
                               0     1     2     3     4     5
                               None                A Great Deal
```

Comments (in any):____

____

21. How well can standards, open architectures, and interoperability be achieved in information presentations with VR computer-interface technology to define a framework across multiple vendors of hardware and software and users? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Poor                                         Excellent
```

Comments (if any):____

____

22. Does special equipment now required for realism - head mounted displays, data gloves - reduce or enhance the ability of the user? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Reduce                                         Enhance
```

Comments (if any):____

____

23. How well can VR tools for the information presentation with VR computer-interface technology be integrated with manufacturing technology tools? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Poor                                         Very Well
```

Comments (if any):____

____

24. How would you rate the applicability of the fidelity of information presentation achieved with VR computer-interface technology in manufacturing technology for discrete part production in each of the following areas? (Please indicate with an "x" on the scales):

```
24a. Training?                /-----/-----/-----/-----/-----/
                              0     1     2     3     4     5
                              Poor                  Excellent

24b. Product design?          /-----/-----/-----/-----/-----/
                              0     1     2     3     4     5
                              Poor                  Excellent
```

24c. Process design? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

24d. Process validation? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

24e. Enterprise integration? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

Comments (in any):

25. Can the US manufacturing industry afford to apply high-fidelity, customized information presentations with VR computer-interface technology? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
Can not Can

Comments (in any):

26. How much will cost of equipment to support a high quality graphical and interaction interfaces (future generations of workstations, head-mounted displays, and data gloves) effect acceptance of a virtual workplace? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
None A Great Deal

Comments (in any):

27. Do you know of direct requirements for VR interface presentations for any manufacturing systems? (Please check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):

28. Will information presentation with VR computer-interface technology have an overall worth in integrating companies, enterprises, or industries more intelligently into the manufacturing process? (check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):____

____

29. Will information presentation with VR computer-interface technology integrate vendors/suppliers to a greater extent into the manufacturing process? (Please check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):____

____

30. Please make any additional comments below:

APPENDIX II

SURVEY REPORT

Activities Preliminary To Convening A Workshop On The Application Of Virtual Reality To Manufacturing: Results Of A Survey (August 94)

CONTENTS

1.0 PURPOSE

The purpose of this project was to perform certain activities preliminary to convening a workshop on the application of virtual reality (VR) to manufacturing. In the course of the work, we performed a literature search to determine the state-of-the-art of virtual reality as it relates to information and interface technology for virtual and distributed manufacturing of discrete parts. We found nothing relevant to the subject of interest. The main task was to perform a survey to determine some of the issues in the application of information and interface technology for virtual and distributed manufacturing of discrete parts.

2.0 THE SURVEY

An enquiry form was designed as given in Appendix A. About half the recipients of the survey responded, a satisfactory response rate. The respondents are listed in Appendix B.

2.1 Motivation

The National Institute of Standards and Technology (NIST) is supporting new initiatives in manufacturing technology which promise to have a major impact on the national economy. The Intelligent Systems Division (ISD) of NIST is exploring the potential applications of human information and interface technology for virtual and distributed manufacturing. The purpose of the enquiry is to determine some of the issues in human factors and virtual reality for manufacturing from the user's perspective and to build a new vision for manufacturing systems.

Key questions relate to the attributes of human information interactions through IO interfaces and their impact on potential leveraging of manufacturing technology. Who needs to look at information? What kinds of information are appropriate for each user to support real-time, collaborative decision-making? What differences are there in information needed for different users - individually or in new collaborative process within a "virtual" presentation environment? What are the important issues in how users choose to view information - both text or graphics? What human factors issues and design considerations should be included in a VR computer-interface? How can the information content and presentation best be approached with VR computer-interface technologies?

Manufacturing technology is currently a focus of national initiatives sponsored by numerous government organizations and industrial consortia. There is a commitment of funding by programs in the Department of Commerce (Advanced Technology

Program [ATP]), Department of Defense (Technology Reinvestment Program [TRP]), as well as the Department of Energy, NASA, and other Federal and state agencies. All of these programs address the necessity of boosting US manufacturing capabilities.

In this regard NIST has been given an expanded role in standardizing technological infrastructures and applications in such programs as:

* Manufacturing Research Technology Centers (METCs), which have become major regional technology resources

* The Automated Manufacturing Research Facility (AMRF), an open architecture test-bed for the automated manufacture of discrete parts.

* The PDES-STEP (Product Data Exchange using STEP - Standard for the Exchange of Product Model Data) Program for standardizing manufacturing data representations.

Virtual reality is rapidly becoming technically and economically feasible. VR has many definitions and formats. At the ambitious end of the spectrum, VR allows a user to have the illusion that he is immersed in a synthetic or remote environment. He experiences sensory information, such as three-dimensional vision and binaural sound, that is generated by a computer or originates from remote sensors (or is a combination of the two sources). He interacts kinesthetically with computer generated or teleoperated objects. At the less ambitious end of the spectrum, VR allows a user to operate in a text-based interactive modes (i.e., on-line dungeons and dragons) or a graphics-based mode to manipulate objects, or interact with an environment, as displayed in two dimensions on a monitor (computer or workstation) or on a head-mounted-display. For the purposes of manufacturing applications, the more modest version of VR is acceptable along with the more ambitious version.

The Intelligent Systems Division (ISD) and the Factory Automation Systems Division (FASD) of the Manufacturing Engineering Laboratory (MEL) at NIST are concerned with standardizing information protocols and interface technologies and techniques for manufacturing technology. ISD is examining the human factors involved in interfaces for appropriate information interactions. NIST is interested in exploring virtual and distributed manufacturing with initial testbed efforts in the production of discrete parts. Primary target areas include: Engineering Design, Product Planning, Process Planning, Factory Simulation, Monitoring and Control.

ISD is working with users and developers to coordinate standard information protocols and interfaces, which will eventually be reflected in the integration of virtual reality in a manufacturing framework. This human factors initiative will have a major impact in: information content for each user; presentation bandwidth and fidelity; presentation modality - real time or non-real time and mixes of text, graphics, pictures, videos, and other sensory modalities.

Virtual reality may be able to integrate intelligent manufacturing systems: products, processes, and enterprises. The potential impact of virtual reality may be dramatic. VR, which will be defining itself from the user pull and the technology push over the next several years, has several common threads:

* Virtual reality provides new worlds for one or more users. Related terminology is: artificial worlds, virtual environments, and synthetic environments.

* Some VR systems attempt to give the user a sense of telepresence by immersive sensation (vision, sound, tactile (pressure), haptile (force). Virtual reality may apply to single sites with human/machine interfaces to co-located computers, or to interconnected, distributed systems at distant sites linked through communications networks.

* Virtual reality establishes a framework which will ultimately integrate many areas of technology: human factors, computer hardware and software, and communications.

* Virtual reality permits each user to participate in a collective effort.

Virtual reality is supported by enabling technology programs in the following areas:

* Communications: the National Information Infrastructure (NII)

* High performance computation: High Performance Computing and Communications (HPCC)

* Data and interface standards: PDES-STEP

* Hardware including head mounted displays (HMDs), body suits, exoskeletons, data gloves, large screens

* Human factors studies.

VR to date has been focused primarily in four application areas:

(1) Simulation - which yields new views and perspectives which are unattainable by current methods.

(2) Teleconferencing participation - for "meeting at a distance," with a sense of telepresence, in a collaborative, immersive environment for joint activities, including discussions, interviews, planning, and training

(3) Training and Education, including:

* Integration of training for personnel at distributed sites with distributed elements

* Using simulations or synthetic environments to achieve cost savings by not using "real elements; when "real" elements are unavailable; and to protect personnel in training for hazardous operations and environments, e.g., nuclear environments, toxic contamination, or live-fire conditions

* Students using educational virtual reality toolsets to build their own virtual worlds, to immerse themselves, and to interact in "what if?" situations

* Students can learn by interacting with unavailable and out-of-size components and environments, such as observing a real-time manufacturing process through a magnifying glass.

(4) Mutual participation in shared activities in a synthetic environment. The most striking current participatory applications of virtual reality are for: Entertainment (several theme parks have simulator rides and other are currently being design as entire virtual reality theme parks); Military (to test new technology or tactics, and to train personnel at distributed sites in synthetic environments).

2.2 Survey Results

The results of the survey are presented in the context of the enquiry form. All of the figures (graphs) are clustered at the end of this section.

1. With respect to VR, are you a potential: (Please check one)

(a) Developer [8] (b) User [2] (c) Researcher [24]
n=34 (some gave more than one response)

The majority of respondents were researchers, as shown in Figure 1. Comments from the respondents included:

(1) Anticipate the use of VR technology for planning and control applications in manufacturing.
(2) Mostly vision and software research, some graphics.
(3) Have $1 M grant from NSF to study educational implications of VR.

(4) UTRC would be a combination of all three.

(5) We are researching text and graphics-based VR for distributed manufacturing systems.

(6) Particular focus in manufacturing applications (to include design of prod/process).

(7) I develop S/W for VR and perform extensive research in its use in education, training, and data visualization.

(8) All three choices apply - I've worked on training PD with virtual images, currently doing basic VR research.

(9) We've built our own system.

(10) Currently manage a seven-person VR research team.

(11) Our effort involves both research and development.

2. How much do you know about virtual reality? (Please indicate with an "x" on the scale):

```
        0         2          6          11         10
  /---------/----------/----------/----------/---------/
  0         1          2          3          4         5
   Don't Know Much                      Very Knowledgeable
```

n	Mean	Sta. Dev.	Range
29	3.50	1.03	0-5

Most of the respondents are quite knowledgeable about VR, as illustrated in Figure 2. Comments include:

(1) UTRC has spent the last three years developing a VR lab.

(2) MSE from the advanced interfaced program at UW, currently in PhD program.

(3) I was involved in original studies at NASA-ARC in 1986.

3. How would you best characterize the field of "Virtual Reality"? (Please indicate with an "x" on the scale):

```
        1          1          4         10         13
  /---------/----------/----------/----------/---------/
  0         1          2          3          4         5
   Figment of Imagination                        Realistic
```

n	Mean	Sta. Dev.	Range
29	3.60	1.02	0-5

The great majority of respondents believe that VR is a feasible endeavor, a "real" field, as shown in Figure 3. But there are some cynics. Comments include:

(1) Some real meat, mostly hype.

(2) Except for flight simulators, VR has been a lot of hype. For VR to succeed it needs practical applications

(3) VR is definitely within reach, but technical, political,

and economic forces make for quite a dynamic environment.

(4) That's a funny question. By definition, VR is a "figment of imagination" that is very "realistic." I'll assume, however, that you're asking about the promise of the field!

(5) Concern is that it is used in appropriate situations.

(6) The range of "system" spans this scale 0->3.5 in my judgment.

(7) Projected rapid improvement.

(8) Realistic, but still limited.

(9) Competitively intensive, RT critical and therefore computer HW is expensive.

(10) I'm not sure what you're getting at--the technology already exists. The press is quite misguided.

(11) But very overhyped, leading to unrealistic expectations & disappointment.

4. How much do you know about human factors/ergonomics for defining information presentations with computer-interface technology and techniques? (Please indicate with an "x" on the scale):

```
          0          3          7          12          7
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Don't Know Much                     Very Knowledgeable
```

n	Mean	Sta. Dev.	Range
29	3.14	1.06	0-5

Most of the respondents are reasonably or very knowledgeable about the human factors relevant to the topic at hand, as depicted in Figure 4. Comments include:

(1) We have a consortium of 75+ small and large companies. In addition, we have coordinated with a couple hundred machine shops to research and document issues related to information views and human factors/ergonomics.

(2) Few IE courses and psychology seminars.

(3) I have a "seat-of-pants" reaction, but no formal insight into human factors/ergonomics.

(4) We will be moving into human factors in the next FY.

(5) Very strong knowledge of auditory display; less so regarding traditional visual displays, though fairly good with VR visual displays.

5. How would you best characterize the areas of human factors/ ergonomics for defining information presentations with computer-interface technology and techniques? (Please indicate with an "x" on the scale):

```
          2         11          7          6          1
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Inadequate                                Well Developed
```

n	Mean	Sta. Dev.	Range
27	2.13	0.90	0-5

As Figure 5 shows, most of the respondents feel that the technology is lacking and needs much more work, although there are a few optimists. Comments include:

(1) Great strides made, still a long way to go.
(2) Few <u>well known</u> sources of information that provide guidelines to developers.
(3) Well-developed for 2-D displays - we have much to do in 3-D/VR displays - especially multi-sensory displays
(4) The bottleneck in VR isn't hardware or software, it's the human factors of interfaces.
(5) Traditional factors may not apply to VR.
(6) It is strong in evaluative terms, less so in generative terms. I've worked on analytic modeling (pm forms).
(7) It needs more "Kan-sei" design engineering principles & approaches to it.

6. Are information presentations currently adequately embedded in the manufacturing process? (Check one)

(a) Yes [1] (b) No [17] (c) Maybe [9]
n=27

Only one lone respondent is certain that there are adequate presentations of information embedded in the manufacturing process, as graphically illustrated in Figure 6. Comments include:

(1) Interfaces to most control systems are text or at best, iconic.
(2) What I've seen is changing.
(3) Little use of visualization and multisensory presentation of data, telepresence.
(4) Rarely!
(5) Do we even know what information to present, and when to present it?
(6) Some companies are already quite sophisticated, judging from what I hear about Boeing, for example.

(7) From what I know, only a few hi-tech industries have begun to use information technology.

(8) Textual (PC) in most Manufacturing Processes. Typically only Design/Engineering have any workstation class computers.

(9) There are various examples of such techniques.

(10) It depends on applications.

7. For the kinds of manufacturing activities with which you are familiar, what kinds of information would typical users require to perform their job remotely: (Please comment on as many activities as you wish).

Comments are given for each subsection, where respondents recommend information spanning the VR spectrum from "ambitious" to "non-ambitious":

(1) Hard to answer these questions generally--depends on what is being manufactured.

(2) Not familiar with manufacturing activities.

(3) I don't work in manufacturing so my knowledge is limited.

(4) All should have access to all info and stages with priority and "paths" determined by the job.

(5) I have very little knowledge of the manufacturing process and do not know current state of info displays in it.

7a. Shop floor supervisors ______________________________

____

(1) Availability of resources (tools, machines, people) as well as manufacturing capability.

(2) Status trends throughput loads, performance.

(3) Excellent training, layout design for ease of supervision, visual information.

(4) Production schedules, "hot" deliverables, resource status.

(5) Schedules, quality metrics for individuals.

(6) Real-time worker status, including productivity & schedule; production status (versus orders and inventory).

(7) Schemas and Scripts. Process control information; temporal (synchronization) and social (coordination) information about shop workers.

(8) Production status, machine status, master production schedules.

(9) Production, quality parts availability.

(10) All senses.

(11) RT machine-operator-order status.

(12) Scheduling charts.

(13) Job scheduling.

(14) Status of work progressing at different workstations.

7b. Machine operators ______________________________

(1) Part requirements including adequate description of feature and part dimensions, how to perform the operation, NC program.
(2) Machine and process parameters (high level information), routing sheet & process plan.
(3) Multiple views of machine/parts & teleoperation limited to controls & feeders.
(4) Full immersive VR, including audio, tactile, vision and olfactory senses; Real-time machine status.
(5) Dispatch and/or production schedules, machine status, quality/metrology.
(6) Quality, production.
(7) All senses.
(8) Queue of jobs, kitting-fixture-stock location and status, RT solid modeling.
(9) Telepresence techniques.
(10) Close visual and kinesthetic feedback.
(11) Process display of ongoing work at their station.

7c. Inspectors ______________________________

(1) Salient and important characteristics of part together with "what if" scenarios depending upon inspection results.
(2) Status, trends, statistical analysis.
(3) Sensory data and limited control.
(4) Metacognitive skills in problem solving (i.e., they require procedural knowledge about diagnosis or troubleshooting).
(5) Quality criteria per product.
(6) Quality, standards, specifications.
(7) all senses.
(8) High precision visual information.
(9) Graphical displays of applied tests, views of objects.

7d. Material handlers ______________________________

(1) Usage, cost failures, supplies.
(2) More flexible automation, better layout & material flow path design, visual information.
(3) Production schedules, routing sheet.
(4) Total teleoperation.
(5) Movement request queue, priority and time available for completion.

(6) Production, parts availability, parts location.
(7) Telepresence, video/robot end effector.
(8) Diagrams, blow-ups, parts drawings.
(9) Close visual and kinesthetic feedback.

7e. Maintenance and repair personnel ______________________________

____

(1) Machine performance requirements and adequate repair manuals.
(2) Ease of accessibility of equipment, better layout design, text, graphics information.
(3) Total teleoperation.
(4) Not possible except for remote diagnosis.
(5) Procedural information with mental models, good graphics; sometimes semantic information (systems knowledge).
(6) Machine parts availability, machine specifications.
(7) Visual, aural, tactile, force.
(8) Pm schedule
(9) Close visual and kinesthetic feedback.
(10) Results of diagnostic tests, access to virtual manuals.

7f. Supply room personnel ______________________________

____

(1) Materials/tooling requirements and alternatives which can be substituted as required.
(2) Trends, usage shelf life.
(3) Better material tracking, streamlining of material flow, visual & auditory Information.
(4) Total teleoperation.
(5) Simple displays of quantity versus orders; Real-time displays of robot status.
(6) Job and associated tools/materials/fixture requirements.
(7) Parts availability, location.
(8) Vision.
(9) Job orders, production schedule.
(10) Inventory, demand data, supplier data, specs/parts.
(11) Visual information.
(12) Inventory, images of items, item history & location.

7g. Tool room personnel ______________________________

____

(1) Expected performance of specified tooling.
(2) Specifications.
(4) Job orders, kitting list.

7h. CAD-CAM designers ______________________________

____

(1) Communicate with design engineers and process planning engineers to optimize design.
(2) Remote from what? All they need is workstation and "contact" with engineers.
(3) 3D representations of objects tied to physics-based simulations and task-oriented control systems.
(4) Need materials, data/user requirements/gov't constraints/cost trade-off data/environmental (use) data/...
(5) Specifications.
(6) Design, tool/fixture, MT capabilities.
(7) Flexible interactive graphics.
(8) Material views, process visualizations, animation, selected transformations of objects.

7i. Design engineers ______________________________

____

(1) Communicate with CAD/CAM and process planners.
(2) Tools for design optimization interfaced with VR, graphics, text information.
(3) Remote from what? all they need is workstation and "contact" with engineers.
(4) Functional requirements. Users needs. Human factors information relevant to interface design. Anthropometric data on humans.
(5) Feasibility, production process.
(6) Flexible interactive graphics.
(7) All of the above, plus immediate access to "virtual tests" & selected calculations or designs.

7j. Process planning engineers ______________________________

____

(1) Detailed specs and design intent. Communicate with design and CAD/CAM engineers.
(2) Past data (stock, intermediate part representation, and final part representation), resources processing capability and availability.
(3) Feasibility, production process.
(4) MT capabilities & availability process-feature mapping.

7k. Manufacturing consultants ______________________________

____

(1) User requirements.
(2) Varies, depending upon specific expertise.

7l. Plant managers ____________________

____

(1) Resource availability, manufacturing and delivery schedules.
(2) Production schedules (projected and real-time).
(3) High level process flow displays, tied to sales projections, delivery schedules, and financial status.
(4) material, processes, manpower, money.

7m. Schedulers ____________________

____

(1) Machine/resource requirements, delivery requirements, and alternate capabilities.
(2) Process plan, resource availability.
(3) Just hard data and access.
(4) Employee status information; temporal information on all systems; a synchronization matrix.
(5) Time and material.
(6) MT availability & capabilities, job orders, process plans.

7n. Schedulers ____________________

____

(1) Just hard data and access.
(2) Time and material.
(3) MT availability & capabilities, job orders, process plans.

7o. Accountants ____________________

____

(1) Resource consumption and actual cost drivers to produce product.
(2) Just hard data and access.
(3) Access to purchase order files, shipping and receiving info, on-line tax code, access to pending corporate decisions.
(4) Activity based costing/management.

7p. Management information systems personnel____________________

____

(1) Human factors-type data, modeling.
(2) Ability to access all information.

7q. Business consultants ______________________________________

____

(1) Varies depending upon specific expertise.

7r. External environment personnel ____________________________

____

(1) Field information, e.g., outside plant (telephone) engineers need information on existing cable and potential development (housing tract, major hotels).

(2) Job status (customers), inventory status & pending orders (suppliers).

7s. Other (please specify) ____________________________________

____

(1) I believe each of these occupations present situations where VR would prove a good alternative. My own area CAD is a good candidate. Activities where teleconferenced distributed (or network) VR comes into its own would be the first to accept VR interfaces.

8. Are you familiar with interactive text-based virtual reality information presentations (i.e., on-line dungeons and dragons games)? (Check one)

(a) Yes [18] (b) No [3] (c) Somewhat [8]
n=29

As Figure 7 shows, a large majority is at least somewhat familiar with interactive text-based VR information presentations, although some do not consider this type of presentation to be in the realm of VR. Comments include:

(1) I would not call these VR!

(2) Have written articles on MUDs, MUOs, etc. [multi-user...].

(3) We are currently working with text-based VR software to build prototype for machine shop management.

(4) Little "serious" use at this time. Only 5-10 educational systems in place.

(5) Nothing against MUDs, but they are <u>not</u> virtual reality, and calling them text-based VR probably stretches "VR" beyond

usefulness.

(6) Generally, I consider these to be quite poor.

9. When will text-based information presentations using VR-computer-interface technology first be used in manufacturing? (Please indicate with an "x" on the scale):

```
           17            4             0             0
   /-------------/-------------/-------------/-------------
  1995          2005          2015          2025          >2025
```

n	Mean	Sta. Dev.	Range
21	2001	4.68	1995-2025+

The respondents foresee text-base VR for manufacturing available by the year 2001, as shown in Figure 8, although some do not consider this to be VR or a suitable technique. Comments include:

(1) I am planning to work collaboratively with Motorola Inc on such a project.

(2) I do not advocate this first introduction of VR to manufacturing to be based on textual information.

(3) I'm not convinced this kind of presentation is appropriate as a stand-alone solution.

(4) Assume you mean commercial application vs. research.

(5) Educated guess based on the rate of progress of computing applications.

(6) I am not sure they should ever be used when more powerful displays are economic and available.

(8) Instruction manuals.

(9) The phrase is too general to be very meaningful.

(10) Never: Graphics-based systems are already beginning to overtake them.

(11) The question does not make sense to me.

(12) Nils Bohr said "Prediction is difficult, especially the future."

(13) They are already being tested in Japan.

(14) Soonest applications will be in planning, rather than actual operations.

10. Are you familiar with interactive graphics-based virtual reality information presentations (head-mounted displays, small or large screens in entertainment)? (Check one)

(a) Yes [25] (b) No [0] (c) Somewhat [4]
n=29

The respondents are all at least somewhat familiar with interactive graphics-based VR, as indicated in Figure 9.

Comments include:

(1) Current technology has limitation based on size and time/duration user can sustain attention and necessary level of performance.
(2) wide range of capabilities, limitations, and cost.

11. When will graphics-based information presentations on VR-computer-interface technology first be of used in manufacturing? (Please indicate with an "x" on the scale):

21 3 1 0
/-------------/-------------/-------------/-------------
1995 2005 2015 2025 >2025

n	Mean	Sta. Dev.	Range
25	2001	5.61	1995-2025+

As with text-based technology, 2001 is the expected year of availability of graphics-based VR for manufacturing, as shown in Figure 10, although some say it is available now. Comments include:

(1) My forthcoming project with Motorola Inc. will hopefully result in a prototype implementation.
(2) Unsure, too many other underlying technologies are in the critical path of any introduction of VR to manufacturing.
(3) Limited information in a few years (not difficult).
(4) Evolution of "through the monitor window" CAD into all aspects of manufacturing.
(5) Cost is a major player here ... plus processing power and bandwidth.
(6) This is an area of research/application we are involved with.
(7) As above [educated guess] though sooner.
(8) I am aware of a small number of existing applications.
(9) I read that Boeing has worked out assembly steps with such technology.
(10) Boeing is using such for the 777.
(11) They already are--Boeing.
(12) May not make sense to use this technology in manufacturing
(13) I can comment on state and progress of VR technology, but not the needs and plans of manufacturers. If you include automobile companies, for example, the answer is 1994 (now).
(14) Should see this introduced in certain areas before the end of the decade.
(15) For systems (manufacturing) of even moderate complexity.

12. What do you believe are the most important features of

information presentations with VR computer-interface technology for manufacturing?

____

____

Responses varied greatly, but a core characterisitc seems to be the presentation of information such that the user can absorb a maximum of information in a minimum time. Comments include:

(1) More accurately decision making in a multi objective trade-off situation.
(2) Ability to customize interface to users.
(3) That the most appropriate information be presented with the least amount of tedium in the operator request operation, and in the easiest train-of-thought viewing format.
(4) Good displays/interfaces and proper data being displayed.
(5) Visualization, multisensory presentation of data, telepresence.
(6) Collaborate, access to information data base in seamless fashion, and integration of manufacturing with other departments (engineering, design, service, etc.)
(7) The variety of information or data views and representations for manipulation.
(8) Their ability to present large amounts of information in ways that are easily assimilated.
(9) That the information be of such content and in such a structure or representation that it significantly aid the problem-solver (user) in the manufacturing decision he or she must make at this point in time.
(10) Hands-free, ability to use effectively for several hours; rugged; lower cost.
(11) Granularity of information--the ability to control this for VR applications.
(12) Allowing cooperative/shared views with other people.
(13) Robust "scaled" to task, economic, provide true "value-added" compared with previous technology uses.
(14) Planning and process simulation; information exchange.
(15) Spatial representation, registered to the user's eyepoint, and then augmented with functional information.
(16) Cooperative sharing of the workspace; separate components integrated across distributed sites.
(17) Clear, intelligible displays; unobtrusive hardware.
(18) RT data, inventory tracking, production priority & control.
(19) Non-encumbering displays/input devices. Lots of on-line, interactive help and navigation guidance.
(20) Real-time interactivity, multisensory input/output choice of representation.

(21) Resolution; display size (field of view).

(22) Depends somewhat on the manufacturing task. But primarily the flexible and rich visual feedback. (But not necessarily immersive characteristics).

(23) Feedback from applied controls; Seamless switching between monitoring & control to accessing needed information.

13. With respect to VR graphic presentations, which features are most important to you: (Please prioritize: Most important = 1; least important = 5)

(a) Visual quality [ ] (b) Refresh speed [ ] (c) Seamless [ ]
(d) Tactile interactions [ ] (e) Other (specify below) [ ]

	a	b	c	d	e
1	11	8	3	2	3
2	4	7	11	0	2
3	7	4	2	4	2
4	1	2	6	7	2
5	0	0	0	4	2
n =	27	24	19	15	6

Figure 11 displays the respondents's prioritization, 1 through 5, for each of the VR features listed. The results are also shown above in a matrix format. Quality, refresh speed, and seamlessness were deemed the most important of the characteristics, although others wished to include resolution, sound, and other features to be considered as well. Comments included:

(1) Depends on the displays's relevance to the particular parameters and their relationships to the process.

(2) Choice of data and display method, e.g. surface vs. shading.

(3) Field of view also very important.

(4) Data base management.

(5) Accuracy is another feature.

(6) The features that are most important to me are those that are required by the user, and they are TBD.

(7) Visual quality (resolution), field of view.

(8) Most important is a and b with high scene complexity.

(9) In my opinion, visual quality is not all that important for engineering application.

(10) "Refresh speed" should be broken into update rate and throughput delay. Need >15Hz and <.1 sec., resp.

(11) Stereo [5], Sound [6], Force feedback [7]

(12) Scale is of significant importance. Will this system provide sufficient information?

(13) The choices do not make sense, e.g. graphic

presentations are tactile (?). Resolution, latency, registration, e.g. are important, but application specific.

(14) Ease of access and use.

(15) Flexibility of viewpoint (interactivity--but not necessarily tactile).

(16) Information lookup & access

14. What do you think of the likelihood that information structures and VR user interfaces, customized to support specific users will be useful and valuable in manufacturing:

```
            2         1          4          7         15
       /---------/----------/----------/----------/---------/
   P=  0        .2         .4         .6         .8       1.0
       Low                 Moderate              High      Certain
       Probability         Probability           Probability
```

n	Mean	Sta. Dev.	Range
29	0.71	0.22	0-1

Respondents assigned a high probability (expected value of 0.71) to the prospective utility in manufacturing of information and VR interfaces, as illustrated in Figure 12. Some have caveats to the optimism, as indicated in the comments:

(1) Only true if question 12 is met.

(2) Pushes development down the learning curve more rapidly.

(3) Manufacturers, in general, cannot afford associated cost for unique approaches.

(4) VR is simply the natural evolution of interfaces towards using human capabilities.

(5) It is just a matter of time.

(6) PC's are not yet commonplace in manufacturing.

(7) Almost certain in some kinds of manufacturing, e.g., where collaboration and experimental prototyping are important.

(8) This is a vague question. It depends upon what kind of manufacturing.

(9) Not clear that technology will mature to point of usefulness.

15. What would be the value added by customized information presentations on VR computer-interface technology for manufacturing? (Please indicate with an "x" on the scale):

```
            1         1          5          7         12
       /---------/----------/----------/----------/---------/
       0         1          2          3          4         5
       None                    Moderate                  High
```

n	Mean	Sta. Dev.	Range
26	3.52	1.04	0-5

The respondents are optimistic about high value added, as shown in Figure 13, with again some caveats expressed in their comments:

(1) It depends, e.g. for inspection it is high, for handling it is low to moderate.

(2) Increased ability to model processes.

(3) Customization will improve utilization of system. Customization of CAD systems have demonstrated this.

(4) Again, to be determined by evaluation of the interface in comparison to conventional manufacturing procedures.

(5) Always concerned with maintenance of specialized software/hardware.

(6) Potential is high.

(7) Hard to estimate.

(8) Depends on the application.

(9) At the moment, it is low.

(10) The ability to provide appropriate information is very relevant.

(11) Rapid low-cost experimental prototyping; training without real world hazards; perceptualization of complex information.

(12) Again, it depends on the application.

(13) High value in distributed and reconfigurable (i.e. JIT) applications.

16. Who will drive information presentations and VR computer-interface technology for manufacturing? (Check one)

(a) Developers [7] (b) Users [6] (c) Both [16]
n=29

A majority of respondents believe that both developers and users will drive the technology, as depicted in Figure 14, although the remainder are almost evenly split between users versus developers as technology drivers. Comments include:

(1) Those that require quick acceptance.

(2) Users drive the need and ultimately, the success. Developers drive level of available technology. If users don't buy, it's dead. If developers don't provide technology to meet users' needs, users don't buy, and it's dead.

(3) A widely used application is used by VR industry to drive down costs and increased developers/researchers.

(4) Developers cannot create for a merchant without involving the customers (at least not if they expect to be successful financially!).

(5) I hope!

(6) Developers need to find proponents in the user community who can effectively sell these new ideas.

(7) Purely technology looking for application!

(8) Currently the feedback loop is critical to the full development of VR.

(9) It is unfortunate that developers will be the drivers, but it too often does seem to be the case with new technology.

(10) Developers are always the drivers.

(11) High cost applications and low-tech users => developers are driver.

17. Who will be primary funding sources for information presentations with VR computer-interface technology for manufacturing? (Check one)

(a) Developers [6] (b) Users [9] (c) Government [12]
n=27

As shown in Figure 15, a plurality chooses the government as the primary funding source, with a substantial number picking the users. Few think that the developers will pick up the tab. Comments include:

(1) Government funding is needed for "proof of concept."

(2) Unless a widely used application is selected by government, user (industry) will have to provide funding.

(3) Government will fund at least until there is a cost incentive.

(4) The money will come from sale of commercial products--government (i.e. DoD) isn't enough.

(5) Government will fund only initially--when potential is seen users and developers will almost certainly drive development.

(6) Government will fund until several good examples are fielded and widely known.

(7) Realistically, government funding is probably needed as lead funding.

(8) Government and developers have clear important roles too (even though users will be the primary funding source).

(9) Unfortunately, organizations, especially manufacturing organizations, do not have the capital for such R&D.

(10) Government will fund at first--but then also industry's (user's) research arms.

(11) Vendors will develop hardware/software, manufacturers will purchase it. Perhaps government will fund R&D.

(12) Venture capital

(13) Unless intellectual property rights can be vested with developers, they will resist Government and user funding.

18. Which technologies do you believe must be exploited to make information presentations with VR computer-interface technology for manufacturing workable and affordable to users?

The respondents listed a variety of technologies in their comments, but graphics seems to be important to many. Some say we have all the hardware we need, that software is the limiting technology, especially intelligent software:

(1) Communications hardware and software.

(2) Crystallized Eyeware (head mounted devices).

(3) Knowledge Engineering, Knowledge/Data/Information base work. You must be able to maintain information to be presented.

(4) Communications and high speed, high resolution graphics displays.

(5) Imaging/graphics. Modular/object software good display and graphics speed.

(6) HPCC, force feedback, visual displays, audio.

(7) Improved immersive/augmented display devices, tracking devices, tactile feedback, database management, parallel processing.

(8) Telecommunications (fiber, ATM, ...); graphics; I/O architectures.

(9) Passive sensors; tactile-haptile technology.

(10) Human factors technologies to ensure that the users get the right information in the right form at the right time.

(11) Hardware (VLSI) and decreasing size w/ increasing portability.

(12) The hardware technologies already exist for VR + information presentations (not embedded graphical types of VR; but text based with simple graphics). So software + human factors need to be developed.

(13) Robust, adequate visual displays; multi-sensory displays as appropriate; distributed, low-cost graphics computing

(14) Graphic computing and display technologies.

(15) Sensing, wireless communications.

(16) Graphics hardware, network software, database software, graphics software.

(17) CAD Display, SMP, Parallel processing, Digital Video, Sensors, HCI.

(18) Non-intrusive position sensing. High quality see-through displays.

(19) PC based VR, RT shop floor data at low-cost.

(20) High-resolution light-weight small information displays; software/hardware capable of generally large scale environments; appropriate tracking technology.

(21) Low-cost, high-quality displays; intelligent, distributed software; multiple modalities.

(22) In general (because I don't know manufacturing): high performance, low cost, acoustical rendering engines; wide field of view for high resolution, low cost HMDs; improved software packages and standards; force, tactile feedback device development.

(23) Human factors of telerobotics & flight simulation.

(24) Much smaller & lighter, & more ergonomically acceptable

displays; get away from "data glove" type controls.

(25) High-bandwidth, multi-media networking, highly distributed software technology.

19. Which industries or types of processes do you feel can benefit first from information presentations with VR computer-interface technology for manufacturing applications?

The respondents's suggestions ranged from heavy industry, aircraft and automotive systems, to electronics and nanosystems:

(1) Discrete parts manufacturing and assembly, maintenance, repair, and overhaul.

(2) Multi-media.

(3) Discrete parts manufacturing, e.g., electronics, automobile, airplane.

(4) Process planning in a variety of industries.

(5) Diagnostics and maintenance process.

(6) Precision manufacturing, e.g. aircraft, electronics, etc.

(7) Flexible manufacturing systems.

(8) Aerospace, automotive, entertainment, information, telecommunication.

(9) Machined parts; CAD/CAM; CAL; Virtual Co-location.

(10) Product design, process design, process (monitoring and) control.

(11) Processes not requiring high visual detail, e.g., where untextured polygons are sufficient for the task to be accomplished.

(12) Any requiring dissemination of information and communication and state sharing between people.

(13) Custom manufacturing (small-runs, complex designs); hostile materials use, "nano-manufacturing."

(14) High front-end costs in tools/dies/assembly facilities.

(15) Those in which the spatial problems of part fabrication, or component assembly, are dominant.

(16) Prototyping. VR is useful for seeing expensive mistakes before they happen.

(17) Hi-tech, CAD based systems--Automotive, MF, Heavy Equipment.

(18) All.

(19) Hazardous environments--nuclear/toxic with robotic material handling.

(20) Labor-intensive work requiring templates.

(21) Design; maintenance training; process visualization.

(22) Those involved with remote handling of hazardous material; complex product development with multiple inputs (such

as aircraft design).

(23) Aerospace & medical equipment manufacturing; electronics.

(24) High through-put, volatile industries, where flexibility can be readily translated into competitive advantages.

20. How would you rank the <u>necessary</u> growth of the following technological factors for the integration of information presentations on VR computer-interface technology into manufacturing? (Please indicate with an "x" on the scales for each factor):

20a. Computer hardware?

0 3 8 6 10
/-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

n	Mean	Sta. Dev.	Range
27	3.29	1.13	0-5

Improvement of computer harware was deemed very important by most of the respondents, as depicted in Figure 16.

20b. Communications systems?

0 2 8 7 10
/-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

n	Mean	Sta. Dev.	Range
27	3.33	1.02	0-5

Improvement of communications systems, shown in Figure 17, was deemed slighly more important than improvement in computer hardware.

20c. Software?

0 1 2 7 17
/-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

n	Mean	Sta. Dev.	Range
27	3.91	0.90	0-5

As illustrated in Figure 18, the respondents see software improvement as more important than improvement in hardware or communications systems.

20d. Human Factors?

```
  0     1     1    15    10
/-----/-----/-----/-----/-----/
0     1     2     3     4     5
None                 A Great Deal
```

n	Mean	Sta. Dev.	Range
27	3.73	0.74	0-5

While, on the average, the respondents deem enhancement of human factors somewhat less important than improvement in software (although more improtant than improvement in hardware or communication systems), there is more agreement as to its importance (with a smaller standard deviation than the standard deviation for the judgement on software), as can be seen in Figure 19. Comments include a need for standards:

(1) Standards, standards, standards.

(2) Not a technology issue. Manufacturing practices and shop floor control must progress more than any of these!

(3) All of these must be developed a great deal for ideal VR systems, but this does not necessarily mean that the technology could not be useful in its current state for some manufacturing applications.

21. How well can standards, open architectures, and interoperability be achieved in information presentations with VR computer-interface technology to define a framework across multiple vendors of hardware and software and users? (Please indicate with an "x" on the scale):

```
     1          7          3          7          7
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Poor                                           Excellent
```

n	Mean	Sta. Dev.	Range
25	2.92	1.34	0-5

The respondents vary greatly in their expectations, although only one believes the opportunity for achieving standards, open architectures, and interoperability is very poor. The expectation is a bit more optimistic than dead center (2.9), but the standard deviation and range of responses shows the lack of agreement in the group, as graphically displayed in Figure 20. Comments include the view of many that it is premature to worry about standards, even though they will be needed evntually:

(1) I believe it is too early in the development of this technology to answer this question.

(2) Open software will be hard, hardware will be easier.

(3) Similar challenges as in other types of applications.

(4) Unfortunately, with VR really in its infancy, standards could slow growth but will be needed.

(5) This is a challenge - there is no question.

(6) It has been done in other domains; why not here?

(7) Standards and agreed upon architectures will be needed to gain critical mass of users.

(8) Tough call--standards here are a must for VR interfaces to succeed.

(9) This is an unknown. Different approaches must be tried before a standard can be developed.

(10) They can be, but there is only modest movement in the fragmented VR industry and research commonly toward this goal.

(11) Too early in the game for standards.

(12) It is hard for me personally, to envision such a broad scope of application.

(13) A great deal can be done on standardizing file formats, Communication protocols, etc. Dynamics are harder.

(14) VR is not fundamentally different from any other technology.

(15) It is much too early to standardize!

(16) Experience shows that "defacto" standards are usually accepted.

(17) They have been very poorly achieved to date, and may be premature before the technology has further matured.

(18) They could if they existed, but it's premature.

(19) Field has to shake out first.

(20) Can't be developed in a vacuum--need some technology base before meaningful guidelines can be developed.

22. Does special equipment now required for realism - headmounted displays, data gloves - reduce or enhance the ability of the user? (Please indicate with an "x" on the scale):

```
      2          5          5          7          6
/---------/----------/----------/----------/----------/
0         1          2          3          4          5
Reduce                                            Enhance
```

n	Mean	Sta. Dev.	Range
25	2.80	1.44	0-5

The respondents views are quite scattered, with no agreement, as shown in Figure 21, but on the average they lean toward the view (with a mean of 2.8) that the special equipment enhances the ability of the user. Comments include views on the advantages and disadvantages of the special equipment:

(1) It is application-dependent.

(2) Highly dependent on the particular application and quality of the display.

(3) Enhances quality, reduces comfort.

(4) Enhances focus, reduces mobility.

(5) A lot of devices, today are crude, but with significant improvements, one can see the potential.

(6) No question! But costs and biological as well as psycho-social reactions to the systems will play a role.

(7) An empirical question that probably gives a differed answer for each task.

(8) We <u>believe</u> they enhance, but we have little quantitative evidence.

(9) Getting used to a new technology presents an initial cultural shock, which once overcome will prove valuable.

(10) This depends very much on the task being performed.

(11) Hard to say since I've seen <u>both</u> enhancement and reduction depending on application & technology used.

(12) "Ability of the user"--to do what?

(13) Datagloves are pointless without tactile/force feedback. HMD's are probably on the way out with the HITL VRD.

(14) Not the manufacturing roadblock.

(15) What other choices are there?

(16) Depends <u>heavily</u> on application.

(17) Depends on what you mean by "the ability of the user." Enhances some abilities, reduces others.

(18) It enhances cognitive/perceptual ability but with present technology at some cost in cumbersomeness and "simulation sickness."

(19) There needs to be lots of improvement here, as I've noted before.

(20) Cumbersome with limited capability.

23. How well can VR tools for the information presentation with VR computer-interface technology be integrated with manufacturing technology tools? (Please indicate with an "x" on the scale):

```
     2         1          7          4          9
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Poor                                          Very Well
```

n	Mean	Sta. Dev.	Range
23	3.10	1.26	0-5

Most believe that VR tools and interface technology can be integrated at least reasonably well with manufacturing technology (with a majority seeing integration going quite well), as shown in Figure 22. Comments include the view that it is already done, or that it will be difficult to do:

(1) I am involved in such a project involving manufacturing cell layout flow path design.

(2) Currently?

(3) The information display/operator-interface systems <u>must</u> be integrated with manufacturing tools.

(4) Augmented reality (superimpose graphics on real world) is promising.

(5) Deneb Robotics has demonstrated this.

(6) Very well, but it will take an effort (i.e. money, support, R&D).

(7) In many cases, they overlap. CAD-CAM is certainly on the VR dimension.

(8) We expect that VR is like color--when appropriate all will wonder how we did without - but it can always be misapplied.

(9) I suspect some changes in manufacturing practices are needed to fully integrate VR.

(10) Where there's a will, there's a way.

(11) Depends on what manufacturing technology tools you're interested in.

(12) In my opinion, hard to predict.

(13) Supporting infrastructure cannot handle VR demands.

(14) Augmented reality provides a direct mechanism for integration.

(15) This will be more of a problem than many believe - I think the <u>control</u> aspects are most problematic.

(16) In theory-great; in practice there is no existing software or communications infrastructure in manufacturing.

24. How would you rate the applicability of the fidelity of information presentation achieved with VR computer-interface technology in manufacturing technology for discrete part production in each of the following areas? (Please indicate with an "x" on the scales):

24a. Training?

0 1 3 2 18
/-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

n	Mean	Sta. Dev.	Range
24	3.93	0.94	0-5

The response was overwhelming that fidelity is applicable to training, as shown in Figure 23.

24b. Product design?

0 2 3 9 12
/-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

n	Mean	Sta. Dev.	Range
26	3.61	0.93	0-5

The respondents also think that fidelity is very applicable to product design, but somewhat less so than for training, as depicted in Figure 24.

24c. Process design?

```
   3     4     2     5    11
/-----/-----/-----/-----/-----/
0     1     2     3     4     5
Poor                  Excellent
```

n	Mean	Sta. Dev.	Range
26	3.10	1.45	0-5

The views on process design are more diverse than for product design, as shown in Figure 25, with fidelity being seen as somewhat less applicable.

24d. Process validation?

```
   1     4     4     4    11
/-----/-----/-----/-----/-----/
0     1     2     3     4     5
Poor                  Excellent
```

n	Mean	Sta. Dev.	Range
24	3.28	1.33	0-5

Fidelity is believed to be a bit more important for process validation than for process design, as graphed in Figure 26, but there is a diversity of views (as evidenced by a standard deviation of 1.3).

24e. Enterprise integration?

```
   3     4     5     3     8
/-----/-----/-----/-----/-----/
0     1     2     3     4     5
Poor                  Excellent
```

n	Mean	Sta. Dev.	Range
23	2.88	1.54	0-5

Fidelity is not seen as highly applicable to enterprise integration, as shown in Figure 27. Comments for the applicability of fidelity to the various functions include:

(1) Validation requires simulation modes well beyond current VR.
(2) Product design harder because higher visual fidelity important.
(4) Fidelity is not always necessary or desirable.
(5) I am a little uncertain of the meaning/intent of this question.

(6) In process design, mostly due to poor models; in enterprise integration, graphic representations are quite poor.

25. Can the US manufacturing industry afford to apply high-fidelity, customized information presentations with VR computer-interface technology? (Please indicate with an "x" on the scale):

```
        1         5          4          4          6
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Can not                                            Can
```

n	Mean	Sta. Dev.	Range
20	2.84	1.30	0-5

The views on affordability are all over the scale, but the group leans toward the view (with a mean of 2.84) that the manufacturing industry can afford to apply high-fidelity, customized information presentations with VR computer interface technology, as shown in Figure 28. Comments also vary across the spectrum:

(1) If competitors can afford it, can they afford not to?
(2) The industry cannot afford not to apply high quality display techniques.
(3) Can afford it, but with limited "customization."
(4) Cost of not doing so is expensive, downstream rework.
(5) At this time the benefits have not been clearly demonstrated to industry.
(6) How can it NOT from a global competitive perspective.
(7) Certain industries will gain some advantage irrespective of cost to use VR.
(8) It cannot afford not to for the future.
(9) In specific cases it can afford it.
(10) Can't afford PC's yet.
(11) It can if the parts costs drop.
(12) Things are getting rapidly cheaper.
(13) Do not know enough about economics of manufacturing, though I'd be surprised if the answer were "cannot."
(15) Depends on the industry.
(16) Not now - applicable mostly to "niche" markets - need subsidies to be developed to point of viability.
(17) Not with today's technology--need 5-10-fold decrease in costs.

26. How much will cost of equipment to support a high quality graphical and interaction interfaces (future generations of workstations, head-mounted displays, and data gloves) effect acceptance of a virtual workplace? (Please indicate with an "x" on the scale):

```
          0          3          4          5          12
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
None                                         A Great Deal
```

n	Mean	Sta. Dev.	Range
24	3.62	1.06	0-5

Cost is deemed a very important influence on acceptance of the virtual workplace, as shown in Figure 29. However, as the comments indicate, benefits must also be part of the equation:

(1) It should really be a cost versus benefit question.
(2) This is so strongly dependent on the particular application that I can't give one rating value.
(3) HMD's will live or die by price.
(4) If benefits are clear, price will not be a significant barrier in the long run.
(5) The bottom line for Industry is cost versus benefits.
(6) Cost must go down and revenue incentive must go up.
(7) Extremely important.
(8) High quality, head-mounted displays are not necessary.
(9) Major driver for all international manufacturing companies.
(10) Price is very important - when desktop PC dropped into the $10K range they become available.
(11) I think changes in <u>cost</u> without improvement in <u>quality</u> might have little effect.
(12) Depends on benefits.
(13) The question is <u>not</u> cost. It is <u>added</u> value! Usually you can't introduce equipment like this alone in one part of an enterprise.
(14) American industry is resistant to high-capital technologies - if not then affordable, VR will be bypassed.

27. Do you know of direct requirements for VR interface presentations for any manufacturing systems? (Please check one)

(a) Yes [5] (b) No [11] (c) Maybe [8]
n=24

Only 21% of the respondents know of a direct requirement for certain, as shown in Figure 30. Nearly half are certain they do not know of a requirement. Comments include:

(1) For manufacturing cell layout and material flow systems.
(2) For VR specifically - NO. For user interface presentation in general - YES.
(3) Ease of use and setup.
(4) Deneb Robotics.
(5) The WVHTC Foundation "Virtual Company Distributed

Manufacturing Project."

(6) I don't know if you'd call them "requirements," but there are standards, etc., in for example the OSI ISO Reference Model. Standards for "open" systems--interoperability.

(7) Maintenance/accessibility of equipment; facility design/ operation.

(8) To a limited degree.

(9) Textile industry.

(10) Boeing 777. Several aspects of VR technology were useful in design process.

28. Will information presentation with VR computer-interface technology have an overall worth in integrating companies, enterprises, or industries more intelligently into the manufacturing process? (Check one)

(a) Yes [20] (b) No [0] (c) Maybe [7]
n=27

Not one respondent is certain that there is no integrating utility of VR technology, as graphed in Figure 31. Comments include:

(1) Don't understand what (who?) is being integrated: manufacturing companies in manufacturing?

(2) Data visualization promising for financial flow.

(3) Absolutely!

(4) Absolutely. The ability to convey enormous amounts of information in a VR environment will allow people and surroundings to communicate and interact in ways which are much more natural and certainly more flexible than text, databases, and drawings.

(5) Potential is high but ..

(6) Absolutely, they present the potential for serious cycle time reduction.

29. Will information presentation with VR computer-interface technology integrate vendors/suppliers to a greater extent into the manufacturing process? (Please check one)

(a) Yes [21] (b) No [0] (c) Maybe [6]
n=27

Again, the respondents are optimistic about the utility for achieving integration as a result of using the technology, as shown in Figure 32. Comments include:

(1) If vendors/suppliers provide "components for VR" engineering part models for evaluation.

(2) Manufacturing has to improve integration with vendor/ supplier to be competitive.

(3) Certainly expect it will.

(4) Potential is high but ...

(5) Good question, and my answer is a firm yes.

(6) VR does not solve any integration problems.

(7) Mainly because everything will be in the digital domain making it more probable.

(8) They'd better, if they are worth the effort!

(9) Only if systems are OPEN, proprietary technologies will create isolation, not integration.

30. Please make any additional comments below:

(1) I found this questionnaire difficult to respond to for the following reasons:

(a) All computer based systems (which is essentially everything today, from cars and appliances to large manufacturing systems) have an absolute requirement for information presentation to various levels of users. Therefore, all of these systems must have good displays and VR technologies are an evolutionary step in this area.

(b) The quality of displays relative to this information being presented and the operator's needs is critical but not well developed or understood at the present time. As a result, a "bad" display is worse than no display at times and a lot of VR displays are still at the "bad" stage, so a judgement on them is hard to make.

(2) Sorry, must miss NIST workshop.

(3) VR both text and graphics based will play a significant role in the development of the WVHTC Foundation's "Virtual Company Model" and most importantly with respect to it efforts with distributed manufacturing.

(4) I think it's very valuable to have a workshop on these issues now. We have made some gains in "VR in training," and we should see if the same principles apply in "VR in manufacturing." By opening up a "second front" so to speak, we will make faster progress to attain the benefits that VR interfaces afford.

(5) While high quality graphical displays + head mounted displays are nice, I think that a lower tech solution (workstation quality displays, Pentium class machines) would provide adequate solutions. Also a missing component of many VR systems is the people. Once inside a VR world, a person still gets a great deal of benefit by sharing information with others.

(6) As I've indicated, I have so little knowledge of manufacturing that, in spite of my VR and human factors

expertise, I cannot give useful answers to many of these questions without having more information about processes and challenges in manufacturing.

(7) My philosophy is that VR is not a single "thing" or "entity," but consists of a series of "features" (high res. graphics, stereo, interactivity, data glove, etc.) any of which can be present or absent. Some of these features matter more than others for cost effectiveness of this technology to any particular application area.

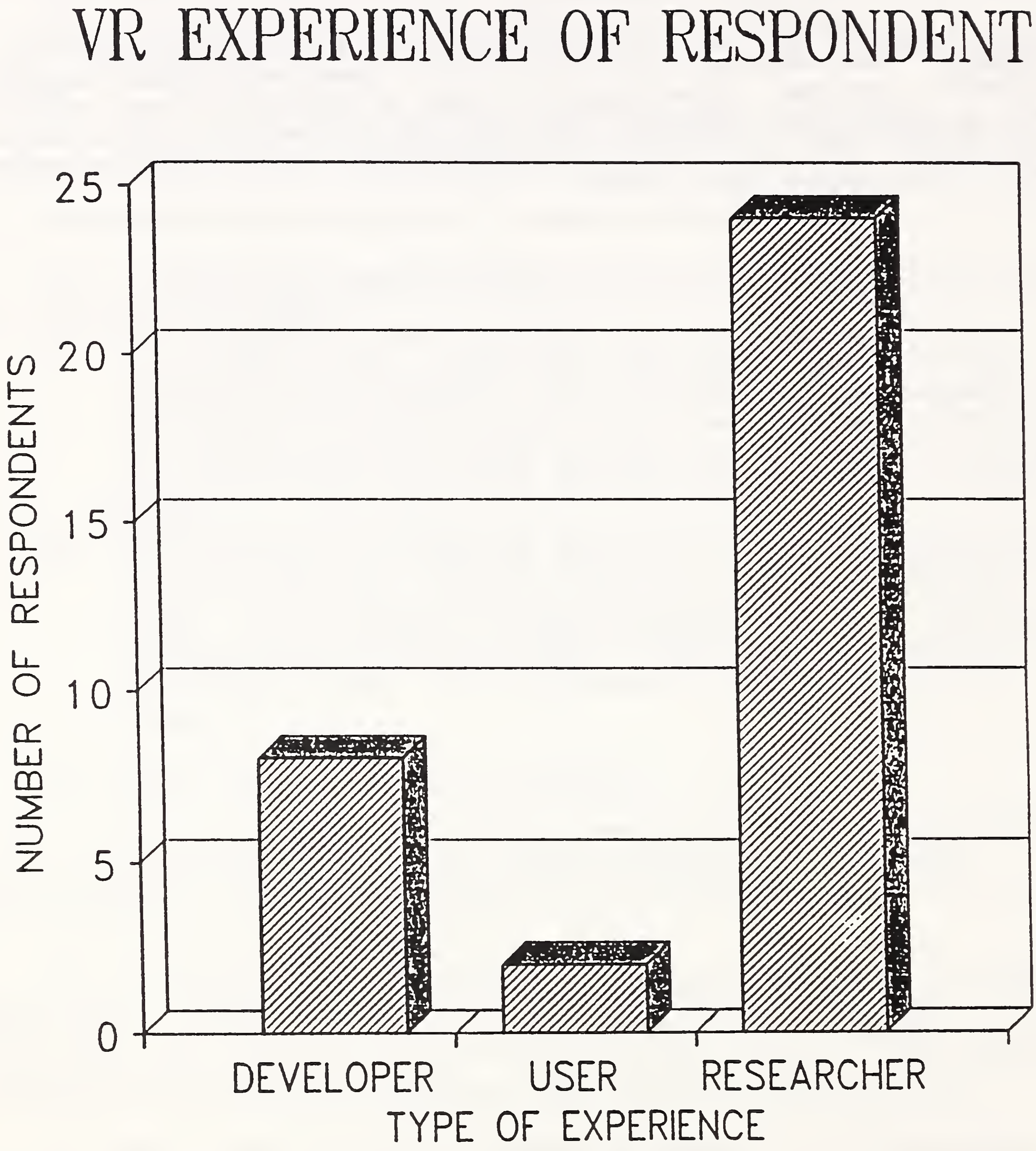

VR EXPERIENCE OF RESPONDENT
NUMBER OF RESPONDENTS
0
5
10
15
20
25
DEVELOPER
USER
RESEARCHER
TYPE OF EXPERIENCE

Figure 1

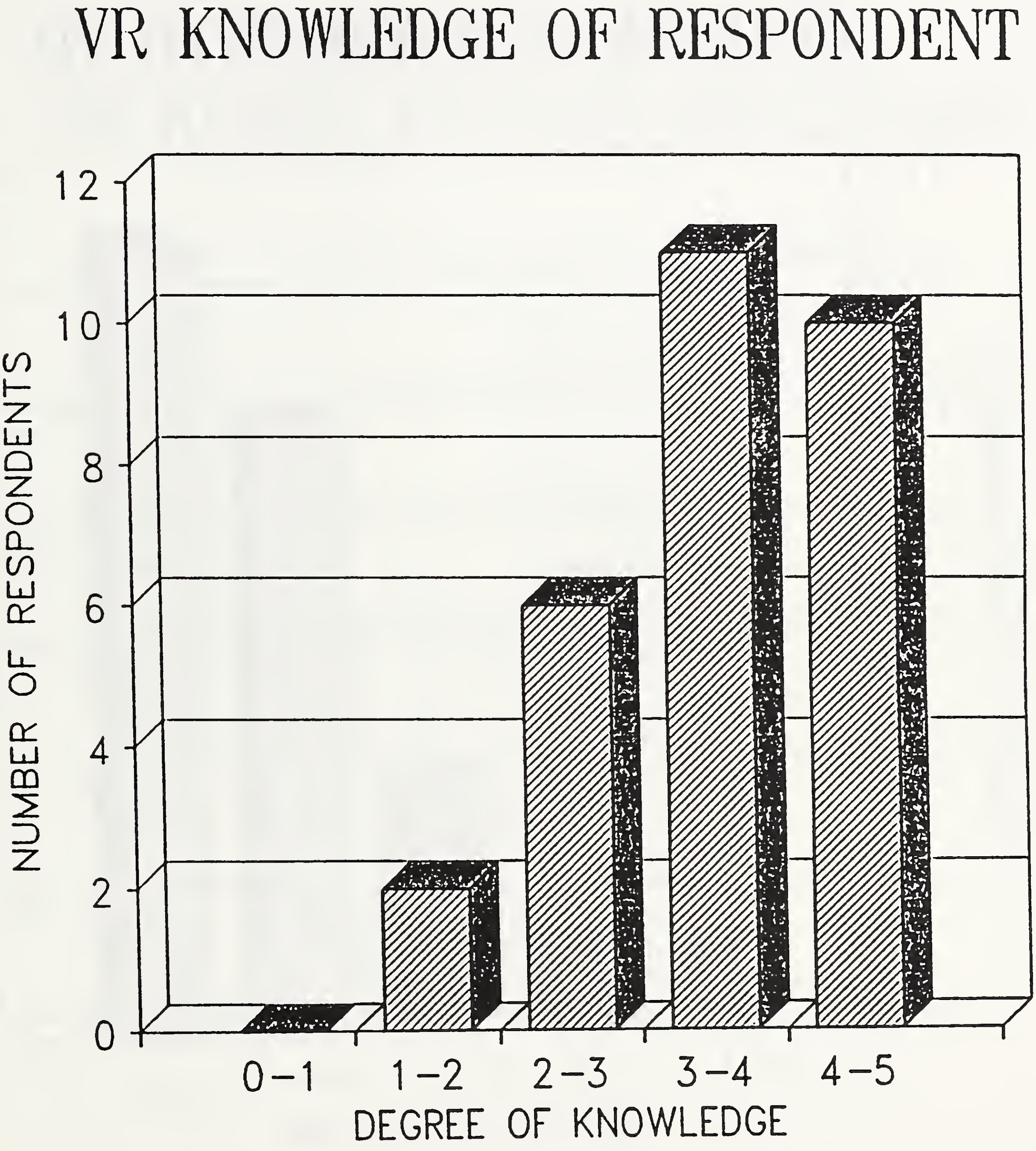

VR KNOWLEDGE OF RESPONDENT
NUMBER OF RESPONDENTS
0
2
4
6
8
10
12
0-1
1-2
2-3
3-4
4-5
DEGREE OF KNOWLEDGE

Figure 2

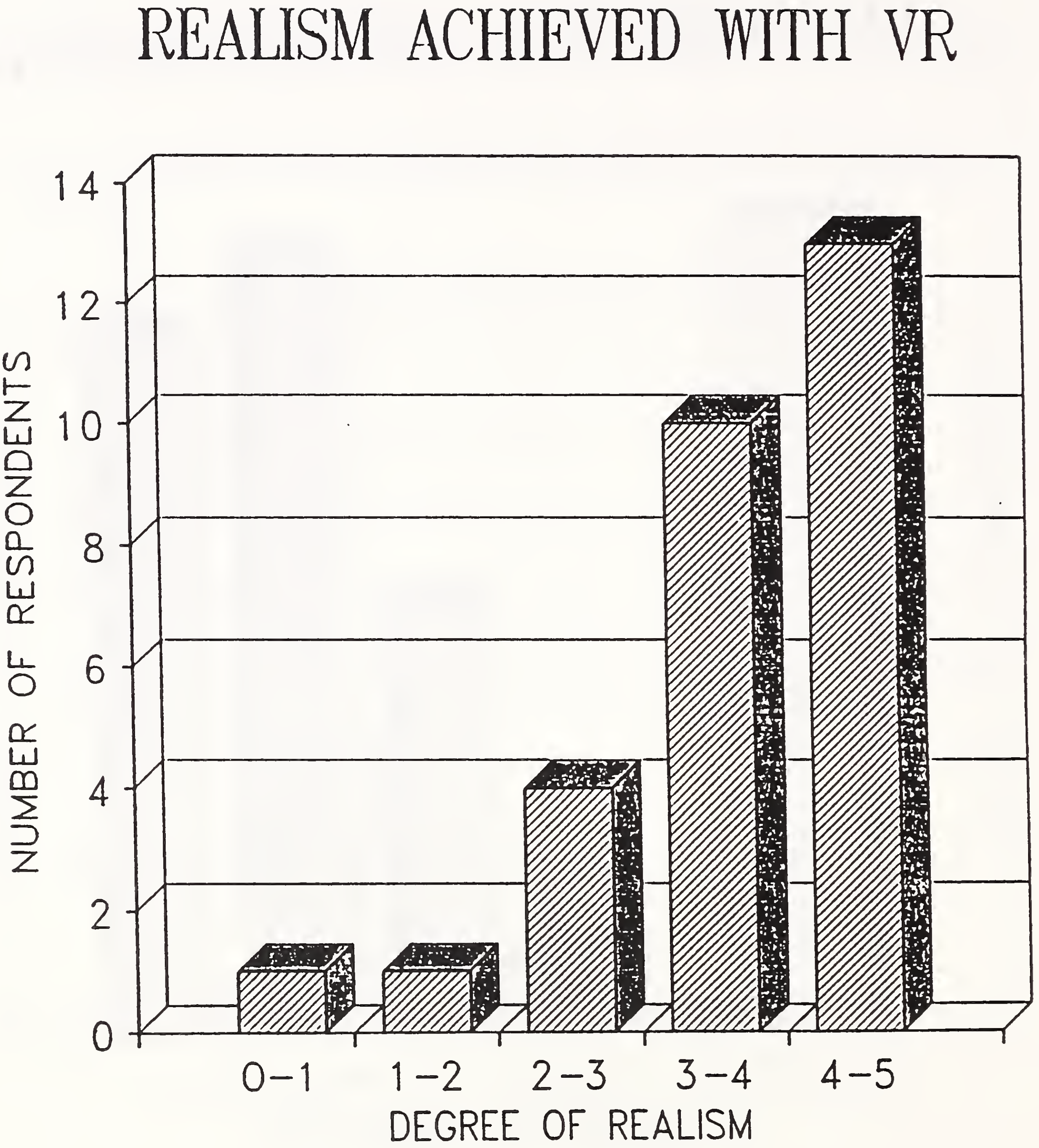

REALISM ACHIEVED WITH VR
NUMBER OF RESPONDENTS
0
2
4
6
8
10
12
14
0-1
1-2
2-3
3-4
4-5
DEGREE OF REALISM

Figure 3

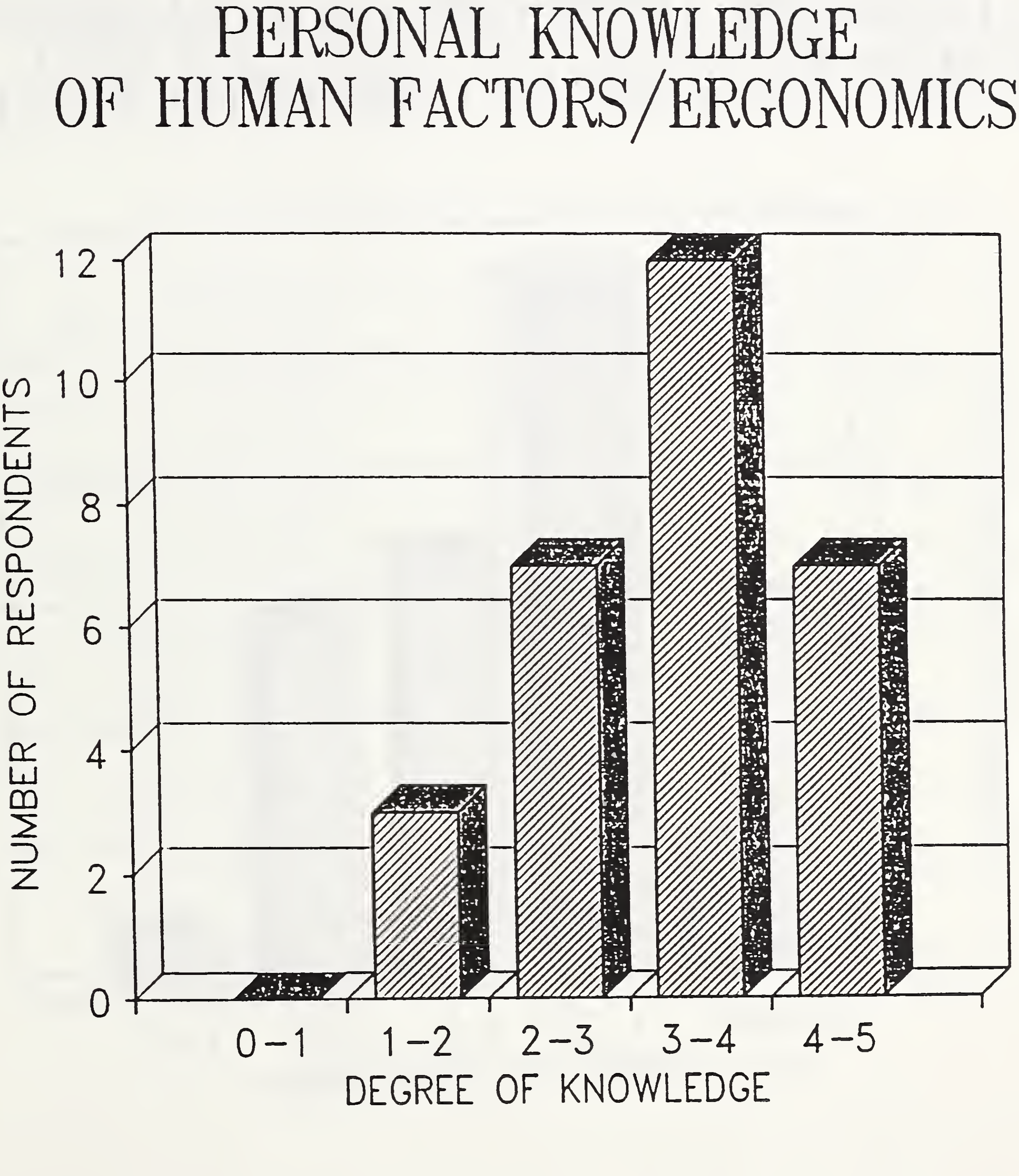

PERSONAL KNOWLEDGE
OF HUMAN FACTORS/ERGONOMICS
NUMBER OF RESPONDENTS
0
2
4
6
8
10
12
0-1
1-2
2-3
3-4
4-5
DEGREE OF KNOWLEDGE

Figure 4

CURRENT LEVEL OF DEVELOPMENT IN HUMAN FACTORS IN COMPUTER INTERFACE

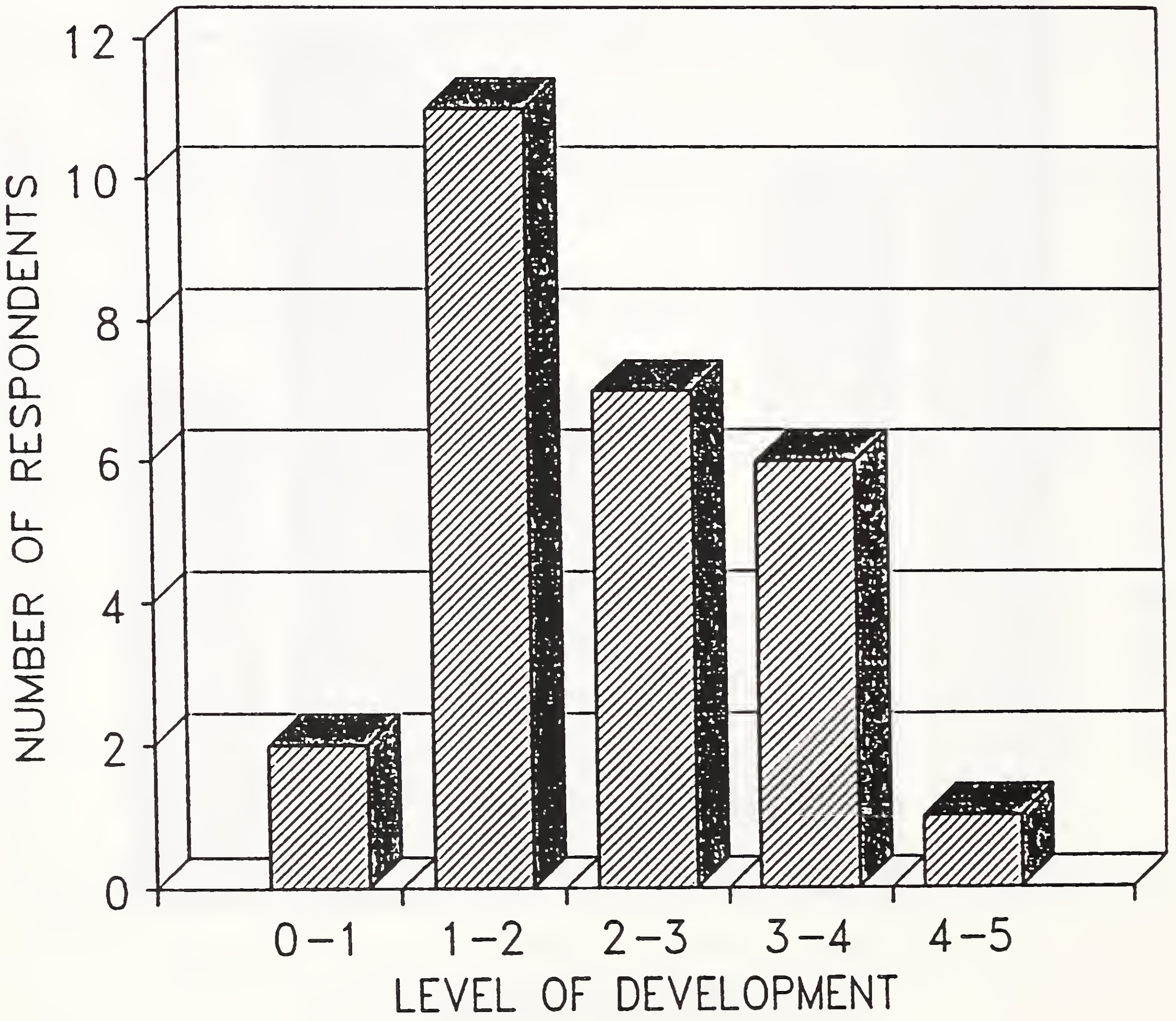


Figure 5

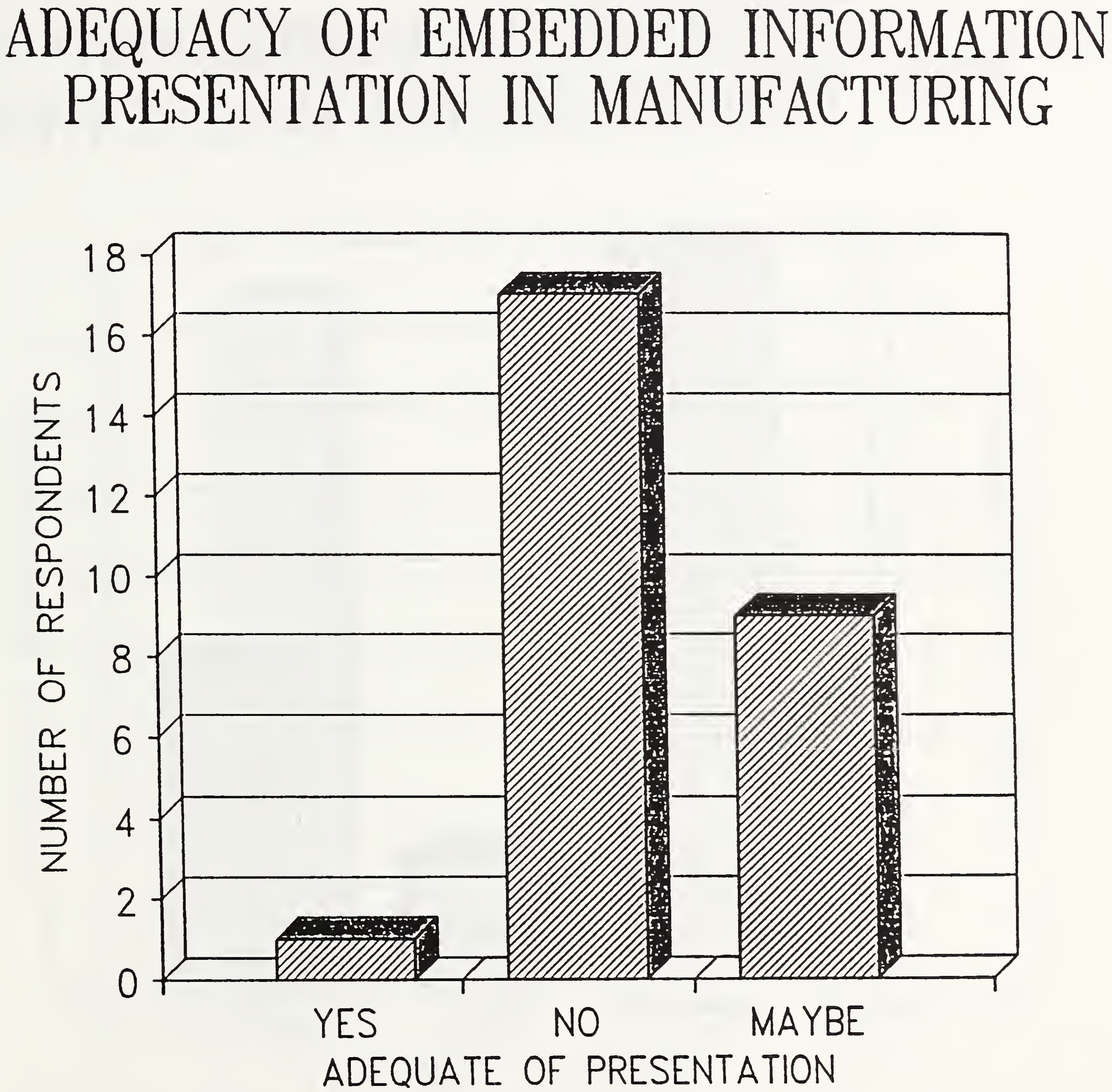

ADEQUACY OF EMBEDDED INFORMATION PRESENTATION IN MANUFACTURING
NUMBER OF RESPONDENTS
0
2
4
6
8
10
12
14
16
18
YES
NO
MAYBE
ADEQUATE OF PRESENTATION

Figure 6

RESPONDENT'S FAMILIARITY WITH TEXT-BASED VR PRESENTATIONS

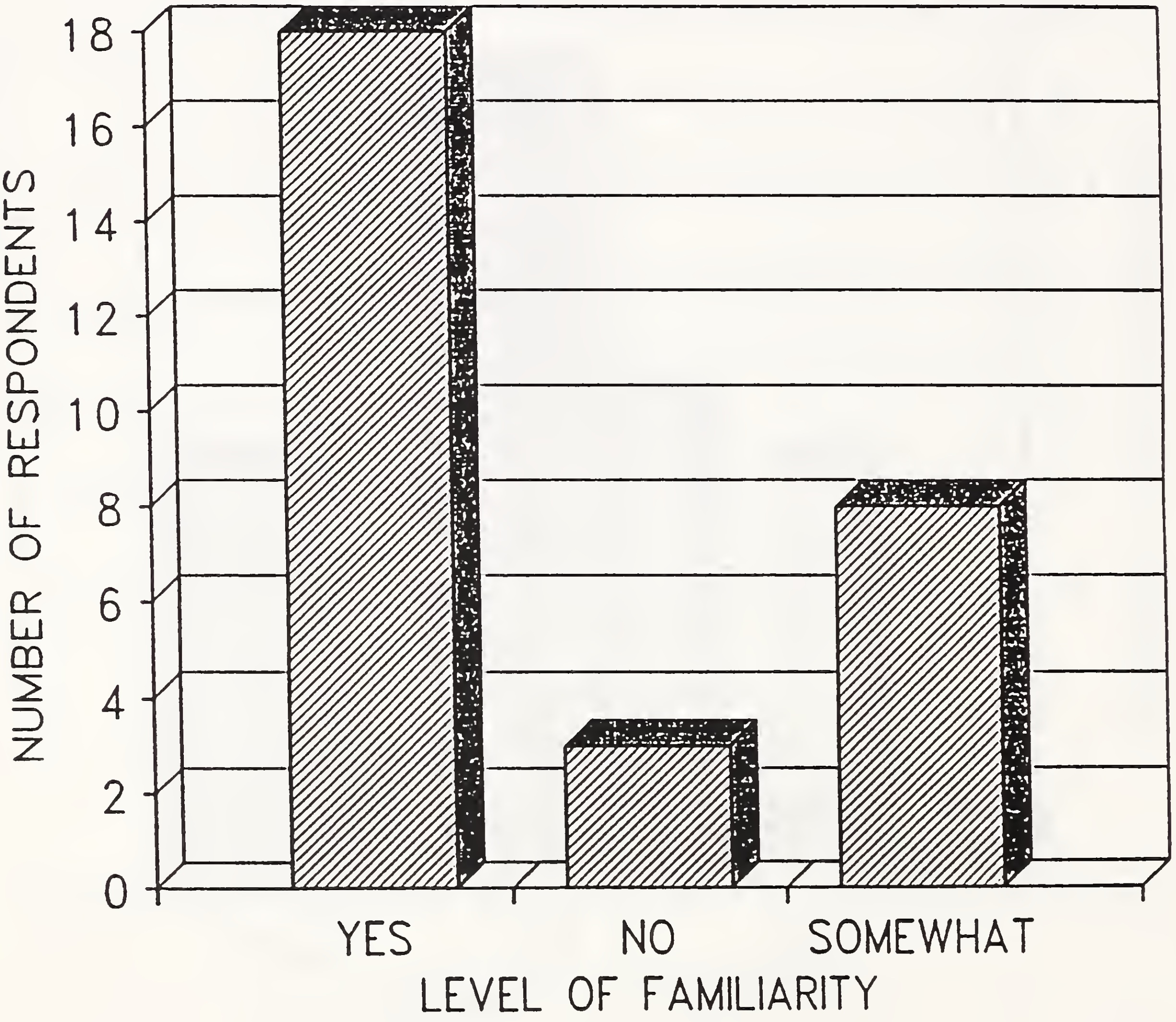


Figure 7

INITIAL TEXT-BASED VR PRESENTATIONS IN MANUFACTURING

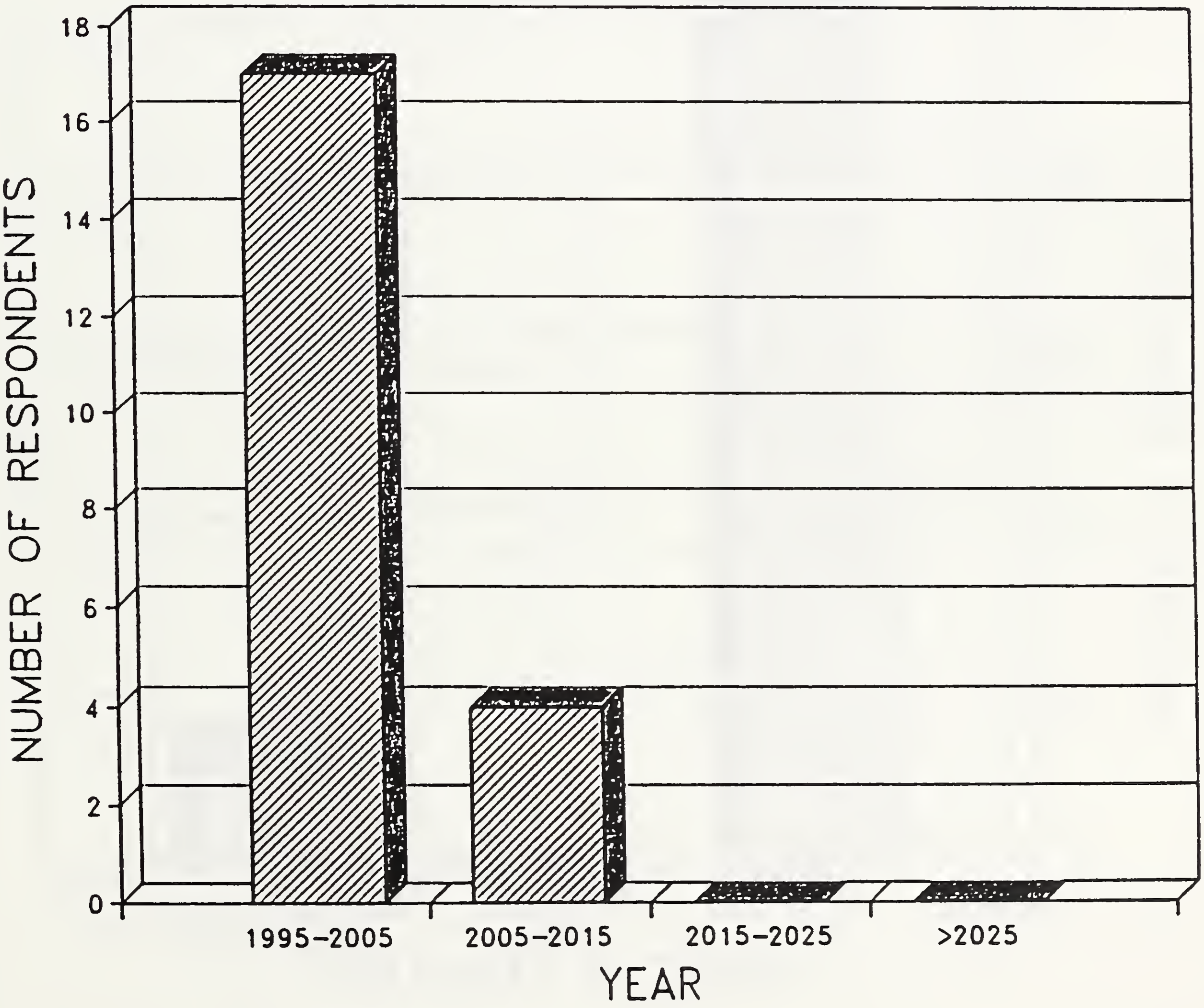


Figure 8

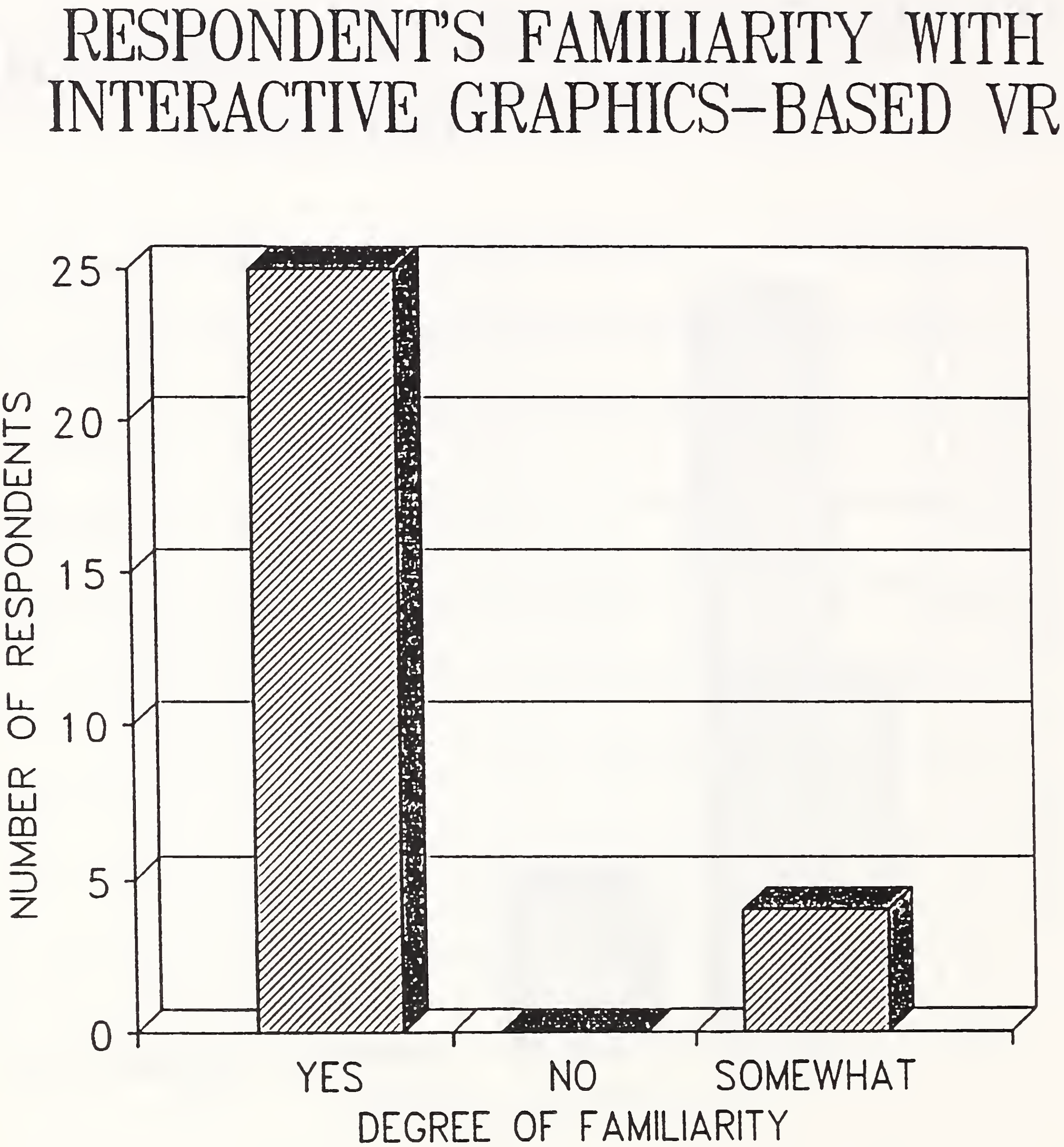

RESPONDENT'S FAMILIARITY WITH INTERACTIVE GRAPHICS-BASED VR
NUMBER OF RESPONDENTS
25
20
15
10
5
0
YES
NO
SOMEWHAT
DEGREE OF FAMILIARITY

Figure 9

INITIAL GRAPHICS-BASED VR PRESENTATIONS IN MANUFACTURING

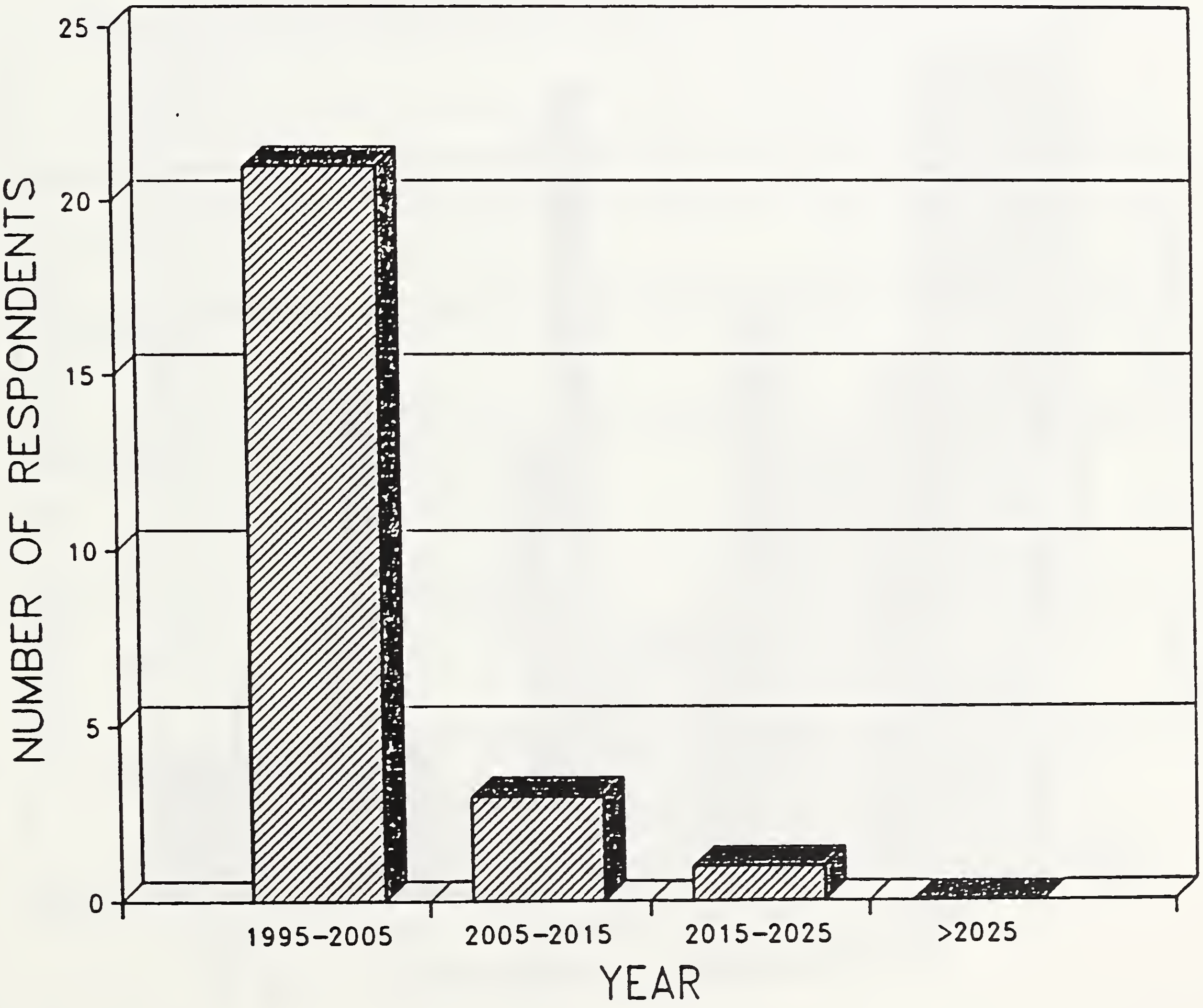


Figure 10

PRIORITIZED FEATURES IN VR PRESENTATION

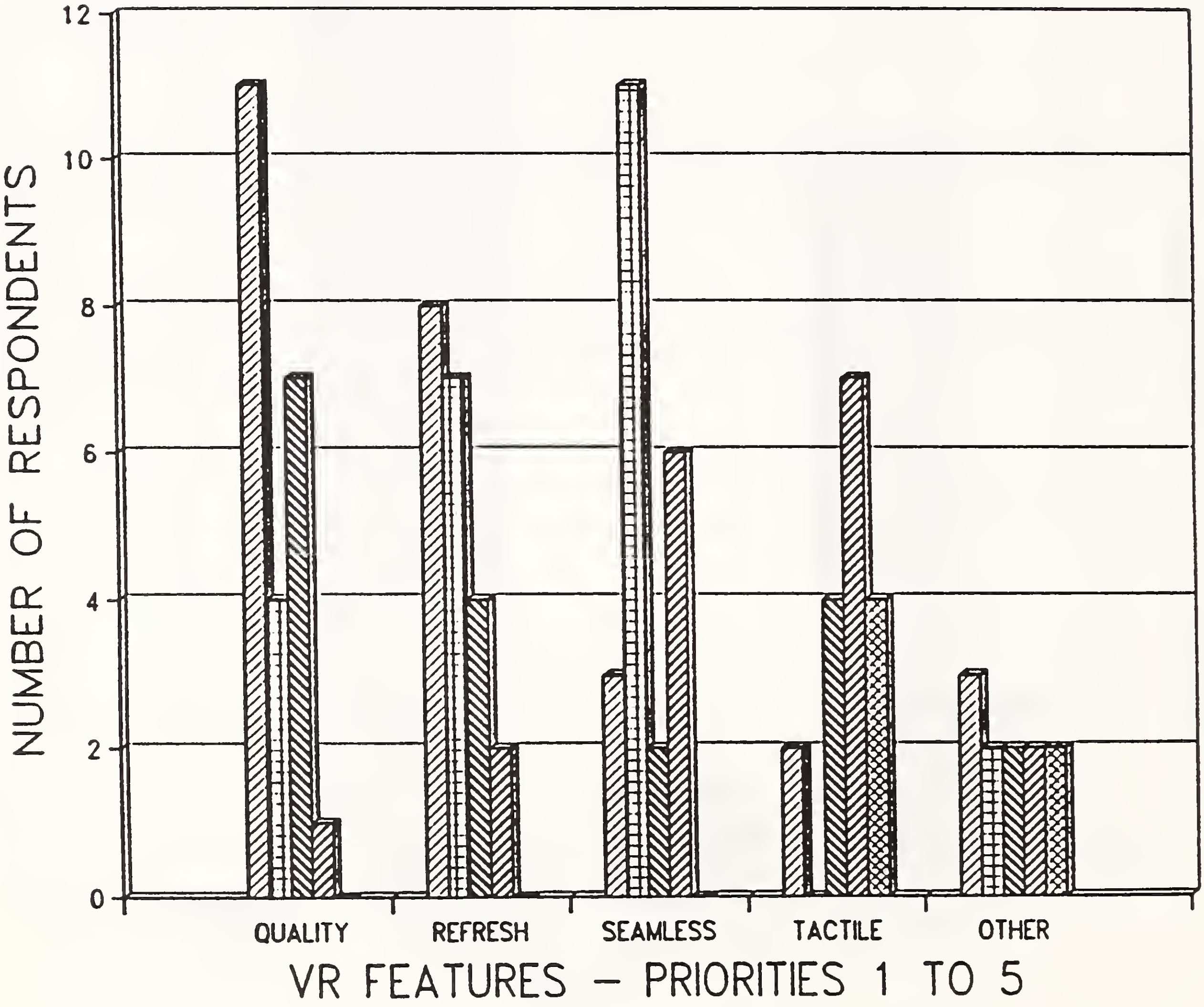


Figure 11

PROBABILITY OF USEFUL AND VALUABLE VR USER INTERFACES IN MANUFACTURING

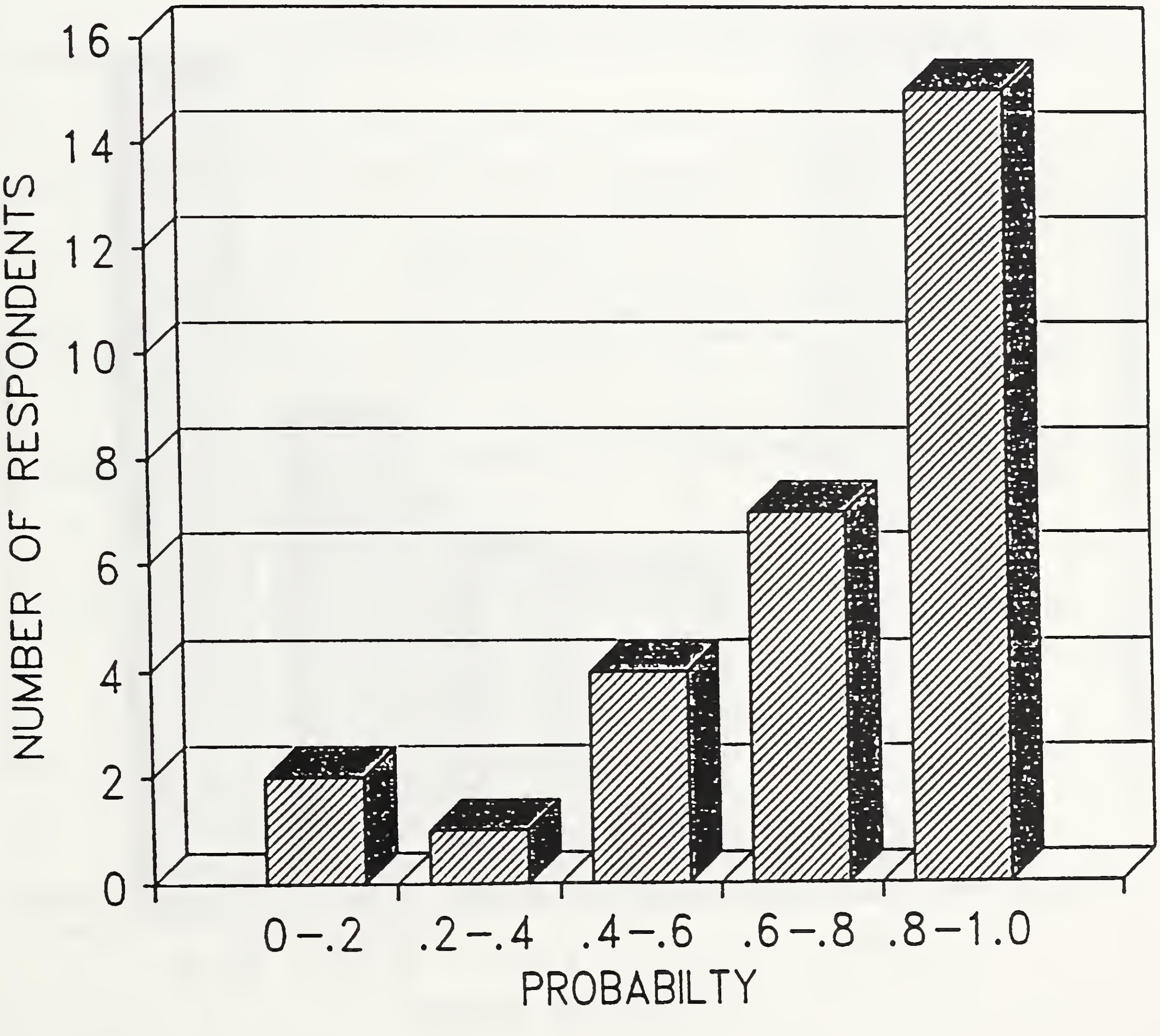


Figure 12

VALUE ADDED WITH CUSTOMIZED PRESENTATIONS IN MANUFACTURING

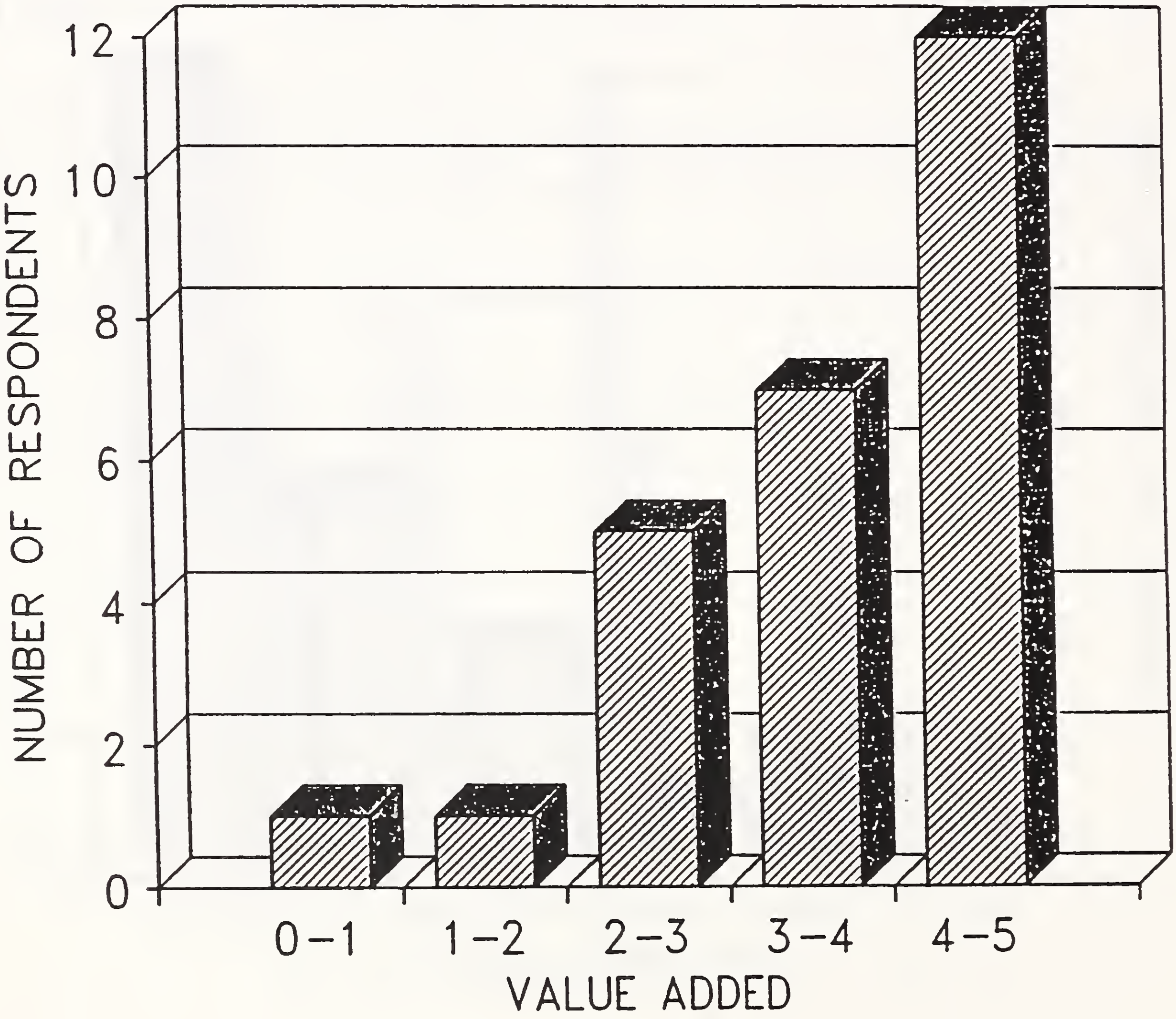


Figure 13

DRIVERS OF INFORMATION AND INTERFACES FOR MANUFACTURING

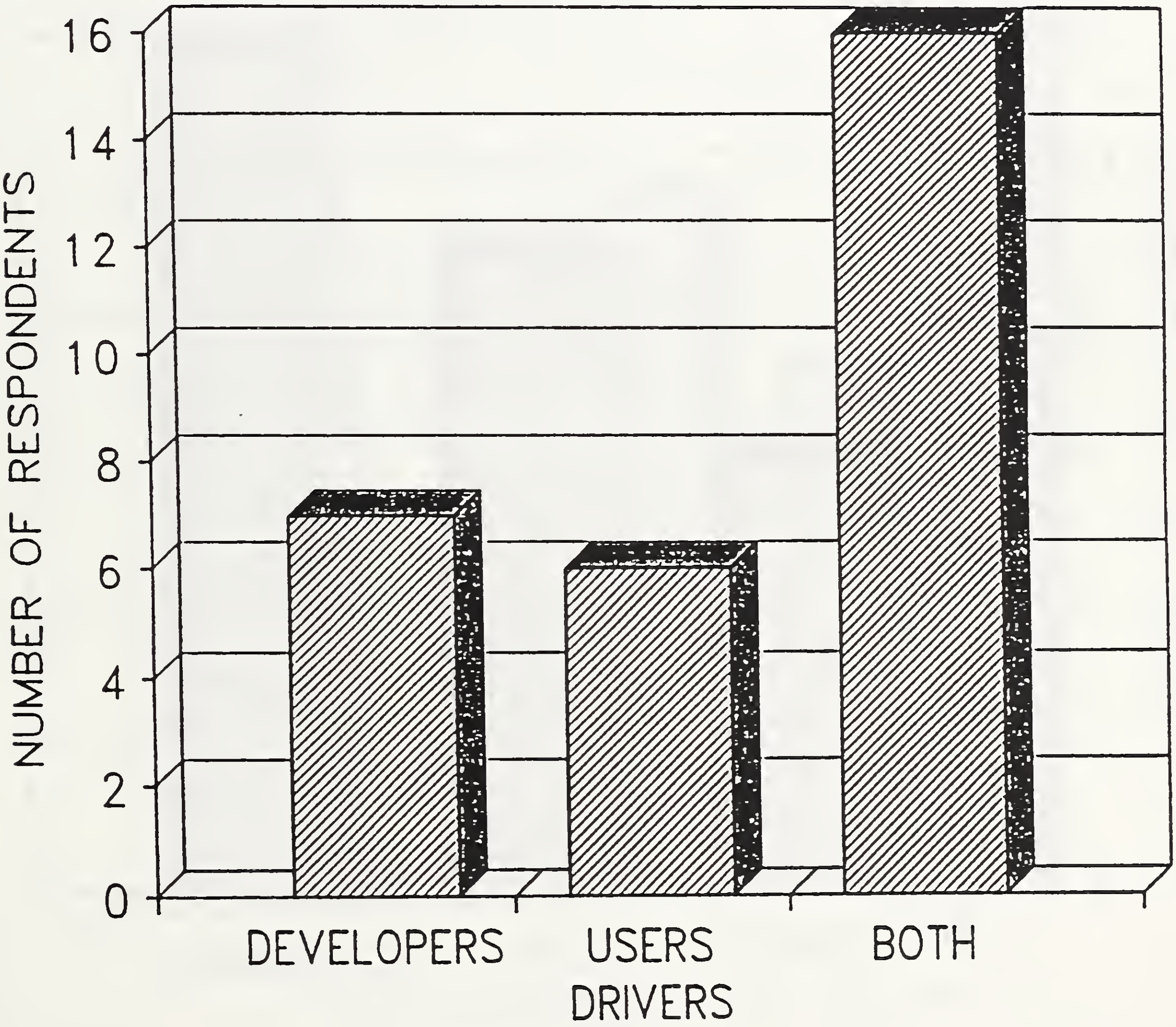


Figure 14

FUNDING SOURCES FOR VR INFORMATION AND INTERFACES FOR MANUFACTURING

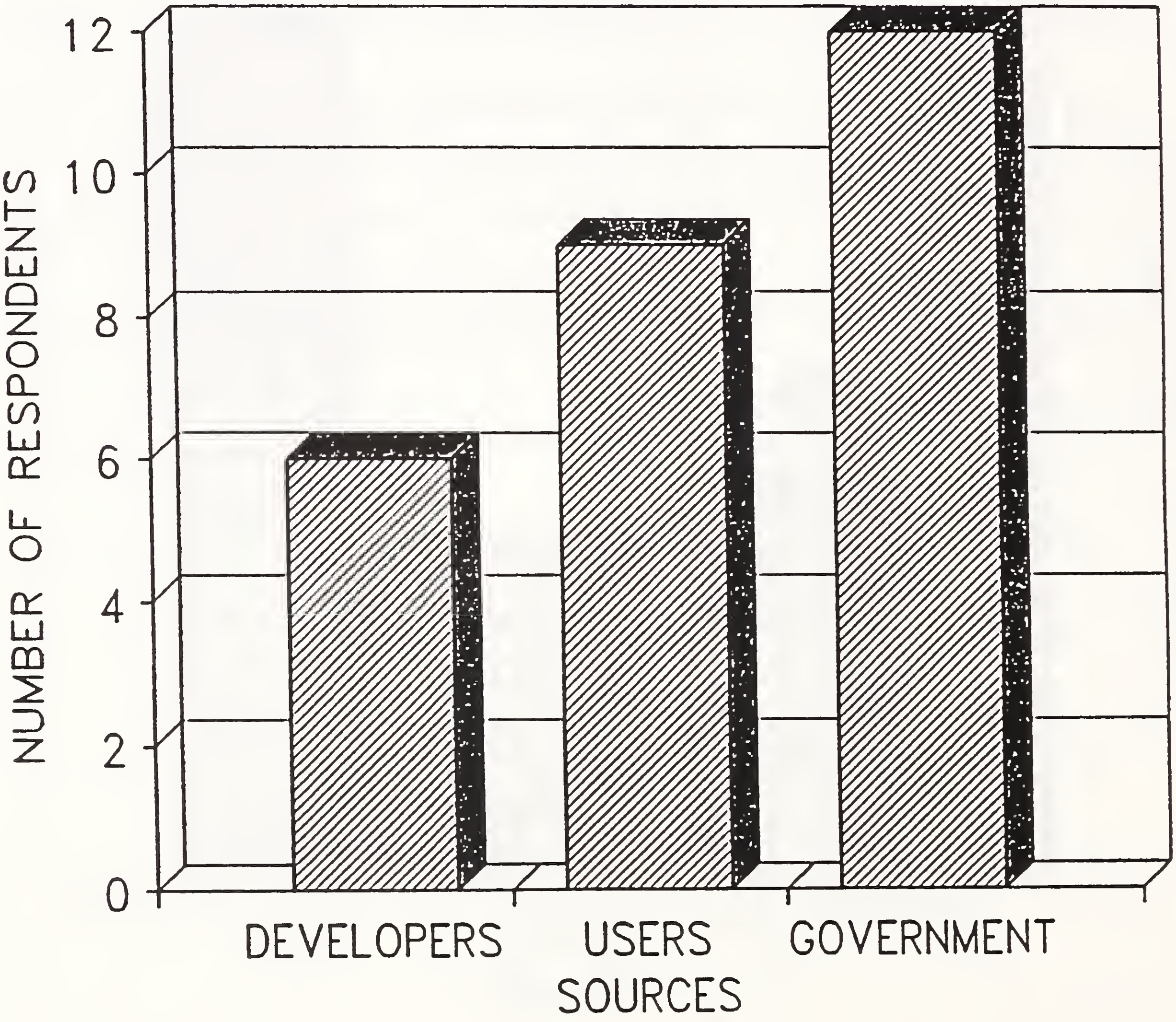


Figure 15

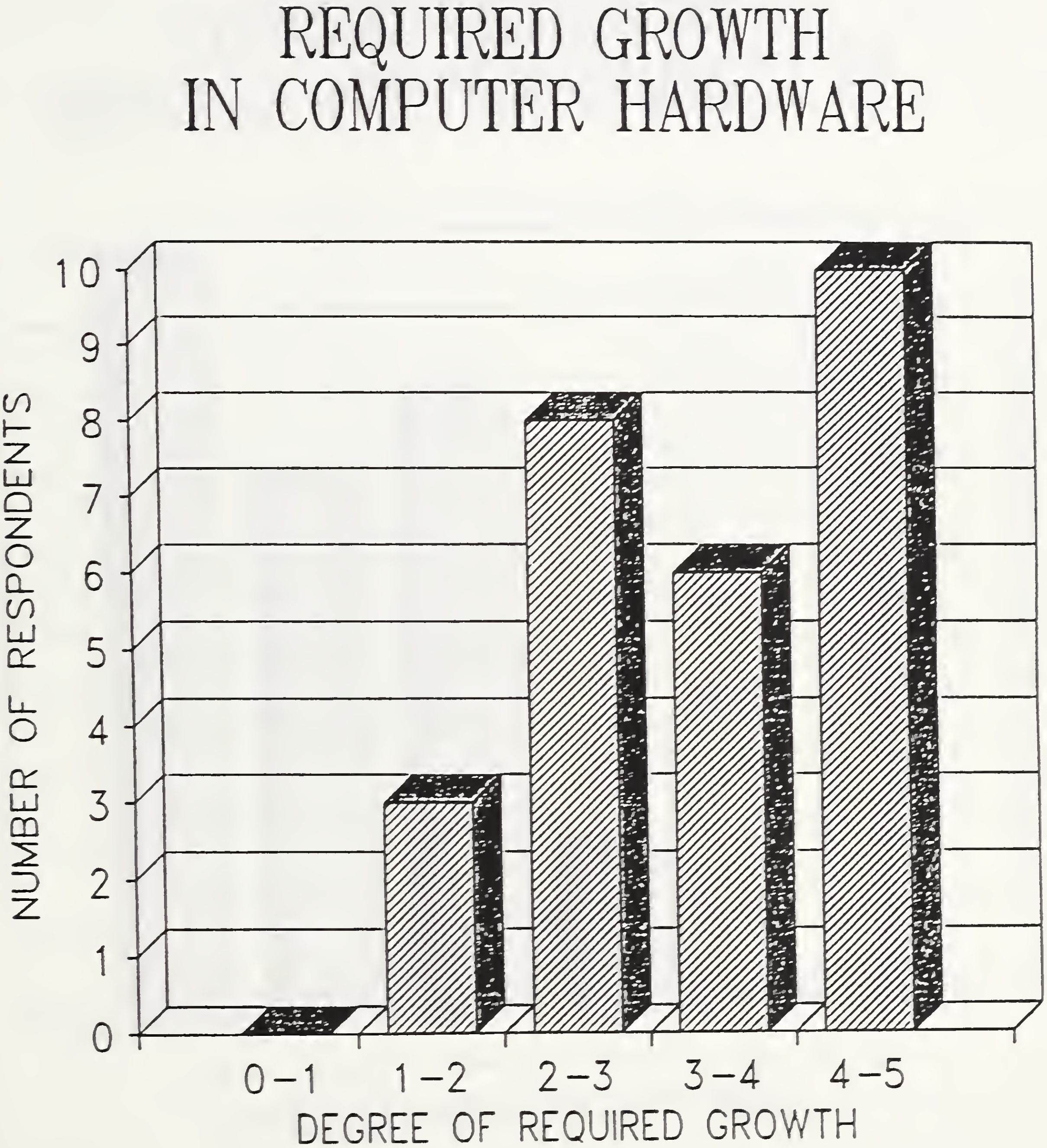

REQUIRED GROWTH
IN COMPUTER HARDWARE
NUMBER OF RESPONDENTS
0
1
2
3
4
5
6
7
8
9
10
0-1
1-2
2-3
3-4
4-5
DEGREE OF REQUIRED GROWTH

Figure 16

REQUIRED GROWTH
IN COMMUNICATION SYSTEMS

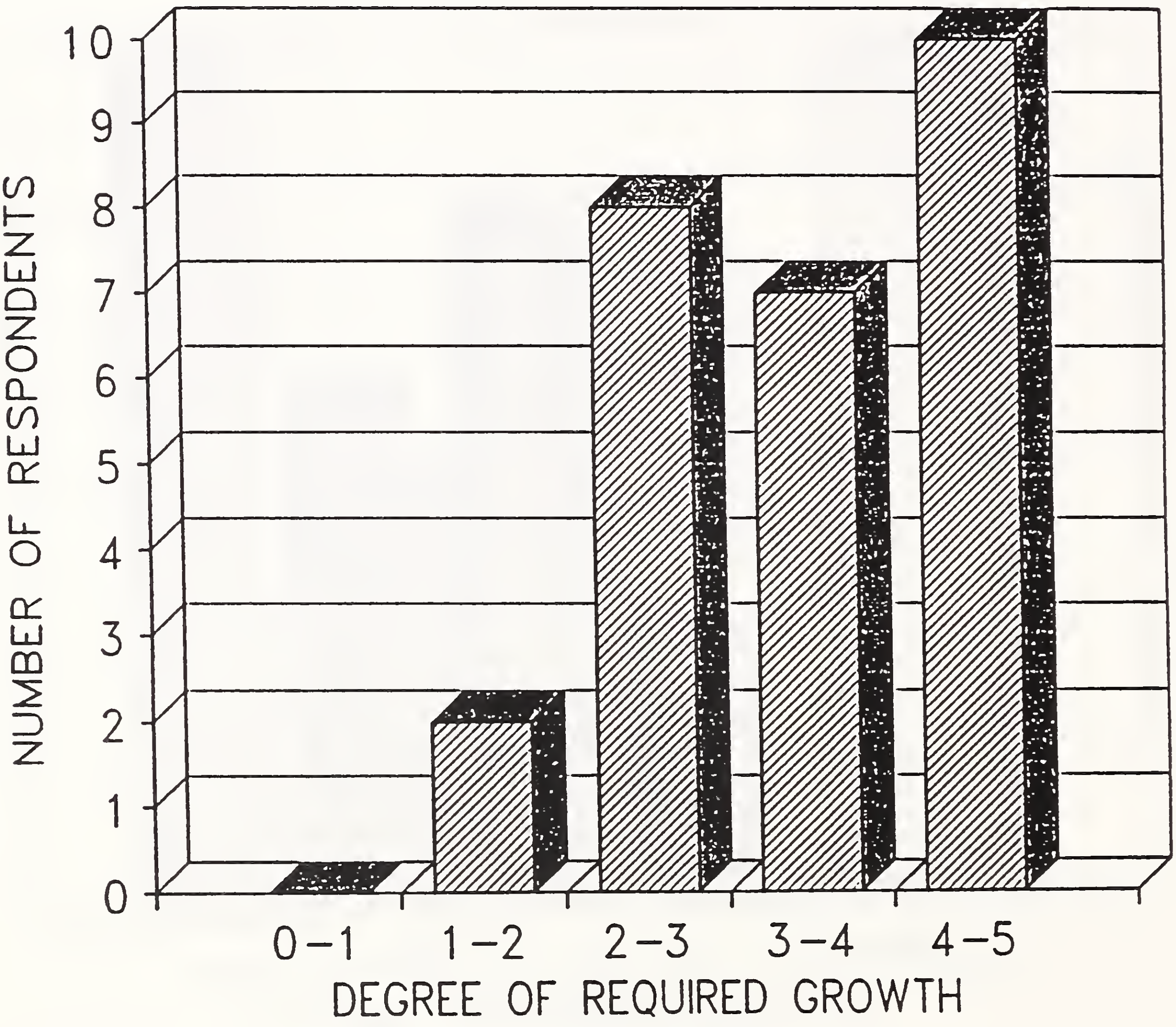


Figure 17

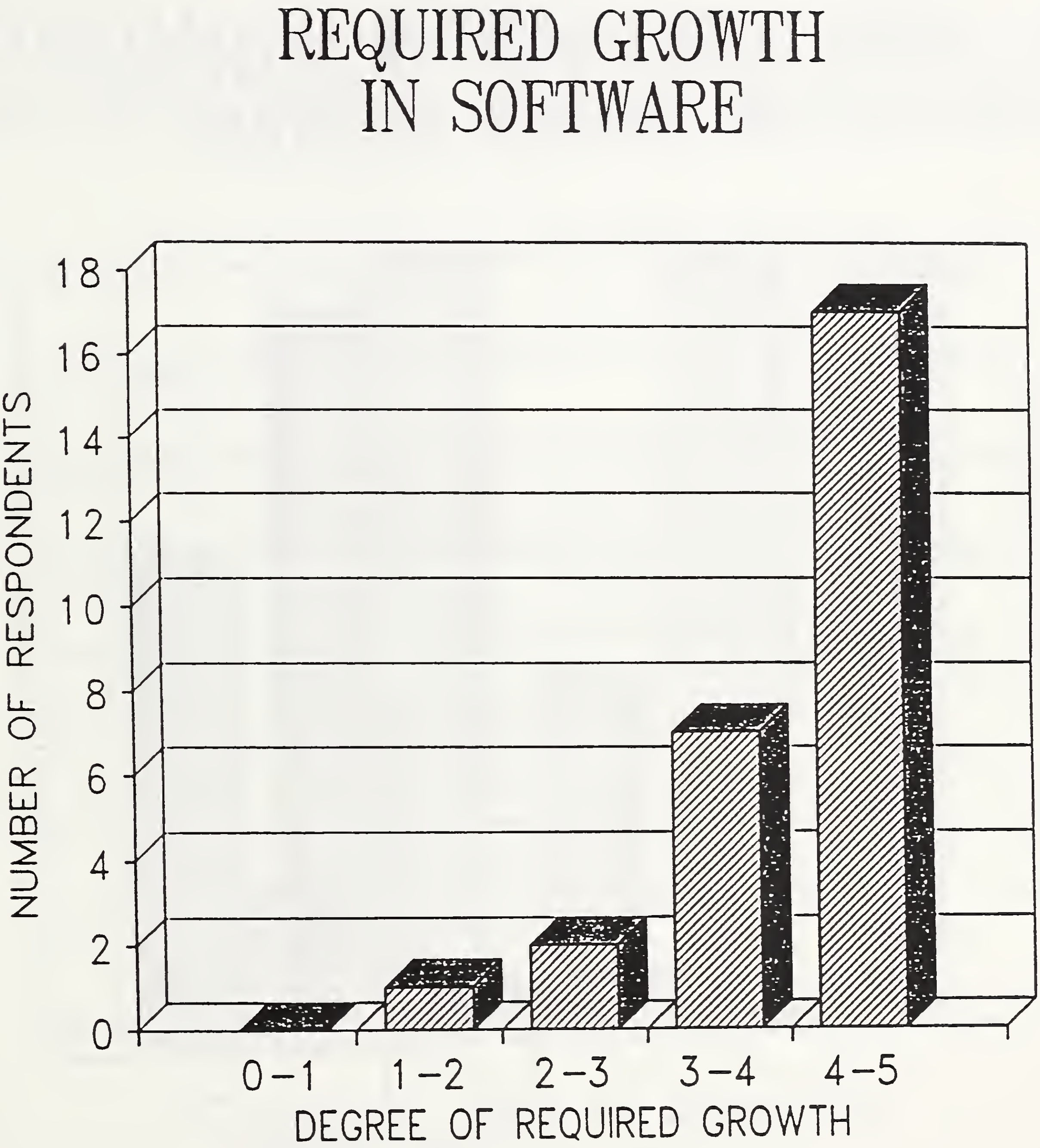

REQUIRED GROWTH
IN SOFTWARE
NUMBER OF RESPONDENTS
0
2
4
6
8
10
12
14
16
18
0-1
1-2
2-3
3-4
4-5
DEGREE OF REQUIRED GROWTH

Figure 18

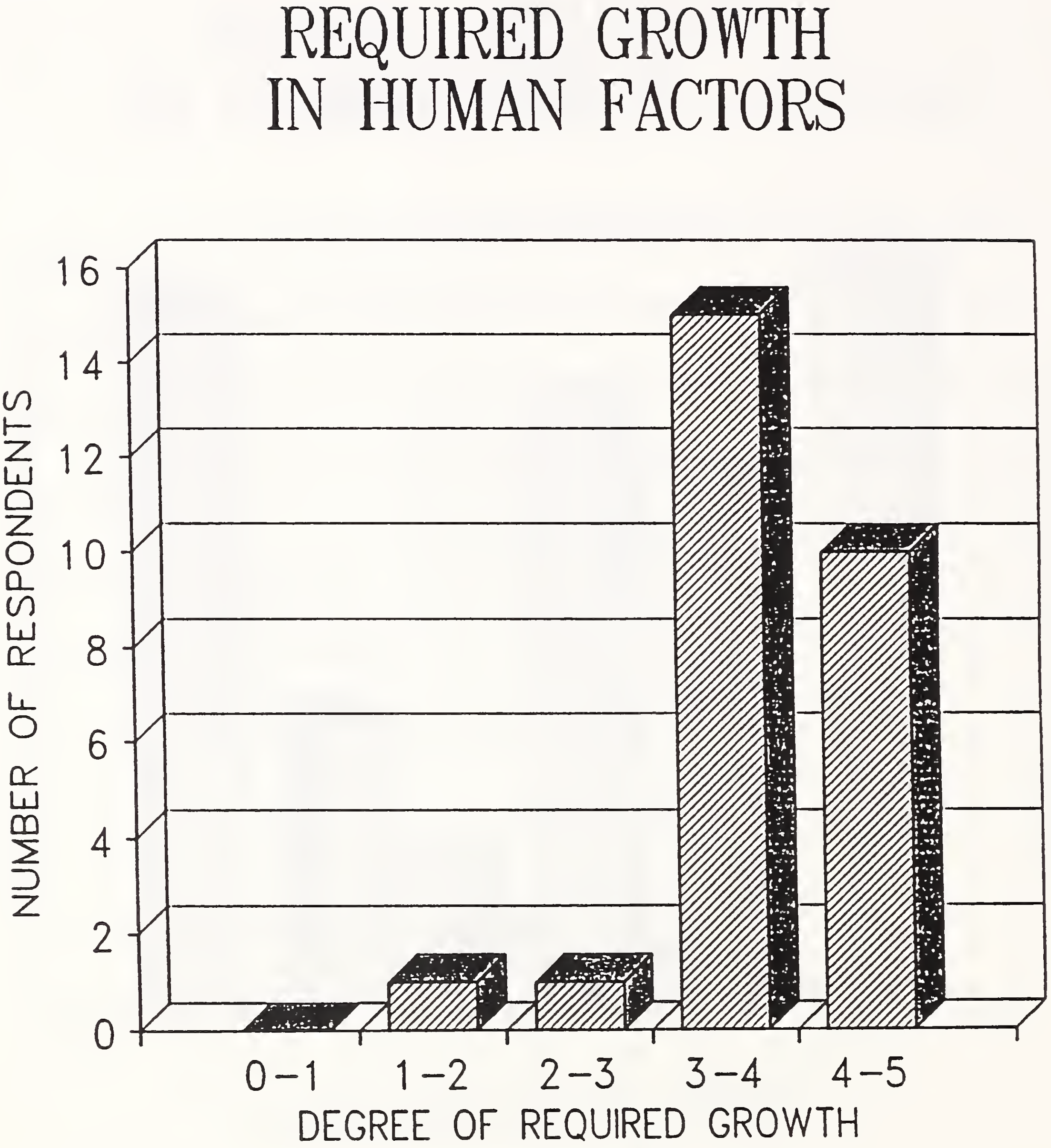

REQUIRED GROWTH IN HUMAN FACTORS
NUMBER OF RESPONDENTS
0
2
4
6
8
10
12
14
16
0-1
1-2
2-3
3-4
4-5
DEGREE OF REQUIRED GROWTH

Figure 19

POTENTIAL TO ACHIEVE STANDARDS, OPEN ARCHITECTURE, AND INTEROPERABILITY

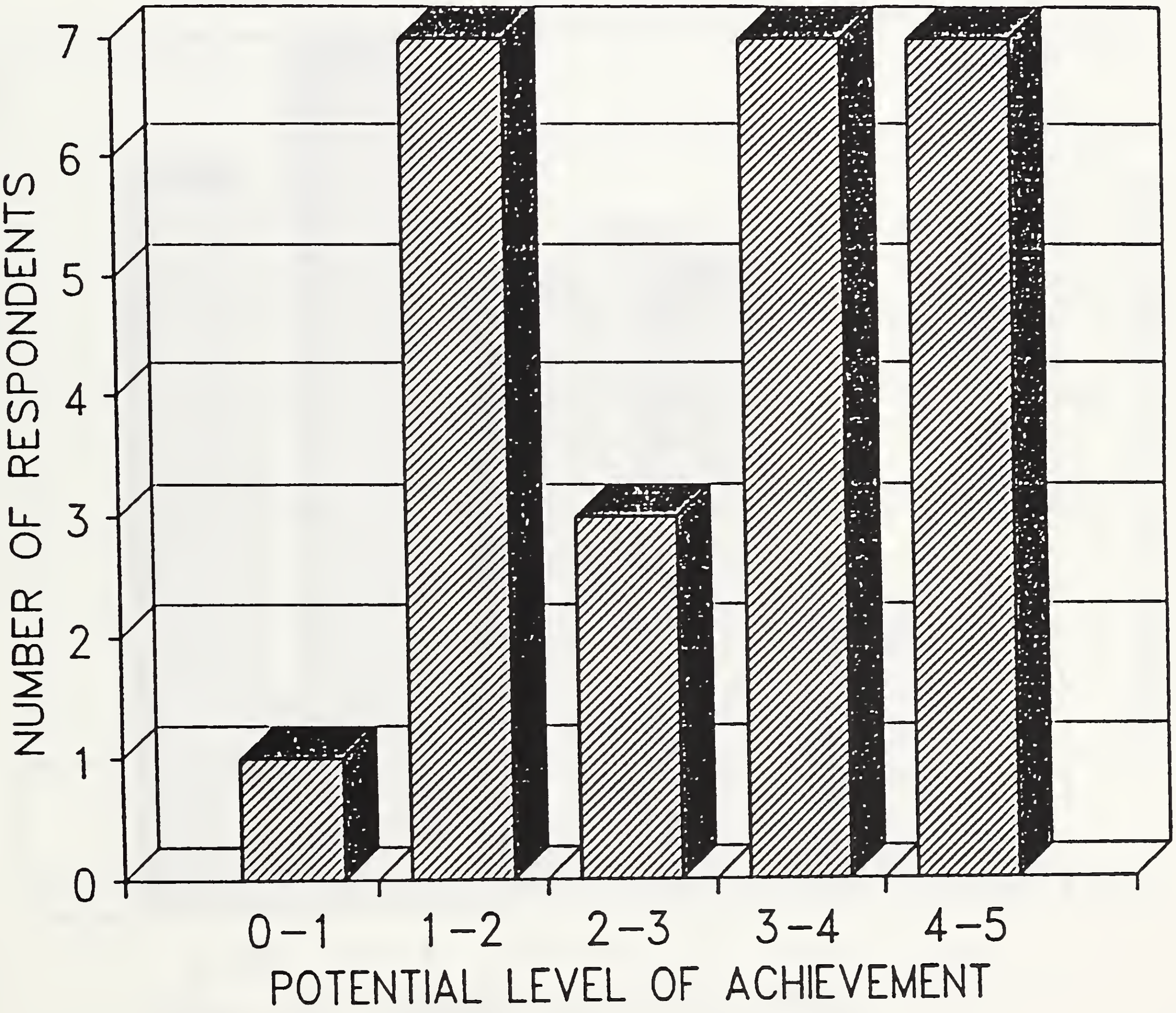


Figure 20

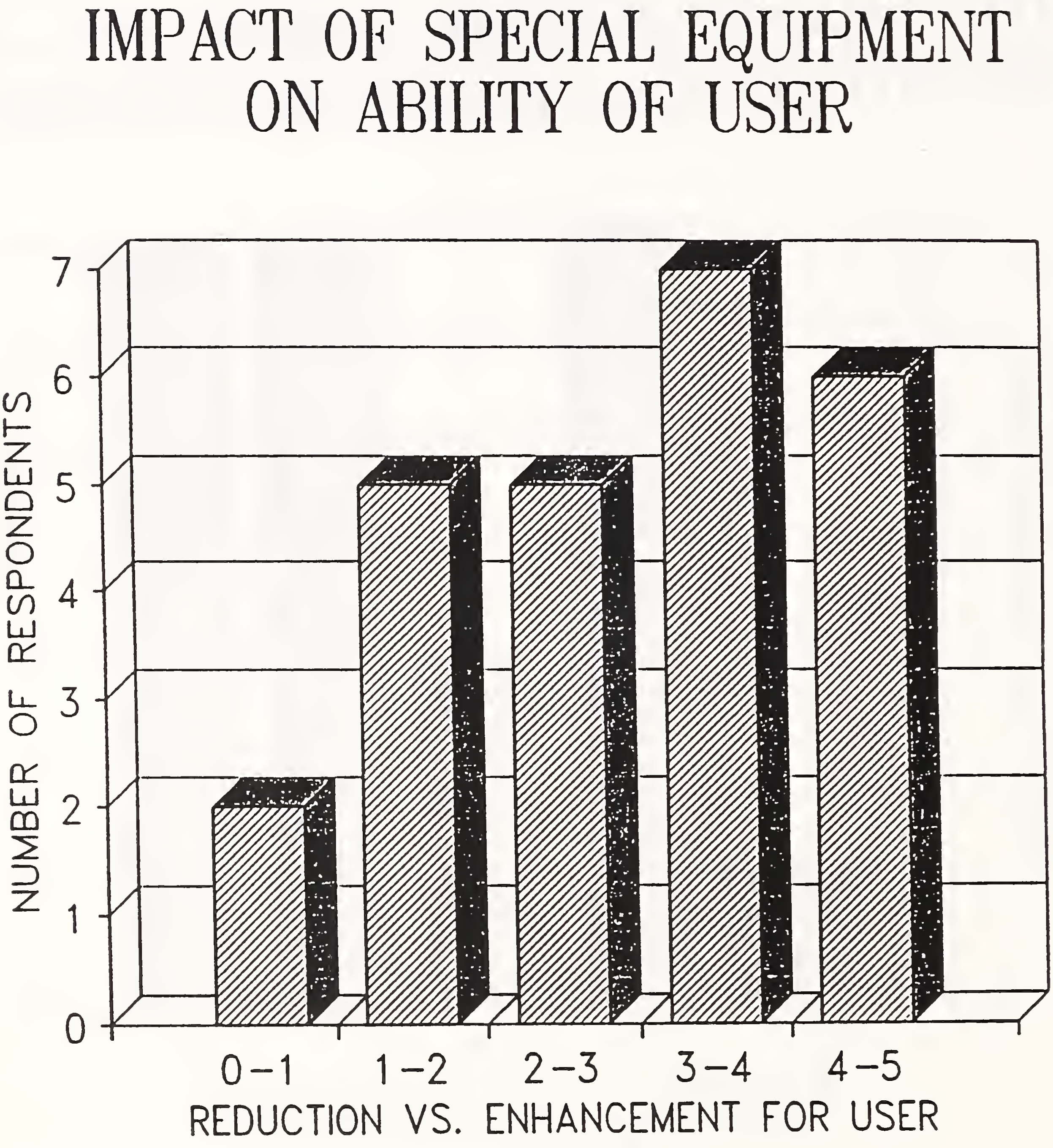

IMPACT OF SPECIAL EQUIPMENT
ON ABILITY OF USER
NUMBER OF RESPONDENTS
0
1
2
3
4
5
6
7
0-1
1-2
2-3
3-4
4-5
REDUCTION VS. ENHANCEMENT FOR USER

Figure 21

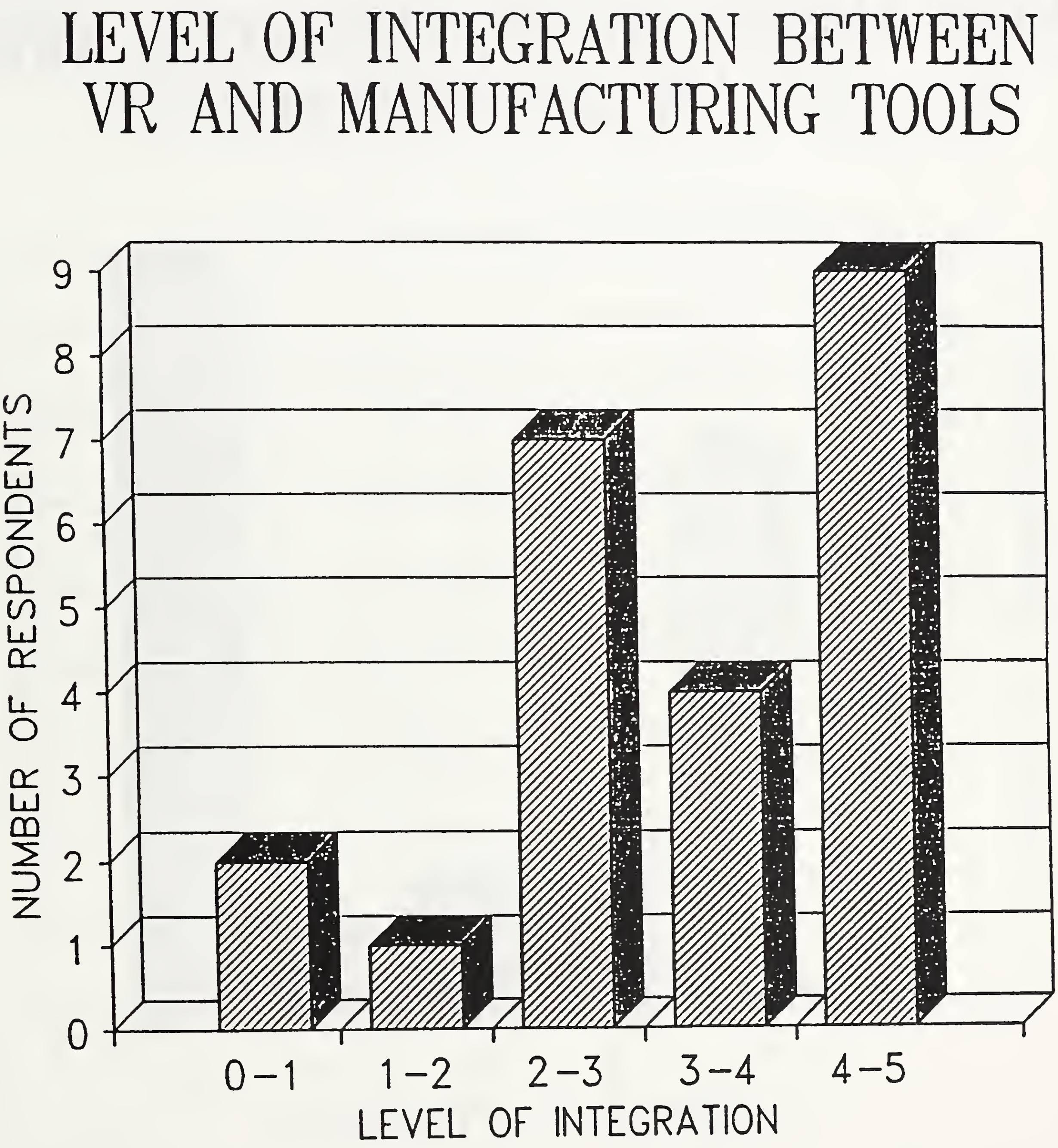

LEVEL OF INTEGRATION BETWEEN VR AND MANUFACTURING TOOLS
NUMBER OF RESPONDENTS
0
1
2
3
4
5
6
7
8
9
0-1
1-2
2-3
3-4
4-5
LEVEL OF INTEGRATION

Figure 22

APPLICABILITY OF PRESENTATION FIDELITY
IN VR-BASED TRAINING

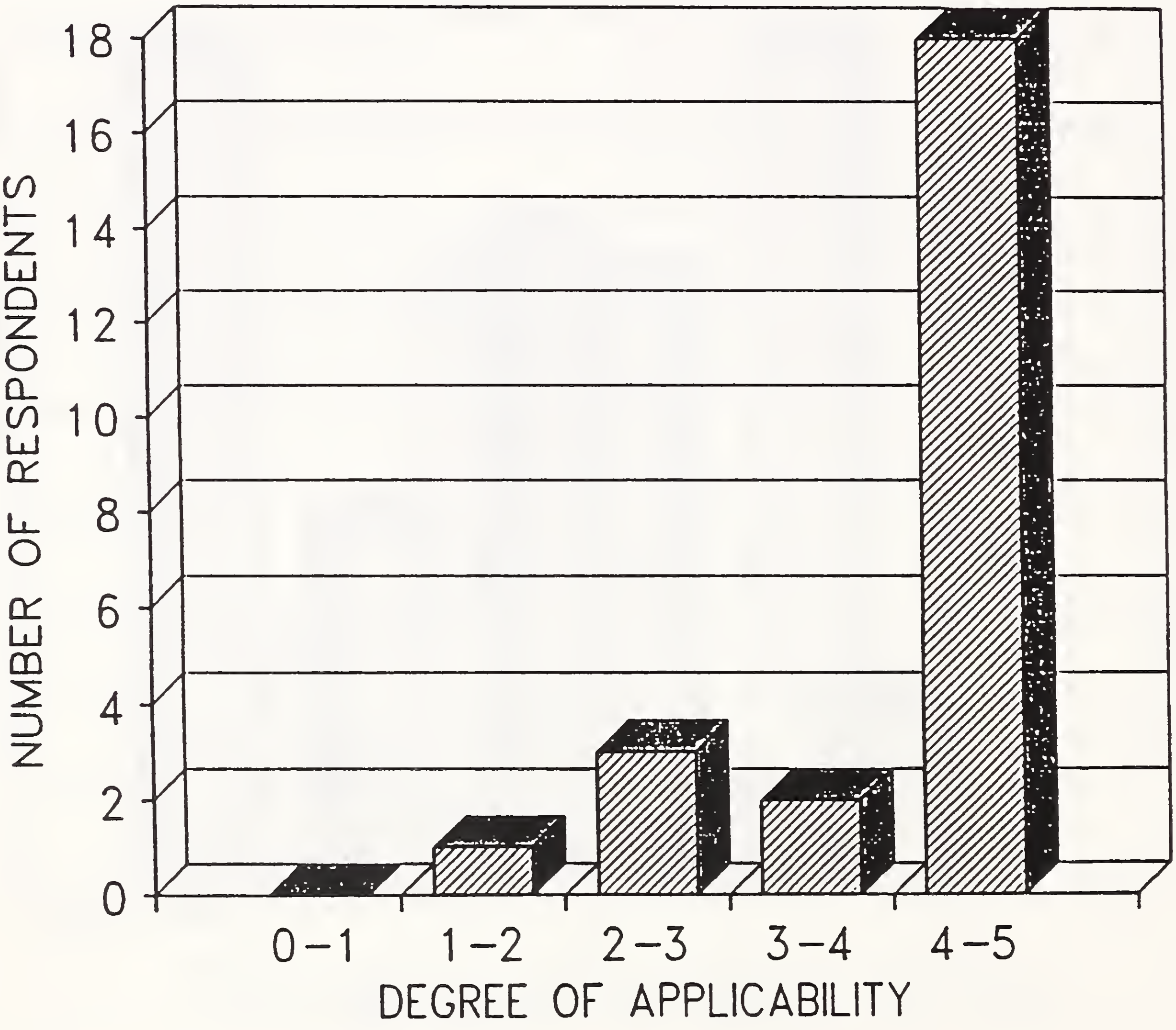


Figure 23

APPLICABILITY OF PRESENTATION FIDELITY IN VR-BASED PRODUCT DESIGN

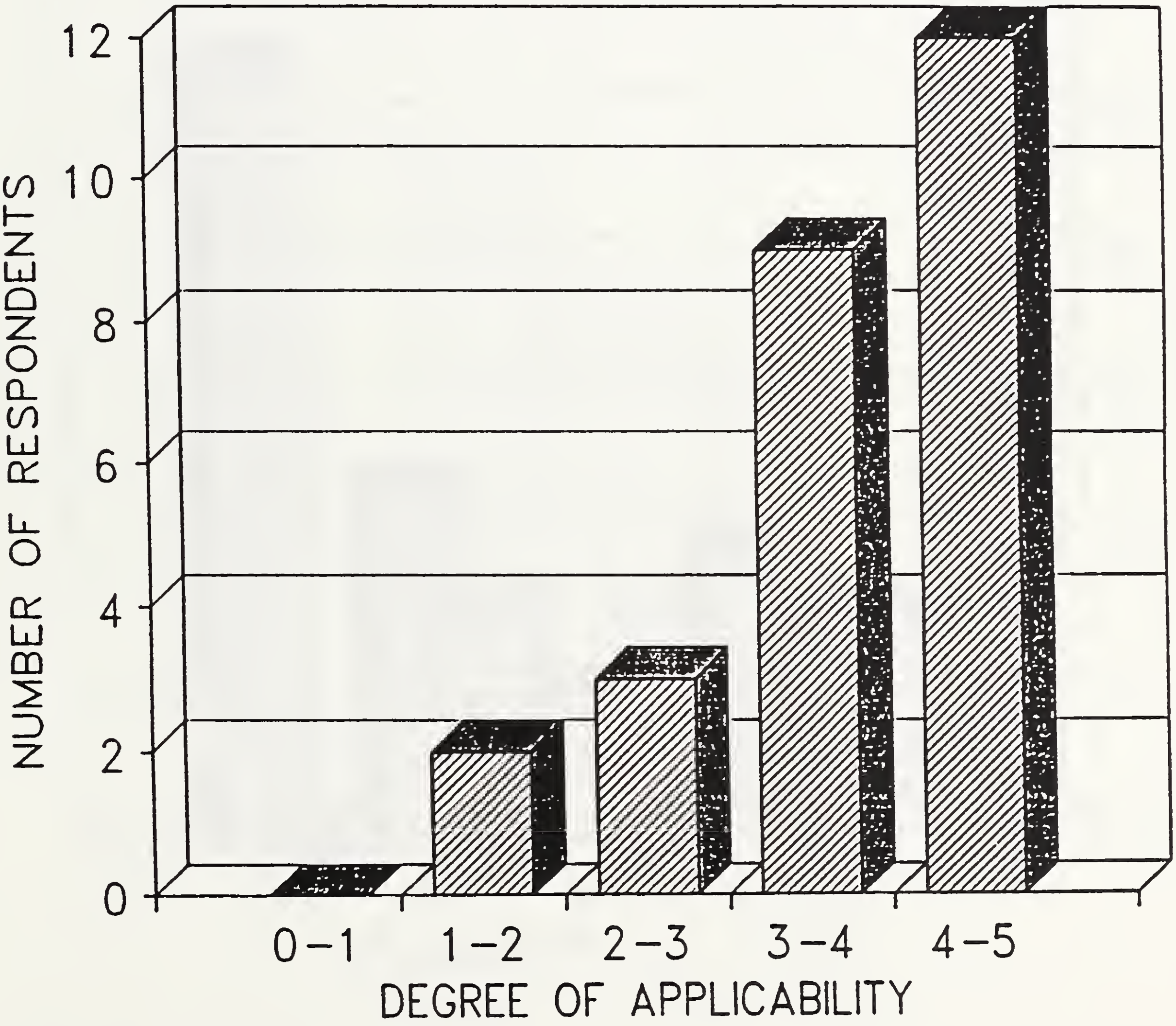


Figure 24

APPLICABILITY OF PRESENTATION FIDELITY IN VR-BASED PROCESS DESIGN

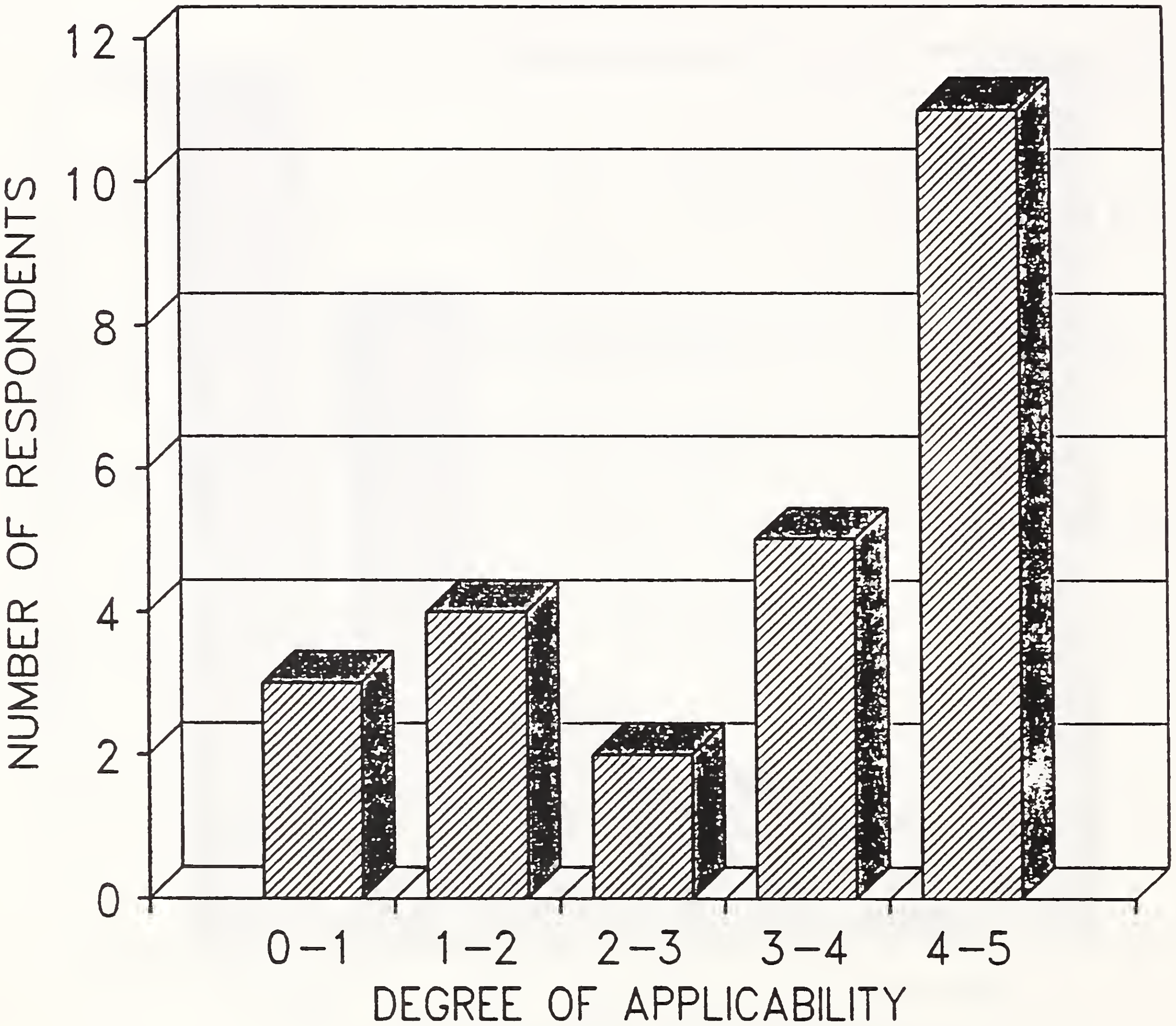


Figure 25

APPLICABILITY OF PRESENTATION FIDELITY IN VR–BASED PROCESS VALIDATION

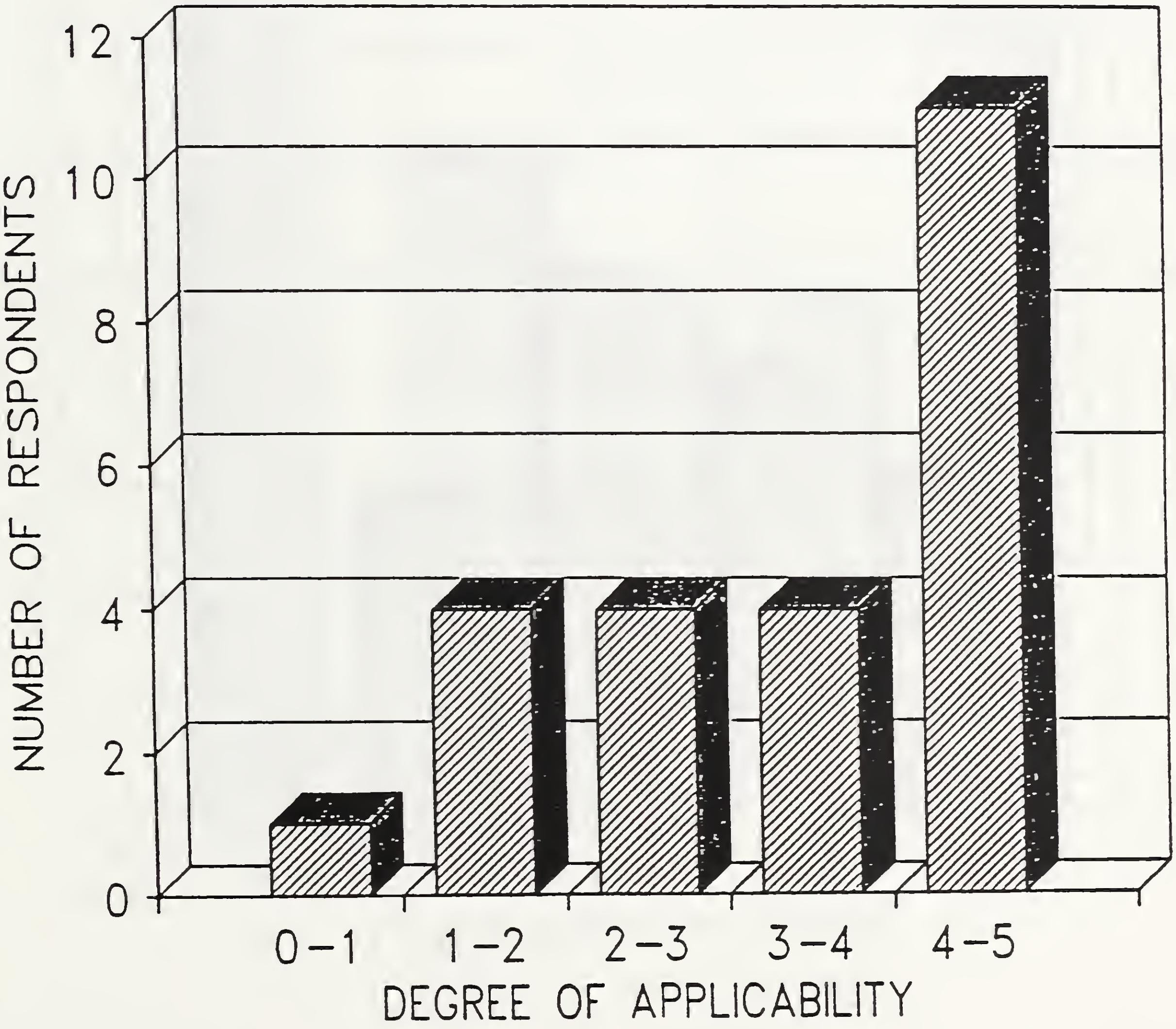


Figure 26

APPLICABILITY OF PRESENTATION FIDELITY IN VR-BASED ENTERPRISE INTEGRATION

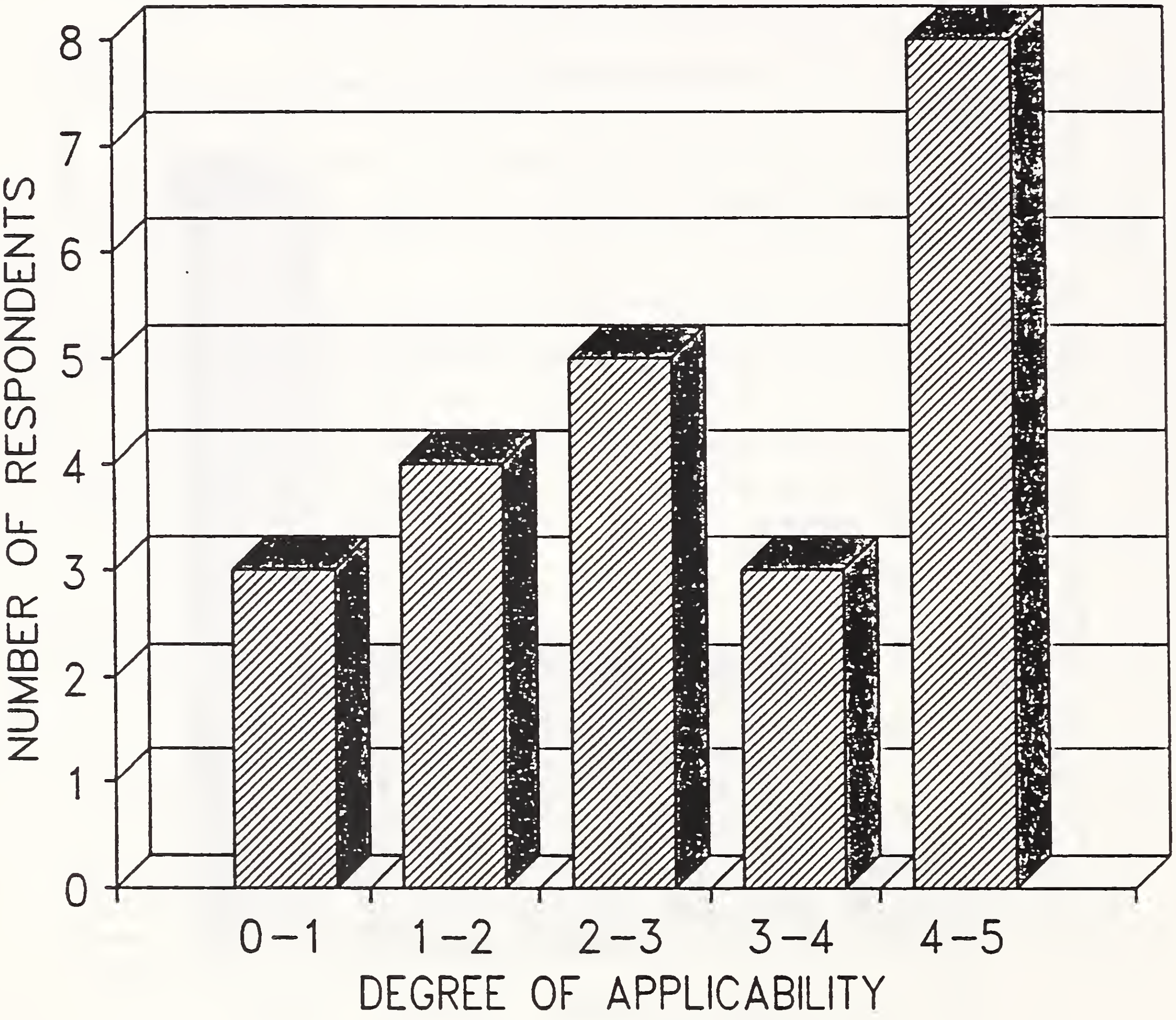


Figure 27

AFFORDING CUSTOMIZED INFORMATION PRESENTATION IN VR INTERFACES

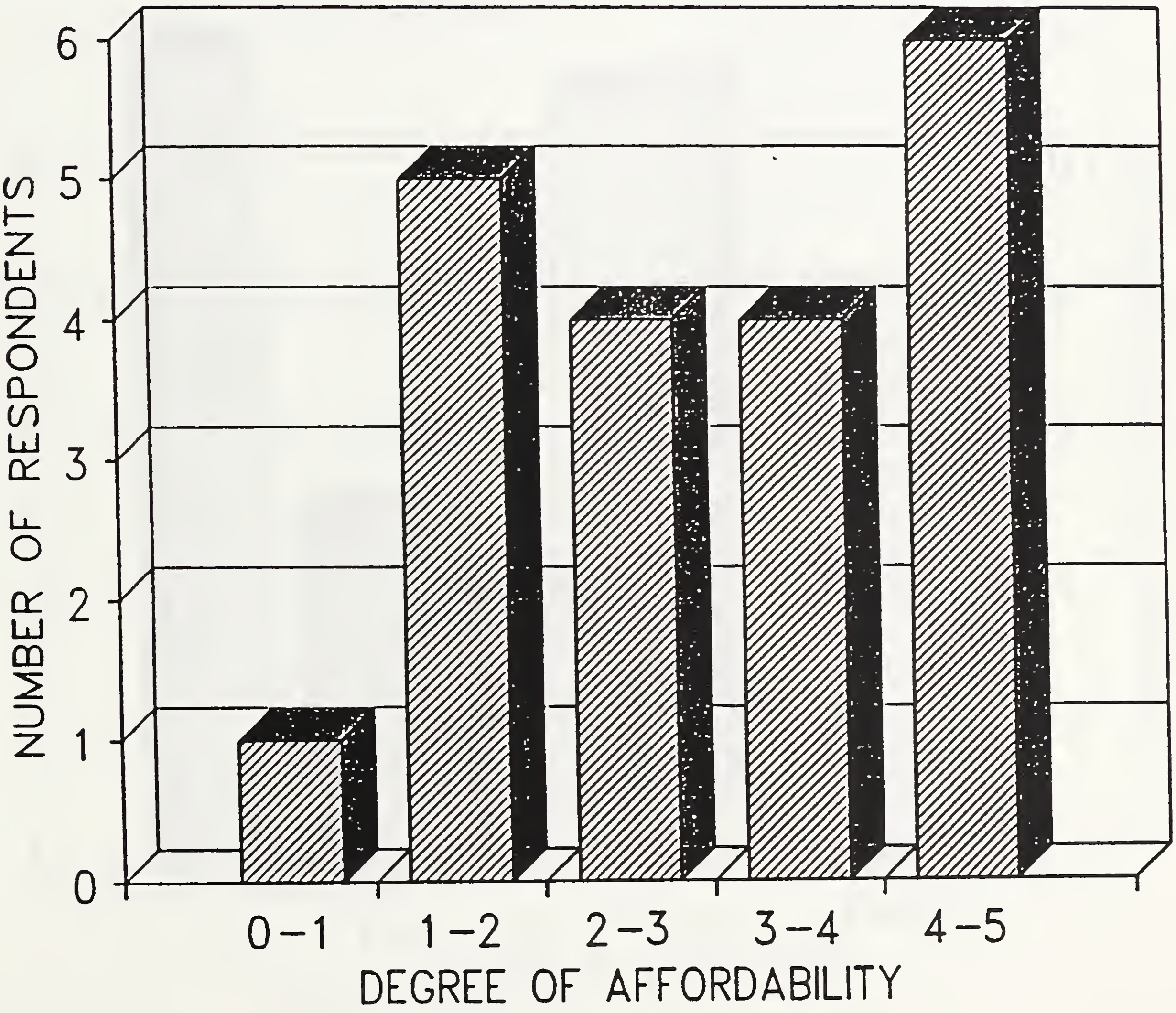


Figure 28

EFFECT OF EQUIPMENT COST ON ACCEPTANCE OF A VIRTUAL WORKPLACE

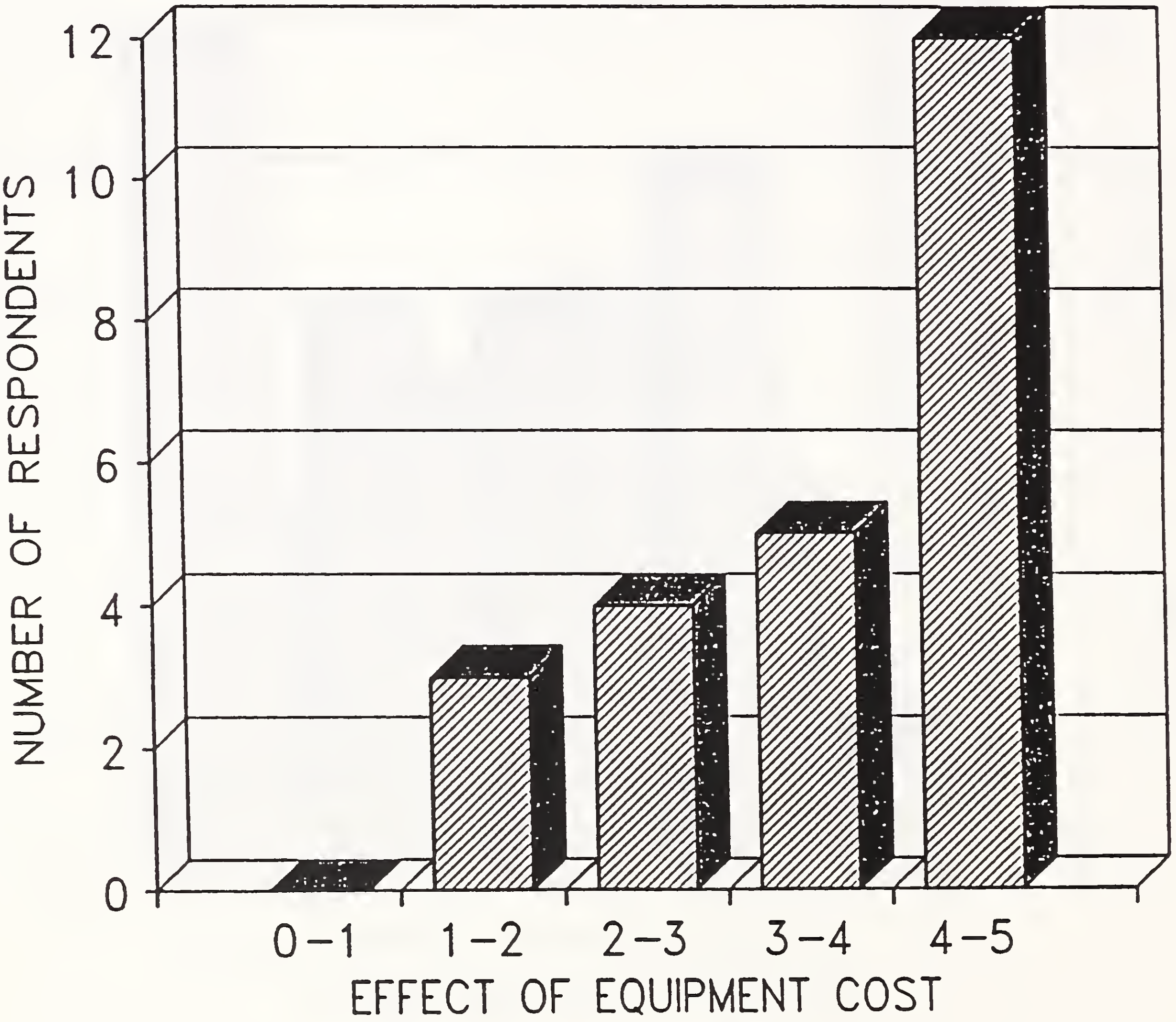


Figure 29

KNOWN REQUIREMENTS FOR VR PRESENTATIONS FOR MANUFACTURING

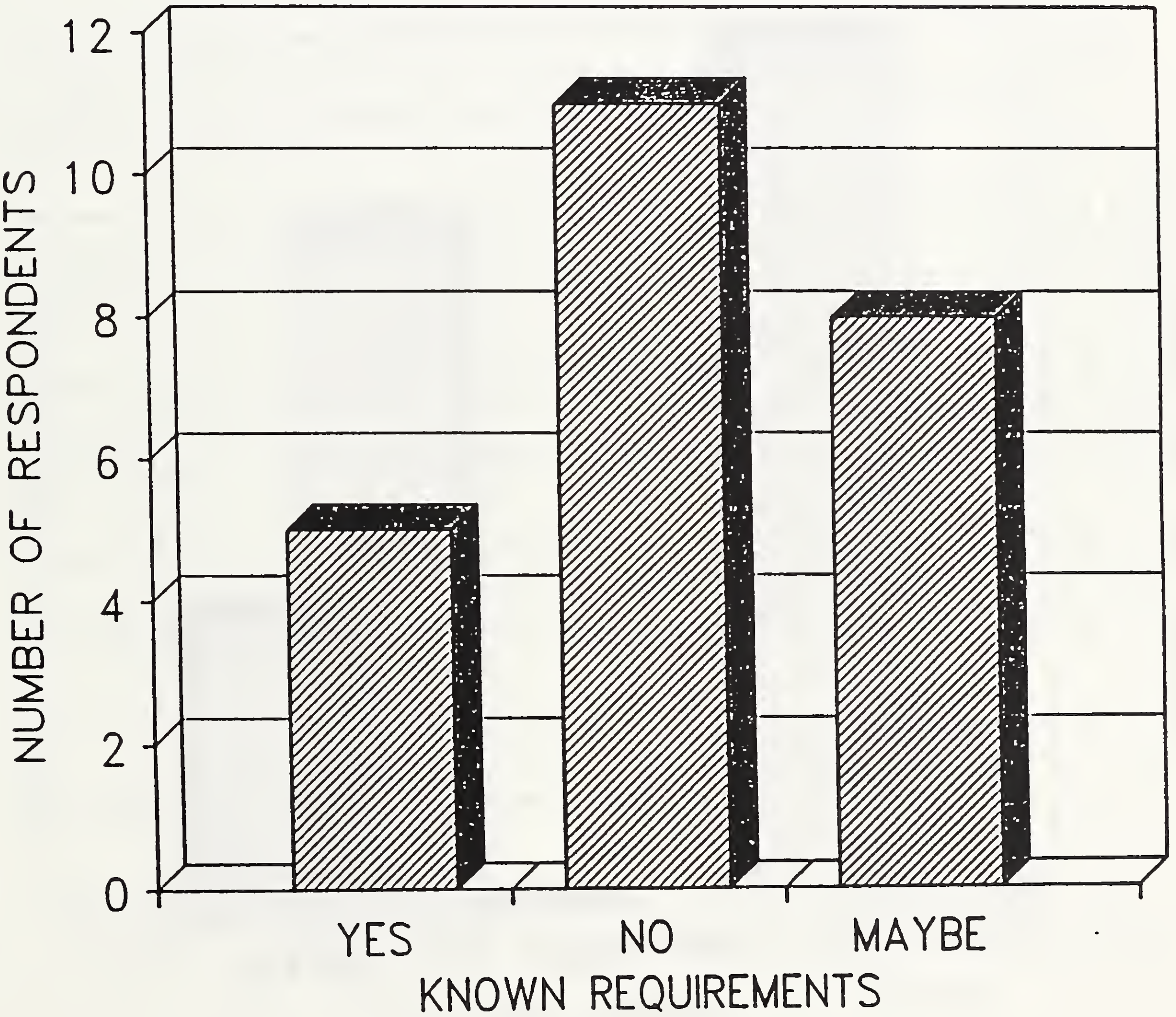


Figure 30

WORTH OF VR-PRESENTATION IN INTEGRATING COMPANIES, ENTERPRISES

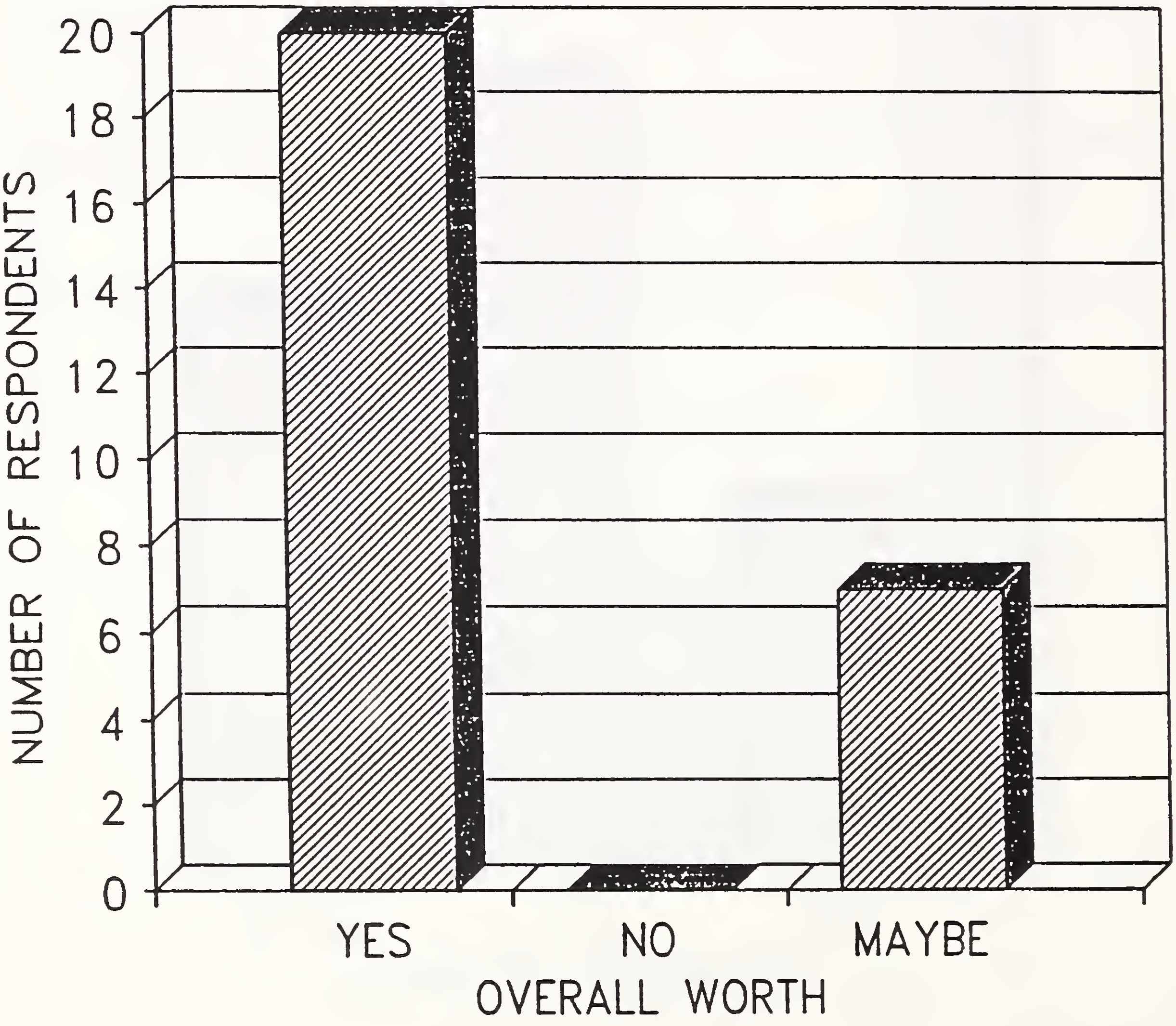
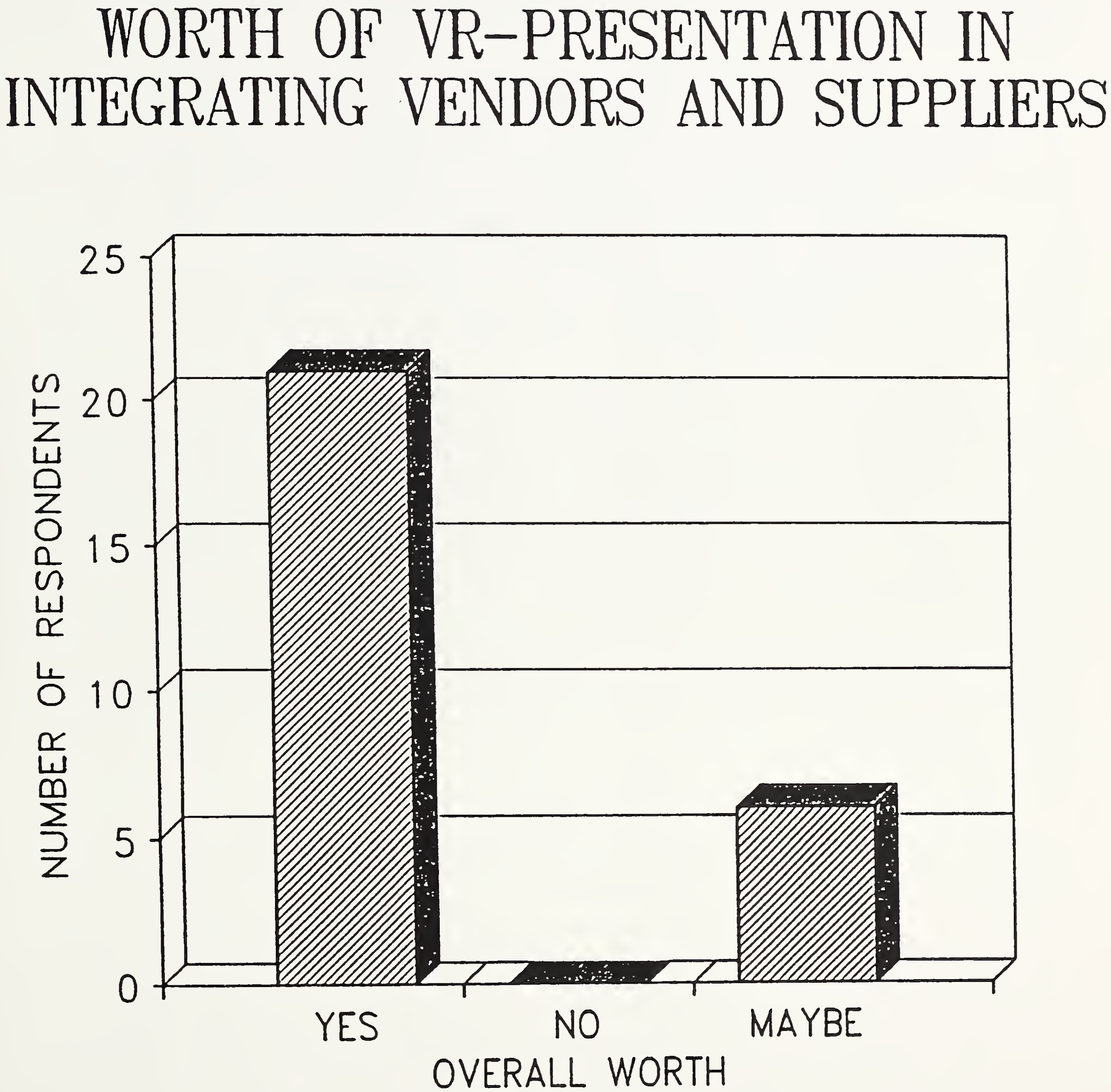


Figure 31



WORTH OF VR-PRESENTATION IN INTEGRATING VENDORS AND SUPPLIERS

Figure 32

APPENDIX A

ENQUIRY FORM

BACKGROUND INFORMATION:
APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PURPOSE

The National Institute of Standards and Technology (NIST) is supporting new initiatives in manufacturing technology which promise to have a major impact on the national economy. The Intelligent Systems Division (ISD) of NIST is exploring the potential applications of human information and interface technology for virtual and distributed manufacturing. The purpose of the enclosed enquiry is to determine some of the issues in human factors and virtual reality (VR) for manufacturing from the user's perspective and to build a new vision for manufacturing systems.

Key questions relate to the attributes of human information interactions through IO interfaces and their impact on potential leveraging of manufacturing technology. Who needs to look at information? What kinds of information are appropriate for each user to support real-time, collaborative decision-making? What differences are there in information needed for different users - individually or in new collaborative process within a "virtual" presentation environment? What are the important issues in how users choose to view information - both text or graphics? What human factors issues and design considerations should be included in a VR computer-interface? How can the information content and presentation best be approached with VR computer-interface technologies?

NEW INITIATIVES

Manufacturing technology is currently a focus of national initiatives sponsored by numerous government organizations and industrial consortia. There is a commitment of funding by programs in the Department of Commerce (Advanced Technology Program [ATP]), Department of Defense (Technology Reinvestment Program [TRP]), as well as the Department of Energy, NASA, and other Federal and state agencies. All of these programs address the necessity of boosting US manufacturing capabilities.

In this regard NIST has been given an expanded role in standardizing technological infrastructures and applications in such programs as:

* Manufacturing Research Technology Centers (METCs), which have become major regional technology resources

* The Automated Manufacturing Research Facility (AMRF), an open

architecture test-bed for the automated manufacture of discrete parts

* The PDES-STEP (Product Data Exchange using STEP - Standard for the Exchange of Product Model Data) Program for standardizing manufacturing data representations.

Virtual Reality

Virtual reality is rapidly becoming technically and economically feasible. VR has many definitions and formats. At the ambitious end of the spectrum, VR allows a user to have the illusion that he is immersed in a synthetic or remote environment. He experiences sensory information, such as three-dimensional vision and binaural sound, that is generated by a computer or originates from remote sensors (or is a combination of the two sources). He interacts kinesthetically with computer generated or teleoperated objects. At the less ambitious end of the spectrum, VR allows a user to operate in a text-based interactive modes (i.e., on-line dungeons and dragons) or a graphics-based mode to manipulate objects, or interact with an environment, as displayed in two dimensions on a monitor (computer or workstation) or on a head-mounted-display. For the purposes of manufacturing applications, the more modest version of VR is acceptable along with the more ambitious version.

ISD Initiative in Information and Interfaces for Manufacturing

The Intelligent Systems Division (ISD) and the Factory Automation Systems Division (FASD) of the Manufacturing Engineering Laboratory (MEL) at NIST are concerned with standardizing information protocols and interface technologies and techniques for manufacturing technology. ISD is examining the human factors involved in interfaces for appropriate information interactions. NIST is interested in exploring virtual and distributed manufacturing with initial testbed efforts in the production of discrete parts. Primary target areas include: Engineering Design, Product Planning, Process Planning, Factory Simulation, Monitoring and Control.

ISD is working with users and developers to coordinate standard information protocols and interfaces, which will eventually be reflected in the integration of virtual reality in a manufacturing framework. This human factors initiative will have a major impact in: information content for each user; presentation bandwidth and fidelity; presentation modality - real time or non-real time and mixes of text, graphics, pictures, videos, and other sensory modalities.

VR Threads

Virtual reality may be able to integrate intelligent manufacturing systems: products, processes, and enterprises. The potential impact of virtual reality may be dramatic. VR, which will be defining itself from the user pull and the technology push over the next several years, has several common threads:

* Virtual reality provides new worlds for one or more users. Related terminology is: artificial worlds, virtual environments, and synthetic environments.

* Some VR systems attempt to give the user a sense of telepresence by immersive sensation (vision, sound, tactile (pressure), haptile (force). Virtual reality may apply to single sites with human/machine interfaces to co-located computers, or to interconnected, distributed systems at distant sites linked through communications networks.

* Virtual reality establishes a framework which will ultimately integrate many areas of technology: human factors, computer hardware and software, and communications.

* Virtual reality permits each user to participate in a collective effort.

Virtual reality is supported by enabling technology programs in the following areas:

* Communications: the National Information Infrastructure (NII)

* High performance computation: High Performance Computing and Communications (HPCC)

* Data and interface standards: PDES-STEP

* Hardware including head mounted displays (HMDs), body suits, exoskeletons, data gloves, large screens

* Human factors studies.

VR to date has been focused primarily in four application areas:

(1) Simulation - which yields new views and perspectives which are unattainable by current methods.

(2) Teleconferencing participation - for "meeting at a distance," with a sense of telepresence, in a collaborative, immersive environment for joint activities, including discussions, interviews, planning, and training

(3) Training and Education, including:

* Integration of training for personnel at distributed sites with distributed elements

* Using simulations or synthetic environments to achieve cost savings by not using "real elements; when "real" elements are unavailable; and to protect personnel in training for hazardous operations and environments, e.g., nuclear environments, toxic contamination, or live-fire conditions

* Students using educational virtual reality toolsets to build their own virtual worlds, to immerse themselves, and to interact in "what if?" situations

* Students can learn by interacting with unavailable and out-of-size components and environments, such as observing a real-time manufacturing process through a magnifying glass.

(4) Mutual participation in shared activities in a synthetic environment. The most striking current participatory applications of virtual reality are for: Entertainment (several theme parks have simulator rides and other are currently being design as entire virtual reality theme parks); Military (to test new technology or tactics, and to train personnel at distributed sites in synthetic environments).

ENQUIRY FORM:
APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PURPOSE

The purpose of this questionnaire is to determine a vision for human factors in information and interfaces needed to integrate virtual reality technologies into the virtual and distributed manufacturing of discrete parts. You are asked to address: (1) a definition of the requisite information and interfaces for virtual and distributed manufacturing applications, (2) human factors approaches in information and interface technologies, and (3) leveraging of efforts in specific topical areas. The results of this questionnaire will allow the Intelligent Systems Division (ISD) and the Manufacturing Engineering Laboratory (MEL) of the National Institute of Standards and Technology (NIST) to determine needed standards and protocols for information and interfaces. Robotic Technology Inc. is working on this questionnaire under contract to NIST.

PROCEDURE

You have been provided with brief background information describing human factors and virtual reality for manufacturing. Please familiarize yourself with this material before answering the questions using your expert judgment and opinion.

Please **fax** only this completed form (not the background information), as soon as possible, to **(301)-983-2509**. If you have any questions or comments, please call: Dr. Joe Iseman, Robotic Technology Inc., (301)-983-2465. *Thank you for your participation and cooperation.*

YOUR NAME______________________________
Last First

POSITION or TITLE______________________________

ORGANIZATION/AGENCY______________________________

ADDRESS______________________________

____

PHONE______________________________

FAX______________________________

E-Mail______________________________

1. With respect to VR, are you a potential: (Please check one)

(a) Developer [ ] (b) User [ ] (c) Researcher [ ]

Comments (if any):

2. How much do you know about virtual reality? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
Don't Know Much Very Knowledgeable

Comments (if any):

3. How would you best characterize the field of "Virtual Reality"? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
Figment of Imagination Realistic

Comments (if any):

4. How much do you know about human factors/ergonomics for defining information presentations with computer-interface technology and techniques? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
Don't Know Much Very Knowledgeable

Comments (if any):

5. How would you best characterize the areas of human factors/ ergonomics for defining information presentations with computer-interface technology and techniques? (Please indicate with an "x" on the scale):

```
/---------/----------/----------/----------/---------/
0         1          2          3          4         5
Inadequate                                Well Developed
```

Comments (if any):____

____

6. Are information presentations currently adequately embedded in the manufacturing process? (Check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):____

____

7. For the kinds of manufacturing activities with which you are familiar, what kinds of information would typical users require to perform their job remotely: (Please comment on as many activities as you wish)

7a. Shop floor supervisors ____

____

7b. Machine operators ____

____

7c. Inspectors ____

____

7d. Material handlers ____

____

7e. Maintenance and repair personnel _________________________________

____

7f. Supply room personnel ____

____

7g. Tool room personnel ______________________________

____

7h. CAD-CAM designers ______________________________

____

7i. Design engineers ______________________________

____

7j. Process planning engineers ______________________________

____

7k. Manufacturing consultants ______________________________

____

7l. Plant managers ______________________________

____

7m. Schedulers ______________________________

____

7n. Schedulers ______________________________

____

7o. Accountants ______________________________

____

7p. Management information systems personnel ______________________________

____

7q. Business consultants ______________________________

____

7r. External environment personnel ______________________________

____

7s. Other (please specify) ______________________________

____

8. Are you familiar with interactive text-based virtual reality information presentations (i.e., on-line dungeons and dragons games)? (Check one)

(a) Yes [ ] (b) No [ ] (c) Somewhat [ ]

Comments (if any):____

____

9. When will text-based information presentations using VR-computer-interface technology first be used in manufacturing? (Please indicate with an "x" on the scale):

```
    /-------------/-------------/-------------/-------------
  1995          2005          2015          2025          >2025
```

Comments (if any):____

____

10. Are you familiar with interactive graphics-based virtual reality information presentations (head-mounted displays, small or large screens in entertainment)? (Check one)

(a) Yes [ ] (b) No [ ] (c) Somewhat [ ]

Comments (if any):____

____

11. When will graphics-based information presentations on VR-computer-interface technology first be of used in manufacturing? (Please indicate with an "x" on the scale):

```
    /-------------/-------------/-------------/-------------
  1995          2005          2015          2025          >2025
```

Comments (if any):____

____

12. What do you believe are the most important features of information presentations with VR computer-interface technology for manufacturing?

____

____

13. With respect to VR graphic presentations, which features are most important to you: (Please prioritize: Most important = 1)

(a) Visual quality [ ] (b) Refresh speed [ ] (c) Seamless [ ]
(d) Tactile interactions [ ] (e) Other (specify below) [ ]

Comments (if any):____

____

14. What do you think of the likelihood that information structures and VR user interfaces, customized to support specific users will be useful and valuable in manufacturing:

```
       /---------/----------/----------/----------/---------/
   P=  0        .2         .4         .6         .8        1.0
       Low                 Moderate              High     Certain
       Probability         Probability           Probability
```

Comments (if any):____

____

15. What would be the value added by customized information presentations on VR computer-interface technology for manufacturing? (Please indicate with an "x" on the scale):

```
       /---------/----------/----------/----------/---------/
       0         1          2          3          4         5
       None                   Moderate                   High
```

Comments (if any):____

____

16. Who will drive information presentations and VR computer-interface technology for manufacturing? (Check one)

(a) Developers [ ] (b) Users [ ] (c) Both [ ]

Comments (if any):____

____

17. Who will be primary funding sources for information presentations with VR computer-interface technology for manufacturing? (Check one)

(a) Developers [ ] (b) Users [ ] (c) Government [ ]

Comments (if any):______________________________

____

18. Which technologies do you believe must be exploited to make information presentations with VR computer-interface technology for manufacturing workable and affordable to users?

____

____

19. Which industries or types of processes do you feel can benefit first from information presentations with VR computer-interface technology for manufacturing applications?

____

____

20. How would you rank the <u>necessary</u> growth of the following technological factors for the integration of information presentations on VR computer-interface technology into manufacturing? (Please indicate with an "x" on the scales for each factor):

20a. Computer hardware? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

20b. Communications systems? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

20c. Software? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

20d. Human Factors? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
None A Great Deal

Comments (in any):______________________________

____

21. How well can standards, open architectures, and interoperability be achieved in information presentations with VR computer-interface technology to define a framework across multiple vendors of hardware and software and users? (Please indicate with an "x" on the scale):

```
/----------/-----------/-----------/-----------/----------/
0          1           2           3           4          5
Poor                                                 Excellent
```

Comments (if any):____

____

22. Does special equipment now required for realism - head mounted displays, data gloves - reduce or enhance the ability of the user? (Please indicate with an "x" on the scale):

```
/----------/-----------/-----------/-----------/----------/
0          1           2           3           4          5
Reduce                                                 Enhance
```

Comments (if any):____

____

23. How well can VR tools for the information presentation with VR computer-interface technology be integrated with manufacturing technology tools? (Please indicate with an "x" on the scale):

```
/----------/-----------/-----------/-----------/----------/
0          1           2           3           4          5
Poor                                                 Very Well
```

Comments (if any):____

____

24. How would you rate the applicability of the fidelity of information presentation achieved with VR computer-interface technology in manufacturing technology for discrete part production in each of the following areas? (Please indicate with an "x" on the scales):

```
24a. Training?                /-----/-----/-----/-----/-----/
                              0     1     2     3     4     5
                              Poor                 Excellent

24b. Product design?          /-----/-----/-----/-----/-----/
                              0     1     2     3     4     5
                              Poor                 Excellent
```

24c. Process design? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

24d. Process validation? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

24e. Enterprise integration? /-----/-----/-----/-----/-----/
0 1 2 3 4 5
Poor Excellent

Comments (in any):

25. Can the US manufacturing industry afford to apply high-fidelity, customized information presentations with VR computer-interface technology? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
Can not Can

Comments (in any):

26. How much will cost of equipment to support a high quality graphical and interaction interfaces (future generations of workstations, head-mounted displays, and data gloves) effect acceptance of a virtual workplace? (Please indicate with an "x" on the scale):

/---------/----------/----------/----------/---------/
0 1 2 3 4 5
None A Great Deal

Comments (in any):

27. Do you know of direct requirements for VR interface presentations for any manufacturing systems? (Please check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):

28. Will information presentation with VR computer-interface technology have an overall worth in integrating companies, enterprises, or industries more intelligently into the manufacturing process? (check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):____

____

29. Will information presentation with VR computer-interface technology integrate vendors/suppliers to a greater extent into the manufacturing process? (Please check one)

(a) Yes [ ] (b) No [ ] (c) Maybe [ ]

Comments (if any):____

____

30. Please make any additional comments below:

APPENDIX B

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VR WORKSHOP ATTENDEES

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APPENDIX IV

DR. ERNIE KENT: CHARTS

1. Why is NIST sponsoring this workshop?

2. Why am I here?

3. What's in it for me?

* NIST perceives an evolving interest in the intersection of a new technology with manufacturing/industrial methods.

* Maintaining competence and assisting industry in such cases is a traditional NIST role.

* We want to solicit the guidance of technology and industry experts in how best to fulfill that mission.

* We have tried to identify a small group of knowledgeable people in:

- VR technology
- Human factors
- Manufacturing

to come together for a day to identify and discuss the relevant issues.

* Possibly learn something from one another.

* Participate in forming a community of interest, and establishing lines of communication.

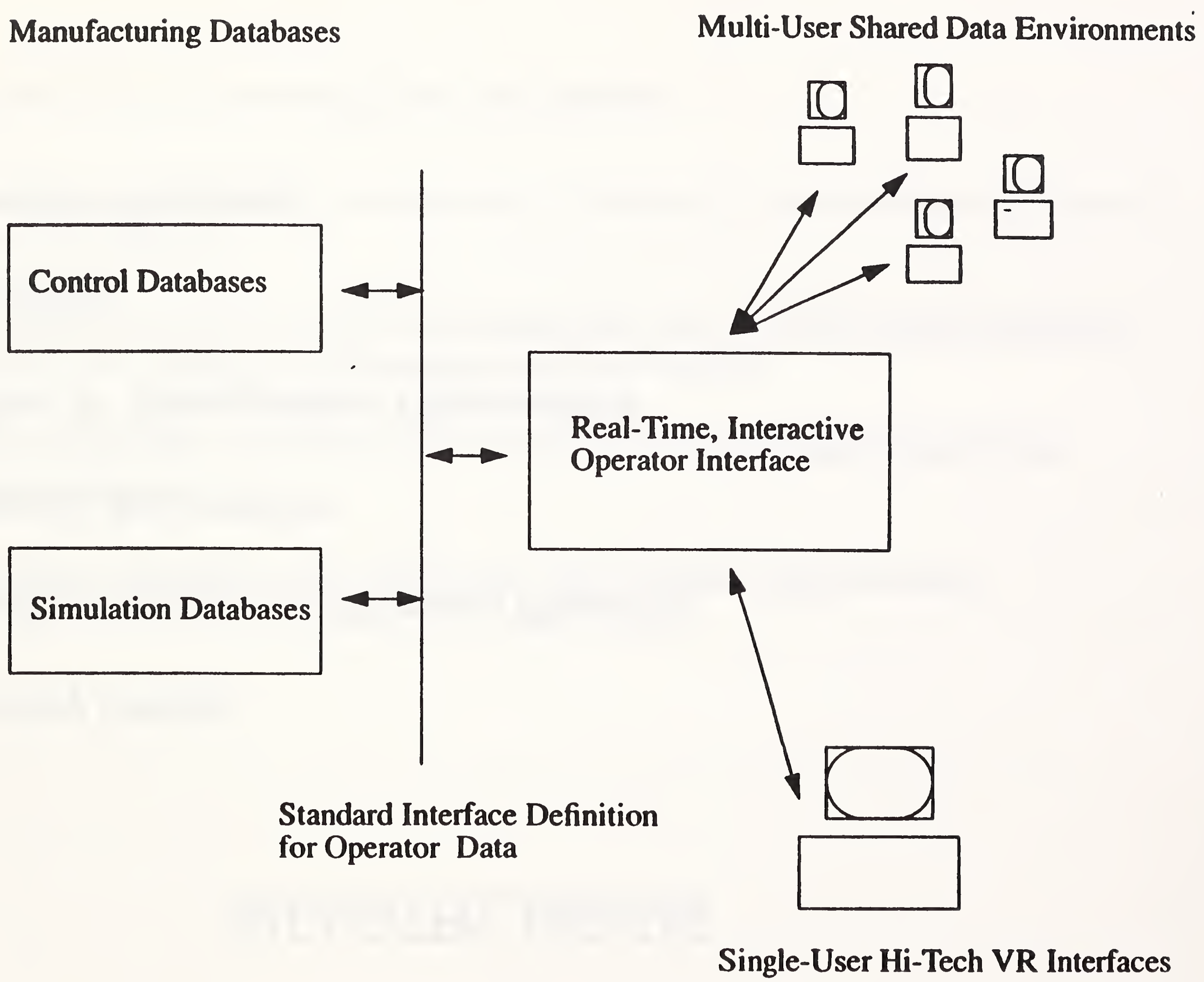
* Become involved in a NIST program that can provide testbed facilities and act as a source of information and assistance.

* Help steer NIST activities into issues of interest to your industry or organization.

* Maintain cognizance of NIST grant and contract opportunities.

INDUSTRY NEEDS

- Factory Design
- Product Design and Process Planning
- Remote Supervision
- "What If" Management Discussions
- Training
- Trouble Shooting


Manufacturing Databases
Multi-User Shared Data Environments
Control Databases
Simulation Databases
Real-Time, Interactive Operator Interface
Standard Interface Definition for Operator Data
Single-User Hi-Tech VR Interfaces

Workshop Objectives.

Identify Industry Pull.
Identify Technology Push.
Target Meaningful Opportunities in Overlap.

Format.

Discussions between representatives of three areas of expertise.

Manufacturing Industry
Human Factors
VR Technology

Workshop Principal Issues:

What kinds of data should we be focusing on delivering across the Operator Interface?

What are the best formats for presenting this information?

What are the best technologies for delivering the information to the user?

APPENDIX V

DR. BOWEN LOFTIN: CHARTS

Overview of Virtual Reality Technology: A New Tool for Manufacturing

R. Bowen Loftin, Ph.D.
University of Houston
and NASA/Johnson Space Center

Workshop on Application of Information and Interface Technology for Virtual and Distributed Manufacturing of Discrete Parts

National Institute of Standards and Technology

Gaithersburg, MD

August 9, 1994

What's in a Name?

- Artificial Reality—Myron Krueger
- Cyberspace—William Gibson
- Virtual Worlds
- Virtual Environments
- Virtual Reality—Jaron Lanier
- Synthetic Environments

Virtual Reality, etc.

The application of integrated technologies to enable a participant to sense that he or she is occupying, <u>to some degree</u>, an environment other than that which he or she physically occupies

Applications

- Entertainment
- Arts
- Architectural/Engineering Design
- Manufacturing
- Hazardous Operations
- Human/Machine Interaction
- Human Empowerment and Amplification
- <u>Medical Procedures</u>
- <u>Data Visualization</u>
- <u>Training and Education</u>

Technologies

- Graphics Computers
- Graphics Software
- Displays
  - Visual
  - Auditory
  - Haptic
- Tracking Devices
- Input Devices
- Communication/Networking
- Other

Participants

- **Robert T. Savely, Chief Scientist**
  Advanced Software Technology, NASA/JSC
- **Chris Culbert, Chief**
  Software Technology Branch, NASA/JSC
- **Laura Pusch, Software Technology Branch, NASA/JSC**
- **Dr. R. Bowen Loftin, Principal Investigator**
  University of Houston
- **Lac Nguyen, I-Net**
- **Tim Saito, Mark Voss, Pat Kenney & Mark Engelberg, LinCom**
- **Students: Robin Benedetti, Mark Gruetzner, Robert Jones, Mason Menninger, Steve Hardt, Wayne Herbert, Sean McCrae**

Graphics Computers

- Computing Spectrum
  - PC (Amiga)
  - Workstation (Silicon Graphics)
  - “Cost is no object” (Evans & Sutherland)
- Key Elements
  - Graphics Optimization
  - Multidisplay Capability
  - Synchronization
  - Parallel Processing
  - Speed
  - Cost

Graphics Software

- Elements
  - Rendering Algorithms
    - » Polygon Generation
    - » Pixel Fill
    - » Texture Mapping
  - Ray Tracing Algorithms
  - Collision Detection Algorithms
  - Lighting Models
- Issues
  - Software Optimization for Parallel Architectures
  - Development Tools

Visual Displays

- Non-Head Mounted
  - Projection Dome
  - Cave
- Head-Mounted
  - CRT
    - » Direct Display
    - » Reflected Display
    - » "Piped" Display
  - LCD Displays
  - Retinal Display
- Issues
  - Resolution
  - Field of View

Auditory Displays

- Elements
  - 3-D Localization
  - Registration with Visual Events
- Issues
  - The Pinna
  - “Generic” Models
  - “In the Head” vs. “Out of the Head”
  - Fidelity
  - Speaker Frequency Response vs. Size/Weight

Haptic Displays

- Tactile
  - Air Bladder
  - Alloy Wire
  - Electrical Stimulus
  - Mechanical Actuation
- Force
  - Glove-Based
    - Mechanical Actuation
    - Electrorheological
  - Hand-Controller
  - Large Scale
- Thermal

Other (Future) Displays

- Olfactory Displays
  - Only a few examples today
  - Can provide significant value (*e.g.*, medical training)
- Taste Displays
  - No real examples today
  - Some applications could benefit
- Direct "Mental" Displays
  - Permit direct "mapping" of sensory data to the brain
  - Stay tuned . . .

Tracking Devices

- Magnetic
  - Polhemus™ (AC)
  - Ascension (Pulsed DC)
- Acoustic
  - Ultrasonic
- Optical
  - Infrared
  - Visible Light
- Issues
  - Line-of-Sight
  - Noise
  - Range
  - Interference
  - Accuracy

Input Devices

- Hand Gestures
  - VPL DataGlove™ (Fiber Optic)
  - CyberGlove™ (Strain Gauge)
  - Video Capture (Krueger)
- Spaceball™
- Joysticks/Hand Controllers
- 3-D Mouse
- Eye Tracking
- Voice Input
- Myoelectric

Communication/Networking

- Current State
  - Local Graphics Generation
  - Protocols for Communicating Environmental Changes
- Issues
  - Local vs. Client/Server
  - Bandwidth
  - Body Representation
  - Communication Protocols
    - » TCP/IP
    - » ATM/SONET
    - » DIS

Equipment

- 2 RB2 Virtual Environment Systems
- 1 HRX & 4 LX EyePhones
- 1 EyeGen head-mounted display
- 10 DataGlove Model 2 Systems
- 4 DataGlove Control Units
- 1 AudioSphere System
- 4 Polhemus Magnetic Tracking Systems
- 2 Macintosh IIfx personal computers
- 2 Onyx/RE^2 graphics workstations
- 2 4D320 VGX graphics workstations
- 1 4D85 GT graphics workstation
- 2 Indigo Extreme^2 graphics workstations
- 1 Sun SparcStation workstation
- 1 Spaceball
- 1 chair equipped with hand controllers for 3-D orientation and translation
- Gloves for thermal, tactile, and force feedback

Objectives

- The Integration of Virtual Environment Technology with Intelligent Computer-Aided Training Technology
- Production of Proofs-of-Concep Applications of Virtual Environments for
  - Aerospace & Defense Training
  - Medical Training
  - Scientific Data Visualization
  - Education
- Capability to Share Virtual Environments, in Real Time, over Long Distances
- Development of Software Tools that Support the Creation and Maintenance of Virtual Environments

Research Issues

- Measuring Training Effectiveness
- Determining Needed Degree(s) of Fidelity
- Integration with Other Systems
  - Intelligent Computer-Aided Training
  - Existing Simulators
- Communications/Shared Environments
- Integration of Haptic Feedback
- Registration
- Enhanced/Additional Capabilities

Applications

- **On-Orbit Payload Interaction**

  Provide EVA Training for "Free" Payload Interactions (as in STS-49); Provide Collision Detection, Impulse Models, Payload Dynamics

- **Space Station Cupola**

  Compare VE Approaches to Cupola Training with Dome Projection and Pancake Windows for Astronaut Assembly from Cupola and Payload Retrieval/Release

- **Shared Virtual Worlds (MSFC & Ft. Knox)**

  Establish Capability to Share Virtual Worlds over Networks or Dedicated Communication Lines; Explore Integrated Payload and Station Operations and Team Training; Explore Concurrent Engineering

Applications (cont'd)

- Hubble Space Telescope Repair & Maintenance Mission Training
- Remote Manipulator System with Astronaut

  Provide Training to RMS Operator with Astronaut Attached to RMS End Effector using Simulator Image Generator Interface
- "Generic" EVA/IVA Training
  - EVA Astronaut Moving along the Truss
  - IVA Training for Space Station
- EVA/IVA Procedures Development

Applications (cont'd)

- Scientific Data Visualization
  - Investigate Structure of
    - » Proteins and Viruses
    - » Cells
    - » Molecules
  - Navigate and Explore Large Digital Libraries
  - Multisensory Perception, Immersion for Discovery
- Medical Applications
  - Laparoscopic Surgery Training
  - Telemedicine
    - » Diagnosis
    - » Mentoring

Applications (cont'd)

- Education
  - Virtual Laboratory Environment
  - Student Control of Environment
  - Collaborative Education
  - Telepresence Experiences
  - Intelligent Agents

Hubble Space Telescope

- Hubble Space Telescope Maintenance Mission Experiment
  - All major tasks modelled
  - All components related to those tasks modelled
  - Limited ICAT capability (object ID, error detection)
  - Development began 5/93; training began 9/93 and continued until mission launch (STS-61)
  - Training Objectives
    - » Instill mental models of system components and correct interrelationships
    - » Provide experiential knowledge of task procedures
    - » Enhance ability of ground-based flight controllers to interact effectively with crew during mission

Hubble Space Telescope (cont'd)

- Training episodes (121)
  - » typically three subjects per episode
  - » 40 (average) minutes of immersion per subject
  - » 60 (average) minutes "over-the-shoulder" observation
  - » in situ data collected by lab personnel
  - » post-flight evaluation instrument administered
- Results
  - » comments gathered during experiments were generally positive
  - » flight team members believe that the training received in the virtual environment improved their job performance

Observation

"... we feel that it is of historical significance. We believe that this exercise was the first to use VR on this scale, over 100 participants, and for this length of time, over 200 hours of training. It is important that this was real training, not a[n] evaluation of a demo system. Probably most important, everyone involved feels that the VR simulation added value to the training regimen."

Ben Delaney
CyberEdge Journal
January/February, 1994

Requirements

- Increased Visual Resolution
- Increased Graphics Rendering Speed
- Improved Haptic Feedback
- More Accurate/Longer Range Position Sensing
- Wireless Operation
- Integration of Graphics with Digitized Images
- Improved Registration
- Network Capability
- Integrated and Accessible Development Environment
- Robust Hardware and Software
- Data Supporting Training Efficacy
- Lower Cost

Benefits

- Access to Previously Unavailable Training
- Enhance Effectiveness of Existing Training
- Reduce Time Requirements for Unique Facilities
- Increase Training Throughput
- Reduce Cost for Future Training Facilities
- Support Rapid Evolution of Training Environments
- Provide Portability (Currently Limited)
- Address *in situ* Training
- Spinoffs for Education

Benefits (cont'd)

- Exploration of Scientific Data
  - Pattern/Relationship Discovery
  - Interaction with Models
  - Collaborative Research
- Medical Applications
  - Training
  - Procedures via Telepresence
- Education
  - Experiential Based Education
  - Mental Model Development
  - Collaborative Education

Simulation of a Grinding Process in Virtual Reality

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Visualization of Casting Process in Foundries

Lori Freitag

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Using Virtual Reality for Machine Design

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Caterpillar, Inc. and National Center for Supercomputing Applications

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Virtual Environments for Automotive Design

Jerry Bishop

General Motors Corporation

Dimensional Verification and Automated Correction of Five-Axis Numerically Controlled Milling Tool Paths

Yungching Huang

James H. Oliver

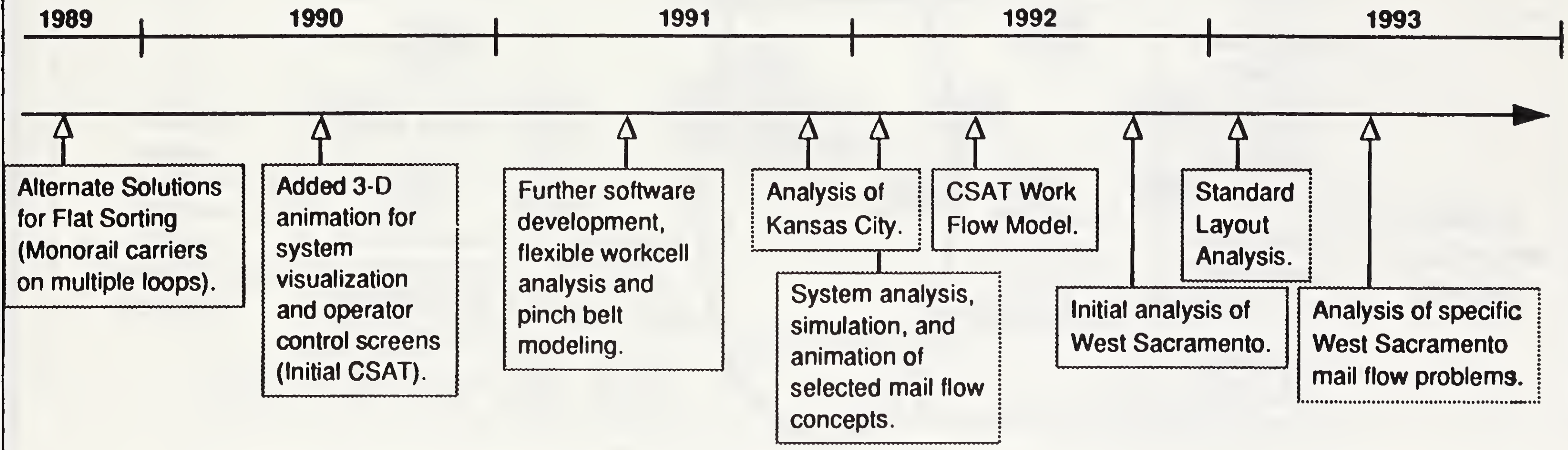
Iowa State University

APPENDIX VI

DR. CLYDE FINDLEY: CHARTS

Control, Simulation and Analysis of a Virtual Mail Processing Facility

CSAT Evolution



1989

1990

1991

1992

1993

Alternate Solutions for Flat Sorting (Monorail carriers on multiple loops).

Added 3-D animation for system visualization and operator control screens (Initial CSAT).

Further software development, flexible workcell analysis and pinch belt modeling.

Analysis of Kansas City.

System analysis, simulation, and animation of selected mail flow concepts.

CSAT Work Flow Model.

Initial analysis of West Sacramento.

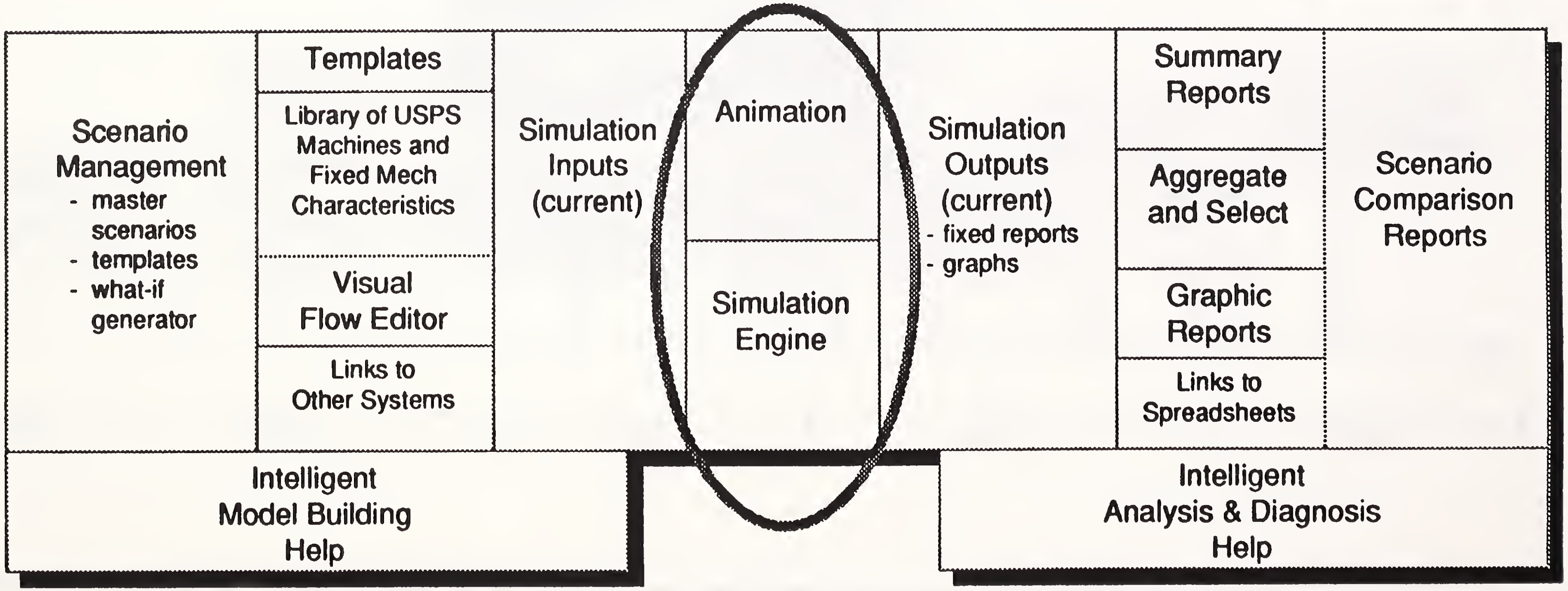
Standard Layout Analysis.

Analysis of specific West Sacramento mail flow problems.

Original Postal Service CSAT Concept

- From existing simulations:
  - » Probabilistic, event-based.
  - » Post-processed graphics.

- To integrated process design:
  - » Accurate 3D models.
  - » Accurate device emulation.
  - » Real-time control system.
  - » Real-time graphics.



Scenario Management
- master scenarios
- templates
- what-if generator

Templates

Library of USPS Machines and Fixed Mech Characteristics

Visual Flow Editor

Links to Other Systems

Simulation Inputs (current)

Animation

Simulation Engine

Simulation Outputs (current)
- fixed reports
- graphs

Summary Reports

Aggregate and Select

Graphic Reports

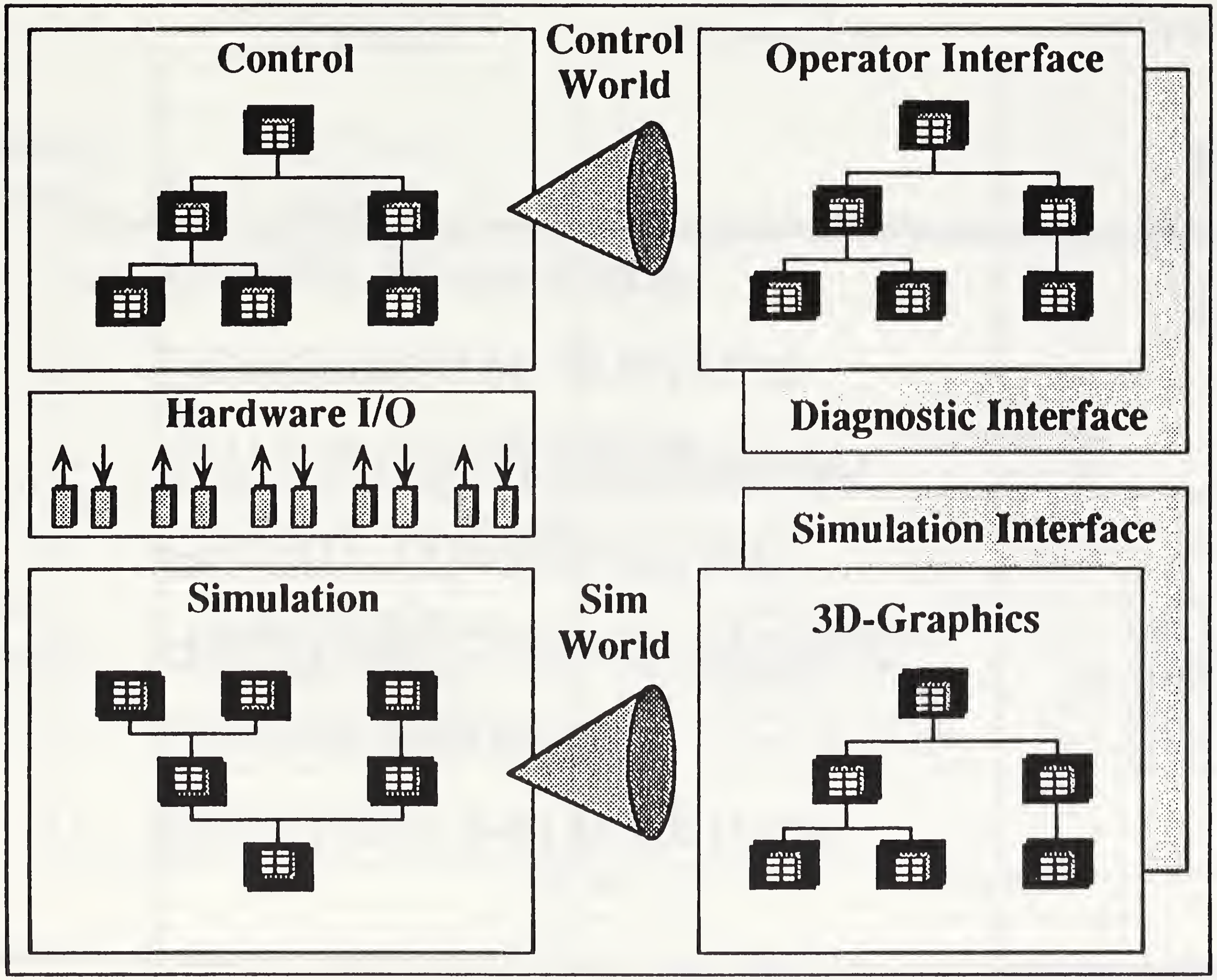
Links to Spreadsheets

Scenario Comparison Reports

Intelligent Model Building Help

Intelligent Analysis & Diagnosis Help

CSAT Components



Control

Control World

Operator Interface

Diagnostic Interface

Hardware I/O

Simulation

Sim World

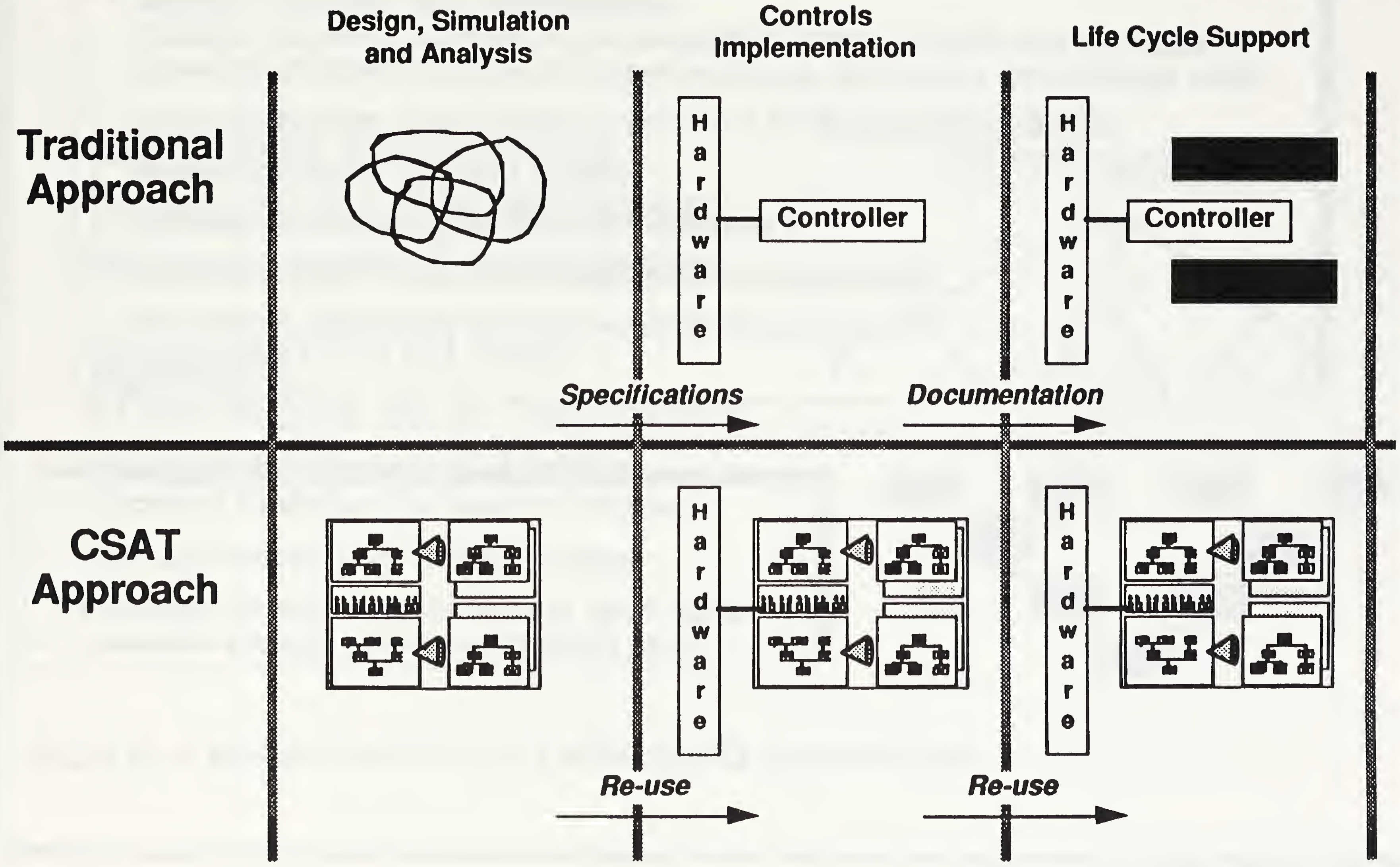
Simulation Interface

3D-Graphics

CSAT Capabilities

- Real-time 3-D graphics.
- Device emulation.
- Real-time control system.
- Facility configuration.
- Environment simulation.
- Performance analysis.
- Report generation.

CSAT Versus Traditional System Development



Design, Simulation and Analysis

Controls Implementation

Life Cycle Support

Traditional Approach

CSAT Approach

Specifications

Documentation

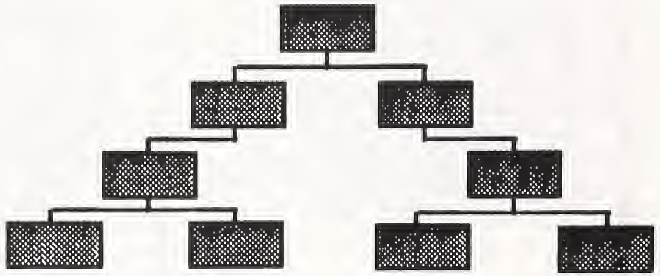
Re-use

Re-use

The Real-time Control System

RCS is a Methodology for Organizing Information

- Developed at NIST in the Automated Manufacturing Research Facility in the 1970-1980s
- Uses Structured Task Decomposition
- Discovers relationships between *actions*

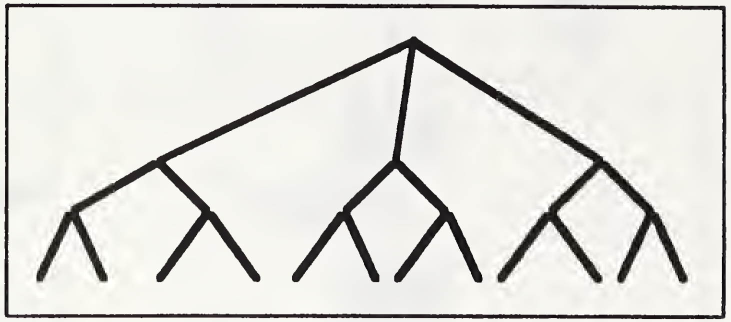


<u>INCLUDES</u>:

- Information gathering techniques (scenario building)
- Hierarchical structure to organize action relationships
- Iterative analyze-design-code-test methods
- Generic software building blocks
- General-purpose task-oriented interactive programming language
- Powerful methods of viewing software control structures that enables large, complex software systems to be developed piece by piece in a way that is reliable, verifiable, and maintainable

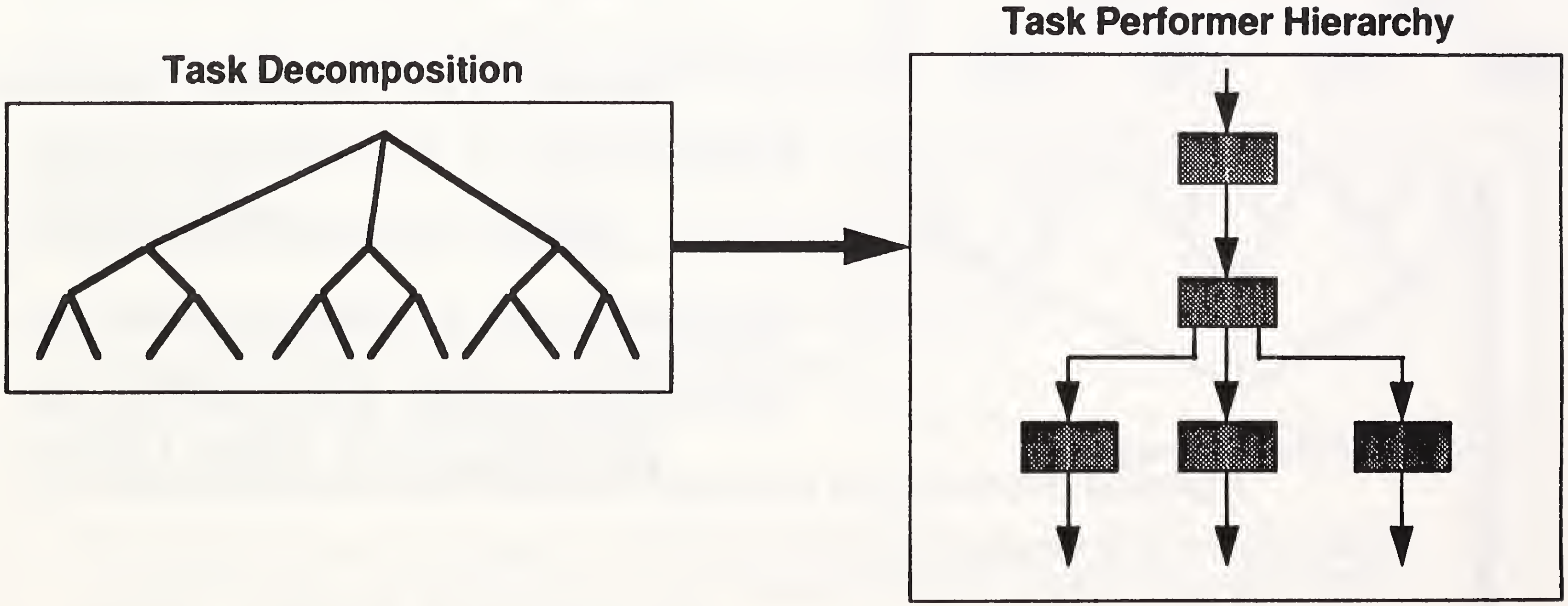
The RCS Methodology, Step 1

- Gain task knowledge through the development of narratives & scenarios.
- Represent that task knowledge as a hierarchy of decomposed tasks.


Task Decomposition

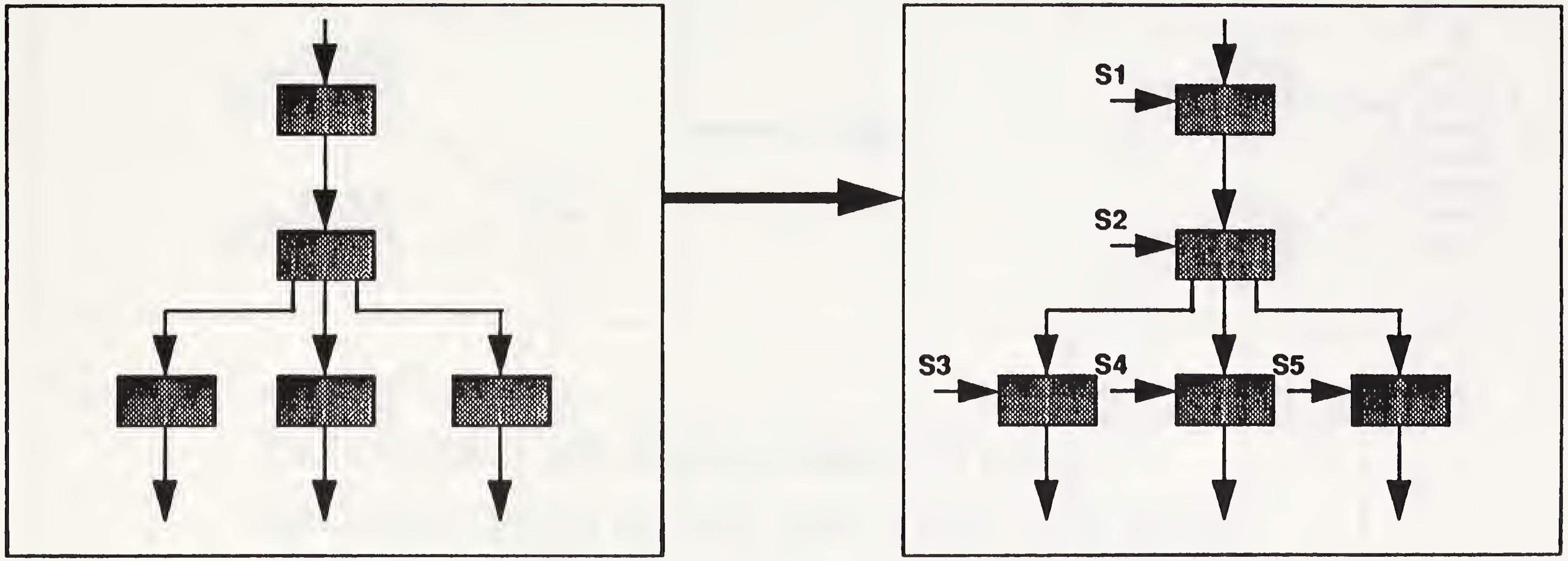
The RCS Methodology, Step 2

- Convert the task hierarchy into an organizational framework of task performers.



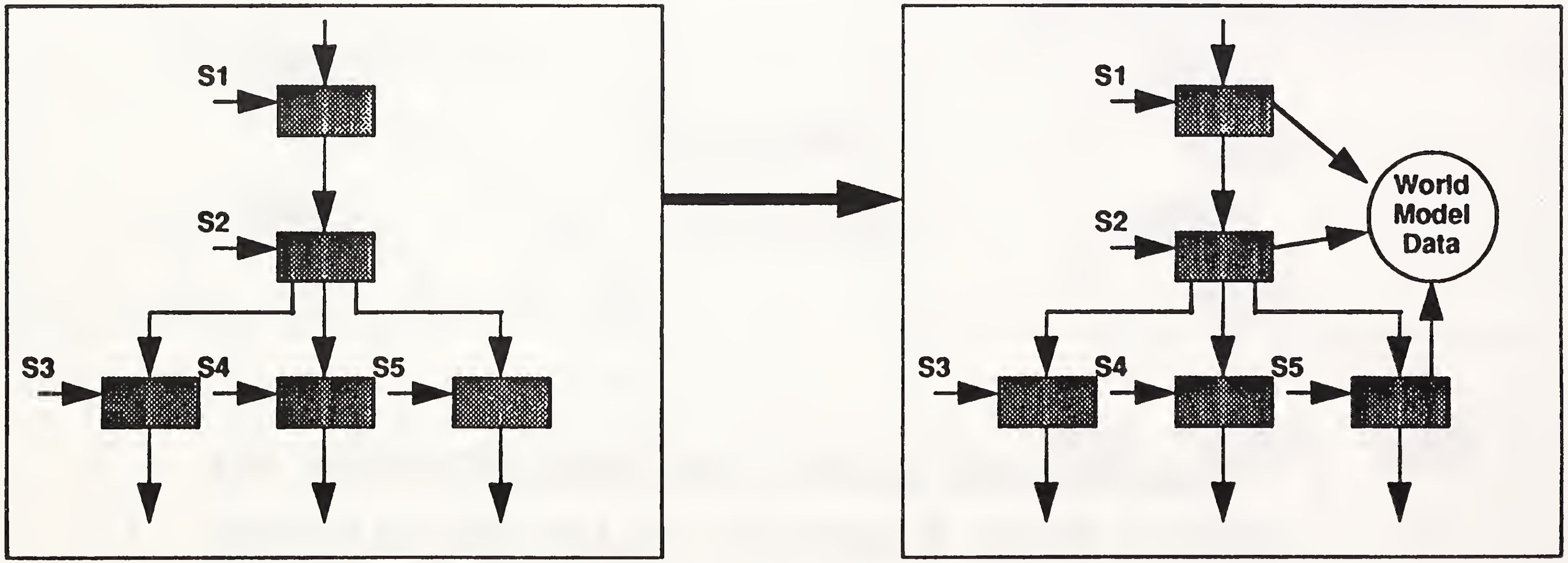
The RCS Methodology, Step 3

- Determine what *sensory data* might be appropriate for each performer.



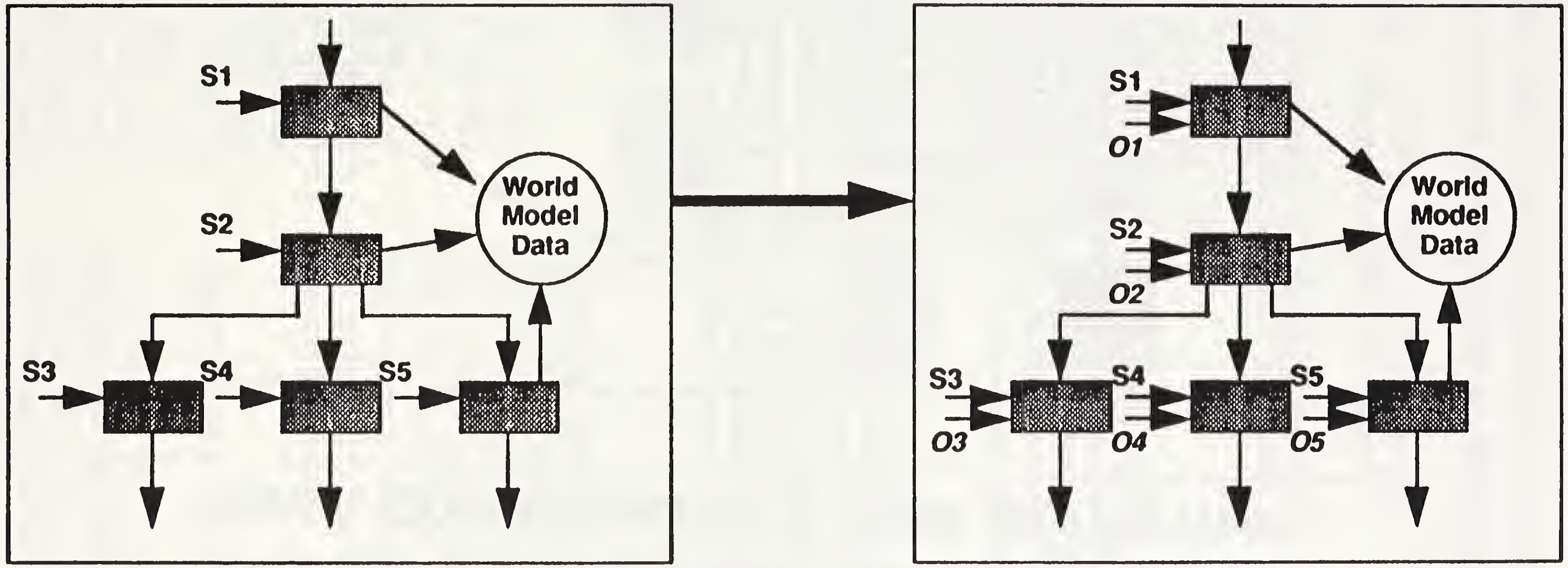
The RCS Methodology, Step 4

- Determine what internal and *world model data* must be kept by and provided to each performer.



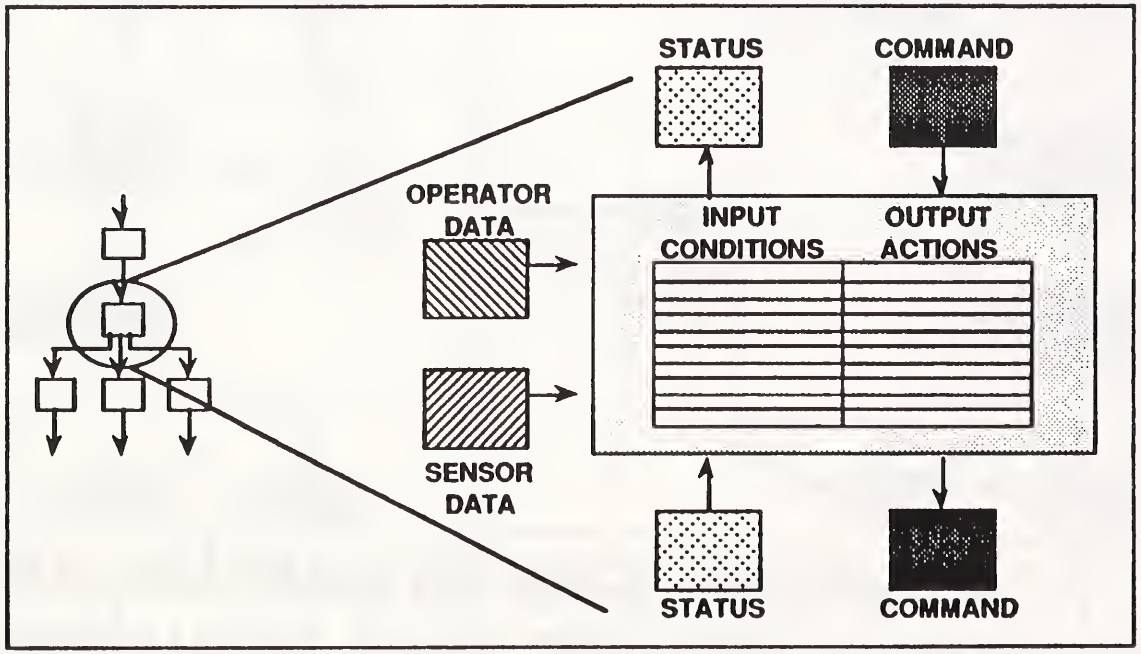
The RCS Methodology, Step 5

- Determine what *operator interactions* are required by each performer.



The RCS Methodology, Step 6

- Create a *state table of task rules* for each command in a *task performer*.



A 3-D CONTROL AND SIMULATION ANALYSIS TOOL FOR THE UNITED STATES POSTAL SERVICE

Anthony J. Barbera, Ph.D., Chris J. J. Lu,
M. L. Fitzgerald, Clyde E. Findley

Advanced Technology & Research Corporation
14900 Sweitzer Lane, Laurel, MD 20707-2926

The design of new mail processing facilities and the upgrade of old facilities are complex tasks requiring extensive analysis. To achieve the desired mail flow rates, the analysis must address overall system layout, mechanization requirements, and associated economic factors. The difficulty of understanding what effects changes made within one part of the system will have on the performance of the system as a whole gives rise to the need for an integrated design, analysis, and simulation tool that will supply these capabilities.

This paper describes a software product called the *Control and Simulation Analysis Tool* (CSAT) that assists in the design, analysis, and control of mail processing facilities. CSAT creates a very detailed, high fidelity, three-dimensional graphic representation of a facility that helps the designer understand and take advantage of the interdependence among processing, staging, and transport systems, and test different configurations and combinations of each system under a variety of mail volumes and characteristics. Not a traditional simulation, CSAT is rather a real-time control system developed using a task decomposition methodology that provides a high degree of fidelity and realism.

INTRODUCTION

The United States Postal Service, as part of its corporate goals, has made a commitment to automate the processing of all types and classes of mail. This automation is currently accomplished through the use of facer-cancelers, optical character readers, and bar code sorters. These high-speed processing activities must be supported with high speed material handling systems in order to achieve the desired throughput rates. The USPS is interested in methods to more accurately simulate large mail processing facilities, as well as ways to analyze the effects of introducing new material handling systems and re-configuring existing ones.

The Control and Simulation Analysis Tool (CSAT) is a multi-functional computer animation and device emulation program, capable of modeling, in real time, material handling systems and mail processing equipment. It is able to emulate the behavior of mail processing machines that exist in the Postal Service today, as well as systems that are envisioned in the future, and link them using a common software architecture to create an integrated system that functions as a unified whole.

TRADITIONAL SIMULATIONS

Virtually all computer programs that simulate the behavior of equipment employ methods borrowed from operations research and computer-aided design and manufacturing (CAD/CAM).

Simulations that use these traditional methods are extremely important. They can be used to provide a wealth of information to feed initial estimates relating to system capacity, overall processing requirements, and equipment performance values.

However, traditional simulations are unable to form the basis for actual control systems. Since, by their nature, they embed control assumptions within their simulations, it is generally not possible for to separate what is control from what is simulation.

These programs combine control logic with statistical approximations of behavior in a manner that makes it very difficult to either determine and understand the control issues, or to independently verify performance values.

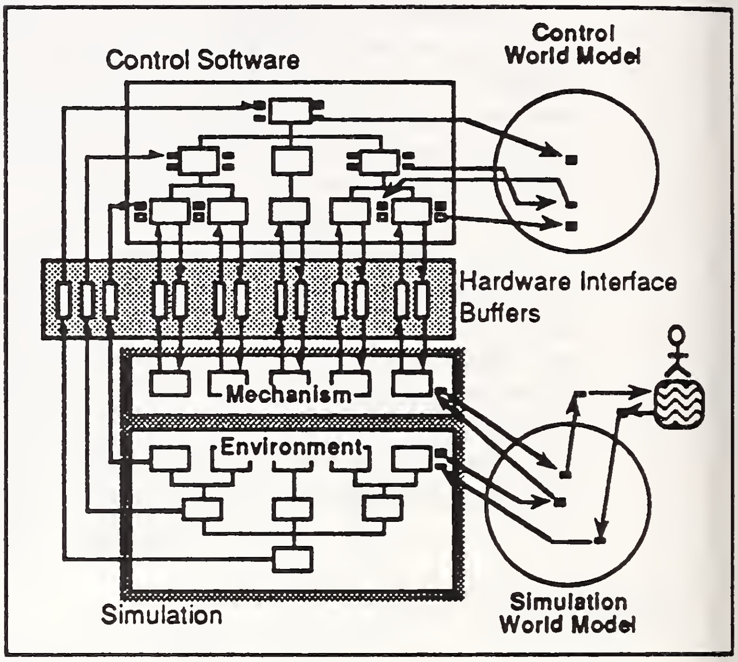
THE RCS METHODOLOGY

Initially developed at the National Institute of Standards & Technology (NIST), the Real-time Control System (RCS) architecture forms the foundation of the CSAT product. Now being promoted by NIST as a standard for real-time control software, the RCS methodology has evolved for over 15 years to become a viable system for generic real-time control of complex systems.

The RCS methodology prescribes a software framework requiring all real-time control systems to be modeled as hierarchically structured organizations of layered responsibilities. It further requires that these layers be built from generic control module structures as unit building blocks.

These generic control modules are designed in such a way that the lowest level modules correspond exactly to the actual hardware devices that will be controlled in a real system. Connected to these device controllers in a one-to-one relationship are mechanism simulators that emulate the behavior of real devices. An environment simulation module combines the low-level device operations (such as conveyors, photocells, and diverters) with physical characteristics of objects (such as trays and sacks of mail) in the environment to determine how these objects will move in response to device movement.

The combination of both simulations (mechanism and environment) creates a model of the behavior of the hardware system that is separate from the control software which resides in the upper layers of the RCS hierarchy.



RCS Environment

Because of this clean separation between control logic and simulation software, the control software, with very little modification, can be connected to real hardware immediately, and with a degree of confidence that is not possible with traditional approaches to simulation.

CSAT CAPABILITIES

Although it is designed to be an integrated and comprehensive solution to a variety of problems, the general functions of the CSAT program can be broken into eight separate areas, each providing a unique set of capabilities.

3-D Walk-Through

A real-time, three-dimensional "walk through" of a mail processing facility is provided as a standard capability through the use of a Silicon Graphics computer with a high-resolution color display. All mail processing equipment is represented, as well as all material handling components, including conveyors, self-guided vehicles, tray management systems, and automatic storage and retrieval systems. All relevant building structures are visible, and may be viewed from any angle and from any distance.

Equipment Emulation

All mail processing machines, as well as the material handling equipment and people that support and integrate them, are emulated in real time. The actual sort algorithms that are used by the mail processing machines are executed, using a representative database of individual mail pieces. Mail flow rates and mail arrival profiles may be modified by the operator to generate detailed analyses on machine and material handling performance based on different input conditions.

Letter Processing

The entire letter processing path of a mail processing facility is emulated. The capability to move hardware and reconfigure the system is available. Modeled hardware includes such components as staging towers, monorails, conveyors, vertical lifts, and Postal Automated Staging and Retrieval Systems, as well as letter sorting machines. Each device has associated attributes including mail processing rates. The operator has the ability to choose from among a variety of devices in order to configure a complete system. The tool allows re-configuration of the machine layout, showing the effects of mail flow for each given sort scheme.

Flats & Parcels

The capability to process "flats", small parcels, and bundles is also provided. Mechanism simulators include flat sorters, small parcel and bundle sorters, sack and tray sorters, and automatic loader-unloaders.

Coordinated Control

One of the most difficult aspects of integrating real-time control and simulation software is the coordination and integration of all the various devices used in a mail processing facility. In order to achieve optimum mail processing rates, the ability to experiment with different transportation schedules, both into and out of the mail processing facility is provided, as well as the ability to control groups of heterogeneous, cooperating machines.

CAD Input & Report Output

Layout descriptions of equipment generated from CAD drawings can be brought in through numerical files and interpreted by CSAT. Furthermore, reports are generated that outline any information requested by the operator, such as number of trays of a particular zip code and mail processing rates for a given piece of hardware.

Cost Estimation

A module has been added to CSAT to provide complete pricing and parts count information for each given configuration. Outputs from this module are displayed on the screen or included in output reports.

Operator Interface Module

CSAT is being designed to be as user-friendly as possible, and allows the operator to use common input devices to configure the system, change operating/simulation parameters, request analysis and displays of data, request present operating status and inventories, and enter data and operational commands. CSAT processes information for display to the operator, including selected sort plans and currently activated mechanisms. It also retrieves and displays such information from hardware controllers and simulators as the number of trays of mail destined for delivery to a particular zip code.

CONCLUSION

CSAT is being designed to interface with real-time hardware systems, bringing in sensor and actuator values in real time so that the display becomes the operator's display of the actual operating facility. This reuse of the display capability saves a considerable cost in the development of the operator's display for the running systems. Operator input devices such as touch screens will allow the operator to point at a component, determine its status, direct its operation, and check its maintenance schedule.

All simulation/animation systems must address the issues of accuracy and believability. Because the CSAT software is written to control and emulate actual hardware devices down to the motor/actuator level, the issue of accuracy is no longer a question of the assumptions used to estimate performance of high-level machine behavior, but rather of the performance characteristics of the machines themselves. This translates directly into more believable simulation results.

ACKNOWLEDGMENTS

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APPENDIX VII

DR. JAMES GEIWITZ: CHARTS

OBJECTIVES

STANDARDIZATION OF PROTOCOLS

FOR THE APPLICATION OF INFORMATION AND INTERFACE TECHNOLOGY

FOR VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

INTEGRATION OF HUMAN FACTORS

VIRTUAL REALITY

MANUFACTURING SYSTEMS

VISION NEEDED:
HUMAN FACTORS IN INFORMATION AND INTERFACES NEEDED TO INTEGRATE VIRTUAL REALITY TECHNOLOGIES INTO THE VIRTUAL AND DISTRIBUTED MANUFACTURING OF DISCRETE PARTS

PARTICIPANTS WILL ADDRESS:
1. DEFINITION OF REQUISITE INFORMATION AND INTERFACES FOR VIRTUAL AND DISTRIBUTED MANUFACTURING APPLICATIONS
2. HUMAN FACTORS APPROACHES TO INFORMATION AND INTERFACE REQUIREMENTS
3. LEVERAGING OF EFFORTS IN SPECIFIC TOPIC AREAS

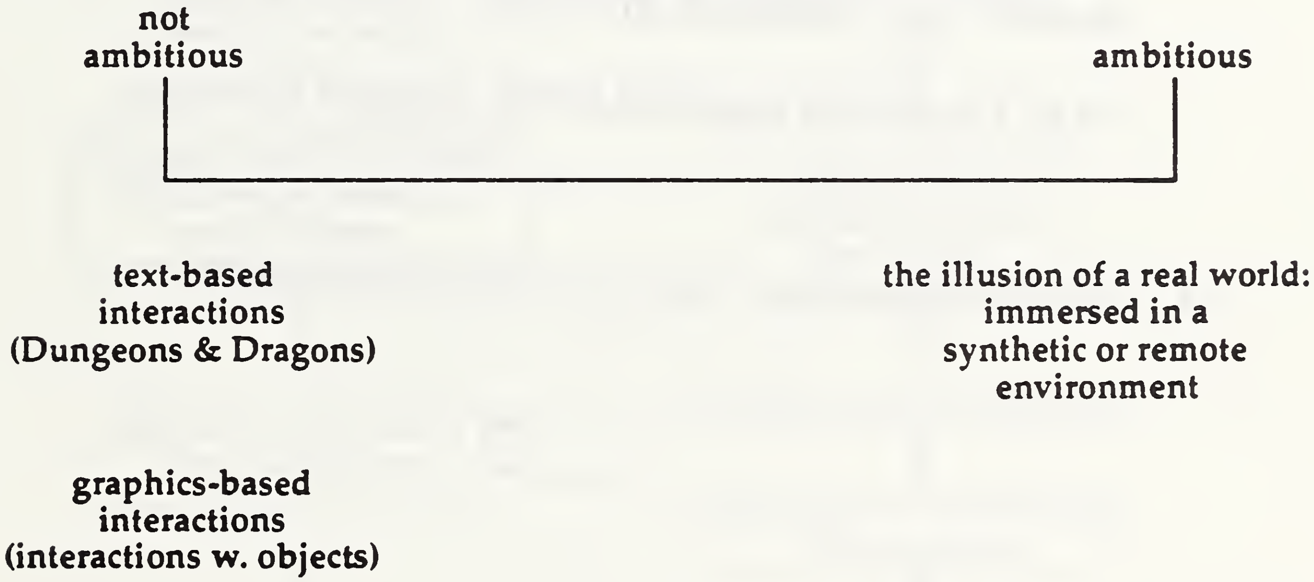
VIRTUAL REALITY

WHAT IS VIRTUAL REALITY?

WHAT IS THE DIFFERENCE BETWEEN VIRTUAL REALITY AND
- ARTIFICIAL WORLDS?
- SYNTHETIC ENVIRONMENTS?
- TELEOPERATION?
- TELEVISED ENVIRONMENT?

VIRTUAL REALITIES LIE ON A DIMENSION

BUT WHAT IS THE DIMENSION?
- SIMILARITY TO REAL WORLD?
- NUMBER OF VIRTUAL FEATURES? MODES?
- AMBITION!



not ambitious

ambitious

text-based interactions (Dungeons & Dragons)

the illusion of a real world: immersed in a synthetic or remote environment

graphics-based interactions (interactions w. objects)

VIRTUAL REALITY =
THE TRUE-TO-FORM REPRESENTATION OF THE OBJECTS IN THE REAL WORLD AND THEIR INTERACTIONS

TELEVISION AND TELEROBOTICS: PRESENTATION OF THE REAL WORLD, NOT REPRESENTATION

ARTIFICIAL WORLDS: NOT NECESSARILY CONSTRAINED BY REAL-WORLD LIMITATIONS, e.g., THE LAWS OF PHYSICS

MODES OF VIRTUAL REALITY

I. CONCEPTUAL (e.g., text-based VR)

II. SENSORY:

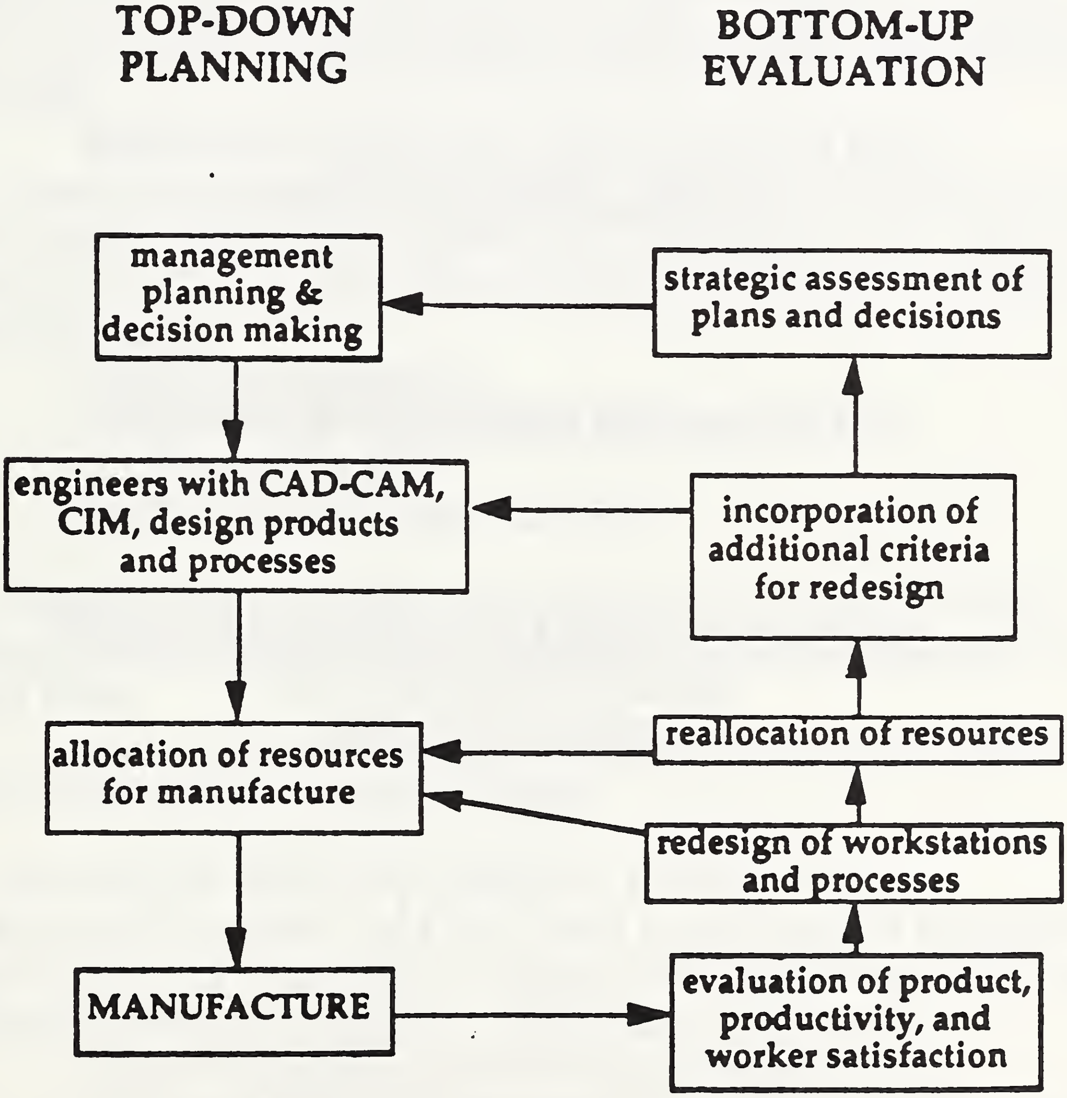
- VISUAL (e.g., SIMNET)
- AUDITORY (e.g., LOOMIS/KLATZKY NAVIGATIONAL AID)
- HAPTIC (e.g., SENSING ROBOTS)
- TASTE & SMELL (e.g., SCRATCH & SNIFF MOVIES)

III. MOTOR (interactions with the virtual environment)

MANUFACTURING SYSTEMS

A (USUALLY AUTOMATED) DEVICE OR SET OF DEVICES THAT AIDS IN SOME ASPECT OF THE MANUFACTURING PROCESS (e.g., REACTOR PROTECTION SYSTEM (process control), CAD-CAM)

MANUFACTURING AS A FEEDBACK SYSTEM
(after Helander, 1993)



PRIMARY TARGET AREAS (from invitation);

ENGINEERING DESIGN	PRODUCT PLANNING
PROCESS PLANNING	FACTORY SIMULATION
MONITORING & CONTROL	

THE HUMAN-FACTORS ISSUES

WHAT DOES THE USER NEED TO KNOW TO PERFORM THE TASK?

WHEN IS THE KNOWLEDGE NEEDED?

IN WHAT FORM IS THE KNOWLEDGE MOST CONDUCIVE TO EFFECTIVE USE?

A FEW RELEVANT RESEARCH STUDIES

1. GENERAL MOTORS (1980s): INVESTED $80 BILLION IN AUTOMATED MANUFACTURING; $20 BILLION DIDN'T WORK
   – main problems: poor task analysis, poor functional allocation, inadequate training

2. Helander & Furtado, 1992: ROBOTS FOR PRODUCT ASSEMBLY; ROBOTS w. NO VISION AND POOR FINGER DEXTERITY (too expensive), SO PRODUCT HAD TO BE REDESIGNED FOR EASY ASSEMBLY (e.g., "use snap and insert assembly").
   RESULTS: CHANGES MADE MANUAL ASSEMBLY EASIER TOO, TO THE EXTENT THAT IT WAS CHEAPER TO USE MANUAL LABOR!

3. CONCURRENT ENGINEERING: PRODUCT DESIGNERS & PROCESS DESIGNERS WORKING TOGETHER TO DESIGN A PRODUCT THAT CAN BE MANUFACTURED BY CERTAIN STANDARDS:
   - EASE OF ASSEMBLY
   - DESIGN FOR MAINTAINABILITY
   - INTEROPERABILTY
   - WORKER AND USER SAFETY

4. COMPUTER-INTEGRATED MANUFACTURING (CIM): Siemierniuch (1992): 9 million pounds sterling, CIM project, TOTAL FAILURE
   – main problems: poor task analysis, poor knowledge acquisition, poor pre-implementation validation

5. NO MAJOR FIELD STUDIES OF AUTOMATED MANUFACTURING; IN FACT, THE LAST MAJOR FIELD STUDY OF ANY KIND OF MANUFACTURING PROCESS WAS 1935, THE HAWTHORNE STUDIES AT WESTERN ELECTRIC
   - improved lighting improved productivity, BUT
   - degraded lighting (returned to normal) also improved productivity
   - workers who got attention from supervisors (lighting changes) responded with increased production (the Hawthorne Effect)

TARGET TASKS

1. INVITATION:

- ENGINEERING DESIGN,
- PRODUCT PLANNING,
- PROCESS PLANNING,
- FACTORY SIMULATION,
- MONITORING & CONTROL

2. TEAM TASKS:

- COMPUTER-SUPPORTED COOPERATIVE WORK
- TELECONFERENCING IN VIRTUAL ENVIRONMENTS
- NETWORKING IN VIRTUAL ENVIRONMENTS
- DISTRIBUTED DECISION MAKING
- CONCURRENT ENGINEERING

MAJOR HUMAN FACTORS ISSUES

1. GROUP COGNITIVE TASK ANALYSIS
    - FUNCTION ALLOCATION
    - COORDINATION
    - SYNCHRONIZATION

2. KNOWLEDGE ACQUISITION
    - SEMANTIC & PROCEDURAL KNOWLEDGE
    - EXPERT MAY NOT BE ABLE TO ARTICULATE KNOWLEDGE
    - KNOWLEDGE ACQUISITION GUIDEBOOK (55 KATs)

3. NEUROPSYCHOLOGICAL STUDIES OF PERCEPTION
    - VISION
    - AUDITION (voice recognition)
    - HAPTICS (data glove, finger exoskeleton)
    - MOTOR BEHAVIOR

4. MODELS OF THE MANUFACTURING PROCESS

5. MODELS OF AUTONOMOUS, INTERACTIVE AGENTS
    - SIMNET & V(INT)^2: playing the OPFOR

APPENDIX VIII

DR. JAMES GEIWITZ: POST WORKSHOP COMMENTS

HUMAN FACTORS ISSUES IN VIRTUAL REALITY INTERFACES FOR MANUFACTURING

A Report on the NIST Workshop, August 9, 1994
By
James Geiwitz, Carnegie Mellon Research Institute
for
Ernest W. Kent, National Institute of Standards and Technology

1. The purpose of this report is to summarize the human factors that were raised during the day-long workshop on virtual reality interfaces for manufacturing. These issues were raised during morning presentations and their discussions or during the afternoon breakout sessions. The objective of the workshop was the integration of three areas of R&D: human factors, virtual reality technology, and manufacturing systems.

2. In Dr. Geiwitz's presentation, he identified the three basic human factors issues: What does the user need to know to perform the task? When is the knowledge required? In what form is the knowledge most conducive to effective use? Dr. Harold Van Cott, a prominent human-factors psychologist, suggested adding a "basic issue" to cover the testing and evaluation of the VR interface: Compared to conventional methods of manufacturing, is the VR interface more effective and/or more efficient? We might also add a determination of cost effectiveness, that is, is the higher cost of VR interfaces worth the increase in performance?

3. The issues in #2 depend on a thorough task analysis. A task analysis not only describes the steps in task performance, it analyzes them for the knowledge and skills required to perform the task proficiently. In this case, we need a cognitive task analysis, because some of the steps in task performance will be mental -- a decision, an inspection. Cognitive task analysis uses the techniques of knowledge acquisition to analyze the knowledge-skill requirements. In distributed manufacturing tasks, a group-cognitive-task-analysis (GCTA) is required, in which the steps performed by different individuals (at possibly different locations) are analyzed; the group task, such as communication, coordination, and synchronization, must also be analyzed. A methodology for GCTA has not yet been developed, although Ed Salas of ONR has been working on it for team training purposes. Jim Geiwitz has developed the theoretical basis for GCTA and is presently developing the methodology.

4. In addition to the task analysis, an information needs analysis is required, to answer the three basic human factors questions described in #2.

5. An important question that surfaced quickly is, What is virtual reality? Dr. Loftin defined it as, "To some degree,

occupying an environment other than the physical environment of the moment." Dr. Geiwitz defined it as, "The true-to-form representation of the objects in the real world and their interactions." The participants discussed the differences between VR and various other representations: artificial worlds, synthetic environments, teleoperation, a televised environment, augmented reality (graphics superimposed on the real world). Most preferred "synthetic environment" to VR environment. An artificial world is not necessarily VR; it may relieve the constraints of the real world, such as the laws of physics. Augmented reality raises some interesting human-factors issues of its own. For example, as shown by Dan Weintraub at NASA-Ames, a VR graphic of the landing strip can be presented to a pilot, an immense aid to the pilot's approach before he or she can see the strip visually. When the pilot breaks through the clouds and can see the strip, the graphic remains as augmented reality, superimposed on the real runway. The problem is, the graphic may interfere with normal vision, with potentially disastrous consequences: Weintraub was able to show that if the real runway had a plane parked on it, an extremely dangerous landing situation, the pilot could not perceive the other plane until too late to avoid a crash. The VR graphic dominated the pilots's perception, at the expense of the perception of the real world.

6. Is this a VR experience? I don't drink, so when I join friends at a bar, I order a nonalcoholic beer, such as O'Douls. On one occasion, another friend joined us late. She saw my beer and ordered one for herself. She did not know it contained no alcohol. After 4 or 5 O'Douls, she got drunk, slurring her words, stumbling around, and laughing inappropriately at bad jokes. Was she in a VR environment created by her own imagination? Certainly she was occupying an environment other than the physical environment of the moment. Food for thought.

7. Dr. Geiwitz brought up the question of a dimension on which VR environments lie. Everyone seems to agree that such a dimension exists, but the participants argued about the nature of the dimension. What is it a dimension of? The background material for the workshop called it a dimension of "ambition." At the ambitious end of the dimension, the illusion of a real worlds is created and the user is immersed in a synthetic or remote environment. At the not ambitious end of the dimension are such environments as those created by text alone (as in Dungeons and Dragons) or simple graphics representing the real world (I suppose Weintraub's VR runaway would be an example). Dr. Loftin called it a dimension of fidelity, that is, how exact is the mapping of real world onto the VR world? Fidelity has at least two components: 1) stimulus similarity and 2) the number of modes used and represented. Presumably, a VR environment with visual, auditory, and haptic displays has more fidelity than one with only visual displays. The importance of this dimension, whatever one calls it, is that one would like to create just

enough VR to improve performance; any more than this is costly and unnecessary. Slight advances in fidelity may not improve performance enough to balance the increased cost. The human-factors issue here, as stated by Dr. Loftin, is the determination of the required degree of fidelity -- a very difficult task.

Several participants returned to the idea of a dimension later in the workshop. Some of the proposed dimensions were design vs manufacture, training vs manufacturing, teleoperation vs direct operation, controller end vs controllee end, distant in time vs distant in space, engagement vs immersion, dynamic vs static, interactive vs no interactive.

8. Dr. Geiwitz identified three primary modes of VR: conceptual (e.g., text-based VR), sensory (visual, auditory, haptic, olfactory, and gustatory), and motor (interactions with the VR environment). Most VR today is visual, with auditory a distant second. Dr. Loftin identified haptic displays as an important area of VR research, and Dr. Stansfield (Sandia) is about to begin a research program on haptic VR. In nuclear power plants where much of process occurs in the dark or under water, haptic displays may be more important than visual or auditory ones, especially for maintenance activities.

9. Dr. Geiwitz reviewed a few relevant research studies, which indicate some of the problems that the implementation of VR environments for manufacturing are likely to have. In almost all cases, inadequate task analysis was the fundamental cause of the failure of VR and other automated manufacturing systems (e.g., CIM). Poor knowledge acquisition was another common problem. Other problems included poor functional allocation (allocating subtasks to humans or machines), inadequate training for the use of the systems, and poor pre-implementation validation. Dr. Loftin noted a number of technical problems that arise with VR: Eye tracking devices do not work very well (yet); nausea, headaches, and eye strain are common among VR users; and, finally, won't somebody invent a good 3-D mouse to facilitate interaction?

10. Research has discovered some interesting aspects of VR development. For example, in one study of the use of robots for object assembly, the robots had on vision and poor finger dexterity (cost considerations). The product therefore had to be redesigned for easy robot assembly, e.g., "use snap and insert assemblies, wherever possible." These changes, however, made manual assembly easier, too, to the extent that it became cheaper to use manual labor for assembly; the robots were junked! On the other hand, research like this led to the development of Concurrent Engineering, in which the products designers and the process designers work together from the beginning, to design a product that can be manufactured by certain standards, such as ease of assembly, design for maintainability, interoperability,

and worker/user safety. (Conventional engineering has product design first, then process design).

The last major field study of manufacturing process was the Hawthorne studies at Western Electric in 1935! Hawthorne found that improved lighting improved productivity, but degraded lighting (return to normal) also improved productivity. The conclusion was that workers who got attention from their supervisors, even if it meant a change for the worse, responded with increased production. This has since been called the Hawthorne Effect; it must be considered when making any kind of change that is expected to increase performance.

11. Clearly, the absence of manufacturing engineers at the workshop hindered the discussion of human factors issues. The human factors engineers focused on the task: Task analysis is the first step in the design of an effective VR system. But what is the task? We could only speculate, and that at a fairly generic level. Here are some of the manufacturing tasks to which VR technology might be applied (if the task analysis shows they might benefit): engineering design, product planning, process planning, factory simulation, and monitoring and control (process control). A number of group/team tasks were also discussed during the workshop, including computer supported cooperative work, teleconferencing in virtual environments, distributed decision making, and concurrent engineering.

12. Research is needed on knowledge acquisition, a component of cognitive task analysis. The expert has two kinds of knowledge, semantic (what to do) and procedural (how to do it). Knowledge engineers often elicit the semantic knowledge alone, which is essentially worthless without the corresponding procedural knowledge. Experts often cannot articulate their procedural knowledge -- imagine you were asked how to run down a flight of stairs -- and therefore ingenious techniques must be developed to elicit such knowledge. An example of this problem and how it might be solved is the college physics developed by Fred Reif and Jill Larkin at Carnegie Mellon. Students who take a conventional physics course have semantic knowledge of physics, but they have no procedural knowledge. They do not know how to solve physics problems; their average score on the final exam is around 35%! Reif and Larkin specifically teach them how to describe their problem in terms that afford a solution, and then teach them how to apply the principles and theories of physics to solve the problem; they teach procedural knowledge to go with the principles and theories, the semantic knowledge. Reif & Larkin's students average around 85% correct on the final exam, an incredible improvement.

13. One major problem in the development of interactive VR systems is how to program autonomous, interactive agents (rather than objects). To predict what an agent will do in any given

situation is a difficult task, one that psychology has been working on for two centuries. Fortunately, the range of behavior in most VR systems is limited, so the problem is less than it might be. Dr. Geiwitz was involved in the development of OPFOR agents in SIMNET. In this case, the domain of behavior was combat; we had only to develop a model of an agent doing mission planning and reacting to the combat maneuvers of the SIMNET user (tank companies or battalions).

14. Some of the applications of VR technology discussed during the workshop include scientific data visualization, in which the engineer-designer navigates through large libraries of data, with multisensory perception, immersion for discovery, e.g., walk around inside molecules (Loftin); facility walkthru, visualize maintenance during product design, object identification in remote environments, determine wheelchair access in a building (Stansfield); use VR instead of full scale mockups, sales -- show customer what a customized airplane, according to his specs would look like, feel like, try out flight deck designs immersed in the body of a 5% female, augmented reality for touch-labor tasks (transparent graphics on real equipment) (Boeing); post office needs design to handle peak volume, identify bottlenecks and eliminate, simulations for design and for training, real-time situation awareness: what is happening, what has happened, what will happen, estimate costs (Clyde); several people made the point that a lot of manufacturing involves the need to know state of processing activity at one point, to plan to handle it at some later point.

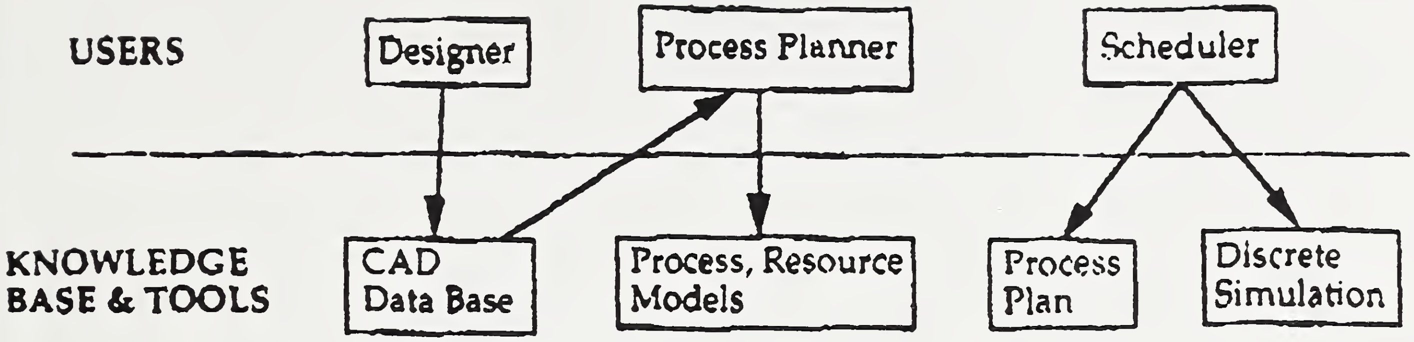
15. Some of the applications discussed in the breakout sessions include whole company use at Sikorsky: design, manufacturing, finance, sales, etc. (problem is integration of domain models, interactions among them; part of the solution is to have more generalists and fewer specialists); in design, design and test (simulation), to prevent errors in manufacturing before process begins; crane operator, needs to see what he's doing; and, of course, teleoperation.

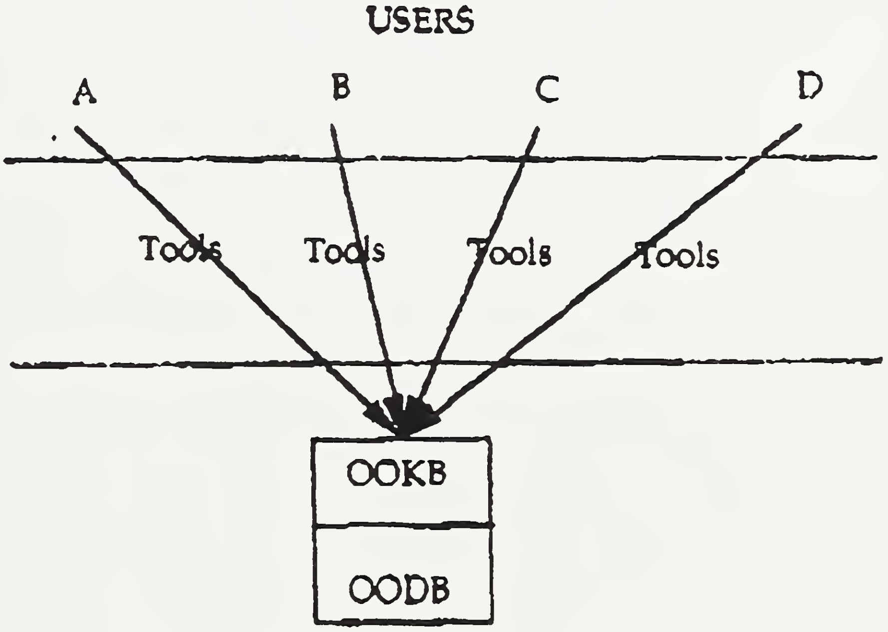
16. The role of reference models surfaced several times during the workshop. The primary purpose of a reference model is to promote interoperability or open systems. Typically these models are layered, so interactions between models can be coordinated at several levels, from the CEO issuing a command to the switching packets for electronic communication between systems, at all seven levels. One participant described her needs for standards and protocols: standards for storage of data for VR: CAD-->process planning--> simulation, pp also--> scheduling, all arrows involve protocols (sometimes informal); OOP (object oriented programming) is good for manufacturing schedules, because schedules vary, but objects remain the same, so do object interactions; phrased in terms of responsibilities -- what has to be done -- not when; OOP is good for reference models as well, is

what we used for the Command and Control Reference Model for combat decision aids.

17. Miscellaneous human-factors issues: Several participants commented on position trackers, don't work very well, do not locate well, also lag in time. Boom VR systems are preferred to head mounts, because of weight. Voice commands are preferred to data glove (Stansfield). Boeing representative urged caution on generic test beds (but, in my opinion, the obstacles are no worse than in most complex domains (e.g., I was told that I could never construct certification tests for mechanics in nuclear power plants because every plant had different equipment and different procedures, but we did it, and the general skills and knowledge turned out to be the most predictive of performance on the job. IN other words, I wouldn't be concerned about the NIST testbed; if we do it right, it will facilitate the development of VR systems for manufacturing AND speed their implementation; I think a generic testbed at NIST is a wonderful idea.)

18. One of the participants in my breakout session drew a diagram of how she saw the VR systems work. I thought it was an excellent diagram and therefore reproduce it here (next page). She is describing the construction of a graphics environment, or a VR graphics database: The designer builds a CAD data base, the process planner builds process and resource models, the scheduler develops a process plan and tests it in simulation form. In the bottom diagram, the users use intelligent, domain-specific tools to interact with giant object libraries, called knowledge bases (KB) and data bases (DB). As she indicated, this is also (roughly) the model used by ARPA in its initiative on VR and training.


USERS
Designer
Process Planner
Scheduler
KNOWLEDGE BASE & TOOLS
CAD Data Base
Process, Resource Models
Process Plan
Discrete Simulation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