Application of HTML/VRML to Manufacturing Systems Engineering

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Abstract

Manufacturing systems are complex entities comprised of people, processes, products, information systems and data, material processing, handling, and storage systems. Because of this complexity, systems must be modeled using a variety of views and modeling formalisms. In order to design and analyze manufacturing systems, the multiple views and models often need to be considered simultaneously. However, no single tool or computing environment currently exists that allows this to be done in an efficient and intelligible manner. New tools such as HTML and VRML present a promising approach for tackling these problems. They make possible environments where the different models can coexist and where mapping/linking between the models can be achieved. This research is concerned with developing a hybrid HTML/VRML environment for manufacturing systems modeling and analysis. Experiment was performed to compare this hybrid-modeling HTML/VRML environment to the traditional database environment in order to answer typical design/analysis questions associated with manufacturing systems, and to establish the potential advantages of this approach. Analyzing results obtained from the experiment indicated that the HTML/VRML approach might result in better understanding of a manufacturing system than the traditional database approach.

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CHAPTER 1
INTRODUCTION

1.1. Manufacturing Systems Modeling

Manufacturing systems are complex entities comprised of people, processes, products, information systems and data, material processing, handling, and storage systems. Manufacturing systems modeling is required in order to design effective and efficient systems and integrate the various components. Because of system complexity, however, systems must be modeled using various views, e.g., functional, informational, resource and organizational (Vernadat, 1996). A vast array of models have been proposed, developed, and used over the years for this purpose. Software applications employing various modeling formalisms can be used to develop models in each view. Some examples of modeling formalisms include IDEF (IDEF Users Group, 1992), EXPRESS (ISO 10303 -11, 1994), flowcharts, 2D and 3D simulations, system and data flow diagrams, plant layouts, part designs, organization charts, process plans, Gantt charts, and various text specifications.

For manufacturing systems analysis and design, these multiple views and models must often be considered simultaneously. At present, no single tool or computing environment exists that allows an arbitrary set of views and models to co-exist and to be used together in an efficient way. It is also difficult to map different models with existing environments. Additionally, incompatibility between file formats exists, as most of these applications were not intended to work together. Because of these deficiencies, users are often forced to deal with multiple tools simultaneously, switching from one application to another as required. The use of modeling tools in this manner is both inefficient and detrimental to the decision-making process, and seriously impacts the time it takes to design manufacturing systems and products. A software environment that allows different representations to be combined, shows the various relationships between different models, and can deal with incompatible file formats is needed to design and analyze manufacturing systems in an effective manner.

1.2. HTML/VRML

The World Wide Web (WWW) has changed the way we access information. The WWW interaction and navigation techniques follow an intuitive point-and-click paradigm. This technique of using hypertexts allows users to follow hyperlinks and helps them move down to underlying data. Hypertext tools developed for the WWW such as Hypertext Markup Language (HTML, 1995) and Virtual Reality Modeling Language (VRML, 1997) follow these techniques. Currently, HTML remains a common standard for providing formatted, inter-linked text. HTML is an ASCII file format containing certain nodes that dictate the structure of the displayed text and graphics. It also contains information regarding the destination of the links of the page. HTML can be viewed with any Internet browser (Netscape communicator[1], Internet Explorer[2], etc.). A recent advancement in the area of hypertext is Microsoft Active Server Pages[3] (ASP), which can be used to create dynamic, interactive content to the web page. ASP provides the user with the power to interact with a database over the Web.

VRML has become a popular de-facto standard for producing 3D graphics within Web environments. VRML is a way of describing 3D objects and scenes over the Internet, based on Silicon Graphics' Open Inventor[4] file format. VRML defines the

[1] Netscape Communicator is a registered trademark of Netscape Communications Inc.
[2] Internet Explorer is a registered trademark of Microsoft Corporation.
[3] Active Server Pages is a registered trademark of Microsoft Corporation.
[4] Open Inventor is a registered trademark of Silicon Graphics Corporation.

layout and content of 3D worlds with links to more information. The links can be to either HTML pages or VRML worlds. Unlike HTML, VRML worlds are spacious and inherently interactive -- filled with objects that react to users and to each other. VRML 1.0 (VRML 1.0, 1995) was restricted to representing static 3D worlds. VRML 2.0 (VRML 2.0, 1997), which offers several improvements, can be used to represent dynamic environments. To view VRML worlds using a standard web browser, one might need to download a plug-in such as Computer Associates Cosmoplayer[5], which works with the common Internet browsers such as Netscape and Internet Explorer.

1.3. Problem Statement

As previously noted, manufacturing systems are extremely complex entities that must be studied using multiple views and models. The sheer amount of information, variety of information types, and relationships that exist for such systems makes it extremely difficult for any user to obtain an accurate, detailed understanding of a manufacturing system developed using stand-alone applications. At the same time, the incompatibility of the various file formats used for different applications hinders the ability to develop integrated modeling environments. Currently, there are few software environments which can deal with multiple views and models simultaneously. HTML and VRML offer a promising approach for tackling these problems. They can be used to develop a software environment in which movement and linking between different models and views are possible. The links can be used to connect to different types of modeling artifacts (e.g., physical object, function box, information flow, etc.) via the use of different modeling formalisms (e.g., layout diagram, activity network, data flow graph, etc.). Multiple viewpoints allow the user to "move" to particular locations within

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[5] Cosmoplayer is a registered trademark of Computer Associates Pvt. Ltd.

a model and then view the various objects in the model from that position, using various orientations. An additional advantage of HTML and VRML is that both languages are platform-independent. Because of its neutral file format, many of the formats employed by different modeling packages can be translated to VRML. This allows for easy and efficient use of various modeling formalisms in the same VRML world.

Thus, the problem being addressed in this research is that of dete rmining how HTML/VRML can be applied to manufacturing systems modeling and analysis, in such a manner as to address the above concerns.

1.4. Research Objectives

The goal of this research is to show how HTML/VRML technology can be applied to manufacturing systems modeling. The objectives of this research are as follows:

1. Develop/identify suitable HTML/VRML mechanisms for manufacturing systems modeling. For example, a feature common to both HTML and VRML is "hot links." Hot links can be used to link between an artifact in a physical model (e.g., part) to the associated information in an information model (parts routing, due date, BOM, etc.).
2. Demonstrate the use of the HTML/VRML mechanisms described in step 1.
3. Evaluate the concept of employing HTML/VRML for manufacturing systems analysis, as described in step 1 and shown in step 2.

1.5. Outline of this Document

The remainder of this document is divided into seven chapters as follows:

- Chapter 2 presents a review of the literature on three different areas - manufacturing systems modeling, HTML/VRML and their applications to manufacturing, and experimental work in user interface design.
- Chapter 3 presents the research approach and the details of the experiment. In this chapter, various HTML/VRML mechanisms, as well as how these mechanisms can be applied for modeling manufacturing systems are discussed. In addition, an experimental design for evaluating the concept is presented.
- Chapter 4 describes the HTML/VRML environment developed for the research. The chapter gives an overview of the environment and describes in detail how various mechanisms will be provided in the VRML world to link the different views.
- Chapter 5 describes in detail how the HTML/VRML environment was employed for the research. This chapter briefly describes the manufacturing system and the production scenario. A description of how these items were developed using the HTML/VRML modeling environment is also presented.
- Chapter 6 describes in detail the experimental design and presents a brief description of how the experiment was performed.
- Chapter 7 presents a description of the analysis performed on the results of the experiment and the conclusions obtained from the analysis.
- Chapter 8 presents research conclusions and future research directions.

CHAPTER 2
LITERATURE REVIEW

2.1. Manufacturing Systems Modeling

Modern manufacturing systems are data-rich, complex entities, and like any other complex entity, have many associated problems. The complexity associated with manufacturing systems requires that the system be modeled using different views. Each of these views, with its inherent assumptions, typically will be modeled and used independently. The elements and relationships in one model inherently affect the elements and relationships in another model, since these models represent the same manufacturing system. However, for a better analysis of the system it is necessary to represent all the models in a common software environment. Most of the work has been concentrated toward data integrity and inconsistency of data between various software environments (Mize *et al.*, 1992, Gong and McGinnis, 1996, and Koonce *et al.*, 1996). Research work towards modeling of manufacturing systems has been carried out for a long time. A wide range of modeling techniques has been developed and adopted over the years (Askin and Standridge, 1993). Simulation has been used to a great extent to model manufacturing systems (Schroer, 1989, Ketcham *et al.*, 1989, and Ruiz-Mier, 1987). However, most of these simulation environments represent only a single view of the system. Different kinds of modeling formalisms have been developed over the years. Functional modeling of manufacturing systems can be done using IDEF0, and software packages have been developed for this task e.g., WorkFlow Analyzer 4.0 (Meta Software Corporation, 1998). Various techniques such as Petri nets (Petri, C.A., 1965, and Peterson, J.L., 1977) have been developed for information modeling of the system. A need to represent all these models in a single environment has always been desired. The majority of work dealing with simultaneous consideration of multiple views and models in manufacturing has been performed through research on manufacturing (enterprise) architectures, such as CIM-OSA (AMICE Consortium, 1992), the Purdue Enterprise Reference Architecture (Williams, 1992), the GRAI model (Doumeingts *et al.*, 1992), and the IEM approach (Mertins *et al.*, 1991). Software packages such as Artifex and Quid (Bruno *et al.*, 1995) were developed to make these architectures operational. However, the sheer amount of information, variety of information types, and relationships that exist for such systems make it extremely difficult for any user to obtain an accurate, detailed understanding of the system via these two-dimensional models. Even so, very little work has been specifically directed to developing software environments for dealing with multiple views and models simultaneously.

2.2. HTML/VRML and their applications

The combination of infrastructure provided by the World Wide Web (WWW) and the visualization capabilities of VRML and HTML offers a unique opportunity to provide an intuitive interface to models/data associated with manufacturing systems. Leung *et al.* (1996) surveyed various technologies such as multimedia and hypertext and presented an overview of how they can be used in a manufacturing environment. The HTML/VRML environment, however, will be able to provide potential users with a much clearer picture of any manufacturing system via different views and models. This approach is endorsed by He *et al.* (1996), who also points out that the development of generalized models and an open-system architecture is essential to future developmental work for virtual manufacturing.

While both HTML and VRML employ hot links, certain features are specific to VRML. These features include viewpoints, transparency of objects and billboards. Viewpoints are one of the more powerful features of VRML. They allow the user to be transported to specific camera positions within the virtual world. There are no restrictions on the number of viewpoints in a VRML world. VRML also provides the ability to attach animations to viewpoints. This feature is useful if one intends to view animation from a particular camera position. The user also has the ability to move around in the virtual world ("cruise") on his/her own. Additionally, objects in the virtual world can be modeled as "Billboards" that have the ability to orient themselves to the user as the user moves through the virtual world. The "billboards" can be either two-dimensional or three-dimensional. Billboards can also be used to include 2D images in a VRML world and to rotate them so that they are always facing the camera. Animation can be used to show system behavior over time, while turning visibility on and off can be used to effectively isolate select models and/or objects, bringing them to the foreground. Using HTML/VRML environment, objects in different models can be linked with each other using hot-links. Although VRML is new, HTML has been used extensively over the years to help manufacturers share tools and data over WWW (Erkes *et al.*, 1996). With the advent of Active Server Pages (ASP) technology, the use of HTML and its associated tools in the area of electronic commerce has increased tremendously. Most of the manufacturing software that are becoming Internet-based to improve ease of communication are relying on the de-facto HTML standard.

Despite their potential, however, the use of HTML and VRML in manufacturing to-date has been very limited. Most of the work done using VRML has covered applications in the sciences, commercial ventures, and artistic uses (IEEE, 1996). A few reported engineering applications of VRML have been in fields such as civil engineering and architecture (Dodge *et al.*, 1997, Smith *et al.*, 1997) and to illustrate pick-and-place capabilities of robots (VRML, 1997). Commercially, VRML sites specific to manufacturing (Information Assets Inc., 1996) also exist on the web. It has also been shown that a combination of VRML, Common Gateway Interface (CGI) scripts and HTML can be used to access manufacturing data over the web (Ressler *et al.*, 1997). CGI is a method of communicating between a browser and a server for processing user input through a script and generating output. The output of the script is then sent back to the browser and displayed. A review of the literature shows that not much work exists investigating the use of HTML/VRML for manufacturing systems modeling and analysis.

2.3. Graphical User Interface Design

The World Wide Web (WWW) has revolutionized the way information is accessible to users. This is partly due to hypertext, the language used for the WWW. Hypertext has eased the way for a user to access information because it gives him/her the freedom to explore text in a non-sequential manner, moving from one page to another randomly. Research on variation in user performance from linearly organized text to hypertext has been conducted over the years. The influence of spatial ability on user performance with regard to hypertext systems has also researched over the years (Campagnoni and Ehrlich, 1989, Vicente and Williges, 1988). Chen and Rada (1996) conducted a meta-analysis of experimental studies on interaction with hypertext and recommended improvements over the existing hypertext. The literature review of the various experiments conducted on information visualization shows that users' cognitive ability is another important factor. Experiments conducted by Charney and Reder (1986) on designing interactive tutorials have shown that problem solving is a more difficult form of training than guided practice, but it produced better results on tests conducted as part of the experiment. The use of graphics has always been regarded as another factor which has improved user performance in understanding the system and in decision-making (MacGreyor and Slovie, 1986, Benbasat *et al.*, 1986). A variety of experimental work has been performed to test hypertext environments, but a review of the literature shows that not much work has been directed towards testing VRML-based environments. In addition, work addressing the issue of interface design with regard to manufacturing systems modeling was not found.

CHAPTER 3
RESEARCH APPROACH

Manufacturing systems modeling remains an essential activity for understanding and dealing with the complexity associated with manufacturing systems. Although many models are possible, a single environment to deal with the various models and to provide links between these models offers an attractive option for designing and analyzing manufacturing system efficiently. An initial survey of the literature has shown that this aspect of manufacturing systems modeling has not been addressed. Yang (1996) points out that the development of generalized models and an open-system architecture are essential to future developmental work for virtual manufacturing. Therefore, the aim of this research is to address this necessity by developing a modeling environment, where different models can coexist in the same environment and the mapping/linking between the models can be achieved. This approach will result in improved environments for manufacturing systems analysis and design.

The modeling environment will be similar to a web page, where a user can gather variety of information by way of hot links. A user in this hybrid environment will be able to study manufacturing system models via hot links and other HTML/VRML mechanisms, thus obtaining a better understanding of the system. The research approach consists of three steps, each of which satisfies one research objective (Section 1.4). These steps are listed and described as follows[6]:

1. Develop HTML/VRML manufacturing systems modeling environment.
2. Demonstrate use of HTML/VRML manufacturing modeling environment.
3. Evaluate HTML/VRML-based manufacturing systems analysis.

[6] The manufacturing systems modeling work (Krishnamurthy et al., 1998) performed at National Institute of Standards and Technology (NIST) formed the background for this research.

3.1. Develop HTML/VRML Manufacturing Systems Modeling Environment

The first step of the research is to develop an HTML/VRML environment for modeling manufacturing systems. The environment will be similar to a page on a web browser. It will require the identification/development of various mechanisms associated with HTML and VRML, such as hot links, billboards, transparency, etc. Additionally, it will require a technique to allow HTML and VRML to interact with each other using hot links. These links can be of three different types: 2D to 2D (HTML to HTML), 3D to 2D (VRML to HTML) and 3D to 3D (VRML to VRML). Linking from 2D to 3D (HTML to VRML) is currently not possible in this environment, due to certain restrictions in the specifications of VRML. The modeling environment will encompass three views of the manufacturing system: physical, functional, and informational. Functional models will be displayed via the 2D interface (i.e., HTML), and physical models will be displayed via the 3D interface (i.e., VRML). Hot links and other mechanisms will make interaction between these views possible. Active Server Pages (ASP) will be used to retrieve data from the database associated with these models. ASP can be defined as a file that contains a combination of HTML and a scripting language. The script can be either JavaScript or VBScript. The database will be developed and implemented using Microsoft Access'97[7]. One of the reasons for choosing Microsoft Access is the ease of implementation. In addition, since this research does not involve a large amount of data, Microsoft Access seems to be the ideal choice for a database. The MS Access database, which will be used to store/retrieve information describing the state of a manufacturing system, serves to link functional and physical data with the informational data. The hot links in the functional and physical views can be used to retrieve data from the database. When a user clicks on a hot link, the data associated with the particular link will be retrieved from the database and presented as an HTML

[7] Access is a registered trademark of Microsoft Corporation.

document. The interaction between the visual interface and the database will be made possible using ASP. The database interaction is mainly provided so that the data associated with various manufacturing activities are not "hard-coded."

3.2. Demonstrate use of HTML/VRML Manufacturing Modeling Environment

The second step of the research is to develop an integrated HTML/VRML model of a manufacturing system using the environment from step 1. The manufacturing system will have a limited scope. The model will consist of a small physical shop with an inventory and an engineering office attached to it. The machines will serve as hot links and informational data associated with the machines will be obtained by clicking on the hot links. The data will be retrieved from the database using Active Server Pages, as described in Section 3.1. The engineering office will include terminals, desks, worktables, and staff. The terminals on the virtual shop floor, as well as in the engineering office, will be connected to a server through a network.

Two modeling approaches for material flow within the factory level are widely used: “Push” and “Pull”. The push system is a schedule-driven system. All input materials are processed at each process and "pushed" down stream according to its material-flow. Meanwhile, the "pull" system is a WIP-driven system. In this system, each station has a collection of input and output buffers. A station will pull inventory from up-stream stations whenever its input buffer becomes too low. A station will receive a request for new production orders when the WIP level in its output buffer is too low. A third approach called "hybrid push-pull" is becoming more common for modeling material flow within the factory level (Umeda, 1992). In this model, a part of the material flow is schedule-driven and another part is based on the inventory. For this research, “hybrid push-pull” model is assumed. The production scenario will consist of simple hypothetical end items with single-level bills of materials.

In any manufacturing environment, the main product realization functions are: design engineering, manufacturing engineering and production. The first two phases and a significant part of the third phase are aimed towards proper planning of the actual manufacturing process on the shop floor. Although there are a lot of activities involved in planning the process, four major activities are important for any planning process. They are product design, NC programming, process plan and production planning. These four major activities will also define the production scenario in the HTML/VRML environment. Data document objects will be associated with these major production activities.

3.3. Evaluate HTML/VRML-based Manufacturing Systems Analysis

The third and final step of the research is to perform an experiment to validate the use of HTML/VRML for manufacturing systems analysis. The main purpose of the experiment will be to demonstrate variations in user performance with regard to the interface, which will help in measuring the differences in solving common manufacturing problems using the HTML/VRML interface and the traditional database interface.

Performing experiments to evaluate a system is one of the ways to learn about how systems or processes work. Experiments are performed to generate data from the process, and then the information from the experiment is used to establish new conjectures, which lead to new experiments and so on. The three basic principles of experimental design are replication, randomization and blocking (Montgomery, 1997).

Replication involves repetition of the basic experiment. Randomization involves randomly determining the experiment material and the order in which the individual runs or trials of the experiment are performed. Blocking is a technique used to increase the precision of an experiment. Montgomery also points out that there are seven basic guidelines for designing an experiment. The guidelines are listed below:

1. Recognition and statement of the problem: This involves developing all ideas about the objectives of the experiment.
2. Choice of factors and levels: This involves varying the factors in the experiment and the ranges over which these factors can be varied.
3. Selection of the response variable: The response variable is selected based on whether the variable really provides useful information about the process under study. A process under study can have multiple response variables.
4. Choice of experimental design: Choice of design involves determining the sample size, the selection of a suitable run order for the experimental trials and to determine whether randomization or blocking restrictions are involved.
5. Performing the experiment: This involves conducting the experiment and monitoring the process to ensure everything is done according to plan.
6. Statistical analysis of the data: This involves using statistical methods to analyze the data so that the results and conclusions are proved objectively. If the design is correct and the experiment is performed according to plan, usually the statistical methods are not elaborate.
7. Conclusions and recommendations: The final step is to draw the conclusions from the analyzed data and make recommendations from the results.

The experiment conducted for this research will consist of comparing the performance of the HTML/VRML environment to that of traditional database environment for answering typical manufacturing system design/analysis questions. The experiment will be conducted using two types of users: experimental users and control users. Experimental users will use the hybrid HTML/VRML environment and control users will use the MS access database environment. Subjects will be selected at random to work on a particular environment. It will also be ensured that the subjects using the environment have sufficient background in manufacturing. To eliminate differences in familiarity with 3D interfaces between the users, a training session will be provided to the subjects, on the specific environment they have been selected to work in. The training will be given using a subset of the actual system. After the training session, each subject (user) will be given three basic design/analysis questions pertaining to the system being modeled. For the experiment, the presentation method (HTML/VRML-based, traditional database based) will be the independent variable, while solution time (T) and solution accuracy (A) will be the dependent (response) variables. It should be noted that solution time and solution accuracy are co-related to each other. For example, a subject can answer a question in a shortest possible time but might not answer the question correctly. So, a third response variable, which is a combination of solution time and solution accuracy, will be used. Let the third response variable be referred by the term "Effectiveness". The third response variable will be obtained by dividing solution accuracy of each question by the corresponding time taken to answer the question.

In a traditional manufacturing environment, users analyzing the system often have access to diagrammatic representations of various entities of the manufacturing system (e.g., layout diagram) in order to properly analyze the system. With this in mind, subjects using the traditional database environment will be given three additional documents:

1. Product Structure diagram and picture of each end item
2. Facility Layout diagram
3. Relationship schema diagram

After the subject completes the three questions, there will be a post-trial session during which the subject will be given two additional questions related to the system. The subject will be expected to answer these two questions without the aid of the environment. This part of the experiment will be carried out to help in analyzing the effect of the model in subject's understanding of the system and how well information was retained.

Hypothesis testing is one of the procedures for analyzing results obtained from experiments. Although hypothesis testing is a useful procedure, on some occasions, analysis can also be performed by defining confidence intervals. One of the main reason is that sometimes hypothesis testing does not present the analysis in its entirety. Therefore, it is often preferable to define an interval within which the value of the parameter in question would be expected. However, for this experiment, hypothesis testing is preferred over the procedure of defining confidence interval due to various reasons. The two samples will be drawn from independent population of subjects and the subjects being randomly selected, procedure of randomization test is considered suitable to perform the analysis. Also, since the use of randomized design helps one to test hypotheses without any assumptions regarding the form of distribution (Box *et al.*, 1978), no extensive concern need to be given to the assumption of normality. The t-test, being a good approximation of the randomization procedure will be adopted to test the hypotheses.

The hypothesis for this experiment is that the hybrid HTML/VRML environment provides a better understanding of the system, thereby statistically validating the HTML/VRML approach. Hypothesis testing starts with specifying a null hypothesis and an alternate hypothesis. To test these hypotheses, the general statistical method is to devise a procedure for taking a random sample, computing an appropriate test statistic, and then rejecting or accepting the null hypothesis [Montgomery, 1997]. In addition, the hypothesis can be a single sided or a two-sided hypothesis. In a two-sided hypothesis, rejection of null hypothesis does not give any idea whether the computed value favors a certain set of sample population. It only indicates that there is a significant difference in the value of the test statistic between the two sets of population. On the other hand, in a single-sided hypothesis, if the null hypothesis is rejected, one can conclude that the test statistic result favors a certain set of sample population. Since the objective of this experiment is to determine whether the HTML/VRML environment provides a better understanding than the traditional database environment, the single-sided hypothesis test will be carried out.

The time taken and the accuracy of results for each question will be obtained from the experiment, and the third response variable (Effectiveness) will then be calculated by dividing solution accuracy for each question by the corresponding time taken to answer the question. The mean for each variable can then be calculated for both the traditional database environment and the HTML/VRML environment. Let $\mu_{T,3D}$ represent the mean for time taken by the subjects using the HTML/VRML environment and $\mu_{T,2D}$ represent the mean for time taken by the subjects using the traditional database environment. Let $\mu_{A,3D}$ represent the mean for solution accuracy obtained by the subjects using the HTML/VRML environment and $\mu_{A,2D}$ represent the mean for solution accuracy obtained by the subjects using the traditional database environment. Let $\mu_{A/T,3D}$ represent the mean effectiveness using the HTML/VRML environment and $\mu_{A/T,2D}$ the mean effectiveness using the traditional database environment. The null hypothesis and the alternate hypothesis for each variable can then be stated formally as

Time Taken: Null Hypothesis: H_0: $\mu_{T,3D} \geq \mu_{T,2D}$

Alternate Hypothesis: H_1: $\mu_{T,3D} < \mu_{T,2D}$

Accuracy: Null Hypothesis: H_0: $\mu_{A,3D} \leq \mu_{A,2D}$

Alternate Hypothesis: H_1: $\mu_{A,3D} > \mu_{A,2D}$

Effectiveness: Null Hypothesis: H_0: $\mu_{A/T,3D} \leq \mu_{T,2D}$

Alternate Hypothesis: H_1: $\mu_{A/T,3D} > \mu_{T,2D}$

It must be noted that a statistical hypothesis is a statement about the parameters of a probability distribution. So, a null hypothesis is rejected or is failed to be rejected just based on statistical mean of the data. It is an indication that the mean of the data is a major component involved in the test and can influence rejection or acceptance of the null hypothesis. If the null hypothesis H_0 fails to be rejected, it will be concluded that the HTML/VRML environment is equal to or worse than the traditional database environment for answering questions. On the other hand, if the null hypothesis is rejected, it will be concluded that the HTML/VRML environment is better than the traditional database environment for answering questions. One way to report the results of the hypothesis test is to state that the null hypothesis is accepted or rejected at a specified alpha-value or level of significance. The level of significance is the probability that a null hypothesis can be rejected when it is true. For this experiment, a level of significance value of 0.05 will be used.

The t-test will be performed for each of the three variables for the main experiment:

1. Time taken by users
2. Accuracy of results
3. Effectiveness.

For the post-trial session, the t-test will be performed only on accuracy of results, since this test will be done to ascertain the user's understanding of the system, and retention of information. The null hypothesis and the alternative hypothesis for post-trial session can be stated as follows:

Accuracy Null Hypothesis: H_0: $\mu_{PT,A,3D} \leq \mu_{PT,A,2D}$

Alternate Hypothesis: H_1: $\mu_{PT,A,3D} < \mu_{PT,A,2D}$

In this case, if the null hypothesis is accepted, then it will be concluded that the HTML/VRML environment is equal to or worse than the traditional database environment in helping subjects understand the system. On the other hand, if the null hypothesis is rejected, it will be concluded that the HTML/VRML environment is better than the traditional database environment and that the subjects using the HTML/VRML environment can understand the system better than their counterparts.

CHAPTER 4
HTML/VRML MODELING ENVIRONMENT

The objective of this research is to develop a hybrid HTML/VRML modeling environment and to evaluate the concept of employing HTML/VRML for manufacturing systems analysis. This chapter describes the HTML/VRML environment developed for the research. The first section gives an overview of the environment and the second section describes in detail how various mechanisms will be provided in the VRML world to link the different views.

4.1. Overview

The HTML/VRML modeling environment will encompass three models/views of the manufacturing system: physical, functional and informational. The top frame of the interface will display the functional view and the bottom frame will display the physical view, and the tables in the Microsoft Access database will represent the informational views. The HTML/VRML environment interface with functional and the physical view are shown in Figure 1. Interaction between these two frames will be achieved using hot links.

In both the HTML documents and the VRML world, the hot links will be associated with either two-dimensional or three-dimensional data. Depending on the information to be displayed, the data will be displayed either as a three-dimensional object in the VRML world or as an HTML document. When data has to be retrieved from the database, the hot links will serve as an interaction between the visual interface and the database. This ability to interact through hot links can be used to advantage for mapping functions between physical, informational and functional views.

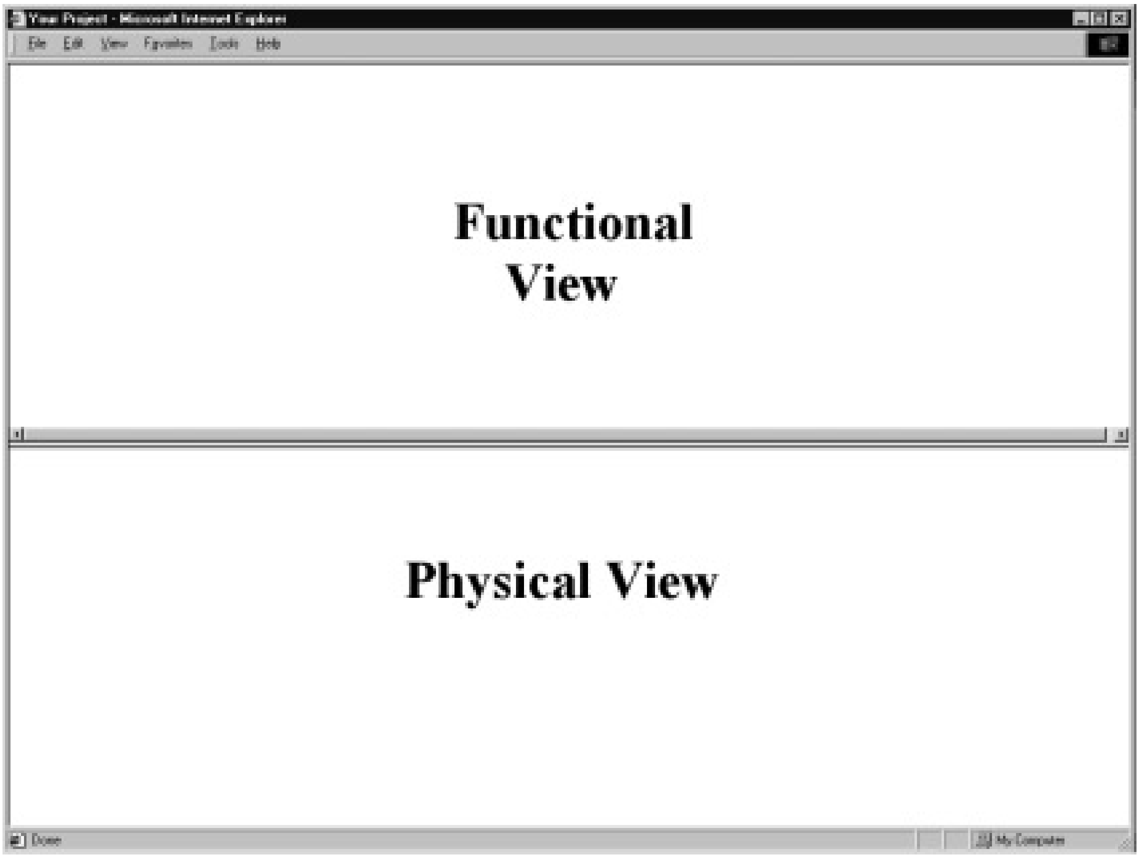


Figure 1 HTML/VRML environment interface.

The functional view of the manufacturing system will be displayed as an HTML document in the top frame. The various functions involved in the manufacturing system will be represented as boxes in the HTML document and mapped both to the information model (database) and to the physical model (VRML worlds) via hot links. The functions are linked based on their hierarchy. The user will be able to move down to the required data by clicking on these boxes. When a user clicks on a box, the data associated with the particular function will be displayed either in two-dimensional form as an HTML document or in three-dimensional form in the VRML world. This allows the user to link between the functional and the informational views.

The physical view of the manufacturing system will be displayed as three - dimensional objects in the VRML frame. The objects in the physical world will be represented as hot links and serve as a portal to the data contained in the informational view. When a user clicks on one of these hot links, the information associated with these objects will be retrieved and displayed either as an HTML document or as a VRML object. This allows the user to link between the physical and informational views. The interaction between the different views is shown in Figure 2.

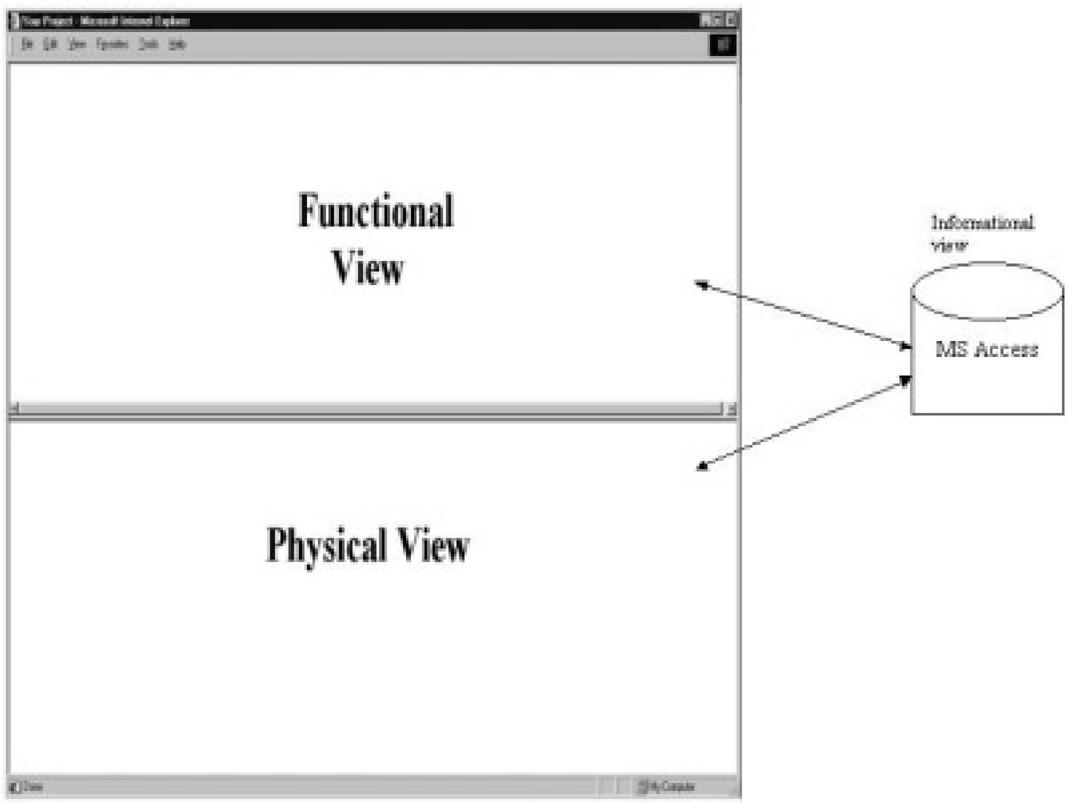


Figure 2 Interaction between views.

The interaction between the physical, functional and informational view will be made possible by using Active Server Pages (ASP). Active Server Pages help in creating platform-independent content that can be displayed as an HTML document on any browser. Active Server Pages refers to scripting done on the server. This scripting code is evaluated dynamically when a page is requested, and the resulting HTML is passed on to the browser. An ASP document can contain both HTML syntax and the scripting code. As mentioned earlier, the scripting code can be either in JavaScript or in VBScript. VBScript is a subset of the popular Visual Basic and has been designed to work only with Microsoft Internet Explorer browser. JavaScript, developed by Netscape is universal in nature, and works with both Internet Explorer and Netscape Navigator. The interaction between Active Server pages and the Access Database will be made possible using Microsoft Web Server. There are two types of web server: Personal Web Server and Internet Information Server (IIS). Personal Web Server is for use on Windows 95 and IIS is for use on Windows NT. Personal Web Server will be used for this research. When a web server receives request from the ASP document, the scripting code connects to the Access Database and retrieves the data. The data is then dynamically evaluated and a HTML file is generated using the combination of both static HTML information and any HTML that is generated by the scripting code. The HTML page is then displayed on the browser. When a user sends back data, the data is passed on to the scripting code from the HTML page, through the web server. The scripting code then sends the data to the Access database to be saved in the database. The system architecture diagram is shown in Figure 3.

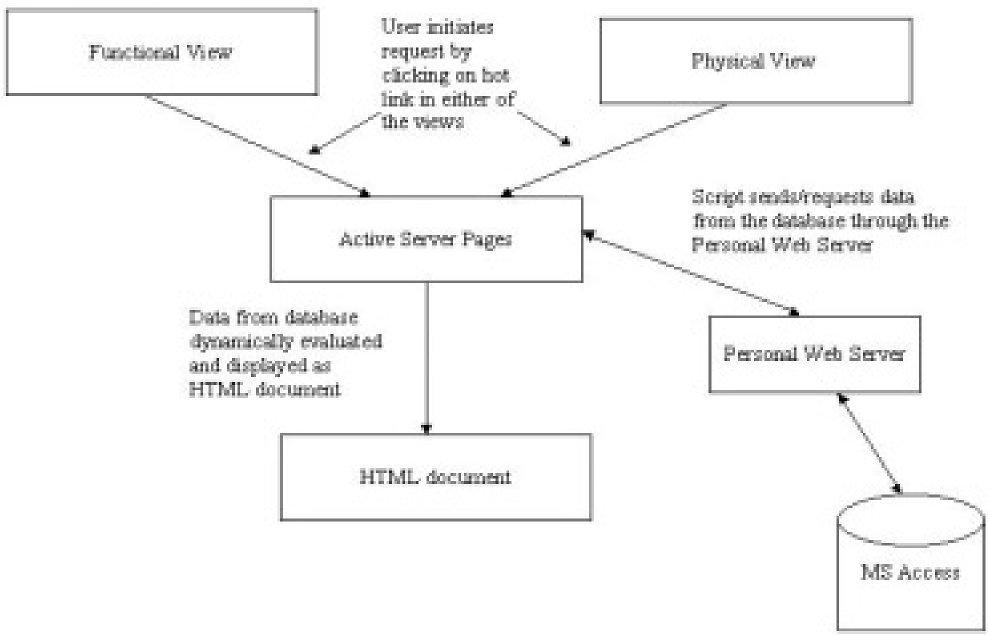


Figure 3 System Architecture diagram.

4.2 HTML/VRML Mechanisms

Default features in HTML such as 'hot links' will be used as part of the HTML interface. One additional mechanism that will be developed as part of this interface is controlling the size of the child window according to the data displayed, as shown in Figure 4. This is made possible by embedding JavaScript within the HTML code. This feature is provided so that the window displaying the data does not completely overlay the parent window. However, to prevent too many child windows spawning on the screen, the number of child windows that can be displayed at anytime will be restricted to one. This will be achieved by specifying the same name fo r the child window whenever a new child window has to be spawned.

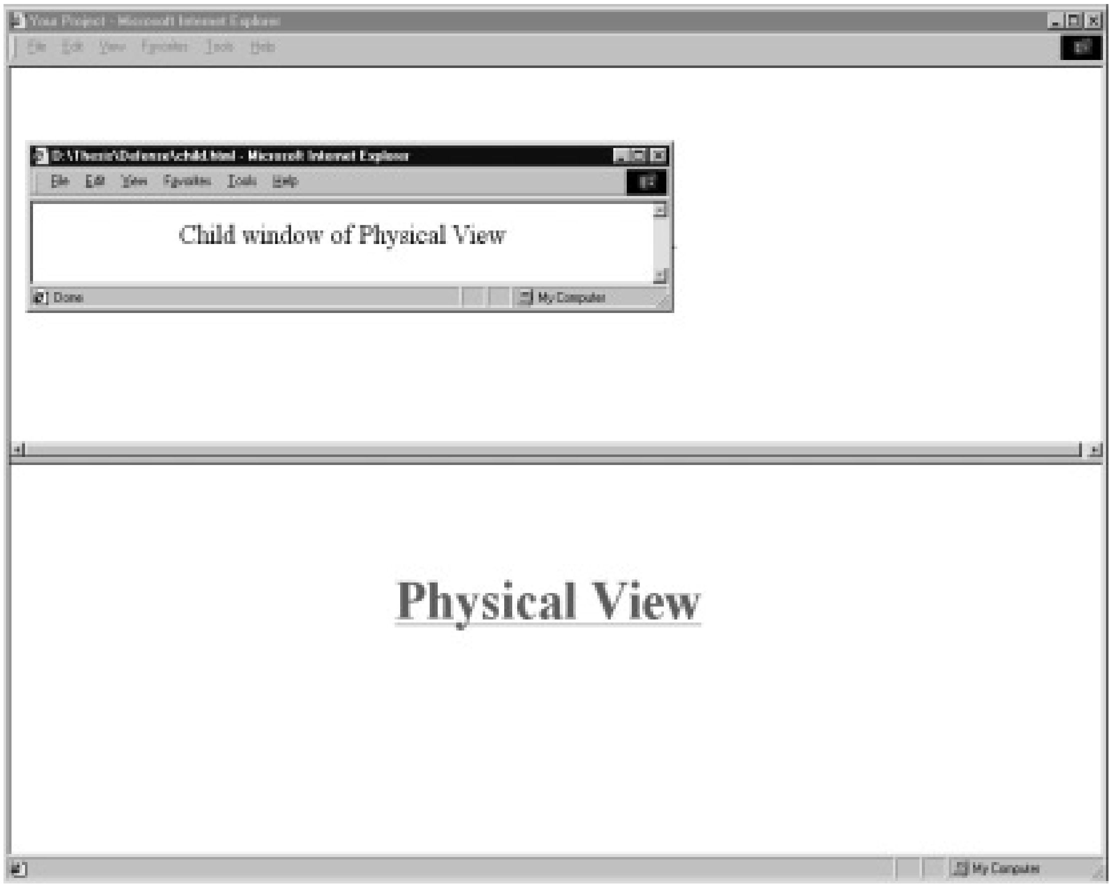


Figure 4 Sizing of window in HTML.

The features that will be developed for use in the VRML world are pop -up menus, tracking of mouse movements, billboards, viewpoints, transparency and variable object rendering. Each of these features is described as follows:

Pop-up menus

Pop -up menus are one of the important features that will be developed for use in the VRML world. Pop-up menus help in providing a better visual interface for the information associated with an object. The options in the menu will be modeled as VRML objects that have links to HTML documents or to a VRML world, depending on the type of information that will be displayed. Retrieving the information associated with a VRML object from the database will be achieved by linking the menu options to active server pages. The input data to active server pages depends on the menu option selected by the user. The active server page will then be used to connect to an MS access database and retrieve the required information. The information can then be displayed as an HTML document.

Tracking of mouse movements

Tracking of mouse movements made by the user is considered a necessity to let the user know that an object is a hot link. In HTML, this is a default feature. However, the same does not hold true in VRML. Tracking of mouse movements in VRML can be accomplished using scripting language such as JavaScript or VRMLScript. The scripting language can be a part of the VRML code. In HTML, when a user moves the mouse over a hot link, the color of the link changes to indicate that it is a hot link. A similar feature will be provided in the VRML world, wherein, when a user moves the mouse over an object, which is a hot link, the color of the object changes to indicate that the object has information associated with it.

Billboards

As mentioned earlier, all the objects on the shop floor which have information associated with them will serve as hot links to data. Billboards will be used to display the data so that the information is displayed irrespective of the orientation of the user. By displaying the information associated with an object as a billboard, the user will be able to cruise to a particular position and view the information from any desired orientation.

Viewpoints

Viewpoints will allow the user to "move" to a pre-established location within the VRML world and then view the various objects in the model from that location in a pre-determined orientation. Providing viewpoints will also give the user the option to backtrack in case he/she loses his/her place in the three-dimensional virtual world.

Transparency

Transparency is a default property in VRML, which if harnessed properly can be a great tool to the user for use in the VRML world. Most of the time a user might be interested in viewing a specific detail but the other objects in the VRML world can be a hindrance. To show a specific detail to the user in a VRML world with all the objects present and at the same time making certain that the user can understand the details presented to him/her is quite a challenge. One way to solve this problem will be to display only the objects associated with the particular information. All other objects in the VRML world will be made invisible by controlling the transparency of the objects. This might help the user understand routing information, for example, better than via documents or database-based linear text. Transparency will also be used to a great advantage to provide a very important feature in this VRML world, which is "Variable object rendering."

Variable Object Rendering

Variable object rendering is an important feature that will be developed as a part of the HTML/VRML environment. The objects in the VRML world takes a long time to load, due to the fact that all the polygons have to be rendered before the models can be displayed. In order to avoid the dependency of VRML models on the computer's speed and capacity, a different way of rendering will be applied. Instead of displaying all the workstations at the start, cubical boxes will be displayed in place of workstations and a user can click on a box to have the corresponding workstation displayed. This is made possible by controlling the transparency of the objects being displayed. This feature also provides better control to the user, who might not interested in viewing all the workstations, to choose what he/she wants to see. This is an important feature in

VRML modeling, as highly detailed objects contain a large number of polygons and it takes a lot of time to render those polygons. Additionally, when a user moves around in the VRML world, these objects have to be rendered repeatedly. By providing this feature, the objects will be rendered at the time of loading and user need not wait for the objects to be rendered every time the user changes position in the VRML world.

CHAPTER 5
DEMONSTRATION OF HTML/VRML MODELING ENVIRONMENT

This chapter describes in detail how the HTML/VRML environment discussed in the previous chapter was employed for the research. The chapter is divided into two sections. The first section describes the manufacturing system and the production scenario in detail. The second section describes how these items were developed using the HTML/VRML modeling environment.

5.1. Manufacturing System and Production Scenario

The manufacturing system envisioned consists of a shop floor, with an inventory and an engineering office attached to it. The shop will house a T30 Cincinnati milicron milling machine, a vertical milling machine, a coordinate measuring machine and a hexapod. A hexapod is a six-axis machine and is a dramatic departure from conventional machine tool design. It has the potential to be a highly reconfigurable, high-precision machine (Sandia Hexapod Testbed, 1999). There are two inventory storage areas: one for the raw materials and the lower-level items (i.e., sub-products) and the other for the end-items (i.e., finished products). There is an assembly station where the lower-level items are assembled to produce the end-items. The engineering office has four main functions associated with it: product design, NC programming, process planning, and production planning. The layout of the shop floor is shown in Figure 5.

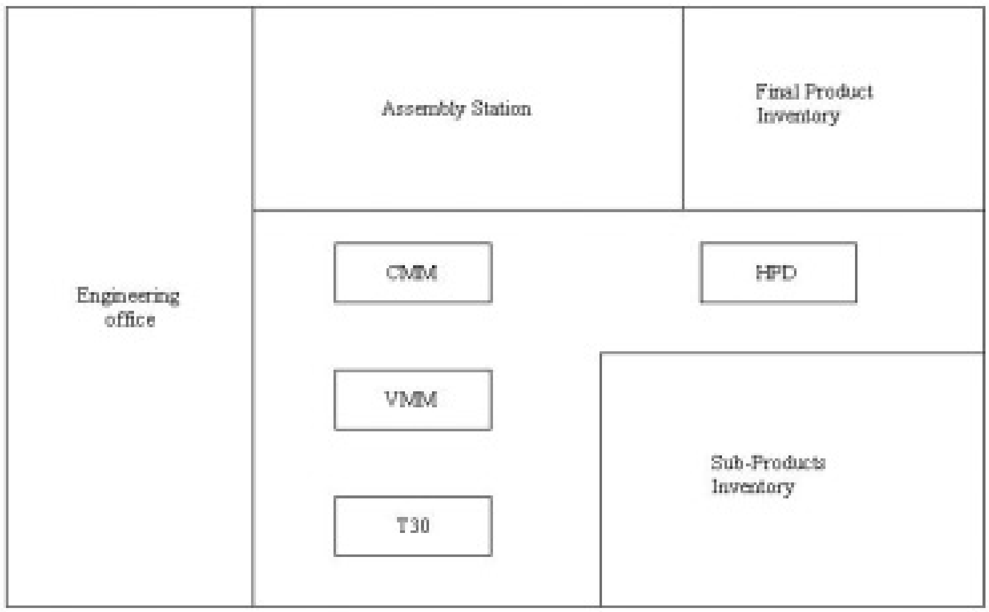


Figure 5 Layout of the Shop Floor.

The production scenario for this manufacturing system consists of simple hypothetical products with single-level bills of materials. There are four end items in the shop floor: Products A, B, C, and D. There are four lower-level items: Cone, Sphere, Cylinder and Square. Each end items is made of at least two lower-level items. Product A is made of 2 cylinders and a square. Product B is made of a cone and a cylinder. Product C is made of a sphere and a cone. Product D is made of a sphere and a box. These lower-level items are machined at the workstations and then assembled at the assembly station. The products, along with product structure diagrams are shown in Figure 6.

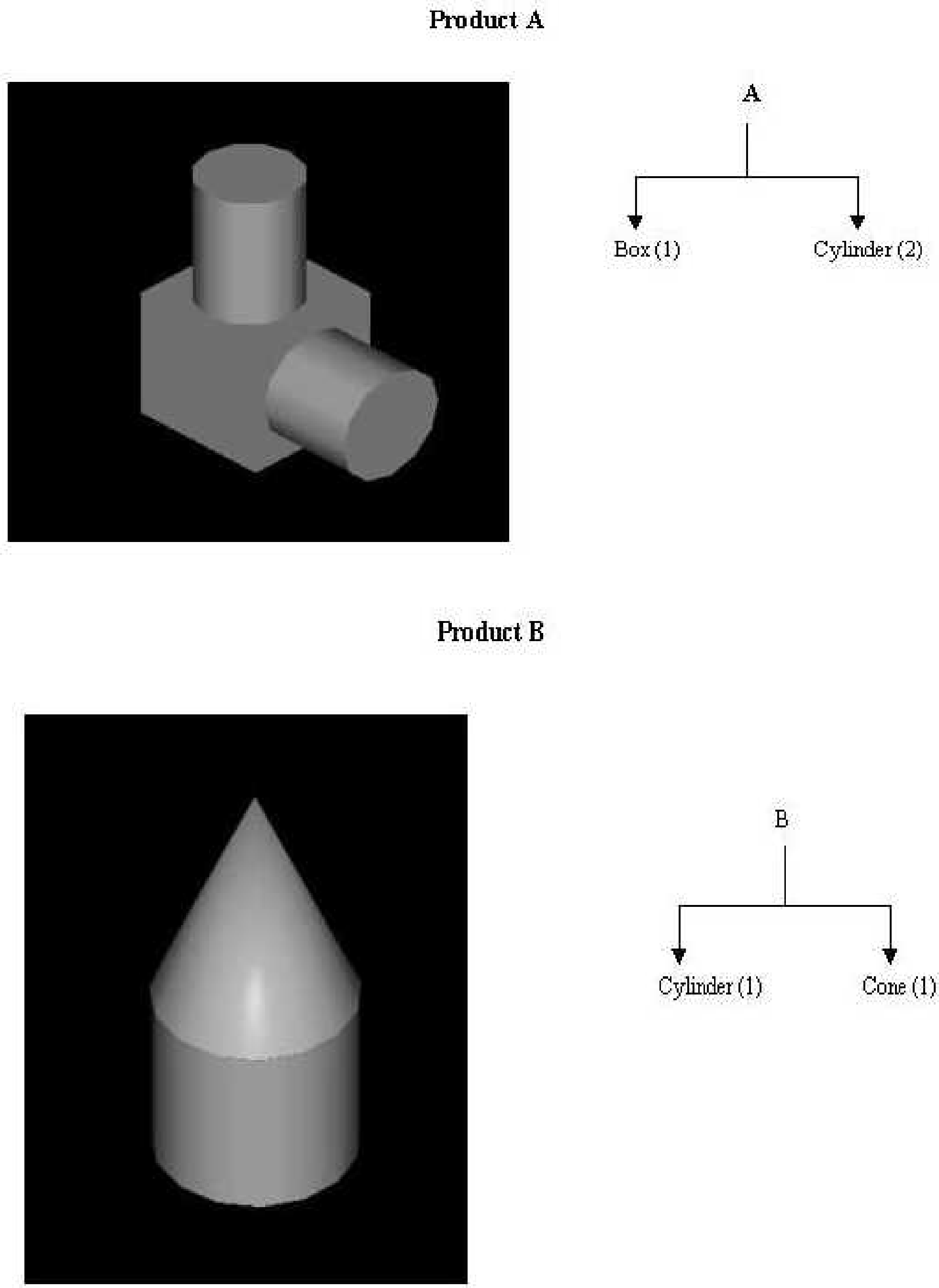
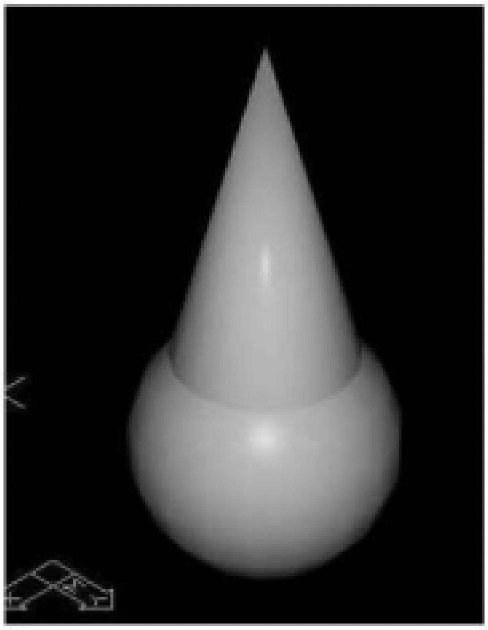
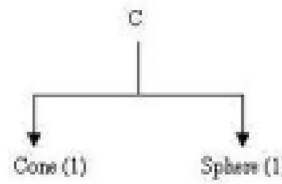


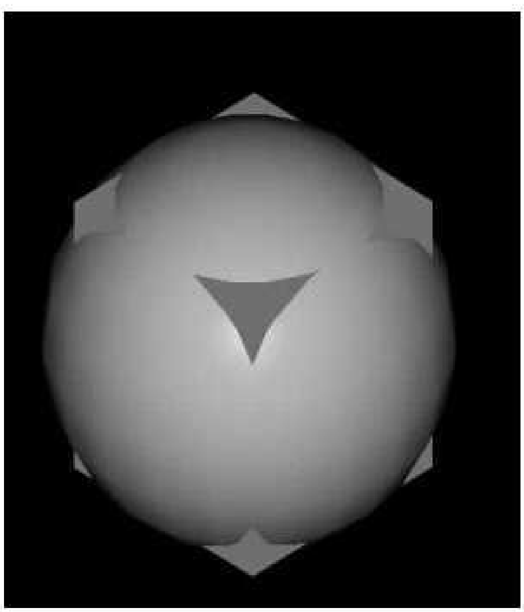
Figure 6 Products and Product Structure diagram for all products.

Product C





Product D



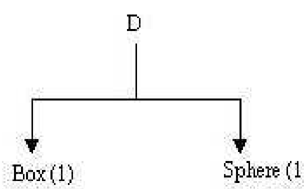


Figure 6 (Continued)

A large variety and amount of information is required to support the manufacturing process. As mentioned in Section 3.2, the production scenario assumed is a “push-based” production scenario. Based on the above scenario and assuming a six period production, the following plans were drawn: aggregate plan, disaggregate plan, master production schedule and material requirements plan for the period. The relational schema diagram for the complete manufacturing system/production scenario is shown in Figure 7. The actual data structures themselves are presented in Appendix 1.

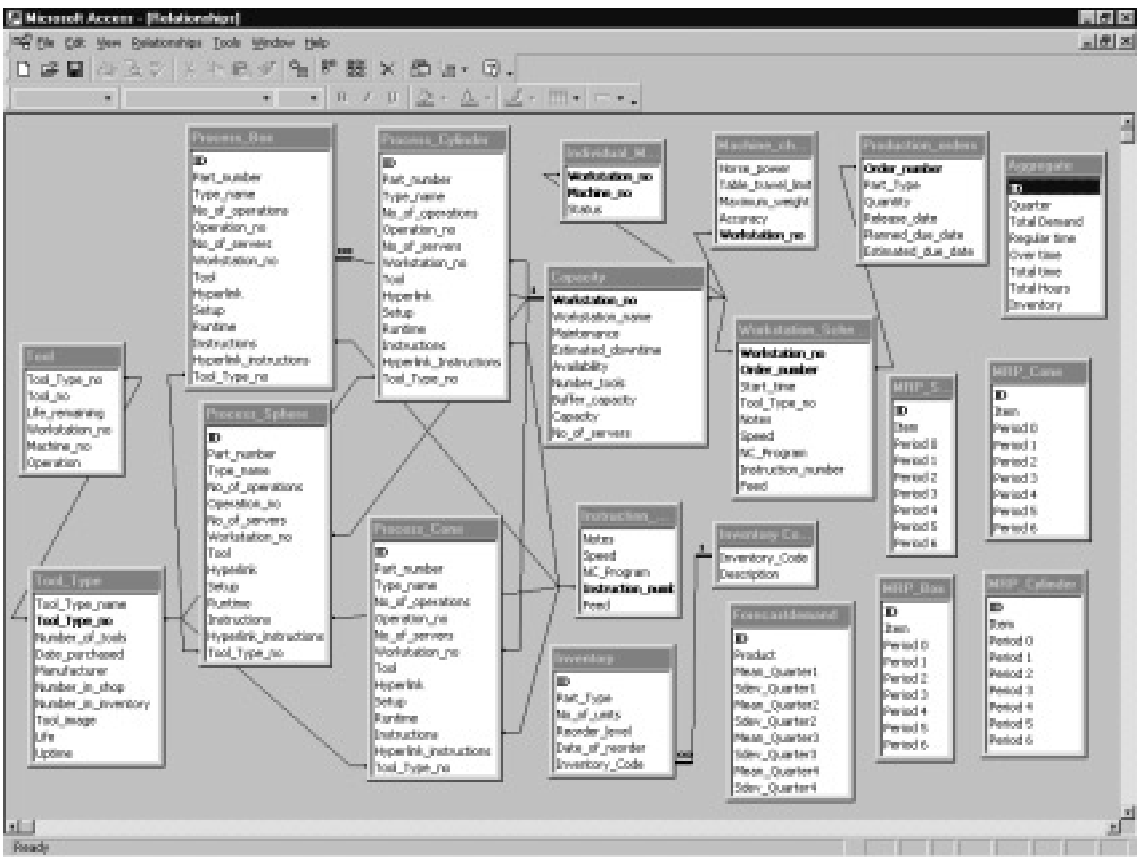


Figure 7 Relational Schema diagram.

5.2. HTML/VRML Modeling of Manufacturing System and Production Scenario

The HTML/VRML environment interface for the above manufacturing system and production scenario is shown in Figure 8.

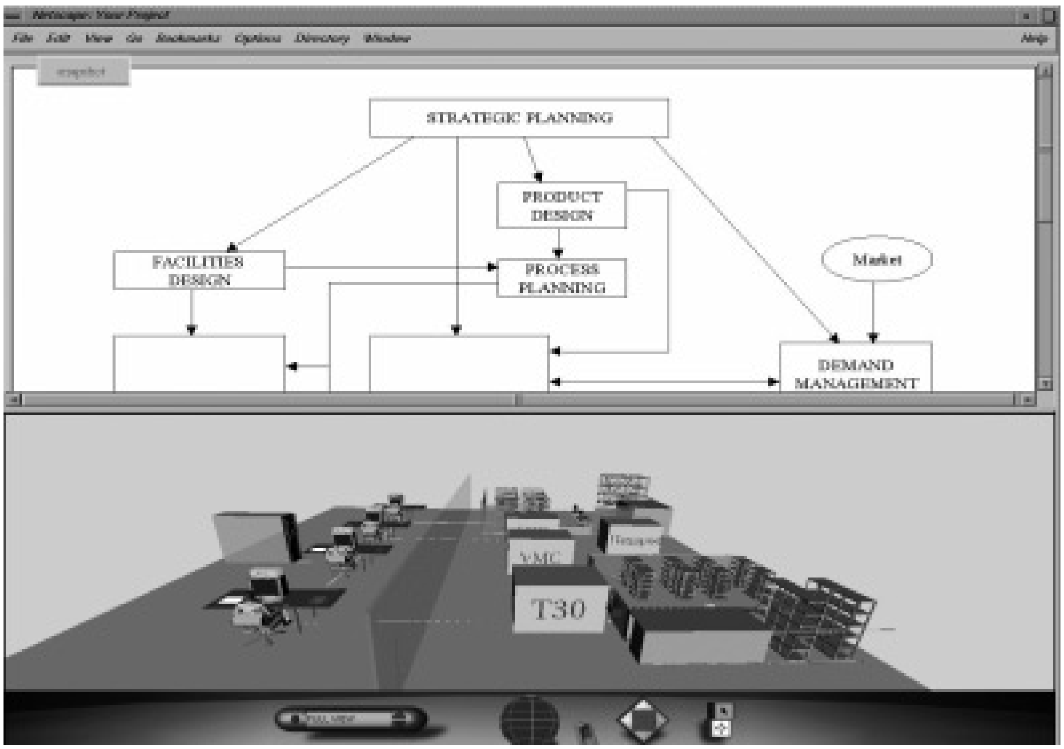


Figure 8 HTML/VRML environment interface.

The VRML world consists of a small physical shop wi th an inventory and an office attached to it. The shop houses the areas/equipment specified in Section 5.1, as shown in Figure 9. Figure 9 shows the floor where the workstations are represented as boxes. The reason is to reduce the time taken to load the VRML world, as described in Section 4.3.

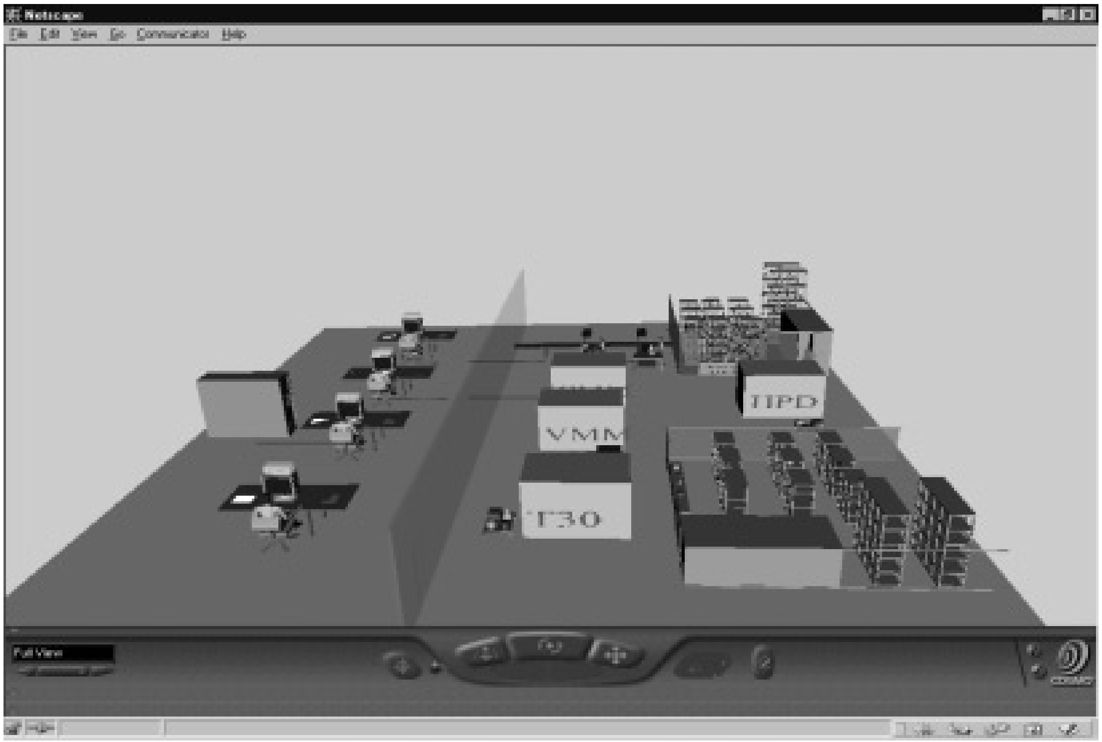


Figure 9   A view of the VRML environment (with workstations rendered as boxes).

Clicking on the box displays a menu as shown in Figure 10. The information associated with the machine is obtained via various menu options. The menu options displayed for each workstation are "individual machines", "capacity", "machine characteristics", "level of detail" and "workstation schedule". For simplicity, the assumption is that all workstations except vertical milling have only one machine.

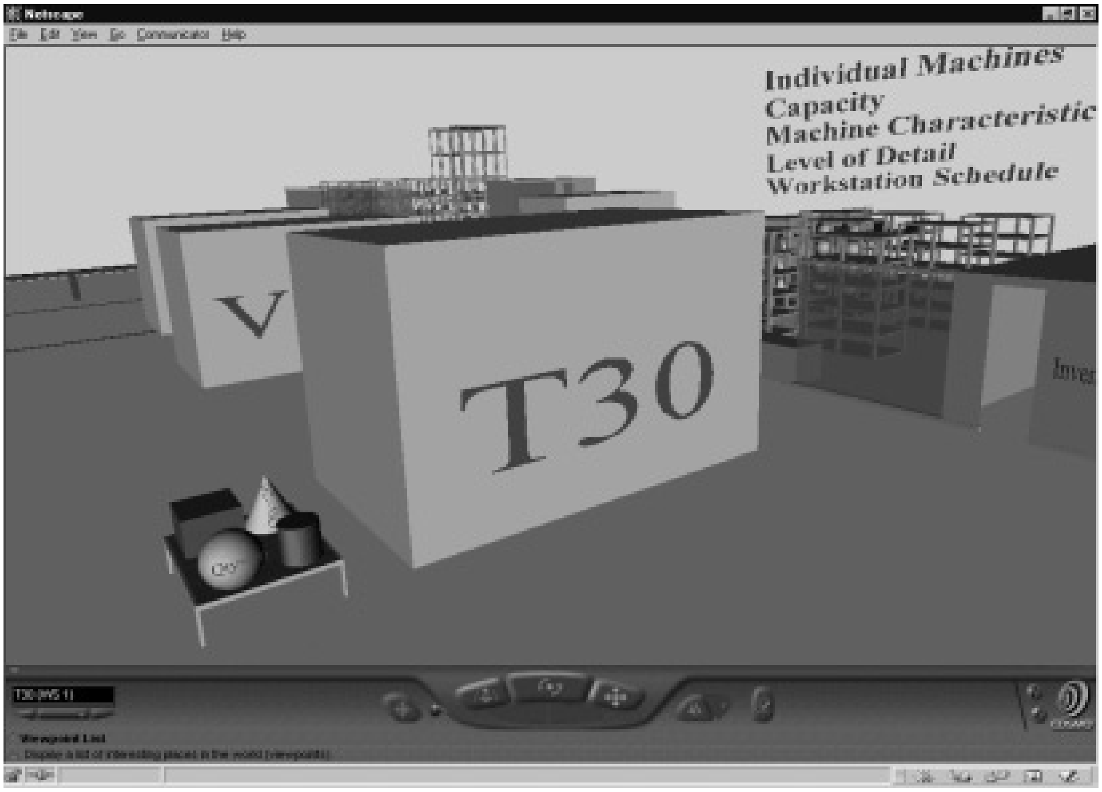


Figure 10 Workstation-related information displayed via a menu.

The menu options serve as hot links to the informational data associated with the machines. Clicking on a menu option retrieves the information from the MS Access database using active server pages and then loads the particular data as an HTML document. The menu options “Capacity”, “Machine Characteristics” and “Workstation Schedule” will display the corresponding information as an HTML document. Figure 11 shows the HTML document that will be displayed by clicking on menu option “Machine Characteristics” for the T30 workstation.

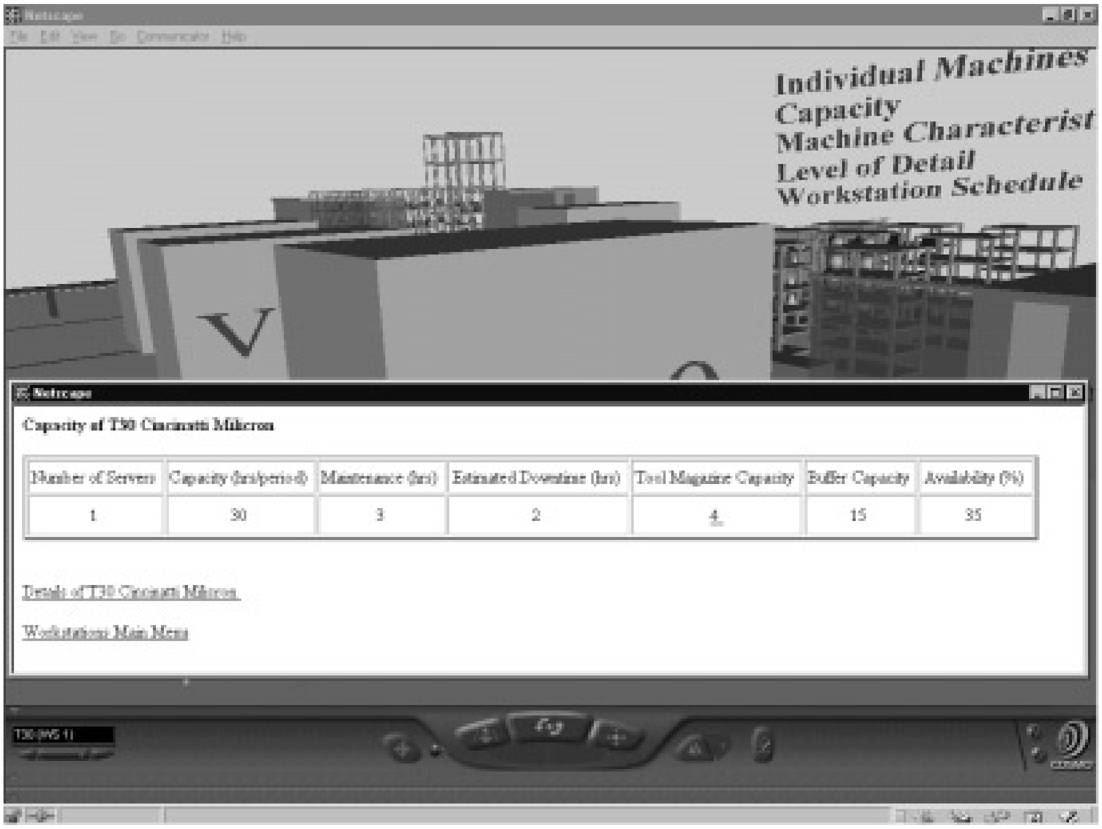


Figure 11 Capacity of Workstation T30 displayed using menu.

The menu option "Level of Detail" is used to provide better detail of the machine. Each click of this menu option increases the polygons representing the machine and hence, the detail. Figure 12 shows the same shop floor where the boxes are replaced by the actual machines. This is achieved by using the variable object-rendering feature as described in Section 4.2.

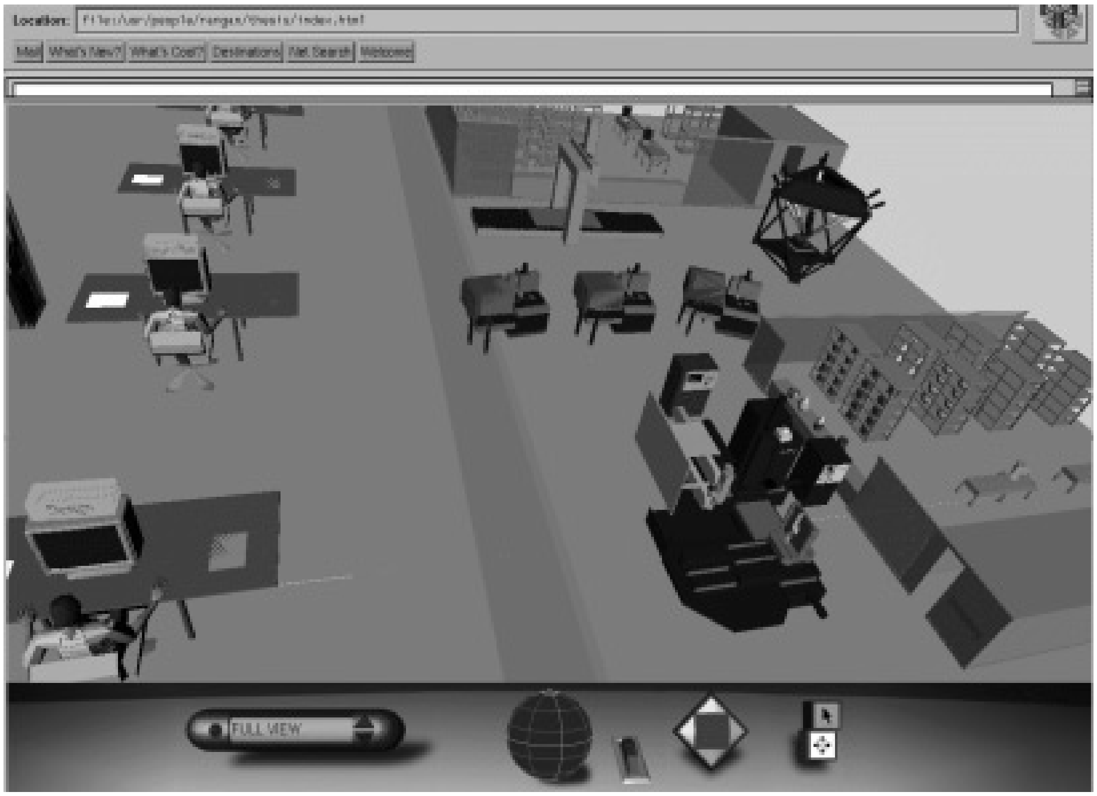


Figure 12   A View of the VRML environment (with actual workstations).

The lower-level items on the shop floor also have menus associated with them. Again, the options in the menu are links to informational data associated with the item. The menu options for each of the lower-level items are “Inventory”, “MRP” (Manufacturing Resource Planning), “Routing” and “process plan”, as shown in Figure 13. By clicking one of the menu options: “inventory”, “MRP” or “process plan”, the corresponding data are loaded using active server pages as shown in Figur e 14.

Figure 13 Lower Level Item on the shop floor and associated menu.

Figure 14 Inventory of a lower-level item displayed in the child window.

When a user clicks on the menu optio n "Routing", only the workstations that are involved in manufacturing the particular lower-level item are made visible, as shown in Figure 15. This has been made possible by with the help of transparency feature in the VRML world, as described in Section 4.2.

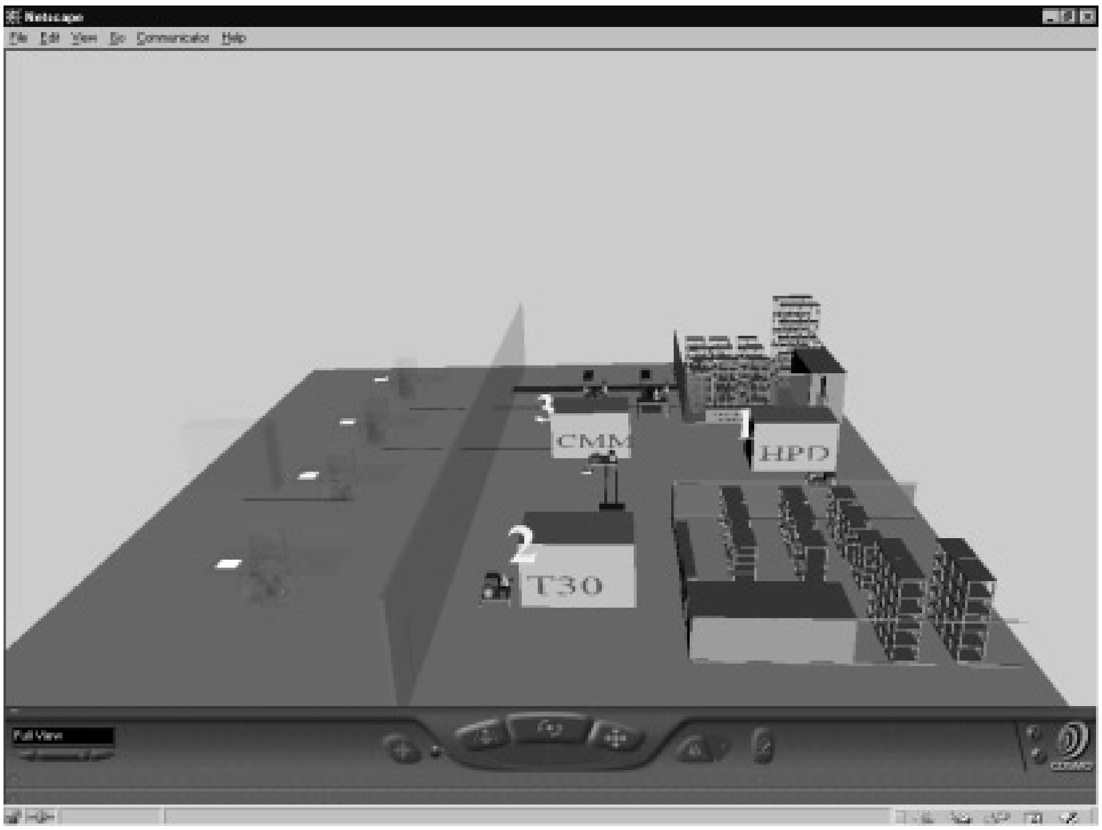


Figure 15 Routing information for a lower-level item.

The end items on the shop floor (A, B, C and D) have the following menu options: "Inventory", "Bill of Materials", "Assembly Plan", and "MPS" (Master Production Schedule), as shown in Figure 16 for end item A. By clicking any of these menu options, the corresponding data are loaded using active server pages as shown in Figure 17.

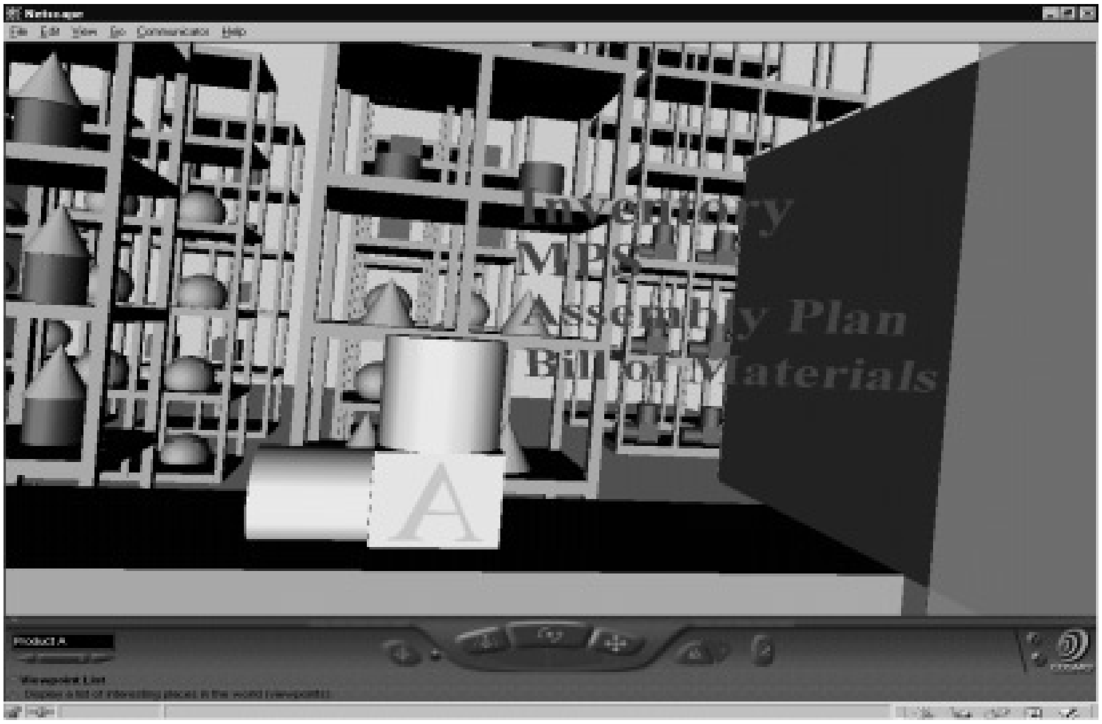


Figure 16 End Item A on the shop floor and associated menu.

Figure 17 Inventory information for end item A displayed in the child window.

The engineering office includes terminals, worktables and staff. The terminals have functional titles written on top to indicate the particular function associated with the terminal: product design, NC programming, process planning, and production planning. Figure 18 shows the engineering office in the VRML manufacturing systems model. Note that a worker is present at each terminal.

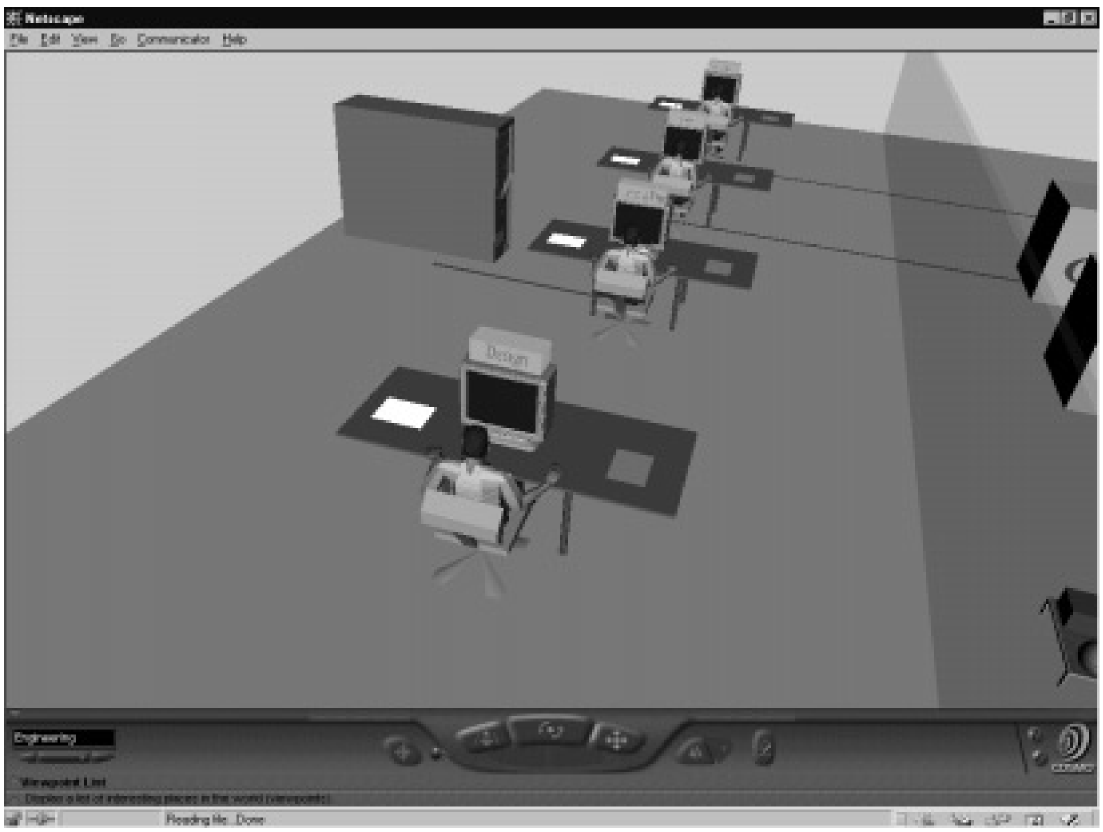


Figure 18 Engineering Office in the VRML model.

The VRML environment is provided with 23 viewpoints so that user can cruise to a particular position and then view the various objects in the model from that position, using a pre-determined orientation. These viewpoints are as follows:

1. Full View
2. Engineering

3. Raw Materials Inventory
4. Pre-Assembled and Finished Goods Inventory
5. Top View
6. T30 (WS 1)
7. Vertical Milling Machine (WS 2)
8. Hexapod (WS 3)
9. CMM (WS 4)
10. Assembly
11. Product A
12. Product B
13. Product C
14. Product D
15. Sub Product – Box
16. Sub Product – Cone
17. Sub Product – Cylinder
18. Sub Product – Sphere
19. Default
20. Buffer – T30
21. Buffer – VMM
22. Buffer – HPD
23. Buffer - CMM

Viewpoints help the user to 'cruise' to a point of interest in the VRML world quickly and accurately. After reaching the required position, the user can change his/her orientation from this pre-determined orientation, if desired.

CHAPTER 6
EVALUATION OF HTML/VRML-BASED MANUFACTURING SYSTEM ANALYSIS

Experiment was performed to demonstrate the validity and applicability of employing HTML/VRML for manufacturing systems analysis. This was achieved by comparing the performance of the HTML/VRML environment to that of the traditional database environment for answering typical manufacturing system design/analysis questions.

6.1 Experimental Design

Experiment was conducted using two types of users, as described in Section 3.2. These users were required to answer three design/analysis questions using the environment they had been given to work in. These questions, and how they can be answered via the HTML/VRML manufacturing systems model and the database model, are described as follows.

Design/Analysis Question 1

Question: What other part-types/sub-products are machined from the tool currently being used on T30? Also, what is the life span of the tool?

Solution: Other products: Box, Sphere and Cylinder. Life Span: 120 hours.

Solution Approach:

<u>Database Environment:</u> In the MS Access environment, the way to obtain this information is to get the schedule of T30 from the “workstation_schedule” table. From

the data, ascertain the current job being processed on this workstation and the tool being used. Then, from the "process plan" table for each of the products, check whether the tool is being used for that product. Then the life span of this tool can be obtained from the "tool_type" table.

HTML/VRML Environment: In the HTML/VRML environment, when a user clicks on the T30 workstation, the menu options are displayed. Clicking on the menu option "Machine schedule" loads the machine schedule for T30 as an HTML document. From the machine schedule, the tool currently being used by the machine can be obtained. Moving the viewpoint to each of the product and clicking on the product would display a menu for that product. Clicking on the option 'process plan' loads the process plan as an HTML document. From the data, it can be determined whether the particular tool is used for manufacturing the part. Clicking on the tool link in the process plan would display the tool list and an image of the tool. From the tool list, the life span of the particular tool under question can be obtained.

Design/Analysis Question 2

Question: What is the Work-In-Process Inventory of the sub products of A?

Solution: Sub-products of A: Cylinder and Box. WIP of Cylinder: 10. WIP of Box: 10.

Solution Approach:

Database Environment: In the MS Access environment, the user has to find out the sub-products of Product A from the product structure diagram. Then, the work-in-process inventory of each of the sub-product can be obtained by linking the "inventory" and "inventory_code" table.

HTML/VRML Environment: In the HTML/VRML environment, this can be obtained by clicking on the VRML model of product A. The bill of materials is one of the menu options. Clicking on the menu option displays the bill of materials as an HTML document with the sub products of product A as hot links. Moving the viewpoint to one of the machines and clicking on the buffer yields the work-in-process inventory of all the sub-products. From the list, the WIP of sub-products of A can be obtained.

Design/Analysis Question 3

Question: For the product next in line on HPD, what is the estimated due date?

Solution: Cylinder, 3/10/99.

Solution Approach:

Database Environment: In the MS Access environment, from the "workstation_schedule" table, the order number that is going to be processed next by the machine Hexapod (HPD) can be obtained. From the "production_orders" table, obtain the product corresponding to that order number and the estimated due date.

HTML/VRML Environment: In the HTML/VRML environment, clicking on the hexapod will display the menu options for the machine. From the machine schedule, obtain the product type that is going to be processed next on the hexapod. Click on the product type link for the details of the product. Click on the individual part-type to obtain the due date.

After the users compl eted answering the three questions, they were given two more questions, which they were required to answer without the aid of the environment. The two questions for post-trial sessions are:

Question 4: Give the sub-products in the system.

Solution: Box, Cone, Sphere and Cylinder.

Question 5: In the environment, what were the functions performed in the engineering department? (Name at least two)

Solution: Design, Process Plan, NC Programming and Production Plan

6.2. Experimental Procedure

The experiment was conducted using 15 subjects for each environment. The subjects were selected from a 4000 level Computer-Integrated manufacturing (CIM) class taught at Virginia Tech in Spring 2000. The subjects were mostly seniors and also included graduate students. The subjects had database background from the CIM course and also had production planning and control background. Subjects were selected at random to work on a particular environment. Approval from the Institutional Review Board (IRB) was obtained to allow subjects participate in the experiment. A fifteen-minute training session was provided to the subjects, on the specific environment they have been selected to work in. The training was given on a subset of the actual system. The VRML model for the training session is shown in Figure 19. The monitor was connected to a video recorder to record the mouse movements on the screen and a video camera was used to record the proceedings from behind the user. An observer was present during the experiment to make sure all the procedures were carried out as planned.

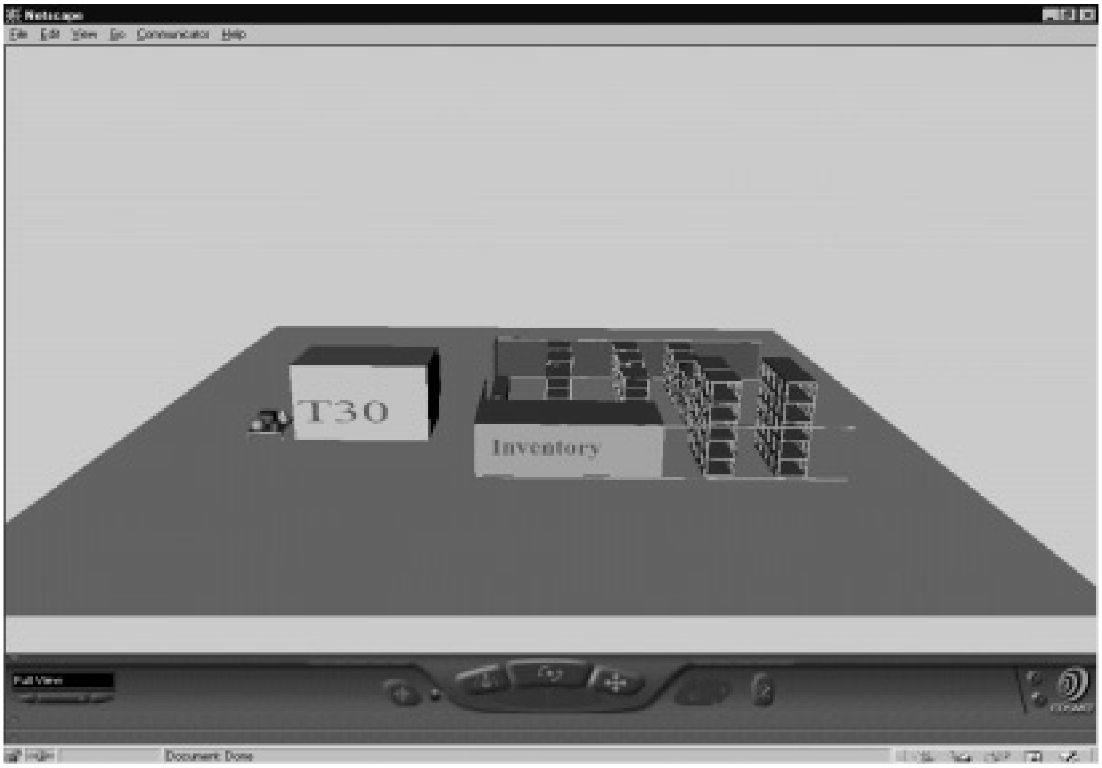


Figure 19 VRML training environment.

At the start of the experiment, the users were asked to authorize their participation in the experiment as required by the IRB. A sample consent form is presented in Appendix 3. The subject were then given a document describing what the users were expected to do and what steps should be taken to make sure the results will not be biased. The document is presented in Appendix 4. The training was carried as follows: Initially the users studied the description of the sub-system. Then, they were asked to view a multimedia file (*.avi file), which explained to them the different controls in the environment and how to operate them. The users were then asked to 'play' with the environment so that they get used to the controls. The training session was for 15 minutes.

After the training session, the actual environment was loaded and each subject (user) was given three questions as described in Section 6.1. The video recorder connected to the monitor recorded the method adopted by the subject to answer each question and the video camera was used to ensure that each question being answered can be matched to the mouse movements on the screen. The users were allowed to answer the questions in any order but were instructed not to switch back and forth between the questions. This was done to know the time taken for each question accurately. Since the time taken to answer each question is a critical factor for analyzing the result, the three questions were provided in sheets of three different colors to help identify the question being answered at any given time and also to identify the sequence in which the questions were answered via the video camera. There was no time limit to answer the questions. The users were asked to let the observer know after they answered each question.

After the users completed answering the three questions, the environment was shut down. The users were now given two more questions, which they were required to answer without the aid of the environment. Again, the users were asked to let the observer know after they completed each question. After the experiment was completed, the users were allowed to comment on the environment, if they wanted.

CHAPTER 7
RESULTS AND DISCUSSION

This chapter presents the results of the experiment and a brief discussion of the results. The experiment was performed to compare the HTML/VRML hybrid environment to traditional database environment in order to answer typical design/analysis questions associated with manufacturing systems. The hypothesis for this experiment was that the hybrid HTML/VRML environment provides a better understanding of the system, thereby statistically validating the HTML/VRML approach. For the experiment, solution time, solution accuracy and effectiveness (accuracy and time combined) were the three response variables. The null hypothesis and the alternate hypothesis for each of the response variable were as follows:

Time Taken — Null Hypothesis: H_0: $\mu_{T,3D} \geq \mu_{T,2D}$
Alternate Hypothesis: H_1: $\mu_{T,3D} < \mu_{T,2D}$

Accuracy — Null Hypothesis: H_0: $\mu_{A,3D} \leq \mu_{A,2D}$
Alternate Hypothesis: H_1: $\mu_{A,3D} > \mu_{A,2D}$

Effectiveness — Null Hypothesis: H_0: $\mu_{A/T,3D} \leq \mu_{A/T,2D}$
Alternate Hypothesis: H_1: $\mu_{A/T,3D} > \mu_{A/T,2D}$

7.1 Results

The time taken by each subject and the accuracy of results for each question are shown in Appendix 2. The results from the analysis of the data in each case is summarized below:

7.1.1.Time taken by users

The time taken by users to answer each question using the traditional database environment was compared against the time taken by users using the hybrid HTML/VRML environment. The t-test was performed on the data and the following result was obtained for each of the questions:

Question 1: The null hypothesis $H_{0:}$ $\mu_{T,3D} \geq \mu_{T,2D}$ was rejected at a level of significance value of 0.05. Rejecting the null hypothesis for Question 1 indicates that the HTML/VRML environment is better than the traditional database environment for answering Question 1.

Question 2: The null hypothesis H_0: $\mu_{T,3D} \geq \mu_{T,2D}$ was failed to be rejected at a level of significance value of 0.05. Therefore, it can be concluded that subjects using the traditional database environment were able to answer Question 2 in the same amount of time or less than subjects using the HTML/VRML environment. Failing to reject the null hypothesis for Question 2 suggests that the HTML/VRML environment is equal to or worse than the traditional database environment for answering Question 2.

Question 3: The null hypothesis H_0: $\mu_{T,3D} \geq \mu_{T,2D}$ was failed to be rejected at a level of significance value of 0.05. Therefore, subjects using the traditional database environment answered Question 3 in the same amount of time or less than their counterparts, suggesting that the HTML/VRML environment is equal to or worse than the traditional database environment for answering Question 3.

Questions	T-value	Null Hypothesis Rejected/Accepted
Question 1	0.016762	Rejected
Question 2	0.077313	Accepted
Question 3	0.209592	Accepted

Table 1 t-test on time taken by users.

7.1.2. Accuracy of Results

The accuracy of results for each question was compared between the subjects using the traditional database environment and the hybrid HTML/VRML environment. The t-test was performed on the data and the following result was obtained for each of the questions:

Question 1: The null hypothesis H_0: $\mu_{A,3D} \leq \mu_{A,2D}$ was rejected at a level of significance value of 0.05, which indicates that the subjects using HTML/VRML environment were more accurate in answering Question 1 than their counterparts. Rejecting the null hypothesis suggests that the HTML/VRML environment is better than the traditional database environment for answering Question 1.

Question 2: The null hypothesis H_0: $\mu_{A,3D} \leq \mu_{A,2D}$ was rejected at a level of significance value of 0.05. This indicates that the subjects using the HTML/VRML environment were more accurate in answering Question 2 than the subjects using the traditional database environment.

Question 3: The null hypothesis H_0: $\mu_{A,3D} \leq \mu_{A,2D}$ was failed to be rejected at a level of significance value of 0.05. This indicates that the subjects using the database environment had comparable or higher solution accuracy than the subjects using the HTML/VRML environment.

Questions	T-value	Null Hypothesis Rejected/Accepted
Question 1	0.001556	Rejected
Question 2	0.043400	Rejected
Question 3	0.293668	Accepted

Table 2 t-test on accuracy of results.

7.1.3 Both Time and Accuracy of Results (Effectiveness)

The third response variable (effectiveness) was generated by dividing the accuracy of result for each question by the corresponding time taken to answer the question. The t-test is performed on the resulting data and the following results were obtained for each question:

Question 1: The null hypothesis H_0: $\mu_{A/T,3D} \leq \mu_{A/T,2D}$ was rejected at a level of significance value of 0.05. This indicates that the subjects using the hybrid environment were able to answer Question 1 accurately in a shortest possible time than subjects using the traditional database environment, suggesting that HTML/VRML environment is better in answering Question 1 than the traditional database environment.

Question 2: The null hypothesis H_0: $\mu_{A/T,3D} \leq \mu_{A/T,2D}$ was rejected at a level of significance value of 0.05. This indicates that the use of HTML/VRML environment is better in answering Question 2 than the traditional database environment.

Question 3: The null hypothesis H_0: $\mu_{A/T,3D} \leq \mu_{A/T,2D}$ was failed to be rejected at a level of significance value of 0.05. Accepting the null hypothesis indicates that the HTML/VRML environment is equal to or worse than the traditional database environment for answering Question 3.

Questions	T-value	Null Hypothesis Rejected/Accepted
Question 1	0.00003	Rejected
Question 2	0.0318	Rejected
Question 3	0.1756	Accepted

Table 3 t-test on both time and accuracy of results (Effectiveness)

7.1.4 Post-Trial Session

For Question 4 an d Question 5, the t-test was performed taking into consideration only the accuracy of results. The following results were obtained after performing the t-test:

Question 4: The null hypothesis H_0: $\mu_{PT,A,3D} \leq \mu_{PT,A,2D}$ was failed to be rejected at a level of significance value of 0.05. This indicates that the HTML/VRML environment is equal to or worse than the traditional database environment in helping subjects understand the system.

Question 5: The null hypothesis H_0: $\mu_{PT,A,3D} \leq \mu_{PT,A,2D}$ was rejected at a level of significance value of 0.05. This suggests that the HTML/VRML environment is better than the traditional database environment for answering this question.

Type of test	T-value	Null Hypothesis Rejected/Accepted
Question 4	0.2132	Accepted
Question 5	0.0160	Rejected

Table 4 t-test on post-trial session.

7.2 Discussion

7.2.1 Time Taken by Users

The results obtained by considering time taken by users as the dependent variable shows that users using the database environment took less time than users using the HTML/VRML environment for answering Question 2 and Question 3. For Question 1, subjects using the HTML/VRML environment fared better than their counterparts. One reason that could be attributed to this result is that subjects using the traditional database environment have to look at least 3 tables to answer question 1, whereas subjects using the HTML/VRML environment have the advantage of hot links to achieve the result. It should also be noted that the accuracy of results is an important factor to be determined, and users can get inaccurate results even if they answered the questions in a shortest possible time.

7.2.2 Accuracy of Results

The accuracy of results shows that subjects using the HTML/VRML environment fared better than subjects using the traditional database environment in Questions 1 and 2. Question 1, as mentioned in the previous section requires a user to look at data in 3 different tables and so, the chances of error is magnified. On the other hand, subjects using the HTML/VRML environment have the advantage of ‘hot links’ to move across the data.

As far as Question 2 is concerned, subjects using the traditional database environment had difficulty understanding the relationship between tables “inventory” and “inventory_code” and were not able to answer the question accurately.

7.2.3 Both Time and Accuracy of Results (Effectiveness)

A look at the results obtained by considering both time taken and the accuracy of results together shows that subjects using the HTML/VRML environment performed better than subjects using the traditional database environment in answering Questions 1 and 2. The performance of the subjects using the traditional database environment were affected by two reasons: One, subjects using the database environment performed poorly in cases where they had to move across different tables to solve a question. Second, subjects using the traditional database environment had to use the product structure sheet given to them in order to answer Question 2 and unless they looked at the sheet, the chances of them solving Question 2 were slim. However, subjects using the HTML/VRML environment were able to answer these questions accurately in a shortest possible time using ‘hot links’ and other VRML/HTML mechanisms.

7.2.4 Post-Trial Session

Questions 4 and 5 were intended to test the user’s understanding of the system. Analysis of the results of Question 4 shows that subjects using the database environment performed at the same level as the subject using the HTML/VRML environment. However, on Question 5, their performance dropped. The reason for this might be that Question 5 was directly related to the Layout diagram given to the subjects. So, unless a subject was familiar with the layout, answering Question 5 was very difficult. On the other hand, subjects using the HTML/VRML environment had the advantage of looking at the three-dimensional model of the engineering department and thereby, had a better understanding of the various functions involved in the engineering department.

7.2.5 Overall Findings

The experiment provided a good insight as far as the users perspective on a given interface. Subjects using the database environment took more time to start answering the questions than their counterparts. This was evident from viewing the video wherein the subjects spent a lot of time trying to understand the database and tables before starting to answer the questions. Although the users were familiar with databases and relationship schema, they found it difficult to relate the information in the database to the system given to them. In addition, most of the users did not concentrate on the additional documents given to them, which made it difficult for them to understand some of the questions. For example, only by looking at the product structure diagram can one deduce that there are two lower-level items for the end-item A. Subjects who did not give much attention to this document found it difficult to answer the question. These users also had difficulty in getting an overall picture of the system. This was evident from the t-test performed on Questions 4 and 5. In fact, some of the users gave up while answering Question 4 because they could not remember all the data or the diagrams given to them.

The HTML/VRML users on the other hand were able to form a better mental model of the system and therefore, knew what was required to answer the questions. In fact, a quick look at the results in Appendix 2 show that the number of users able to answer the question correctly using VRML environment is greater than the users using the database environment. This does encourage us to represent manufacturing systems through HTML/VRML environment to provide a better visual representation of the data. As mentioned in the earlier chapters, manufacturing system data is a combination of physical, informational and functional data. If one needs to visualize all these data in a single environment, a combination of two-dimensional and three-dimensional representation of data is necessary. One of the reasons that the subjects using the VRML environment were able to visualize the system better was mainly because the data in the system was represented in a way indicative of its type – three dimensional data was displayed using VRML and two-dimensional data was displayed using HTML.

As far as the post-trial session is concerned, subjects using the hybrid HTML/VRML environment were able to answer Question 4 better than subjects using the database environment. Some of the users, however, found it difficult to answer this question due to the fact that the engineering section was not a hot link, which did not invite their interest. At the same time, these users were confident that if it had been a hot link, they would have been able to answer the question. This shows that by using proper visualization techniques, a user's understanding of the system can be improved. This is the one of the reasons why a traditional database environment is not suitable for representing manufacturing systems. The fact that the only way to represent the data is via linear-based text presents a major impediment to users trying to understand a system.

To summarize, it can be noted that the subjects using the database environment were comfortable only to a certain extent in answering questions that involved relating two tables in the database. This is evident from the fact that they did not perform well in answering Question 1 and Question 3, which involved relating three or more tables in the database. However, they performed on par with their counterparts in answering Question 2. One of the reasons some of the subjects using the HTML/VRML environment were not able to answer Question 2 is because they did not know where to look for work-in-process inventory. Even though the expectation was that the subjects using the HTML/VRML environment would answer Question 2 with greater ease than their counterparts, their limited understanding about work-in-process inventory proved otherwise. Also, some of the subjects using the HTML/VRML environment were uncomfortable with the three dimensional environment and had difficulty with their spatial ability. This was evident from the fact that they became disoriented many times. Even though viewpoints were specifically provided to help these subjects, the subjects used the viewpoints to a very limited extent. These were some of the observations from the videotape that recorded the proceedings of the experiment. One more observation that was made was that the subjects using the traditional database environment did not use Structured Query Language (SQL) to answer the questions. Even though, the use of SQL in the Access interface was shown to be them during the training session, subjects seem to be more comfortable traversing across tables manually instead of using SQL to formulate their queries. Overall, subjects using the HTML/VRML environment performed better than the subjects using the database environment, which in effect validates the use of HTML/VRML for manufacturing systems modeling and analysis.

CHAPTER 8
CONCLUSIONS AND FUTURE WORK

This chapter divided into two sections. The first section presents the conclusions obtained from the research and the second section briefly points out some of the future research directions.

8.1. Conclusions

There is a clear consensus among researchers that an open environment is needed for manufacturing systems modeling. HTML/VRML appears to be a promising approach for modeling/analyzing manufacturing systems. The results obtained from the experiment indicated that the HTML/VRML approach might result in a better understanding of a manufacturing system than the traditional database environment. However, it should be noted that the result obtained is conservative because the comparison is between a well-developed, standardized DB interface and an experimental HTML/VRML interface. One of the main purposes of this research was to study the effect of providing a better visual interface for studying and analyzing manufacturing systems. Among the different interfaces available today, the web-based medium has proven to be a better and most affordable medium. VRML, being one of the languages providing a 3D interface on the web, automatically qualifies as a very good candidate for future manufacturing research tasks. One important point to be kept in mind while designing these interfaces is that as with HTML based web pages, users are more interested in navigating with the help of hot links. Features like hot links are not provided by default in VRML and it takes a long time to develop this feature in VRML. Maybe future versions of VRML should have some of the default features in HTML included in VRML too. This might make development easier, which in turn will drive future advancement of web-based applications. This in turn will help the manufacturing industry as well, because the development of an open environment for manufacturing systems modeling is dependent upon the availability of suitable modeling languages and platforms.

8.2. Future work

As part of this research work, an experiment was conducted to prove that the HTML/VRML approach is better than the traditional database environment for manufacturing design and analysis. The subjects for this experiment were chosen from a random pool of students. However, no test was performed beforehand to analyze the way a subject processes the information. For example, a subject might have the ability to process information better if it was presented to him/her in a database-based linear text rather than in a three dimensional-based environment due to one's limitation to understanding in a three dimensional spatial environment. Since the subjects were chosen at random to work on a specific environment, a subject might have been asked to work on the HTML/VRML environment instead of the traditional database-based environment and his/her accuracy can suffer due to his/her spatial ability. The ability to maintain a spatial understanding is important if a subject has to understand the manufacturing system presented to him/her. This presents an area for future research work, where subjects can be tested beforehand and segregated based on their ability to process information. The experiment can then be conducted by randomly selecting subjects from their respective pools. This way a subject's ability to process information is also taken into account while arriving at the final result.

As mentioned in the previous section, the results obtained from this research is conservative due to the fact that the HTML/VRML environment developed is an experimental one and no usability testing has been performed on the HTML/VRML environment. This presents an area where future research work can be conducted towards usability testing of the HTML/VRML environment and experiment can be conducted between a well-developed HTML/VRML environment and a well-developed database environment. The usability testing can also help in answering some of the questions raised such as why viewpoints weren't used more by the subjects. Virtual manufacturing has been in practice for quite some time and Internet has made it possible to conduct various manufacturing tasks in locations, which are geographically distant from each other. The various components that make the HTML/VRML environment – HTML, VRML, and Active Server Pages, can be used over the Internet and therefore, present themselves as ideal candidates for future Internet-based manufacturing design and analysis tasks. However, as the amount of data increases, a database that can handle huge datasets might be required. Also, since the connection to the database is over the Internet, the use of a regular database is difficult. Further research is required to determine the various technical problems which must be solved in order to effectively employ the HTML/VRML environment over the Internet. This in turn will help future manufacturing companies function more effectively and interact with one another in this manner.

APPENDIX 1
DATA STRUCTURES

Aggregate Plan

ID	Quarter	Total Demand	Regular time	Over time	Total time	Total Hours	Inventory
1	0	0	20	0	20	0	100
2	1	120	100	50	150	350	90
3	2	300	50	100	150	675	15
4	3	180	150	50	200	605	30
5	4	120	150	100	250	450	60

Capacity

WS #	WorkStation	Maint time	Downtime	Available	# of Tools	Buffer capacity	Capacity	# of Servers
1	T30 Cincinatti Milicron	3	2	35	4	15	30	1
2	Vertical Milling Machine	4	3	20	3	10	40	3
3	Hexapod	2	1	50	6	20	40	1
4	Coordinate Measuring Machine	3	3	40	2	10	50	1

Disaggregate Plan

ID	Product	Inventory	Quarter1	Quarter2	Quarter3	Quarter4
1	A	15	20	45	39	30
2	B	12	30	45	39	30
3	C	36	100	60	117	90
4	D	15	20	25	100	100
5	Total	78	170	175	295	250

Individual Machines

WS #	Machine_no	Status
1	Machine_1	Off
2	Machine_1	On
2	Machine_2	Off
2	Machine_3	On
3	Machine_1	Off
4	Machine_1	Off

Information_MPS

ID	Product	Hours	Holding Cost/Period	SalePrice	Material Cost	Inventory Cost
1	A	2	$0.80	$50.00	$10.00	$30.00
2	B	3	$1.20	$85.00	$20.00	$60.00

ID	Product	Hours	Holding Cost/Period	SalePrice	Material Cost	Inventory Cost
3	C	3	$1.00	$70.00	$15.00	$45.00
4	D	2	$0.90	$80.00	$12.00	$50.00

Machine Instruction Sheet

Speed	NC_Program	Instruction_number	Feed
3000		I1	0.26
3500		I2	0.2
4000		I3	0.1
2000		I4	0.05
1000		I5	0.1

Inventory

ID	Part_Type	No_of_units	Reorder_level	Date_of_reorder	Inventory_Code
1	Raw_Cylinder	100	50	6/4/99	R
2	Raw_Box	100	50	1/5/99	R
3	Raw_Sphere	100	40	2/5/99	R
4	Raw_Cone	100	50	3/4/99	R
6	Product_A	50			P
7	Product_B	30			P
8	Product_C	50			P
9	Product_D	50			P

ID	Part_Type	No_of_units	Reorder_level	Date_of_reorder	Inventory_Code
10	Cylinder	10			L
11	Box	20			L
12	Sphere	10			L
13	Cone	5			L
14	Cylinder	10			W
15	Box	10			W
16	Sphere	5			W
17	Cone	10			W

Inventory_code

Inventory_Code	Description
L	Lower Level Items (Pre-Assembly)
P	Final Product
R	Raw Material
W	Work In Process

Machine Characteristics

HP	Table travel limits	Maximum Weight	Accuracy	WS #
15	10	5000	0.25	1
15	15	4000	0.5	2
10	20	5000	0.25	3
10	8	6000	0.26	4

MPS

ID	Product	Initial Inventory	Period1	Period2	Period3	Period4	Period5	Period6	Total
1	A	23	12	0	0	15	0	0	30
2	B	0	5	5	10	0	5	10	23
3	C	0	18	27	0	18	27	0	100
4	D	0	20	15	0	0	0	27	62
5	Labor Hours	0	133	126	30	84	96	84	553

MRP Box

ID	Item	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	Gross_Required	20	18	27	0	18	27	0
2	Inventory	40	22	0	0	0	10	0
3	Net Requirement	0	0	5	0	18	27	0
4	Plan order received	0	0	5	0	18	27	0
5	Plan order released	0	5	0	18	27	0	0

MRP Cone

ID	Item	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	Gross_Required	0	25	5	10	30	5	10
2	Inventory	40	10	5	0	0	0	0
3	Net_Required	0	0	0	5	30	5	10
4	Plan order received	0	0	0	5	30	5	10
5	Plan order released	0	0	5	30	5	10	0

MRP Cylinder

ID	Item	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	Gross_Required	0	33	27	20	33	27	0
2	Inventory	40	7	0	0	0	0	0
3	Net_Required	0	0	20	0	33	27	0
4	Plan order received	0	0	20	0	33	27	0
5	Plan order released	0	20	0	33	27	0	0

MRP Sphere

ID	Item	Period 0	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6
1	Gross_Required	0	0	5	10	0	5	10
2	Inventory	20	0	15	5	0	0	0
3	Net_Requirement	0	0	0	0	0	0	10
4	Plan order received	0	0	10	0	0	0	10
5	Plan order released	0	0	0	0	10	0	0

Process_Box

ID	Part_ no	Type name	# of operations	Operation #	servers	WS	Tool	Setup	Runtime	Instructions	Tool Type no
1	1	Box	3	10	1	3	Centre_drills_126	0	80	I2	C223984
2				20	1	1	Shank_end_mills_133	6000	110	I4	S239587
3				30	1	4	Twist_drills_163	3000	55	I1	T234098

Process_Cone

ID	Part_ no	Type Name	# of Operations	Operation #	servers	WS	Tool	Setup	Runtime	Instructions	Tool Type no
1	1	Cone	4	10	1	1	Centre_drills_126	2400	50	I2	C223984
2				20	2	2	Shank_end_mills_133	2600	90	I4	S239587
3				30	1	3	Twist_drills_163	1750	125	I1	T234098

Process_Cylinder

ID	Part #	Type Name	# of Operations	Operation #	# of Servers	WS #	Tool	Setup	Runtime	Instructions	Tool Type #
1	2	Cylinder	3	10	2	2	Twist_drills_103	1500	30	I2	T203948
2				20	1	3	Twist_drills_133	1100	170	I1	T230985
3				30	1	4	Centre_drills_126	2100	70	I1	C223984

Process_Sphere

ID	Part #	Type name	# of Operations	Operation #	# of Servers	WS #	Tool	Setup	Runtime	Instructions	Tool Type #
1	2	Sphere	4	10	1	1	Twist_drill_133	4200	20	I2	T230985
2				20	2	2	Centre_drills_126	3500	60	I4	C223984
3				30	1	4	Twist_drill_133	3500	60	I1	T230985

Production Orders

Order_number	Part_Type	Quantity	Release_date	Planned_due_date	Estimated_due_date
B239487	Box	20	1/12/99	1/25/99	2/2/99
C213948	Cone	20	2/23/99	1/3/99	
J239847	Cylinder	15	2/25/99	3/5/99	3/10/99
S239847	Sphere	20	3/3/99	3/15/99	3/17/99

Tool

Tool Type #	Tool #	Life_remaining	WS #	Machine_no
C223984	1	20	1	Machine_1
C223984	2	20	2	Machine_2
C223984	3	20	3	Machine_1
C223984	4	10	4	Machine_1
S239587	1	10	1	Machine_1

Tool Type #	Tool #	Life_remaining	WS #	Machine_no
S239587	2	10	2	Machine_1
T203948	1	10	2	Machine_2
T230985	1	10	1	Machine_1
T230985	2	5	3	Machine_1
T230985	3	15	4	Machine_1
T234098	1	5	2	Machine_3
T234098	2	5	3	Machine_1
T234098	3	5	4	Machine_1

Tool_Type

Tool_Type_name	Tool Type #	No_ of_ Tools	Date_purchased	Manufacturer	Number_in_shop	Number_in_inventory	Tool_image	Life	Uptime
Centre_drills_126	C223984	4	12/12/98	Jefferson Inc.	4	0	centre_drills_126.jpg	120	100
Shank_end_mills_133	S239587	3	1/12/99	Somerset	2	1	shank_end_mills_133.jpg	40	90
Twist_drills_103	T203948	2	1/12/99	RTI Inc.	1	1	tool_vmc.jpg	40	100
Twist_drills_133	T230985	4	12/12/98	Caterpillar	3	1	tool.jpg	40	95
Twist_drills_163	T234098	3	2/2/99	MRN Inc.	3	0	twist_drills_163.jpg	50	100

WorkStation_Schedule

Workstation_no	Order_number	Start_time	Tool_Type_no	Notes	Speed	NC_Program	Instruction_number	Feed
1	B239487	15:00	S239587		3000		I1	0.2
1	C213948	11:00	C223984		2000		I3	0.21
1	S239847	13:00	T230985		1000		I2	0.22
2	C213948	14:00	S239587		1500		I4	0.25
2	J239847	8:00	T203948		2000		I5	0.24
2	S239847	10:00	C223984		2500		I3	0.22
3	B239487	11:00	C223984		3000		I2	0.2
3	C213948	16:00	T234098		1600		I1	0.19
3	J239847	13:00	T230985		1000		I5	0.15
4	B239487	15:00	T234098		1200		I6	0.16
4	J239847	16:00	C223984		2200		I4	0.26
4	S239847	13:00	T230985		1900		I3	0.2

APPENDIX 2
RAW DATA

Experimental Users (Subjects using HTML/VRML environment)

		Question 1				Question 2				Question 3			
		Min	Secs	Secs	Accuracy	Min	Secs	Secs	Accuracy	Min	Secs		Accuracy
1	VRML	9	0	9	1	1	0	1	1	1	0	1	1
2	VRML	3	35	3.5833	0.5	1	25	1.417	0	5	42	5.7	0
3	VRML	6	53	6.8833	1	9	19	9.317	1	12	59	13	1
4	VRML	5	48	5.8	0.5	2	17	2.283	1	7	20	7.33	0
5	VRML	9	8	9.1333	1	7	20	7.333	1	9	20	9.33	0.5
6	VRML	0	0	0	1	3	26	3.433	1	1	41	1.68	1
7	VRML	8	42	8.7	0.5	3	20	3.333	0	7	11	7.18	0
8	VRML	5	30	5.5	1	10	0	10	1	10	0	10	0
9	VRML	5	50	5.8333	0.5	4	51	4.85	0.5	14	9	14.2	0
10	VRML	3	28	3.4667	1	9	10	9.167	1	4	40	4.67	0
11	VRML	12	10	12.167	1	11	45	11.75	0	12	10	12.2	0
12	VRML	15	25	15.417	0	2	10	2.167	1	4	10	4.17	0
13	VRML	8	0	8	1	8	30	8.5	0	8	0	8	1
14	VRML	7	41	7.6833	1	8	10	8.167	1	9	0	9	0
15	VRML	5	42	5.7	0.5	5	15	5.25	1	3	28	3.47	1

APPENDIX 2 (Continued)

Control Users (Subjects using Database Environment)

		Question 1				Question 2				Question 3			
		Min	Secs	Secs	Accuracy	Min	Secs	Secs	Accuracy	Min	Secs		Accuracy
1	Access	13	49	13.817	1	6	35	6.583	1	3	20	3.33	1
2	Access	8	24	8.4	0	11	7	11.12	0	14	49	14.8	0
3	Access	8	59	8.9833	1	15	2	15.03	1	7	5	7.08	0
4	Access	7	7	7.1167	0	4	7	4.117	0	5	36	5.6	1
5	Access	0	0	0	0.5	0	0	0	0.5	0	0	0	0
6	Access	21	13	21.217	0.5	8	35	8.583	1	2	8	2.13	1
7	Access	4	35	4.5833	0	2	0	2	1	6	0	6	0
8	Access	11	52	11.867	0	15	3	15.05	0	6	30	6.5	1
9	Access	35	0	35	0	4	33	4.55	0	2	31	2.52	1
10	Access	6	45	6.75	1	2	0	2	0.5	6	36	6.6	0
11	Access	6	27	6.45	0	7	10	7.167	0	7	40	7.67	1
12	Access	7	6	7.1	0.5	12	45	12.75	0	4	30	4.5	1
13	Access	13	30	13.5	0.5	2	33	2.55	1	5	33	5.55	0
14	Access	11	0	11	0.5	11	2	11.03	0	5	50	5.83	0
15	Access	9	35	9.5833	0	3	5	3.083	0.5	6	40	6.67	0

APPENDIX 3
IRB CONSENT FORM

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Informed Consent for Participants of Investigative Projects

Title of Project: Application of HTML/VRML to Manufacturing Systems Engineering
Investigator(s): Dr.Shewchuk and Mr. Kasthuri Rangan Krishnamurthy

1. Purpose of the Research/Project

The purpose of this research project is to compare a new hybrid HTML/VRML-based software environment to traditional database environment (such as Microsoft Access) in order to answer typical design/analysis questions associated with manufacturing systems.

2. Procedures

The experiment basically consists in comparing the new software environment to a database-based environment. The subjects will be selected at random and will be tested on one of the environment. The subjects will be provided training on the appropriate environment and the training session will last for about 10 minutes. The subjects will then be asked to answer three typical design and analysis questions associated with a manufacturing system using the given software environment. There is no restriction on time to answer these questions but the questions will be framed in such a way that it should take about 20 minutes to answer all the three questions. The environment is shut down and the subject is then given questions related to the system, which he is expected to answer without the aid of the environment. This will help in analyzing the effect of the model in subject's understanding of the system.

3. Risks & Benefits

Participation is voluntary and there will be no tangible benefits by participating in this project.

4. Anonymity and Confidentiality

There won't be any collection of personal data of the subjects other than the name and ID. No one other than the investigators will have access to the data and it will be completely destroyed once all the experiments are conducted.

5. Freedom to Withdraw

Subjects are free to withdraw from the project at any time without penalty.

6. Approval of Research

This research project has been approved, as required, by the Institutional Review Board for Research Involving Human Subjects at Virginia Polytechnic Institute & State University, by the department of Industrial & Systems Engineering.

7. Subject's Responsibilities

I voluntarily agree to participate in this study.

8. Subject's Permission

I have read and understand the informed consent and conditions of this project. I have had all my questions answered. I hereby acknowledge the above and give my voluntary consent for participation in this project.

If I participate, I may withdraw at any time without penalty. I agree to abide by the rules of this project.

____

Signature Student ID

Date

APPENDIX 4
TRAINING DOCUMENTS

1. Instructions for using the Database Environment

Thank you for participating in this experiment. This experiment basically consists of comparing the HTML/VRML hybrid environment to a traditional database environment in order to answer typical design/analysis questions associated with manufacturing systems.

This document and the associated video clip will give you a basic understanding of the Database environment. For the tutorial, I will be using a subset of the actual system to explain about the environment. As you go through the tutorial, try to develop a basic understanding of the various controls in the environment. After that, you will be given 5 minutes to "play" with the model of the actual system. Use this time to explore and understand the actual system. If you finish early, wait until the experimenter tells you to proceed.

Click on the file 'Tables.avi' to see a demo of how the controls in MS Access work. In the video clip, at first you will be shown how to look up at the data in various tables. You will be able to do this by clicking on the table name. When you finish watching the video clip, try to get a 'hands on experience' by going through the environment. Next, you will be shown how to design a query in MS Access. To design a query in MS access, first determine the tables you need the data from, and drag and drop them in the design view. For e.g., suppose we need to find the order numbers on workstation 1 and corresponding tool to use to complete that particular order. As a first step, we need to determine the tables we need the information from – in this case, it is 'capacity' for workstation name, 'workstation_schedule' for order numbers and 'tool_type' for tool details. So, we drag and drop those tables in the design view. Then we have to determine the fields we need from those tables. We drag and drop those fields in the tabular column below. Since we need the data for workstation 1, we enter '1' as the criteria under workstation number. By clicking on the exclamation mark, we execute the query and get the results. Click on the file 'Query1.avi' to see a demo of how to design the query for the first example. When you finish watching the video clip, try to get a 'hands on experience' by trying to design the query using the environment.

In the second example, suppose we need to find whether part type Box is produced in workstation 3 and if so, what is the type of tool that will be used. We select the tables and follow the same procedure in designing the query and finally get the results. After watching the video clip, try to get a 'hands on' experience of the controls. Click on the file 'Query2.avi' to see a demo of how to design the query for the second example. When you finish watching the video clip, try to get a 'hands on experience' by trying to design the query using the environment.

You will receive the following materials before starting the experiment:

1. Product Structure diagram and picture of each end item
2. Facility Layout diagram
3. Relational schema diagram.

Make Sure you receive all the three documents.

Next, you will be given a question sheet with 3 questions. An swer one question at a time. There is no time limit, but answer as quickly as you can while feeling confident with your answer. Take a look at all questions beforehand to decide upon what order you want to answer. Once you start, please do not switch back and forth between the questions. Whenever you have finished a question, let me know. Please note the time from the stopwatch near you. Also, have a look at the above 3 documents before you start answering the questions.

Once all three questions are answered, the computer will be shut off and you will be given two additional questions to answer. Answer one at a time, noting the time taken for each.

Important:

Let me know immediately, if you encounter any problem in accessing the data.

Please, do not discuss about this experiment with other students since it may bias the results.

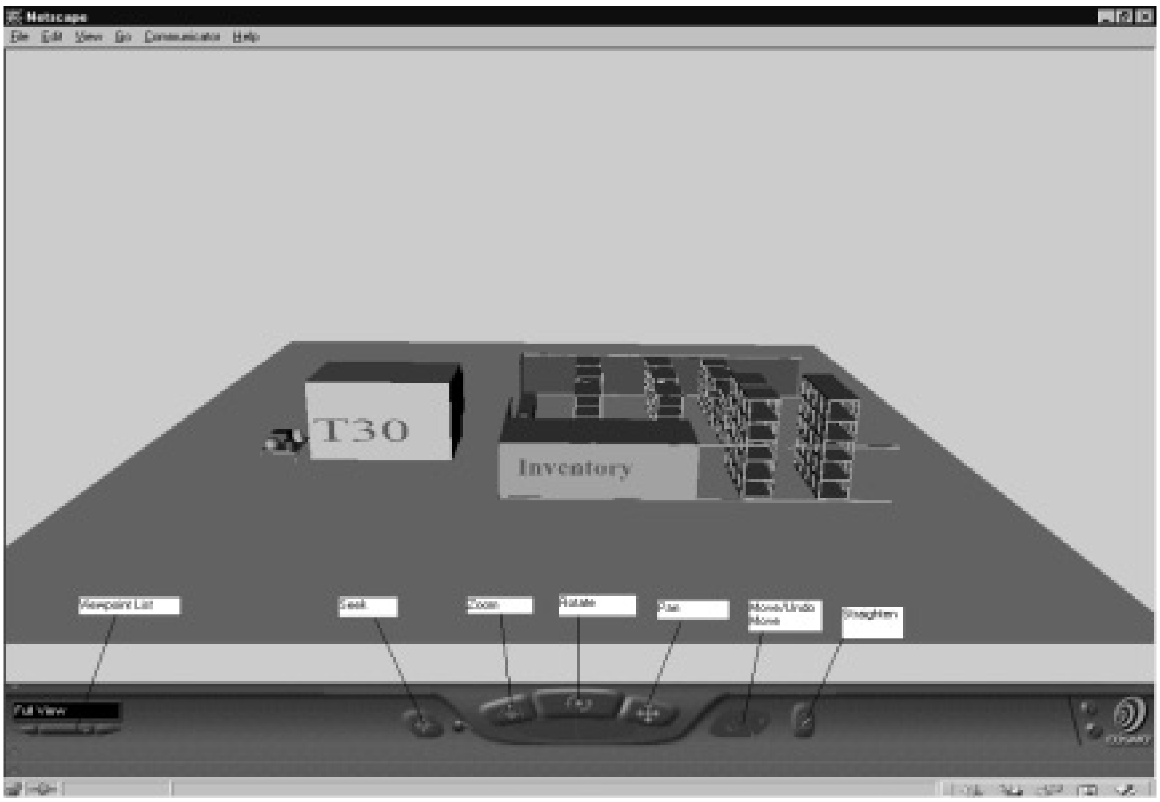
2. Instructions for using HTML/VRML Environment

Thank you for participating in this experiment. This experiment basically consists of comparing the HTML/VRML hybrid environment to a traditional database environment in order to answer typical design/analysis questions associated with manufacturing systems.

This document and the associated video clip will give you a basic understanding of the HTML/VRML environment. For the tutorial, I will be using a subset of the actual system to explain about the environment. As you go through the tutorial, try to develop a basic understanding of the various controls in the environment. After that, you will be given 5 minutes to "play" with the model of the actual system. Use this time to explore and understand the actual system. If you finish early, wait until the experimenter tells you to proceed.

There are three parts to this tutorial. Each part describes a specific functionality associated with this environment.

- Bottom Panel.
- Hot Links
- Level of Detail



Viewpoint List – Viewpoints are fixed camera position, which you can use to move to a particular position within the VRML world.

Seek – Seek, as the name implies can be used to seek a particular object within the VRML world.

Zoom – Zoom can be used to zoom in and out of the VRML world.

Rotate – Rotate can be used to rotate the world.

Pan – Pan can be used to move the world vertically or horizontally.

Undo/Redo Move – This button can be used to undo/redo any of the above motions.

Straighten – This button can be used to straighten the VRML world.

Now click on ‘Panel.avi’ to see a demo of how these controls work. After watching the video clip, try to get a ‘hands on’ experience of the controls.

Hot Links – In this environment, hot links are used to retrieve information about machines and parts in the VRML world. When the mouse is moved over a hot link, the color of the object will change to indicate a hot link. However, the color will not change for machines. Also, when you move the cursor over a link, notice the change in shape of the cursor. The hot links can be activated only when the cursor is shaped like the ‘sun’.

Level of detail – Level of detail is specific to machines. Level of detail helps to define the machines in different levels of rendering detail.

Now click on ‘hotlinks.avi’ to see a demo of ‘hot links’ and ‘Level of Detail’. After watching the video clip, try to get a ‘hand-on’ experience for a better understanding of the hot links and level of detail.

Note - The buffer near each machine is only a representation of the actual buffer. For example, the buffer near T30 workstation contains a sphere, a cone, a cube and a cylinder. These shapes do not indicate that these parts are going to be processed at T30. It is only a representation of the parts that will be processed at T30.

Next, you will be given a question sheet with 3 questions. Answer one question at a time. There is no time limit, but answer as quickly as you can while feeling confident with your answer. Take a look at all questions beforehand to decide upon what order you want to answer. Once you start, please do not switch back and forth between the questions. Whenever you have finished a question, let me know. Please note the time from the stopwatch near you.

Once all three questions are answered, the computer will be shut off and you will be given two additional questions to answer. Answer one at a time, noting the time taken for each.

Important:

Let me know immediately, if you encounter any problem in accessing the data. For example, if you accidentally close Netscape window, let me know immediately.

Please, do not discuss about this experiment with other students since it may bias the results.

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VITA

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