Teaching Process Design using Virtual Reality

Larry Whitman, Ph.D., P.E., Vis Madhavan, Ph.D., Don Malzahn, Ph.D., Janet Twomey, Ph.D.

Wichita State University

Abstract

Virtual reality can be used to configure and build detailed models of factories that can serve as the framework for the cases derived from real-life situations. This paper presents how a model developed from a Boeing manufacturing cell was used to teach activity and process modeling, analysis, and design.

Introduction

Process modeling is typically taught through theory with a few examples. However, it is difficult to provide students with non-trivial examples. The preferred method for industry-based student experience is to provide real-life situations that the student must model, which results in an active learning knowledge construction approach. This method also has drawbacks in establishing contacts and ensuring the students have sufficient access to develop the models. By utilizing a virtual model of an actual Boeing line, students are able to view the process and interrogate the process details. The instructor also has "complete" knowledge of the process as the instructor was the process designer. This ensures that the process has all the desired features to be modeled and allows students to review and correct errors under expert guidance.

The Industrial and Manufacturing Engineering Department at Wichita State University is developing an integrated set of virtual reality models of a manufacturing line at Boeing Wichita. This mega-case will be used throughout the curriculum to vertically integrate the concepts across the curriculum and provide a situated learning experience for our students. This large-scale virtual reality factory modeling effort, "Innovation in Aircraft Manufacturing through System-Wide Virtual Reality Models and Curriculum Integration" has recently been funded by the National Science Foundation through the Partners for Innovation program (http://www.slvr.org).

The objectives of this project are to:

- Foment the use of integrated virtual reality models of manufacturing systems by our partners to design, improve, and operate these systems.
- Teach the workforce (new graduates as well as industrial personnel), using the same integrated virtual reality models, to understand the systems they work with both at the global and local levels and to serve as intelligent initiators and partners for change.

This paper describes one of the initial efforts of this project, which is to use virtual reality models to teach process modeling, analysis, and design in a graduate Industrial Engineering course, "Enterprise Engineering." The paper begins with an overview of process modeling, analysis, and design. Then it presents Virtual Reality and Case Studies and discusses the pedagogical issues. Our approach is presented followed by a conclusion and a discussion of future plans.

Background

This section provides background on process design, the author-reader cycle, virtual reality, case studies, and then presents the pedagogical issues involved.

Process Modeling, Analysis, and Design

Martin discusses how the typical approach to any improvement is to automate and then look for improvements, when the approach should be to redesign the process and then consider automation[1] . Due to this, Davenport and Short stress the need for a new kind of industrial engineer[2,3]. Industry needs those who can integrate business processes with information technology. The authors claim that industrial engineers traditionally have understood both information technology and business processes, but considered them as two separate and distinct tools. Industrial engineers, due to their understanding of the process itself as well as key information technology enablers, are uniquely qualified to integrate the two tools into a competitive advantage. Hammer and Champy define a business process as "a set of activities that, taken together, produce a result of value to a customer"[4]. All of these authors describe the importance for process knowledge. Process knowledge is the understanding concerning enterprise material and information flow.

One concern involved with instructing in process design is to understand the different types of processes. Presley, et al.,[5] propose that business processes may be placed into three categories: (1) those processes which transform external constraints into internal constraints (set direction), (2) those processes which acquire and make ready required resources, and (3) those processes which use resources to produce enterprise results. By providing categories to organize processes, more holistic enterprise designs may be achieved. Figure 1 shows activities (boxes) arranged into business processes (ellipses). The business processes are organized into an enterprise represented by the larger box. At this high level of abstraction, the enterprise itself is represented as an activity that takes inputs and transforms them into outputs using available resources under the bounds of a set of constraints.

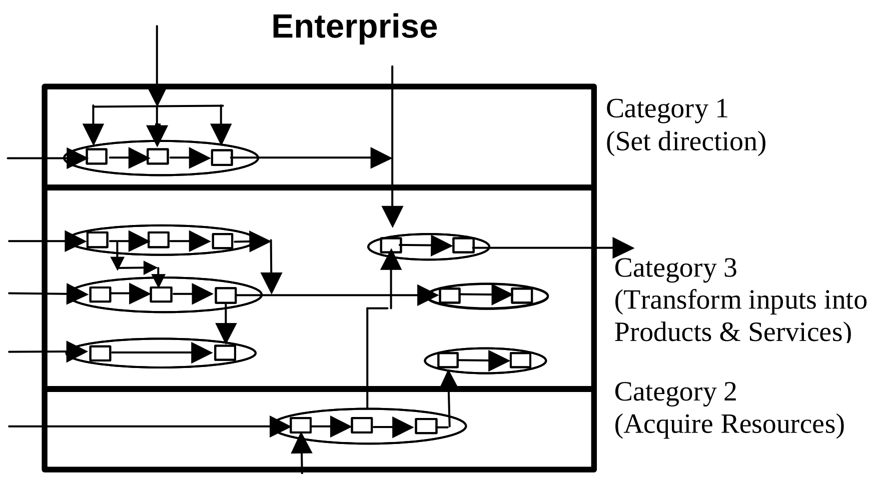

Figure 1: Process Categories (from [5])

Frequently the only activities or processes considered in improvement activities are those listed as category 3, which transform inputs into products and services. However, for lasting improvements, it is important to consider the strategic (category 1) and acquisition activities (category 2) in an enterprise. Understanding the different process categories is vital for developing useful representations of the enterprise as a whole. Categorizing the different processes helps to ensure that the frequently overlooked categories of setting enterprise direction and acquiring and preparing resources are considered. Students viewing the virtual reality models will be tempted to make the same mistake by only focusing on the transforming of inputs. Students learn better after making the mistake themselves, so they will be more likely on future models to consider category 1 and category 2 activities.

A model of the current environment is termed, an "As-Is model" which is generally developed first. This model is used to promote a common understanding of the current system. The resultant model is presented to a wider audience to confirm its accuracy and relevance. It has been our experience that significant benefit is achieved in this seemingly trivial effort. The process of modeling the current environment provides a mechanism to achieve a consensus of the process as well as the outputs, inputs, controls, and mechanisms involved. As mentioned earlier, agreeing on a single viewpoint forces others to view the process differently and many issues and areas for improvement are identified from the modeling effort. Upon completion of the As-Is model, subsequent models, called "To-Be models", are created. Different To-Be models are generated to reflect different design scenarios. These models are then viewed together to identify good design characteristics and these evolve into an implementable, improved design. The use of virtual reality is here primarily directed at developing an ‘As-Is’ model of the virtual environment.

Virtual Reality and Case Studies

If a picture is worth a thousand words, then an interactive 3D model is worth a thousand pictures[6]. Virtual reality (VR) is beginning to be widely used in fields such as entertainment,

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medicine, military training, and industrial design. Virtual reality models of manufacturing systems range in complexity from the level of a single process on a single machine[7], to flexible manufacturing cells[8], to models of entire factories[9]. VR models are typically distributed over the web using the Virtual Reality Modeling Language (VRML) format.

Jones et al.[10] discuss the use of virtual reality to present the results of simulations as a "super" graphical animation that will lead to an expanded role of simulation in decision-making and communication. Lefort and Kesavadas[11] have developed a fully immersive virtual factory testbed for designers to test issues such as plant layout, clusters, and part flow analysis. Many researchers [12-15] have discussed the use of large-scale simulations for studying the virtual behavior of factories. Virtual factories have also been used for simulation-based control of real factories[16], for studying the interaction between business decisions and quality[17], optimal design of large-scale automated facilities such as postal mail process facilities[18], and for optimizing the performance of flexible manufacturing systems by testing different system configurations and control policies[19].

Our approach is to use a virtual model of a real world manufacturing system (mega-case) as a common thread to integrate the content learned in different courses throughout a student's engineering education. This approach has the advantage of requiring minimal modification to the courses and can be easily adopted by other institutions and adapted to other engineering disciplines. A virtual reality model of a Boeing line serves as the case study for the Enterprise Engineering class.

A case study is typically defined as "A problem statement suitable for use by students and set in narrative form. The narrative should provide information that will lead more to a discussion of a problem than to its solution"[20]. The use of cases studies in managerial and business science is pervasive and well documented[20]. The use of case studies in engineering education has just begun to become a useful tool for teaching subjects such as engineering ethics and economics. Recently Raju and Sankar[21] reported on their funded research investigating "Teaching real-world issues through case studies." Their study developed a single case study that was utilized in a single course to impart "cross-disciplinary education (finance, marketing, communication) in the engineering classroom."[21] Raju and Sankar developed their case study according to the traditional business definition highlighting the technical aspects of the problem. Their approach to the development of the case study was well done and will be utilized in part by this research team.

Pedagogical issues

Atman and Turns are using "concept maps" as a mechanism for allowing students to develop their own integration of engineering knowledge and skills. They have shown that these maps become more complex as students progress through their education[22,23]. They propose that the maps produce an "external artifact" that may provide a means for students to integrate and thus recall and apply knowledge and skills acquired during the learning process. Some engineering disciplines have natural "artifacts" (chemical engineering, aeronautical engineering, computer engineering, etc) that can be the focus for organizing knowledge and skills. Industrial and manufacturing engineering have less tangible "products" to use as organizing agents.

The application of a virtual reality model for process design and improvement is a form of situated learning, which includes aspects of constructionist and active learning.

> "In the situated learning approach, knowledge and skills are learned in the contexts that reflect how knowledge is obtained and applied in everyday situations. Situated cognition theory conceives of learning as a socio-cultural phenomenon rather than the action of an individual acquiring general information from a decontextualized body of knowledge ---- It should be noted that situated learning theory has not yet produced precise models or prescriptions for learning in classroom settings"[24].

Situated learning places the learner in the center of the instructional process. It differs from other processes by: 1) content, emphasizing higher-order thinking processes, 2) context, placing the learner in the social, technological and political environment of application, 3) community, providing the setting for social interaction and dialogue, and 4) participation, requiring the engagement of others to develop meaningful systems.

In an effort to summarize the research relevant to the design of a situated learning experience, Jan Herrington and Ron Oliver[25] have reviewed and organized much of the research to date. The researchers conclude, "situated learning is an effective instructional paradigm for advanced knowledge." Table 1 presents the critical elements required for an effective situated learning experience and the realization of these characteristics in the VR process design application.

Approach

A Quest discrete-event simulation model was developed of an actual Boeing manufacturing line. A VRML model was generated from this and placed on the web. Students are able to examine the process though viewing the virtual reality model. Additional annotations are available through web queries of the model. Students can develop the "As-Is" model from this information. Student models are examined to ensure that the process models were developed properly. Students then develop an improved design. Selected designs are implemented in Quest and the resultant VRML model is generated. A class session then can be used to discuss the advantages and disadvantages of each design.

A key component of any improvement effort is the understanding of the current environment and requirements for the future environment. SADT (Structured Analysis and Design Technique)[26], the forerunner of IDEF (Integration Definition), has developed a structured modeling process for the capture of domain knowledge. Knowledge is initially captured through interviews with various sources. These sources include people, documents, and observation of the existing system. It is important that the authors define a clear question for the model to answer. If a model does not answer a question, then the model is of no value. It is easy to try to solve too many problems with a single model. Therefore, the model must have a single subject. This is commonly referred to as 'bounding the model.' It is easy to continually add to the model leading to 'analysis paralysis,' in which the model is never completed. The model must also have only one viewpoint. The students can understand the problem (by investigating all the models including a video interview that is placed on the web) and choose the viewpoint of the shop floor operator, the shop floor supervisor, or the plant manager. From this information, the students compose the diagrams and create the supporting text. All of this information forms a ‘kit’. These kits are composed of a kit cover page, diagrams, text to support the diagrams, and a glossary. A kit is typically one level of diagrams in the hierarchy with the previous level diagram included to provide context. This iterative approach between the creators of the model and the ‘experts’ of the system to correctly complete a model is referred to as the author/reader review cycle and is used to verify IDEF ‘kits’. These kits are sent to the system experts who make comments. For the class project, the instructor reviewed the kits and commented on them with the goal of all student groups resulting in the same kit. This kit represents the current environment. The student groups receive these comments and make the required corrections. The experts verify the corrections. This iterative review process continues until each kit is complete. Student kits typically take about three iterations to complete. The cycle for each review of a kit is usually about a week. The next kit is then created and the review cycle begins for that kit. The kits are created and reviewed in a top-down manner until sufficient detail is captured.

Table 1: Critical characteristics of situated learning experience in VR for process design.

Characteristics of Situated Learning[25]		**VR Process Design**
1	Provide *authentic contexts* that reflect the way the knowledge will be used in real life.	VR model of an existing complex production process that is undergoing continuous improvement.
2	Provide authentic activities.	Documenting the existing process, designing an improved process, and assessing impact are essential activities of practicing professionals.
3	Provide access to expert performances and the modeling of performances.	Models developed by practicing professionals are part of documentation
4	Provide multiple roles and perspectives.	The VR model allows for a variety of team defined roles and perspectives.
5	Support collaborative construction of knowledge.	Individuals *and* teams must interact with the VR model to develop the proposed design.
6	Promote reflection to enable abstractions to be formed.	The nature of the modeling process requires that the level of model abstraction be continually addressed.
7	Promote articulation to enable tacit knowledge to be made explicit.	The product of the process design is an artifact that can be examined.
8	Provide coaching and scaffolding by the instructor at critical times.	Process modeling and design can be performed in stages with feedback provided by the developer of the VR model.
9	Provide authentic assessment of learning within tasks.	At each step of the process design, student products can be compared with those developed by practicing professionals.

The Boeing line is modeled using the Quest discrete-event simulation software. Quest has all the typical simulation features and also allows control over the animation of the simulation displayed. This control aids in providing realism to the model. It is important not only that the model represents a real-world manufacturing environment, but that it also "feels" real. As quoted by Gobbetti and Scateni[27] in 1965, Sutherland stated that the real challenge of VR is that, "the screen is a window through which one sees a virtual world. The challenge is to make that world look real, act real, sound real, feel real." We are addressing this challenge by beginning with a basic model and then adding additional detail over time making the factory seem as close to real as possible. Figure 2 shows the model in the simulation tool, Quest. Figure 3 shows the same model but from the browser using the Cortona VRML viewer add-in. In the browser the user can start the simulation and view the animation in progress. The students can actually see the inventory stack up in front of a bottleneck machine or slow worker; then they can see the inventory being used as additional workers or machines are added. The distance moved by the workers becomes more apparent. Figure 4 shows the same model in a browser but zoomed in on a group of assemblers, so that the students can examine a particular operation in more detail.

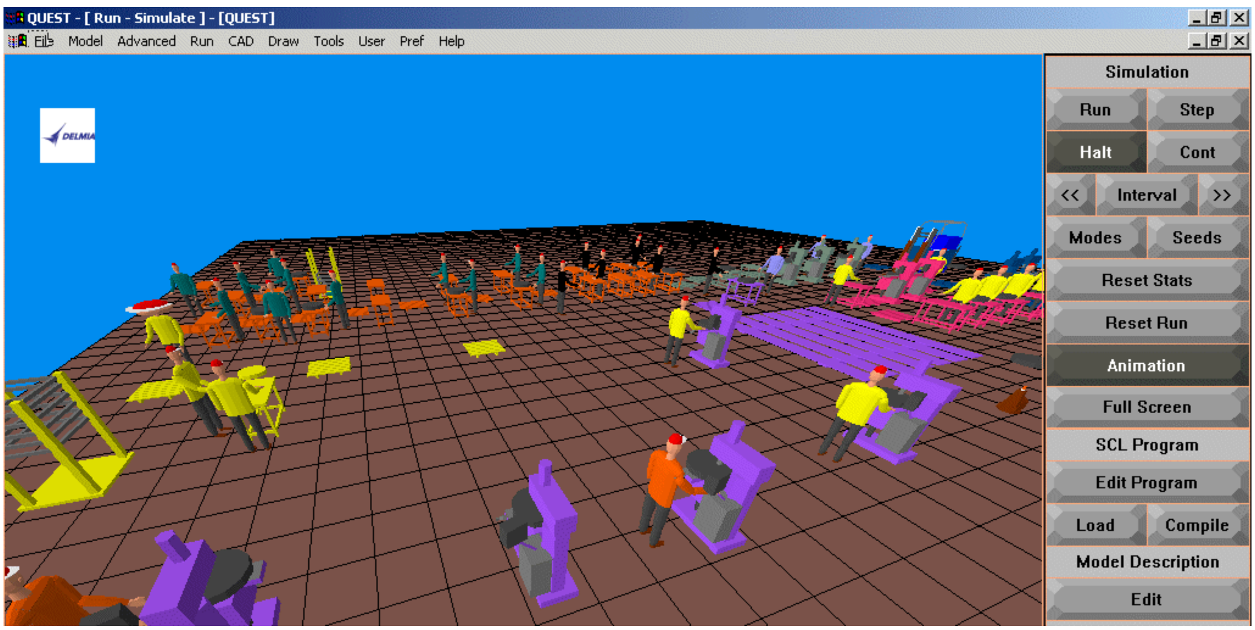

Figure 2: Quest Discrete Event Simulation Model of Line

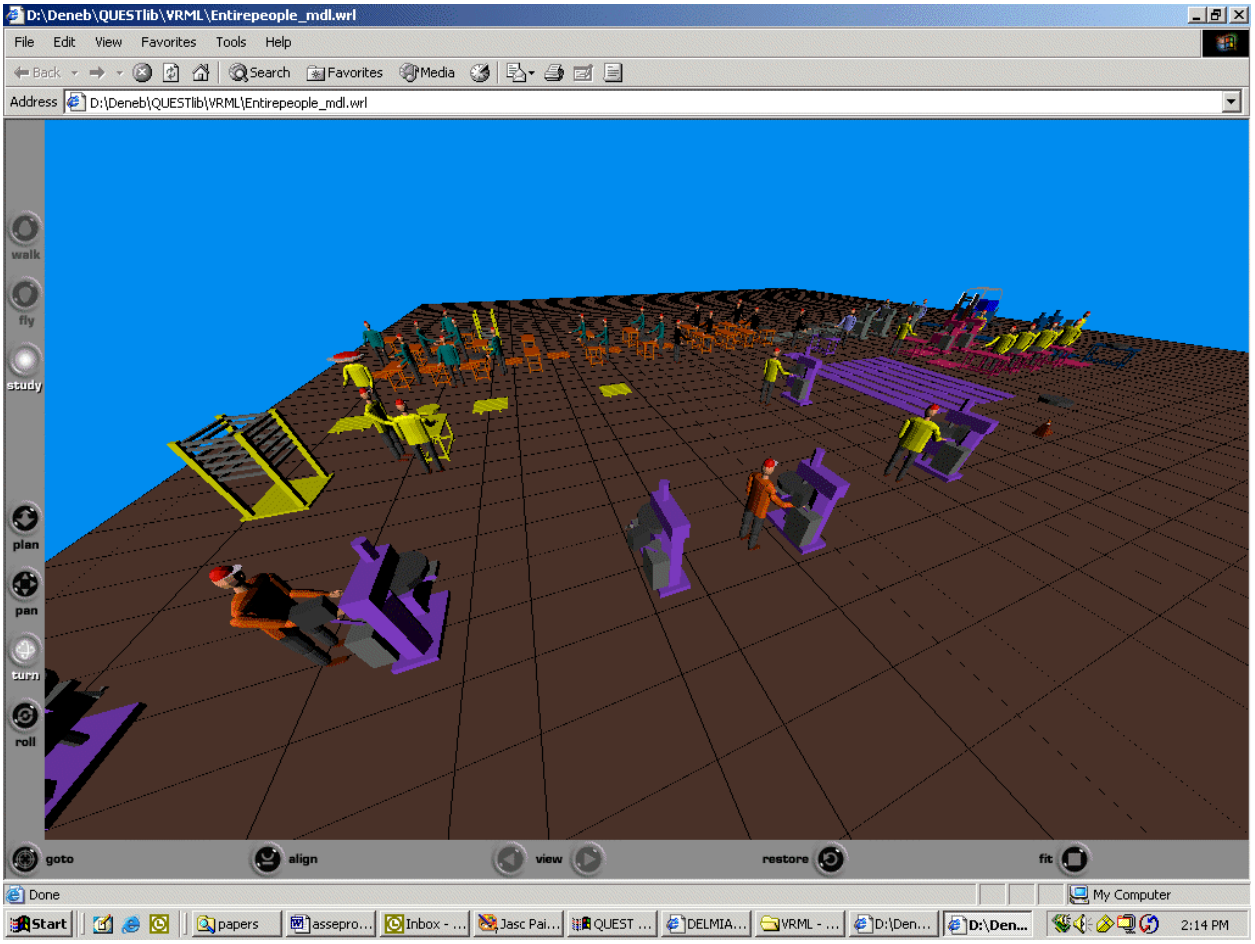

Figure 3: Model Viewed in Browser

IDEF0 is an activity model and IDEF3 is a process model. Students are required to create both views (IDEF0 – activity view and IDEF3 – process view). The students investigate the model and develop an IDEF3 (process description capture method) model which describes the process. The students document the steps in this manner and determine the times and resources required for each step in the process. The IDEF3 model is exported to a simulation tool for a comparison of the results between the As-Is and To-Be scenarios. Each student group presents the final results such as throughput, work in process inventory, and other pertinent details in a written and oral report for both scenarios.

Conclusion and Future Directions

This paper discussed integrating virtual reality with real-world case studies to teach process modeling, analysis, and design. Practicing process modeling and design using a "real-world" process increases student learning. By being able to see the results of their improved designs in the Quest environment, students recognize the disadvantages of different designs as well as the advantages. This type of virtual reality in a course helps to bridge the gap between industry-based projects and classroom case studies. This use of virtual reality was one of the first applications at Wichita State University and is only the beginning of a suite of models aimed at increasing student understanding of Industrial and Manufacturing Engineering concepts.

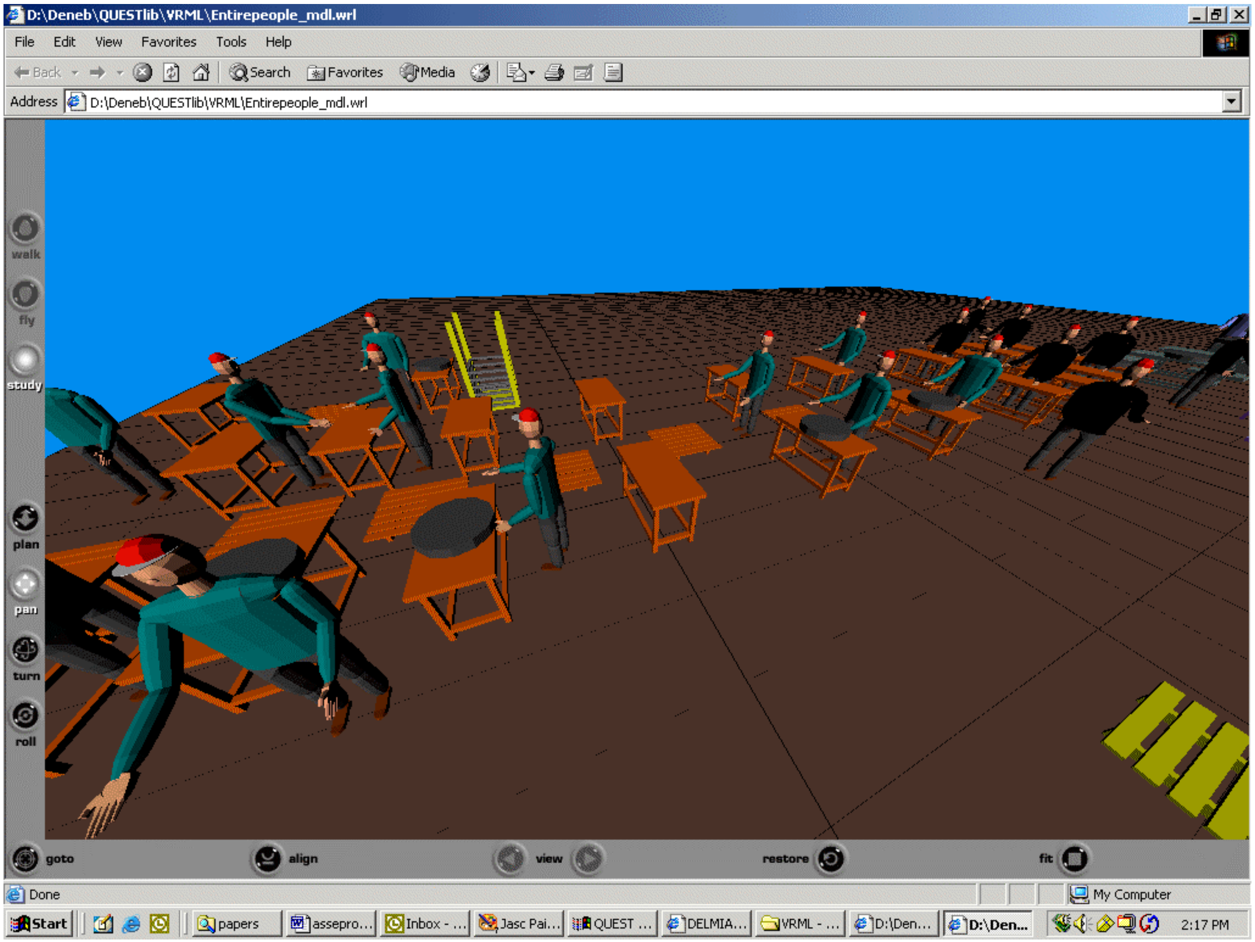

Figure 4: Same Model Zoomed in

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LARRY WHITMAN
Larry Whitman is an Assistant Professor of Industrial & Manufacturing Engineering at the Wichita State University. He received B.S. and M.S. degrees from Oklahoma State University. His Ph.D. from The University of Texas at Arlington is in Industrial Engineering. He also has over 10 years experience in the aerospace industry. His research interests are in enterprise engineering, supply chain management, and lean manufacturing.

VIS MADHAVAN
Vis Madhavan has been working as Assistant Professor of Industrial & Manufacturing Engineering at Wichita State University since 1996 when he earned his Ph.D. from Purdue University. He is currently working on projects in virtual reality, machining and sheet metal forming, funded by Boeing, Bombardier, Cessna, NSF and Raytheon.

DON MALZAHN

Don Malzahn is Professor of Industrial and Manufacturing Engineering at Wichita State University. He has over 28 years teaching experience with research interests in engineering education, decision analysis, and project management.

JANET M. TWOMEY
Jan Twomey is an Associate Professor in the Industrial & Manufacturing Engineering Department at the Wichita State University. Her research and teaching interests are in the areas of simulation, probability and statistics, and artificial neural networks. She is currently on a temporary assignment as a Program Officer at the National Science Foundation.