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Computer-aided Education and Manufacturing Systems with Simulation and Animation Tools*

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Manufacturing is a key economic factor if the United States is to remain competitive globally. Manufacturing education, therefore, has a vital role to play and must be agile enough to adapt to rapidly changing and growing technology. This study introduces the development of computer-aided, interactive simulation/animation tools with a multimedia teaching/learning environment for manufacturing education. The tools are designed to be readily adaptable to technological changes and provide both an efficient and effective teaching/learning environment for manufacturing systems across the engineering curriculum. We envisage that these tools will complement traditional classroom and laboratory teaching methods in providing a learning environment that is scalable to meet varied educational/learning needs at different levels. The tools described here are cost-effective and do not require the expensive development of manufacturing hardware to teach complex manufacturing systems. Interactive learning using these tools involves students exercising with a structured set of manufacturing examples to comprehend the operating principles and key performances. They will be able to manipulate the system control variables and observe changes in the performance of the overall system. The tools will provide visualization of real manufacturing operations and statistical analysis of system performance. Such hands-on experience will help in effectively teaching the abstract concepts underlying several manufacturing systems. Preliminary development of the tools has involved faculty with manufacturing and computer simulation/animation expertise assisted by students with programming skills; both these skills are readily available in most universities. The portability and customizable nature of the tools has also been very useful in conducting preliminary classroom trials in various universities.

1. INTRODUCTION

THE ECONOMIC power of a nation significantly determines the standard of living of its citizens. Further, nations have to compete with each other globally to sustain and enhance their well-being. In this endeavour manufacturing plays a central role as an economic engine in providing a competitive edge. It is well known that the outstanding strength in manufacturing that the United States acquired following the applied research and development efforts during and after the world wars, contributed strongly to its superpower status. It was again manufacturing capability that helped Japan to face the formidable challenge of rebuilding the country and to forge ahead to become one of the top global economic powers. This historic importance of manufacturing was overlooked during the 1970s and early 1980s when the United States lost some of its competitive edge. However, once again there is a renewed awareness of the importance of manufacturing in the United States in both the industry and the government agencies [1], e.g. the formation of the National Center for Manufacturing Sciences (NCMS), an industry-wide coalition to address important problems in manufacturing, and the formation of the Advanced Research Projects Agency (ARPA), a government agency responsible for creating dual-use technology and engineering the conversion of defense-related manufacturing infrastructure for commercial use. All such efforts underscore a growing sense of urgency to improve manufacturing in the United States, and to educate and train engineers to address our needs today and in the future. The movement of low-skilled manufacturing operations overseas coupled with rapid advances in both the product and the process technologies require US manufacturing to have a computer-skilled and well-educated manufacturing work-force. It is therefore important to strive for an effective education in manufacturing.

Lately, the academic community at large has launched a vigorous effort to improve manufacturing in the United States. The numerous centers of manufacturing created to foster university–industry collaboration has certainly helped in this endeavor. Educators and administrators across the country have also been working to devise solutions to promote manufacturing education. These range from new courses and specialized degree programs to a major overhaul of the engineering curriculum.

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All of this has begun to bear fruit as evidenced most noticeably by a significant increase in research and development in manufacturing. On the other hand, these efforts, while addressing the needs of advanced manufacturing education, have not fully addressed the introductory level needs of manufacturing. More recently a university coalition under the guidance of the National Science Foundation have begun to focus on this problem. The inherent complexity of manufacturing systems and the lack of cost-effective, suitable tools to illustrate the concepts and models have hindered progress in imparting manufacturing education to entry-level students. This is further complicated by the fact that entry-level students do not have the interdisciplinary background to grasp the subject matter in a traditional classroom setting. Realistic manufacturing laboratories in universities and centers are not only mostly oriented towards graduate education/students but are also expensive to establish and difficult to maintain up to date due to rapidly changing technology.

However, one other solution, which was regarded as difficult in the past but is now emerging as the most practical and cost effective, is 'interactive computer simulation/animation', i.e. adapting the current state-of-the-art computer simulation/animation technology to provide an interactive, self-paced and computer-based approach to manufacturing education. The success of flight simulators in providing safe and affordable hands-on-experience, is testimony to the effectiveness of this approach. This technology, which is currently used for design and analysis of complex systems including manufacturing, has good potential in improving manufacturing education.

This study describes an attempt to provide a visually interactive, multimedia-oriented, simulation/animation educational tool targeted at improving freshman (or entry-level) manufacturing education. The tools will not only help in the visualization of real system operations but in quantifying their performance (or status) with statistics and graphs. The abstract concepts underlying several manufacturing systems can then be effectively taught with hands-on experience. Students will be able to exercise with a structured set of manufacturing examples (see section 3.3.1 for more details) featured in these tools. They will be able to manipulate the system control variables and observe the changes in the performance of the overall system. The examples featured in the tools will be also completed by videos of real-world operations and expert tutorials, which can be accessed directly using the tool. The objective of the tool and the interactive learning approach is to develop a comprehension of the facts and operating principles of complex manufacturing systems to entry-level engineering students.

Some of the advantages of using computer-based interactive and multimedia simulation/animation tools for instruction/learning in manufacturing education are listed below.

- *Visualize and illustrate complex manufacturing systems*—As noted before, one of the stumbling blocks in introducing manufacturing systems to entry-level engineering students is the lack of suitable tools to illustrate complex systems. Simulation/animation technology is generally regarded as a powerful method of visualizing complex systems. The computer-aided learning tools described in this paper are fashioned to serve specifically as teaching and learning aids in manufacturing education at the entry level. As such they can be incorporated into a freshman engineering course to introduce fundamental and complex manufacturing issues.
- *Characterize the interdisciplinary aspects of manufacturing*—The interdisciplinary nature of manufacturing, and the lack of an interdisciplinary background among entry-level students, make it particularly hard to impart manufacturing education in a traditional classroom. The simulation/animation tools are powerful in depicting the overall behavior of the manufacturing system, and provide a top–down view of how the various engineering disciplines play a role in manufacturing. The tools can therefore provide a holistic—in terms of the synergy of various engineering disciplines—computer-based approach to instruction/learning.
- *Provide a self-paced, customizable and motivating learning environment*—Traditionally, manufacturing education has relied on the print medium, plant tours and classroom instructions. Although these approaches have served well in the past they are ill-suited to explain complex manufacturing systems, particularly to entry-level students. Furthermore traditional methods are less flexible in meeting the varied needs of students. In this respect, simulation/animation tools can complement traditional classroom and laboratory teaching methods in providing a learning environment that is scalable to meet varied educational/learning needs at different levels. It is possible to provide self-paced and individualized teaching using state-of-the-art computer and video technology. The familiarity of modern-day students with such technology through video games is also helpful. In addition to these desirable features, the simulation/animation tools represent an expedient alternative for imparting manufacturing education that matches real-world requirements.
- *Easily adaptable*—As noted above, the simulation/animation tools can easily accommodate varying education/learning requirements. The underlying learning model in these tools is also readily and easily adaptable to be generally applicable. For example, at graduate levels of education across engineering disciplines, and retraining engineers from defense to commercial manufacturing applications. In fact the same tools can be used to demonstrate to visiting high school students who are thinking of a career in

manufacturing. These tools are portable and can be deployed easily.

- *Cost effective*—The simulation/animation tools are cost effective in terms of keeping the instruction material up to date, alleviating the difficulty associated with maintaining expensive laboratories/manufacturing centers. This, along with the aforementioned benefit of easy adaptation to technological changes makes the tools very economical. Also, universities are now well equipped for education using state-of-the-art technology in instruction. Faculty, assisted by students, industry partners and commercial software developers can develop multimedia-oriented, visually interactive computer simulation/animation education tools.

In short, the availability of computers and high-level simulation/animation software and multimedia teaching tools, a large resident programming resource in the graduate students, and the availability of faculty expertise to teach basics in manufacturing as well as industry personnel to teach more realistic complex issues, make computerized instruction (such as that described in this paper) the preferred choice in manufacturing education for the first time.

This paper is organized into seven sections. In section 2, following the introduction, the problems *vis-à-vis* manufacturing in engineering education are identified. The role of technology in manufacturing education is described in section 3, laying the conceptual foundation for *computers*, *multimedia tools* and *interactive computer simulation/animation* as part of an overall learning model for manufacturing for entry-level students. The appropriateness and advantages of using computers in education such as that advocated in this paper and multimedia teaching issues are outlined. A case study illustrating this concept is detailed in section 4. Section 5 overviews the design and development process for simulation/animation tools, while section 6 describes the instructional issues. Finally, the future potential for the underlying learning model and the simulation/animation tools are presented in section 7.

2. MANUFACTURING IN ENGINEERING CURRICULUM

Manufacturing education in engineering curricula has been confined mostly to mechanical, industrial, manufacturing systems and some engineering management majors. Although each engineering discipline constitutes a part of manufacturing, i.e. electrical engineering (control systems), industrial engineering (systems design), chemical engineering (chemical processes), etc., they have never been viewed as synergistic components of a 'whole' in imparting manufacturing education.

The academic community has made extensive efforts in defining the boundaries of each engineering discipline in the education system such as chemical, mechanical, manufacturing, industrial, management, systems, electrical, transportation, etc., though in reality such a well-defined border may not exist. This has also inadvertently helped in isolating engineering students, the work-in-progress of our education system. For example, when a mechanical engineering student is working on a manufacturing project, his/her decisions are completely unaffected by the concerns or innovations a chemical engineer can provide or any other engineering majors. Since each major is largely confined to their respective disciplines, the big picture, of how each engineering discipline interacts and how they can be applied in the final 'manufacturing' stage has been lost. Students are hence ill-prepared for the eventual use of their education: the manufacturing stage or the real world. This has contributed to the dichotomy of education and industry with respect to manufacturing in different ways. Academia is well behind in teaching the state-of-the-art tools and practices used in the industry. At the same time industry has had to train their employees for maybe long periods before they can be fully functional, which can be costly. Hence, educating our engineers in manufacturing must not only be a priority but must also be carried out so as to highlight the role of various engineering disciplines in manufacturing.

Obviously, to accomplish this it is important to begin by introducing an overall perspective of manufacturing systems starting with entry-level engineering students (i.e. freshmen engineers). Targeting the entry-level students and helping them to make a choice toward obtaining manufacturing education is crucial to furthering manufacturing. At the entry level it is important to provide a balanced view of engineering that provides an understanding of the challenges in each engineering discipline, and makes it possible for students to make their choice of specialization in an informative manner. Manufacturing systems and concepts tastefully presented at this stage can be particularly useful to students in relating various topics and how they contribute to the whole.

It is also important to bridge the gap between the needs of industry and the skills taught by academia in manufacturing. The tools and techniques used to impart manufacturing education need to be upgraded to provide students with real-life manufacturing experiences. Although establishing realistic manufacturing laboratories at universities and centers has helped, they do not represent the complete solution. The use of modern computing and video technology to provide computer models of real-life manufacturing systems, where students can gain hands-on experience, opens up new opportunities for imparting manufacturing education in a cost-effective and efficient manner. Further, such teaching/learning tools can easily keep pace with rapid changes in technology.

Some of the computer-based technologies relevant to the description of simulation/animation tools are reviewed next.

3. IMPACT OF COMPUTER-BASED TECHNOLOGIES ON EDUCATION

3.1 *Computers and education*

The design of computer-aided instructional/learning software raises the larger question of when to use computers and when not to use them.

Computers are generally good for educational activity that requires significant interaction. Games and simulations are probably the best examples of this. Other media, such as video, are good for showing real, dynamic sequences, while printed matter is best for presenting a lot of text or graphical information [2]. Hence it is important to consider the unique features of computers in designing instructional software without automating traditional instructional methods that other media can do better. Computer screens, for example, should not be designed like printed pages. Similarly, animation should not be used as a substitute for video sequences. Most importantly, instructional software should be highly interactive. Otherwise, why bother to use a computer? The simulation/animation tools described here are intended to be a multimedia environment where simulation/animation models are used for interactive teaching, while the videos of actual system operations will be available on screen upon request to provide a well-rounded understanding of manufacturing systems.

By virtue of their interactive capability, computers are also good for providing individualized instruction. Students can set their own learning pace rather than working at a pace forced either by the instructors or the rest of the class. The instructional material can also be customized to meet various student needs. Computer-based instruction is particularly beneficial in situations that involve students with diverse backgrounds or ability levels. Such situations typically include engineering courses at the entry level, or retraining sessions for engineers with diverse backgrounds and even languages. Simulation/animation tools are therefore ideal for these situations.

Computers are especially good for explaining complex processes and interactions. For example, suppose one is trying to learn/teach either the basic principles of harmonic motion or the steps in photosynthesis. Through the use of animation and graphics, as well as the capability of changing the value of variables and observing the effects, instructional software can have very powerful explanatory values. Numerous other examples of computer applications clearly demonstrate the power of instructional software in teaching problem-solving or decision-making skills.

3.2 *Multimedia and education*

According to a recent report from Market Intelligence, a California-based market research firm [3], the worldwide multimedia market is projected to be $24 bn in 1998 with a compounded annual market growth of 25%. Education and training applications constitute the single largest component of this market and account for well over 50% of the total market. The report [3] also highlights the role of networks, projecting that multimedia over local area networks (LANs) and wide area networks (WANs) will boost the market and that 'interactive video will emerge on public networks'. These forecasts are all backed up by the current trend in sales and by the products listed in ref [4] for education. Such a significant industry recognition for multimedia in education is in part due to its promise of embodying the natural way in which humans learn and interact, with considerably improved communication and investigation possibilities over classical education tools. Multimedia has had a tremendous impact on instruction in the past ten years [3]. Over this period the usage of both CD-ROMs and video disks has sky-rocketed along with graphics and image-enhancement tools, desktop audio and video editing packages, and multimedia networking products. Such technological tools have enabled education to be targeted for multiple learning styles, and hold out significant promise in dramatically improving retention and comprehension. They can also illustrate concepts in a way that a single medium cannot; multimedia engages both the mind and the imagination. It can bring a 'why you should care' aspect to many disciplines by relating real-world issues for the concepts and skill presented. With regards to manufacturing education, multimedia technology provides the missing tools and the means for illustration of the synergy between various engineering disciplines and their manufacturing applications on the production floor.

Multimedia affects both students and teachers. Students are likely to benefit from the guided learning environments by virtue of the extra insight gained on the subject matter. On the other hand, teachers benefit by being able to communicate complex ideas more effectively and thereby motivating the students. Further, multimedia tools can be easily prepared/adapted to changing technology needs without necessarily undertaking costly changes to the hardware platforms of manufacturing centers/labs. The inherent portability of such tools also makes it possible to share these education tools between educators and among universities. Finally, the latest generation of multimedia technology can bring education back into the home over telephone lines and help refocus attention on learning as a priority in everyday life.

A basic multimedia-ready computer needs sound, graphics, a CD-ROM drive and a fairly large hard disk. For the development of the multimedia simulation/animation education tools, some combination of the following multimedia systems will be needed (or will be used): authoring systems, CD-ROMs, video-editing programs, simulation/animation packages, graphics/statistics software, VCRs, CD-ROM drives, videodisk players, multi-function disk players, video/data projectors, camcorders, scanners, speakers, audio-editing programs, audio input devices, color printers, video printers, mass storage devices and multimedia networks. While simulation/animation tools will feature examples to teach integrated manufacturing concepts, CDs containing motion video clips will provide a fast and ready access to real-life versions of the examples. These video sessions can be augmented by appropriate expert speakers from industry to explain the realistic issues particular to a work environment such as organizational or cultural. Such a multimedia presentation is important in understanding the real problem, which may be overlooked or inadequately addressed in traditional classroom instruction.

3.3 *Simulation/animation and manufacturing education*

Simulation is a powerful analysis tool for complex, real-life systems such as manufacturing systems, while animations can help in explaining the operating characteristics of a system. Collectively they represent the significant power of visualization and statistical analysis and can serve as a vital tool for education. Simulation is featured in numerous game tools, but there does not appear to be any recognized game tool used in manufacturing education. Usually, simulation/animation is used to market a system design or technological investment to the management, or as an instructional tool on the factory floor. By extending this power to the classroom, real-world manufacturing operations can be brought to the students (that otherwise would only be possible through study trips to manufacturing plants or through videos). More importantly, it can be used to illustrate the manufacturing concepts relatively quickly, and in an interactive and motivating manner. The use of computer simulation as a comprehensive systems approach to education is an idea that educators have been proposing for a long time [5]. Although numerous stand-alone packages have been developed, the development of simulation/animation tools has been generally regarded in the past as cumbersome and expensive. However, the advent of powerful new generation, high-level simulation/animation software, the availability of fast-growing simulation expertise among the faculty and good programming skills in the graduate students, and adequate availability of computers to students, make it possible for educational institutions rapidly to prototype powerful interactive simulation/animation tools. A recent survey of industrial engineering departments in universities across the United States [6] revealed that more than 75% of the industrial engineering curricula have several required simulation courses and computing environments to perform simulations. The high-level simulation languages taught in universities can serve as building blocks to quickly develop realistic models that closely match the real system under study. These applications can also be embellished to present the user with an illustration of the concepts as well as to introduce terminology relevant to his/her problem.

Simulation/animation can also be used as an education tool to advance manufacturing concepts in courses such as 'production processes and failures concepts in Manufacturing Courses', 'computer integrated manufacturing and flexible manufacturing concepts in CIM and FMS courses', 'uncertainty and risk concepts in capital investments of engineering economy', 'sampling, inspection and charting in quality control', 'stochastic inventory systems in production control' and many others.

Currently, simulation courses are not necessarily focused on manufacturing systems. The aforementioned survey [6] also revealed that 75% of the IE departments teach more than one graduate simulation course where the majority of faculty spend three-quarters of their time in teaching simulation language or programming. In these courses simulation is not intended to be used as an education tool but rather is taught as an analytical tool that students might use in their future courses or jobs. Besides, due to the need to know a simulation language, the use of simulation tools is limited to senior undergraduate and graduate students. Simulation/animation tools, on the other hand, are specifically designed to impart manufacturing education and address the needs of entry-level engineering students.

3.3.1 *Learning approach using the simulation/animation tool.* In this paper we propose to use the aforementioned power of simulation as an education tool by developing several manufacturing simulation/animation models where students can interactively study the represented manufacturing systems. The animations will be designed to visualize the overall manufacturing systems as well as to illustrate the underlying concepts. Each real system modeled will be complemented, as mentioned before, by video of the real system and made available on the computer screen. Students will be able to compare visually the simulation model to the real system, and consequently gain more insights on how simulation models are built and their strengths as well as their limitations. Such an exercise can be further enhanced if the system that is modeled exists in the laboratory. The students in this case can augment their hands-on experience with the simulation/animation system by running experiments on the actual hardware in the laboratory.

We envisage students using simulation/animation tools to study the operations of a manufacturing system, measure its performance, parametrically alter the behavior of the system, and also play the role in decision-makers in implementing various changes. The interactive capability of the tools will positively affect the students' sense of observation, ability to define and solve problems, and make decisions or reach conclusions. Examples of manufacturing systems/concepts to be featured in the simulation/animation tools can be chosen from any discipline such as chemical engineering (e.g. chemical vapor deposition process used in the manufacture of printed circuit boards [PCBs]), electrical engineering (e.g. computer-aided design of PCBs with attention to design for manufacturing issues), mechanical engineering (e.g. operation of numerical control machines to populate the printed circuit boards), and industrial engineering (e.g. design, operation and management of assemby-line production of PCBs). This example from electronics manufacturing also demonstrates the synergy of various engineering disciplines in contributing to the final stage, namely manufacturing of the finished product.

4. CASE STUDY USING THE SIMULATION/ANIMATION TOOL

The case study illustrates the application of computer-based simulation/animation tools to manufacturing education. In this example an actual electronics manufacturing facility is being simulated. There are 119 machines or resources grouped in five different work-cells. The factory produces electronic products such as television sets. The first work-cell includes 19 automated machines inserting electronic components onto the PCBs. The finished parts may wait in a in-buffer before proceeding to the next work-cell, which includes 38 assembly workers for inserting nonstandard parts onto the PCBs. The boards are inspected in the following work-cell by two inspectors and the ones that need repair are diverted to a repair facility. Conforming parts are then assembled with TV monitors by 62 assembly workers. The final stage is the packaging, which is done by an additional three workers. A buffer is provided between every workstation with a capacity of keeping at least half-an-hour's worth of production (60 units). The machines are subject to failures, which are then repaired. The failure and repair cycles are governed by some common stochastic processes. The PCBs that fail can cycle through the system at most two times, following which, if they still fail, they are discarded (see [7] for more details).

Figure 1 illustrates the animation screen for the

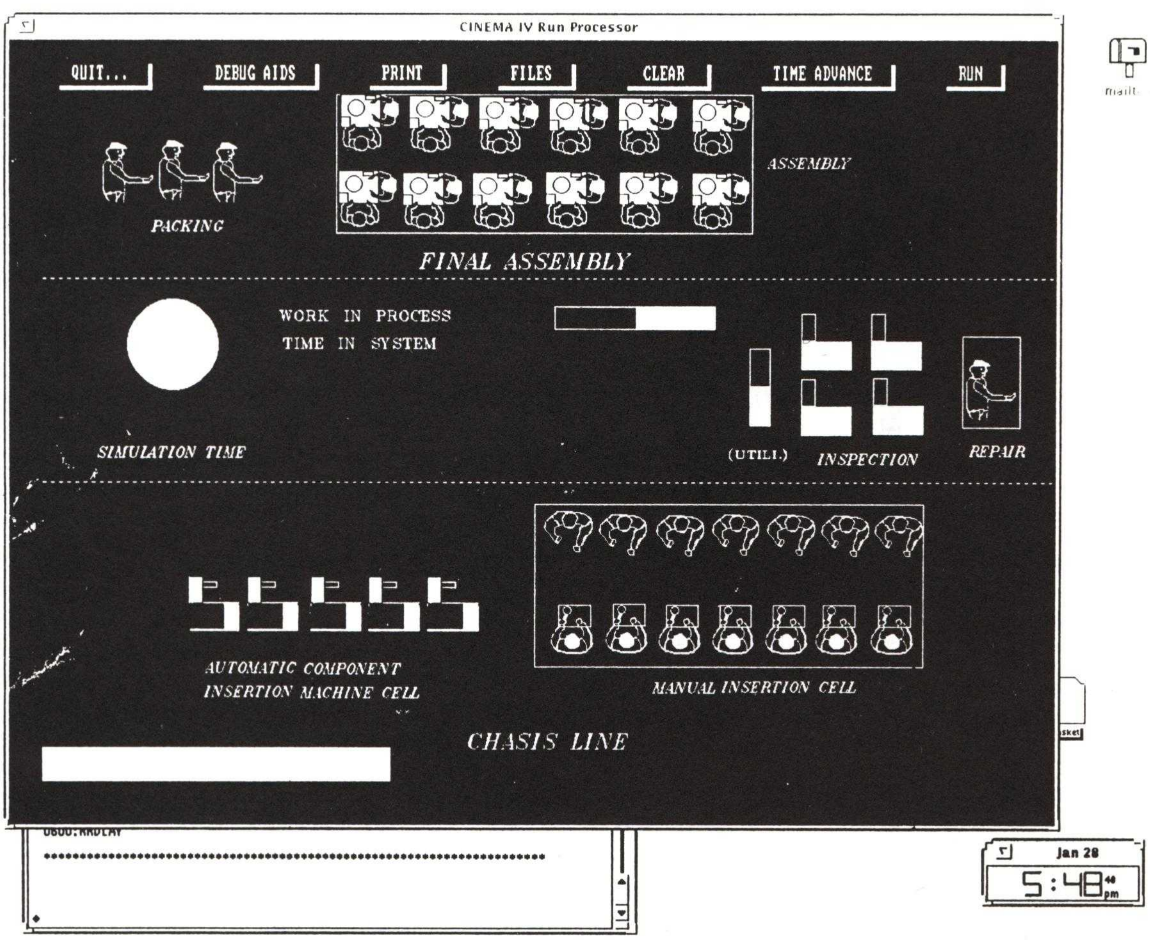

Fig. 1. Simulation/animation of an electronics manufacturing facility.

manufacturing system described above. The key *control variables* for the system are the following:

1. processing rates of 80 machines and their associated distribution;
2. buffer capacities between work-centers and machines;
3. failure distribution and associated parameters; and
4. maintenance time distribution and associated parameters.

The performances measures for the system include:

1. job production rate;
2. utilization of each work-cell and individual workstations;
3. starvation characteristics;
4. blocking characteristics;
5. idleness due to failure; and
6. idleness due to preventive maintenance.

Students can watch the animation for the manufacturing system simulation and interact through user-friendly screens. They can change any of the aforementioned control variables and observe the dynamic behavior of the system. The final results are either printed or saved in files for comparison purposes. See Figs 2 and 3 for illustration of interaction. An example assignment given to students based on a scaled-down version of this manufacturing system is provided in the Appendix.

In this learning exercise, students will be responsible for understanding the behavior of the

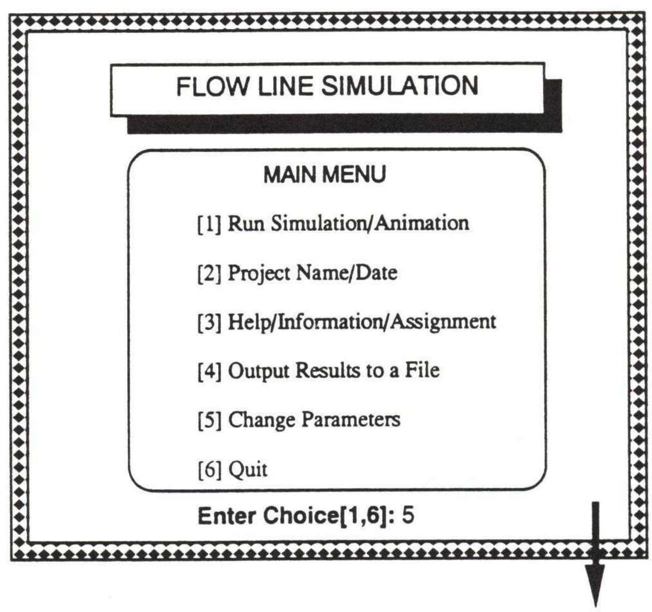

Fig. 2. Sample interaction screen.

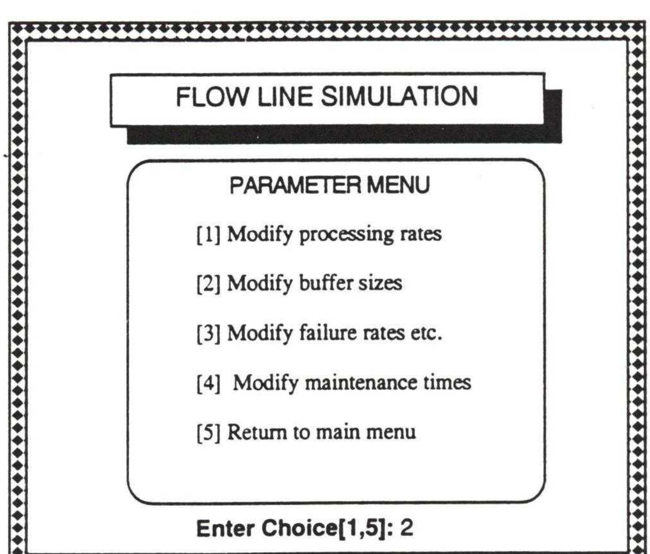

Fig. 3. Sample interaction screen.

system that is introduced by the instructor. The instructor is complemented by an on-line help menu in the simulation/animation tool. Simulation experiments will be executed by students, who change control variables and try to improve system performance in terms of the measures introduced above. The instructor will explain the control variables and how they can be changed, and will encourage students to understand the limitations of these variables through experiments. Students will also be required to conduct a simple cost analysis. Students will work in groups and prepare a written report of their findings. It is preferable sometimes to supplement the exercise by inviting, if possible, or by providing on-line video of an instructor from industry to explain the details of the actual manufacturing system, and its political and sociological constraints in the real world. Evaluation of student performances will be based on their reports and also presentations. For example, a group with the minimum cost solution and good presentation of the results will have high grades. Use of graphics/spreadsheet programs/statistical charts will be enouraged in order to draw conclusions and explain results. The objective of this approach is to motivate teamwork and equip students with writing/presentation skills and tools at the start of their engineering education so that it may help them in the years ahead. In fact, in industry they will require such skills to perform successfully.

5. DESIGN OF SIMULATION/ANIMATION TOOLS

In this section we describe a variety of issues involved in developing multimedia simulation/animation tools for manufacturing education. These issues have been identified based on the author's previous experience in developing simulation/animation models and systems.

5.1 *Basic design considerations*

An instructional software such as simulation/animation tools typically has to meet a number of design considerations. Some basic considerations include the following:

- *User perspective*—The software must be visually stimulating and motivating to the user (instructor as well as students). This implies that the users will have to be involved in some fashion in the design process. The software must also be flexible so that it can be customized easily to suit individual learning/teaching needs. Ease of use is also an important design attribute from the user's perspective.
- *Quality*—The quality of the software has a significant impact on any interactive instruction process. The software must be reliable and free of errors. It must also be accurate and valid in terms of its content. Most importantly the software must be useful. This measure must be evaluated by the experts and then by the users themselves.
- *Portability*—Portability is a very important issue, particularly for simulation/animation software. It should be possible to use the software in a seamless manner across commonly used hardware and software platforms. More importantly the look and feel of the user interface and the software itself should be consistent across the platforms. A recent survey [6] revealed that the most popular simulation language in use in the universities is SIMAN followed by SLAM. Both of these softwares are available on a number of hardware and software platforms.

5.2 *Development team*

The development team must include people with at least the following abilities: good knowledge of the subject matter, expertise in simulation/animation, software design and programming skills, and project management expertise. Often, in a university setting most of these skills reside in the faculty with graduate students to assist in the programming and implementation of the software. For the example illustrated in section 4, the model is taken from a local electronics manufacturing company. Experts on the manufacturing system were consulted. A graduate student worked on the development of the simulation model as part of a thesis requirement. In fact the model initially served as a test-bed for evaluating newly developed scheduling algorithms [7]. The animation screen was developed by another graduate student as part of a simulation course project. In addition to the electronics manufacturing example, a number of other manufacturing applications are featured in the simulation/animation tools. These were developed using commercially available animation screens or during simulation classes as model/animation development projects under the guidance of the instructor. Students in various simulation courses served to critique and evaluate the software, which was continuously improved.

5.3 *Development process*

The three major stages in the development process are computer-aided instructional software in general and simulation/animation tools in particular are as follows:

1. need analysis and setting objectives with priorities;
2. lesson specifications and media selection; and
3. experimentation, evaluation and implementation.

Need analysis. The need analysis and objectives for the simulation/animation tools originated from the efforts of the author in assisting the Gateway project, sponsored by the National Science Foundation. The mission of this project was to improve engineering education. The author worked as part of a team engaged in developing a freshman course in which each student is introduced to the engineering disciplines and related manufacturing concepts with hands-on experiments. The underlying objective was to illustrate the synergy between engineering disciplines *vis-à-vis* manufacturing. It was anticipated that if students can make a better choice of their major, then this will improve the retention rates of students as well as minimize student transfers among disciplines, and consequently help in improving engineering education. As part of this freshman course, the author proposed to design a tool to illustrate manufacturing systems and relevant concepts from IE/ manufacturing and mechanical engineering disciplines.

Lesson specification and media selection. A sample lesson specification based on the example introduced in section 4 is shown in Fig. 4. In terms of programming media/software, it is desirable to have it run on as many different computers as possible. This was achieved after considerable experimentation. The simulation/animation tools can be used in PC DOS or OS2 and Sun/Unix environments.

Evaluation and implementation. The development of examples featured in the simulation/ animation tools can be done by individual faculties. Additionally, commercial education software can be used to complement this effort. The examples can be pilot tested within the institute or by distributing them to other universities or community colleges. Questionnaires can be filled out to elicit reactions such as unexpected responses, unclear explanations and so on. The software can then be fine-tuned based on these critiques.

The tools comprise a collection of programs written in several different common languages. While general-purpose simulation languages are good for complex systems, the manufacturing-specific simulation programs can be used for examples that require special features. For example, graphical illustration of the statistical results of a simulation model can easily be done with PROMOD since it was built specifically for manufacturing simulation. The collection of programs in several languages that make up the simulation/ animation tools further opens up opportunities to familiarize students with a variety of languages. The simulation/animation tools will have a common front-end to invoke the various examples that are written using different languages. Video clips relevant to the featured examples must also be incorporated in the software.

It is also essential to adapt the common high-level simulation software, such as ARENA, SIMAN/ CINEMA, SLAM/TESS, GPSS/PAINT, Simscript/SIMFACTORY, PROMOD, WITNESS, AUTOMOD or others in order to reduce significantly the 'language barrier' and increase the chance of widespread use. The development of interactive simulation/animation tools will also introduce the students to computer simulation technology and its capabilities. Using several simulation software for the development of case studies will introduce different capabilities such as graphical representation of statistical results, database integration and object-oriented modeling, from which students can benefit in their future application of simulation. Software variety also helps in terms of sharing the case studies with other institutes that do not carry the same software.

In the current implementation of simulation/ animation tools, a common simulation/animation language SIMAN/CINEMA and standard programming languages C and FORTRAN (for the front-end) are used. Other simulation and programming languages that are possible candidates for inclusion are: SLAM, GPSS, SIMNET, MORIDS, PROMOD, Simscript, INSIGHT, SIGMA, C^{++} and Witness.

In summary, the development of simulation/

Course: Manufacturing Systems Lesson:FlowLine
Author:GB

The purpose of this lesson is to teach the student the concepts and functioning principles of a manufacturing flow line and understanding key performance measures. This includes utilization and idleness due to starving or blocking or maintenance or failure or others.

The lesson begins with a tutorial which explains these factors. Included in the tutorial are questions which checks the student's understanding of the concepts.

After the student has completed the tutorial, a simulation is provided for practice. The simulation consists of 5 workcenters with machines/labors and illustrating the key performance measures. The student is prompted to run the system at best conditions for specified measures.

After the completion of simulation, the cost measures are provided to be used in calculation of total cost/revenue measures.

Fig. 4. Sample lesson: starting session.

animation tools and their incorporation into manufacturing education involves making the following decisions in sequence: (i) developing appropriate instructional strategies; (ii) choosing suitable 'courseware', i.e., lessons and teaching material in accordance with the strategies; (iii) selection of hardware/software to develop the tools; and (iv) implementing and evaluating the tools for its eventual use.

6. INSTRUCTIONAL ISSUES

For instructional purposes it is important that the software be accompanied by a manual that explains the basic principles of the specific manufacturing systems featured in the software. This can be prepared by the faculty and progressively updated with changes in the software. Software can be integrated into classroom instruction in the form of a hands-on activity such as class projects or laboratory sessions. Each example can be individually exercised and its principles explained and possibly demonstrated, either using available manufacturing equipment in labs or through videos as indicated before. Students can then be encouraged to interact with the software as they would in playing 'computer games' to explore various scenarios. Students will also be required to make decisions that affect the performance of the system. The lessons can be effectively grouped into short modules with clear documentation distinguishing explanatory material from actions that the students can take. Various outcomes of the actions must also be explained to serve as guidelines for students.

Successful hands-on activities will require a classroom equipped with suitable computers. In addition, a video projector and large computer screen projector are necessary so that the instructor can demonstrate the use of the software prior to the students using it. With multimedia it should be possible to use the computer display for video presentations of the material that the students can watch at their own pace. The course materials and manuals on how to use the simulation/animation tools must preferably be available on-line.

7. FUTURE EXTENSIONS

Although the thrust in this paper has been manufacturing, simulation/animation is generally applicable to a wide variety of topics. Furthermore the underlying learning model (self-paced, interactive and holistic) is equally valid in a number of courses in operations research, industrial engineering and other disciplines. In addition to the academic community, such tools/learning models can be useful in industry to retrain staff.

Another promising future extension is to add a distance learning capability. In the future it should be possible for students to access these tools from the convenience of their workplaces or homes through multimedia information networks, without expensive overheads in terms of equipment and access charges. The concept of the virtual classroom has already been supported. Bell Atlantic, for example, is teaming up with Sun MicroSystems to promote distance learning and telecommuting applications for colleges and universities over ISDN phone lines. Sprint plans to use ATM, a packed-based technology particularly suited to multimedia, to create 'virtual classrooms'. They plan to spend more than \$500 m on the project over five years. Computer-aided instructional software such as simulation/animation tools are well poised to use the latest technology to impart education on complex subjects such as manufacturing. The details of multi-media courseware will be published in future.

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APPENDIX

Study the manufacturing system shown on the screen. Improve the production rate of the system measured in parts/hour after observing the affect of key variables on the system with the following exercises in sequence:

Exercises

1. Run the flow line simulation and observe % starvation, % blocking and % utilization of each work center, the production rate in parts/hour, and the mean flow time. Identify the bottleneck work-center, i.e. the center which is utilized the most and the least starvation.
2. Double the number of machines in the work center identified in step 1. Observe changes in % starvation and blocking and utilization of each work-center, and the parts/hour and mean flow time.
3. Double the output buffer size of that work-center. Observe changes in % starvation and blocking and utilization of each work-center and the parts/hour and mean flow time.
4. Increase the reliability of that work-center by reducing its failure rate to half of its initial value. Also improve the response to the failures by reducing the mean time to repair to half of its initial value. Observe changes in % starvation and blocking and utilization of each work-center and the parts/hour and mean flow time.
5. Describe the effect of the above changes on the system performance.
6. Suggest the best system configuration as you can determine by changing the key variables and illustrate your reasoning.

Calculate the average hourly total cost and revenue functions for the above exercises. Assume that only the following are known:

Total cost:

$$C_M M + C_B B + C_P P + C_I(1/f) + (b + s)C_D + (1 - u - b - s)C_0$$

Cost parameters:

C_M = cost of using a machine ($/h)
C_B = cost of using a buffer space
C_P = cost of producing a part
C_I = inventory cost per part per hour
C_D = idle cost of machine
C_0 = repair downtime cost of machine
R = price per part

Variables:

M = number of machines
B = number of buffer spaces.
λ = failure rate
δ = MTTR

Performance measures:

η = utilization
b = blocking
s = starvation
pr = production rate (no. of parts/h)
f = average failure time (h/part)

total revenue = price × avg. no. of parts/h produced
total cost = production cost + holding cost + idle time cost

production cost = production cost/part × avg. total no. of parts/h produced
holding cost = inventory cost/part/h × avg. total inventory in buffers/h
idle time cost = idle cost/h × avg. total idle time of machines/h
idle time = starvation + blocking + maintenance + failure times

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