A VIRTUAL FACTORY TEACHING SYSTEM

IN SUPPORT OF

MANUFACTURING EDUCATION

Maged M. Dessouky[1]
Department of Industrial and Systems Engineering
University of Southern California
Los Angeles, CA 90089
Phone: 213-740-4891 Fax: 213-740-1120 email:maged@rcf.usc.edu

Diane E. Bailey
Department of Industrial and Systems Engineering
University of Southern California
Los Angeles, CA 90089
Phone: 213-740-4897 Fax: 213-740-1120 email:dbailey@rcf.usc.edu

Sushil Verma
Department of Industrial and Systems Engineering
University of Southern California
Los Angeles, CA 90089
Phone: 213-740-7541 Fax: 213-740-1120 email:verma@rcf.usc.edu

Sadashiv Adiga
Control Factory Systems
Hercules, CA 94547
Phone: 510-548-5615

George A. Bekey
Department of Computer Science
University of Southern California
Los Angeles, CA 90089
Phone: 213-740-4501 Fax: 213-740-7512 email:bekey@pollux.usc.edu

Edward J. Kazlauskas
Department of Instructional Technology
University of Southern California
Los Angeles, CA 90089
Phone: 213-740-3288 Fax: 213-740-3889 email kazlausk@rcf.usc.edu

---

[1] **corresponding author**

A VIRTUAL FACTORY TEACHING SYSTEM
IN SUPPORT OF
MANUFACTURING EDUCATION

Abstract

To accommodate increasing product specialization, modern factories are increasingly becoming more flexible. A large measure of this flexibility is achieved via the integration of the various components of the manufacturing system (e.g., design, production, purchasing, etc). To be successful in this new manufacturing environment, an engineering college graduate must understand the total business process from design to production to delivery in order to develop a holistic view of manufacturing systems**.** Yet, traditional pedagogical tools are ill-equipped to develop this holistic view in students. In this paper, we describe a Virtual Factory Teaching System, VFTS, that is under development. The intent of the VFTS is to provide a tool for university instructors to illustrate the concepts of factory management and design as applied in a realistic setting. The focus of this paper is to present our pedagogical approach of the VFTS, the development of the prototype and its use in a senior-level industrial engineering class.

I. Introduction

To be successful in today's business environment, a new engineering college graduate must be educated in all aspects of a manufacturing system. That is, the student must understand the total business process from design to production to delivery in order to develop a holistic view of the manufacturing process [1]. Chisholm [2] contends that many manufacturing engineering program curricula are overloaded with theoretical science content, with little emphasis given to deeper learning of the total manufacturing environment. For example, engineering courses on factory topics such as inventory control, production planning, and operations scheduling focus on teaching mathematical models based on simplifying assumptions, ignoring many of the factors that exist in real factories such as machine breakage and a surge in demand [3].

Traditional pedagogical tools for transferring hands-on learning to students are ill-equipped to handle the complexity that surrounds the modern factory. Manufacturing education tools have traditionally required physical laboratories. However, factory experimentation through full-scale on-campus laboratories is an infeasible alternative for engineering programs due to the high expense associated with development and maintenance. Their lack of flexibility allows them to cover only a small portion of the entire manufacturing spectrum. Additionally they can serve only a single site, inhibiting the creation of teams whose members are not co-located (i.e., "virtual" teams). Working and functioning well on virtual teams that may span continents is increasingly becoming a requirement for engineers [4,5].

In this paper, we describe an on-going National Science Foundation funded project to develop a multi-media collaborative learning network referred to as a Virtual Factory Teaching System (VFTS), whose purpose is to provide a tool for university instructors to illustrate the concepts of factory management and design as applied in a realistic setting. In order to assess the viability of a virtual factory teaching system on manufacturing education, a prototype was first developed which aids students in learning a specific topic in industrial and manufacturing engineering, *factory scheduling*. Over the years, simplification of the models used in such courses has caused them to stray from the realities of complex manufacturing systems [3]. This course thus provides an ideal environment in which to evaluate the uses of and potential gains from the VFTS. The focus of this paper is to describe the prototype VFTS and its use in the Fall 1997 Semester in a senior-level industrial engineering class at the University of Southern California.

II. Literature Review

Numerous studies already indicate the potential for computer-based learning tools to aid in the classroom instruction of students [6,7,8,9]. For this reason, various computer-based learning tools have been designed specifically for courses in engineering and the hard sciences. Examples include the work by Price [10] in CAD, Samaan and Sutano [11] in electrical engineering, Hoburg [12] in electromagnetics, and Smith [13] in nuclear engineering.

While many computer-based tools are designed for use on individual computers, applications designed for networks of students are also on the rise. Harasim et al. [14] document a wide array of learning networks aimed at primary, secondary, and tertiary students. Traditional face-to-face classroom learning is generally assumed to be superior to learning carried out over networks, but Harasim et al. argue that no evidence exists to support this view; in fact, on-line environments were found to lead to learning outcomes equal or superior to those gained in traditional settings [15,16,17]. Bailey and Cotlar [18] outline the benefits of using the Internet in education to stimulate deeper learning from extended interaction. Several universities have already developed network educational tools for instruction (see for example references [1, 19, 20, 21]).

Learning networks do have some disadvantages. Preparation time for teachers is generally longer than for lecture-based courses, and some material is simply ill-suited for network learning [14]. Darby [22] notes that the adoption of computer learning technologies is hampered more by organizational constraints, such as the failure of universities to utilize existing materials, than it is by technical issues. For instance, Sweeny and Oram [23] found that while use of information technologies aided distance learning among students in an MBA program; their instructors failed to make use of those same technologies for communicating with students outside the classroom. Tomlinson and Henderson [24] highlight issues concerning the value, viability, and development of distributed computer-supported collaborative learning software. Blair, Coulson, and Davies

[25] outline some technological requirements for a distributed multimedia application.

A few efforts have been made to re-vamp entire educational programs via the integration of learning networks and computer tools, with traditional course material. For example, Sheater, Martin, and Harris [26] describe a new degree program leading to a Bachelor of Manufacturing Management at the University of Technology, Sydney.

One final note concerns the capabilities of learning networks in promoting collaborative learning. Learning to work as part of a team is an important skill for new engineers and managers [27,28]. Rada et al. [29] found that students working in collaborative groups have been better able to formulate concrete ideas and avoid misconceptions. Group work may further serve to interest female students in engineering careers, as suggested by Heller and Martin [30].

III. Prototype Development of VFTS

The prototype VFTS focuses in aiding students learning one specific topic in industrial and manufacturing engineering, *factory scheduling*. This topic is covered in a senior-level course taught in the Department of Industrial and Systems Engineering at the University of Southern California, Production Planning and Control (ISE 410). This course is a traditional Industrial Engineering course found in many engineering programs; it covers factory topics such as inventory control, production planning, and machine scheduling. Over the years, simplification of the models used in such courses has caused them to stray from the realities of complex manufacturing systems [3]. This course thus provides an ideal environment in which to evaluate the uses of and potential gains from the VFTS.

Factory scheduling is the particular aspect of ISE 410 that the prototype aids the student in learning. Factory scheduling decisions include release and dispatching rules. *Release* rules determine when to release a new lot of raw material into the production line. Release rules are either push-based such as a Materials Requirement Planning (MRP) system or pull-based such as a Kanban system. The push systems tend to generate factory output that closer matches the customer demand pattern while the pull systems tend to minimize factory work-in-process (WIP) inventory. Hence, there is a trade-off between the release rules that factory schedulers must consider with no single rule dominating in all manufacturing situations. *Dispatching* rules select which product(s) to manufacture next at a machine when it becomes idle. Sample dispatching rules include first-in-first-out, shortest processing time, earliest due date, and least slack. The performance of each dispatching rules depends on the performance criteria. For example, the shortest processing time rule tends to minimize WIP while the least slack rule tends to minimize the lateness of the production jobs.

These scheduling rules are interrelated and in most cases no single rule dominates. It depends on many factors including the factory layout, processing times, demand pattern, and machine reliability. VFTS demonstrates these rules on one particular type of a factory, a *hybrid flowshop*. In a traditional flowshop, all part types visit the manufacturing workcenters in the same sequence. In a hybrid flowshop, each manufacturing workcenter may have multiple identical machines. This type of configuration is selected because it is common in many industries such as electronics, garment, chemical, etc., and an instructor can naturally show factory behavior as a function of the dispatching and release using a hybrid flowshop. We provide examples of its usage in the next section.

The prototype resides at http://vfts.usc.edu/ and requires Microsoft Internet Explorer® Version 3.0 or higher. The architecture of the prototype is outlined in Figure 1. The design was kept simple and modular. There are three layers in the design: AweSim [31] Server, VFTS Java Server and Clients. Clients, which are students in our case, use a standard WWW browser like, Microsoft Internet Explorer, to connect to the VFTS Java Server using its Web Page. Most of the communication between the clients and the server takes place using Java applets. The Java Server functions as a mediator between the AweSim factory servers and the clients. The Awesim Server is solely responsible for factory knowledge and simulation. The layers interface using a message protocol set up to minimize bandwidth requirements.

We next describe some of the windows of the prototype. Figure 2 shows the first two windows of the prototype. Students can either create their own factory or join an existing factory. The students’ interaction with the VFTS depends on whether they are building a factory model or running a factory model. The former interaction is typically during the design time, while the latter interaction is during the run time. During the students' design time, the users create a factory model to be used for simulation purposes. Figure 3 shows the VFTS windows which create the factory. As shown in the first window, the student inputs the number of workcenters and whether the factory will be either deterministic or stochastic. In the stochastic case, the input parameters are treated as random variables. The remaining windows allow the student to input information on processing times, due dates, etc. For each workcenter, students can select a dispatching rule from a predefined list. The student also specifies the release rule, either push-based or zero inventory (a strict pull system).

During the run time, students execute simulations, change decision parameters, and interact with other team members in conversations mediated by the system over a network using the built-in chat room. At run time, a complete factory model is fed into the simulation engine along with the simulation parameters. Figure 4 shows a sample simulation window and the control panel. The students can dynamically see plots of the factory status. For example, Figure 5 shows the windows used in the creation and resulting plot of the number of jobs completed as a function of the simulation clock. At the end of a simulation run, outcome reports are broadcast to the team members.

IV. Assessment of the Prototype

In an effort to ascertain the pedagogical benefits of the VFTS, we tested its use in a senior-level Production Planning and Control class, ISE 410, in the fall of 1997. Class performance was compared to that of the fall 1996 class, in which the VFTS was not implemented. The two classes covered the same material in the same order, were given very similar quizzes, homework, and midterm, took the same final, and were taught by the same professor at the same time of day using the same textbook. In other words, everything possible was done to maintain consistency across the two classes, with the exception of the introduction of the VFTS. Students in both classes filled out a survey on the last day of class which captured demographic data, study pattern information, self-assessment of learning outcomes, and interest in the subject matter (see Table 1).

Because the VFTS prototype currently includes only a factory scheduling module, it was not incorporated into the entire curriculum. Rather, it was introduced in the last month of the course coincident with the covering of factory scheduling topics in the lecture. Two homeworks were assigned which were similar in nature to the previous year's homework, except that in the 1997 class, students were to complement their hand calculations by setting up factories on the VFTS, running simulations, and generating reports to verify their calculations. Another difference was that the students were grouped in pairs for the VFTS tasks, with each student given different system accessing capabilities such that participation of both students was required in order for the work to be completed.

It was expected that the VFTS would improve the students' learning outcomes by aiding them in visualizing complex factory dynamics. For example, with the VFTS, students were able to build and analyze larger factories then they reasonably could do by hand. It was thought that such large simulations would help students to better understand how Kanban policies change work-in-process (WIP) inventory patterns. This concept is difficult to convey in classroom chalk lectures, which is largely how it was presented to the 1996 class. Both classes also performed in-class physical simulations using pennies to represent jobs advancing through workstations, but these simulations involved only four workstations with one machine each. Thus, the VFTS added several features to the learning process: scale, simulation with animation, factory creation, and teamwork.

Results of the comparison are presented in Table 2. There were three significant demographic differences between the two classes that could not be controlled: the 1997 class was half the size of the 1996 class, the 1996 class was nearly two years younger on average, and the 1997 class was less strong academically, with an incoming average GPA over .3 lower on a 4-point scale than the 1996 class. These factors would perhaps work against each other, as a smaller class size and older population presumably would benefit the 1997 class, but their lower GPA seemingly would predict lower performance. Other demographic factors were consistent across the two classes: most members were male, spoke English as a second language, had little manufacturing work experience, and were first semester seniors. There was also a difference in academic preparation between the two classes. More students in the 1996 class had taken or expected to take the linear programming course than in the 1997 class, while more students in the 1997 class had taken or expected to take the quality control class.

In terms of study patterns, the 1997 class read the textbook more frequently on average than did the 1996 class. There is also a significant difference in the time spent studying for the midterm, with the 1997 class spending on average nearly twice as much time as the 1996 class. Other study factors were similar between the two classes. Members in both classes paid few visits to the professor or TA, and spent between seven and eight hours on homework each week.

About 70% of the students in each class regularly worked in groups to do their homework.

In rating their own abilities or learning outcomes, the 1996 students felt more confident than the 1997 cohort in the area of demand forecasting, while the 1997 class felt more confident in the area of factory scheduling. The latter is perhaps a positive indicator of the benefit of the VFTS. In all other areas, there are no significant differences in self-ratings.

There are a number of interesting differences in terms of the grades of the students. We hesitate to term the grades objective measures of performance, as all quizzes and exams were graded by the professor, who is an author on this paper. However, every attempt was made to maintain grading consistency. For example, when the 1996 finals were graded, a sheet was maintained of how to deduct points on each problem. The 1996 exams were reviewed problem-by-problem as the 1997 exams were graded, to ensure further that similar errors received the same point deduction. There are two significant differences among the quiz scores, one on machine scheduling, where the 1997 class outperformed the 1996 class, and one on Gantt charts (also used in scheduling), where the outcomes were reversed. Thus, while the former bodes well for the VFTS, the latter's results are perplexing. However, the VFTS does not include Gantt charts in its report generation window, and therefore no doubt adds very little to the student's understanding of them. The more striking difference comes in the comparison of the midterm and final grades. The midterm included no material on factory scheduling, which had yet to be covered. Here, the 1996 class on average outperformed the 1997 class by over 17%. On the final, which included factory scheduling, the gap was lowered to only 4%, and was not significant. The drastic improvement of the 1997 class in the second half of the course bodes well for the benefits of the VFTS. The final course grade was also significant, with the 1996 class scoring better; this result derives from the high weight collectively assigned to homeworks, quizzes, and the midterm in comparison to that of the final (35%).

V. Conclusions and Future Work

While overall our preliminary study appears to show a positive indication of the pedagogical benefits of the VFTS, further extensive testing is required to preclude a conclusive affirmation. In addition to further testing of the VFTS, we plan on expanding the functionality of the VFTS. For example, the domain of our factory model is expected to evolve over the next year. The developed prototype limits the model to that of a hybrid flow shop. Moreover, the modeling done is at an operational level only; the higher-level business processes like forecasting and inventory management are not integrated into the production problem. We plan to steadily expand the domain to general factory layouts, as well as to a variety of business processes, such that an entire enterprise in its essential elements can be modeled.

Acknowledgement

The research reported in this paper was partially supported by the National Science Foundation under grant CDA - 9616373. We thank Ajay Singh, Mohammad Reza Kolahdouzan, Parthiv Patel, H. O. Reed, and Zachary Baker for their help in developing the prototype VFTS. We also would like to thank the members of the advisory board consisting of Mr. Jack Ferrell, Dr. Patricia Heffernan-Cabrera, Dr. Elizabeth Morris, and Dr. A. Alan Pritsker for providing input in the content of the VFTS.

References

1. Sackett, P. and D. McCluney, "Inter enterprise CIM - A Mechannism for Graduate-education," *Robotics and Computer-Integrated Manufacturing*, vol. 9, no. 1, 1992, pp. 9-13.

2. Chisholm, A. W. J., "Manufacturing Science as the Core of Engineering Education," *Robotics & Computer-Integrated Manufacturing*, vol. 9, no. 4-5, 1992, pp. 357-366.

3. Hopp, W. J. and M. L. Spearman, *Factory Physics: Foundations of Manufactuirng Management*, Irwin Publishing, New York, 1996.

4. Adler, N.J, *International Dimensions of Organizational Behavior*, (2nd ed.), PSW-Kent, Boston, MA, 1991.

5. Chidambaram, L. and B. Jones, "Impact of Communication Medium and Computer Support on Group: Perceptions and Performance - A Comparison of Face-to-Face and Dispersed Meetings," *MIS Quarterly*, vol. 17, no. 4, 1993, pp. 465-491.

6. Bostow, D.E., K. M. Kritch, and B. F. Tomplins, "Computers and Pedagogy: Replacing Telling with Interactive Computer-programmed Instruction," *Behavior Research Methods Instruments and Computers*, vol. 27, no. 2, 1995, pp. 297-300.

7. Duplessis, J.P., J. A. Vanbiljon, C. J. Tolmie, and T. Wollinger, "A Model for Intelligent Computer -aided Education Systems," *Computers & Education*, vol. 24, no. 2, 1995, pp. 89-106.

8. Woolf, B.P. and W. Hall, "Multimedia Pedagogues - Interactive Systems for Teaching and Learning," *Computer*, vol. 28, no. 5, 1995, pp. 74-80.

9. Steeples, C., P. Goodyear, and H. Mellar, "Flexible Learning in Higher Education - The Use of Computer-mediated Communications," *Computers & Education*, vol. 22, no. 1-2, 1994, pp. 83-90.

10. Price, T.E., "Computer-assisted Learning in an Electronics Course," *International Journal of Electrical Engineering Education*, vol. 29, no. 3, 1992, pp. 212-223.

11. Samaan, N. and D. Sutano, "An Interactive Computer-aided Package for Electrical Engineering Education," *International Journal of Electrical Engineering Education*, vol. 31, no. 3, 1994, pp. 264-283.

12. Hoburg, J.F. "Can Computers Really Help Students Understand Electromagnetics," *IEEE Transactions on Education*, vol. 36, no. 1, 1993, pp. 119-122.

13. Smith, P.R., "Computer-mediated Learning in Engineering-Education," *Computers & Education*, vol. 19, no. 1-2, 1992, pp. 37-47.

14. Harasim, L., S. R. Hiltz, L. Teles, and M. Turoff, *Learning Networks: A Field Guide to Teaching and Learning Online,* MIT Press, Cambridge, Massachusetts, 1995.

15. Hiltz, S.R., "A Virtual Classroom on E.I.E.S. Vol. 1: Learning in a Virtual Classroom," Research Report 25," Center for Computerized Conferencing and Communication, NJIT, Newark, NJ, 1988.

16. Hiltz, S.R., *The Virtual Classroom: Learning Without Limits via Computer Networks,* Human-Computer Interaction Series, Ablex Publishing Corp, Norwood, NJ, 1994.

17. Wells, R.A., "Distributed Training for the Reserved Component: Remote Delivery Using Asynchronous Computer Conferencing," Report 2Q263743A794, Idaho National Engineering Laboratory, Idaho, Falls, ID, 1990.

18. Bailey, E.K. and M. Cotlar, "Teaching Via the Internet," *Communication Education*, vol. 43, no. 2, 1994, pp. 184-193.

19. McConnell, D., "Managing Open Learning in Computer-supported Collaborative Learning Environments," *Studies in Higher Education,* vol. 19, no. 3, 1994, pp. 341-358.

20. Fay, D.Q.M. "Internet and the Electronic Classroom," *Microprocessing and Microprogramming,* vol. 40, no. 10-12, 1994, pp. 847-850.

21. Dwyer, D., K. Barbieri, and H. M. Doerr, "Creating a Virtual Classroom for Interactive Education on the Web," *Computer Networks and ISDN Systems*, vol. 27, no. 6, 1995, pp. 897-904.

22. Darby, J. "The Future of Computers in Teaching and Learning," *Computers & Education*, vol. 19, no. 1-2, 1992, 193-197.

23. Sweeny, M.T. and I. Oram, "Information Technology for Management Education - The Benefits and Barriers," *International Journal of Information Management,* vol. 12, no. 4, 1992, pp. 294-309.

24. Tomlinson, H. and W. Henderson, "Computer-supported Collaborative Learning in Schools - a Distributed Approach," *British Journal of Educational Technology,* vol. 26, no. 2, 1995, pp. 131-140.

25. Blair, G. S., G. Coulson, and N. Davies, "System Support for Multimedia Applications: an Assessment of the State of the Art," *Information and Software Technology,* vol. 36, no. 4, 1994, pp. 203-212.

26. Sheater, G., R. Martin, and D. Harris, "Partners in Excellence - a New Model for Cooperative Education," *Educational & Training Technology International*, vol. 30, no. 1, 1993, pp. 5-31.

27. Reich, R. B. "Entrepreneurship Reconsidered: The Team as Hero," *Harvard Business Review*,

vol. 65, no. 3, 1987, pp. 77-83.

28. Committee on Analysis of Research Directions and Needs in U.S. Manufacturing and Manufacturing Studies Board, "The competitive edge: Research priorities for U.S. manufacturing," Commission on Engineering and Technical Systems, National Research Council, National Academy Press, Washington, D.C., 1991.

29. Rada, R., S. Acquah, B., Baker, and P. Ramsey, "Collaborative Learning and the MUCH System," *Computers & Education*, vol. 20, no. 3, 1993, pp. 225-233.

30. Heller, R.S. and C. D. Martin, "Attracting Young Minority Women to Engineering and Science - Necessary Characteristics for Exemplary Programs," *IEEE Transactions on Education*, vol. 37, no. 1, 1994, pp. 8-12.

31. Pritkser, A. A. B, J. J. O'Reilly, and D. Laval, *Simulation with Visual Slam and AWESim*, John Wiley & Sons, New York, New York, 1997.

SELF-ASSESSMENT

Please indicate how well each statement matches *your* assessment of your skills, knowledge, and abilities in each area we have studied:

	Not at All	Some-what	Pretty Well	Very Much So
MACHINE SCHEDULING				
I understand the various objectives related to scheduling jobs on machines (e.g. minimize average cycle time).	☐	☐	☐	☐
I know which rule to apply (e.g. SPT, EDD) to achieve various objectives.	☐	☐	☐	☐
I can build Gantt charts and interpret them.	☐	☐	☐	☐
I understand the difference between serial and parallel arrangement of machines.	☐	☐	☐	☐
I feel confident that I could solve machine scheduling problems on the job.	☐	☐	☐	☐
DISPATCHING SYSTEMS				
I know how to draw and interpret Gozinto charts.	☐	☐	☐	☐
I can construct, interpret, and use bill of materials (B) and total requirements (R) matrices.	☐	☐	☐	☐
I can apply the MRP procedure to problems with demand over time.	☐	☐	☐	☐
I understand conceptually how push-based systems like MRP differ from pull-based ones like JIT/Kanban.	☐	☐	☐	☐
I can draw and interpret Gantt charts using Kanban release policies.	☐	☐	☐	☐
I feel confident that I could operate an MRP system in a factory.	☐	☐	☐	☐
I feel confident that I could operate a JIT system in a factory.	☐	☐	☐	☐

Table 1. Sample Questions from the Student Survey

		Mean		Significance	
		1996	1997	Level	
Demographics	Sample size (number of students)	25	13		
	Age	22.16	23.92	0.06	*
	Gender (1=male, 0=female)	0.80	0.77	0.84	
	Number of semesters including the current one	7.08	7.15	0.58	
	Manufacturing experience (1=yes, 0=no)	0.28	0.23	0.75	
	Language (1=English is second, 0=English is first)	0.72	0.69	0.87	
	Grade point average prior to taking the course	2.92	2.58	0.01	*
Previous Coursework	Manufacturing class	2.58	2.69	0.81	
(4 point scale [1])	Linear programming, operations research class	1.08	1.46	0.01	*
	Queueing theory, operations research class	2.04	1.92	0.74	
	Facility design and layout class	2.24	2.08	0.64	
	Quality control class	2.44	1.62	0.01	*
	Simulation class	1.40	1.84	0.14	
Study Patterns	Time spent reading the textbook (5 point scale [2])	1.96	2.62	0.06	*
	Time spent in professor's office hours (5 point scale [3])	1.92	1.85	0.81	
	Time spent in TA's office hours (5 point scale [3])	1.80	1.69	0.74	
	Study in a group (1=yes, 0=no)	0.72	0.69	0.90	
	Size of the study group	2.46	1.62	0.23	
	Hours spent working in a group on homework	1.94	2.54	0.51	
	Hours spent on homework (total)	7.14	8.42	0.14	
	Hours spent studying for the midterm	8.14	15.77	0.02	*
Self-assessment	Dispatching (29 pts max)	20.88	23.00	0.14	
	Forecasting (16 pts max)	12.88	11.23	0.06	*
	Fundamentals (20 pts max)	13.36	13.31	0.96	
	Production planning (16 pts max)	11.44	12.23	0.44	
	Scheduling (20 pts max)	16.36	17.84	0.10	*
	Integration (20 pts max)	15.20	15.84	0.58	
	Inventory (32 pts max)	24.80	24.38	0.80	
Grades	Quizzes (25 pts max)				
	Forecasting	15.32	15.58	0.90	
	Production planning	13.28	16.50	0.16	
	Inventory - EOQ models	13.88	12.69	0.54	
	Inventory - EMQ models	14.72	11.23	0.11	
	Machine scheduling	16.04	19.92	0.03	*
	Gantt charts	22.64	19.31	0.05	*
	Material requirements planning	16.24	17.33	0.60	
	Average quiz score	0.70	0.66	0.39	
	Midterm exam grade (75 pts max)	55.76	42.69	0.00	*
	Final exam grade (120 pts max)	79.68	74.69	0.37	
	Course grade (percentage)	0.75	0.65	0.02	*
Impact	Level of interest in the course prior to taking it	2.48	2.15	0.29	
	Level of interest in the course after taking it	3.42	3.69	0.22	

* items with an asterik are significant at the .10 level or below

[1] 1= already taken, 2= currently taking, 3= will take, 4= will not take

[2] 1= never, 2= once or twice, 3= for half the HW or less, 4= for over half the HW, 5=for all the HW

[3] 1=never, 2= once or twice, 3= 3-7 times, 4= 8-12 times, 5= 13 times or more

Table 2. T-test Results Comparing the 1996 and 1997 ISE 410 Classes

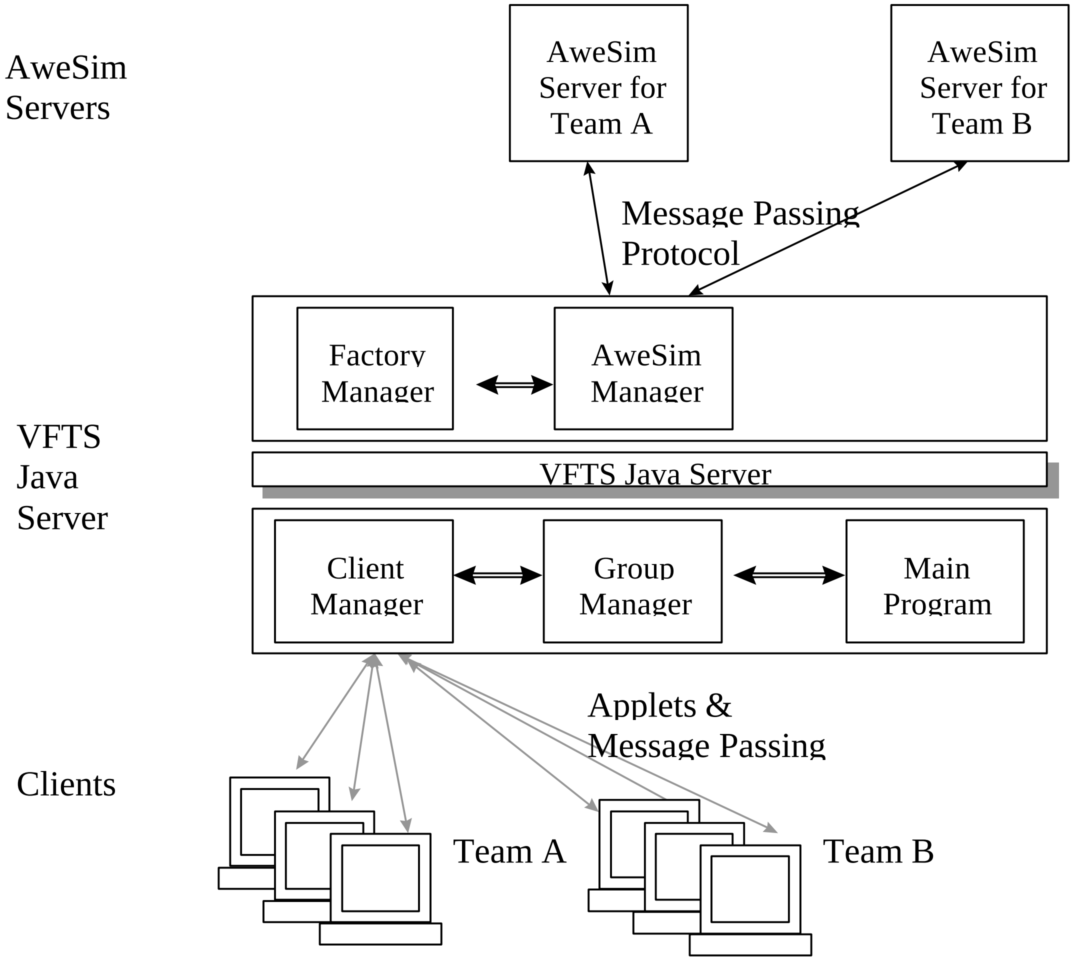
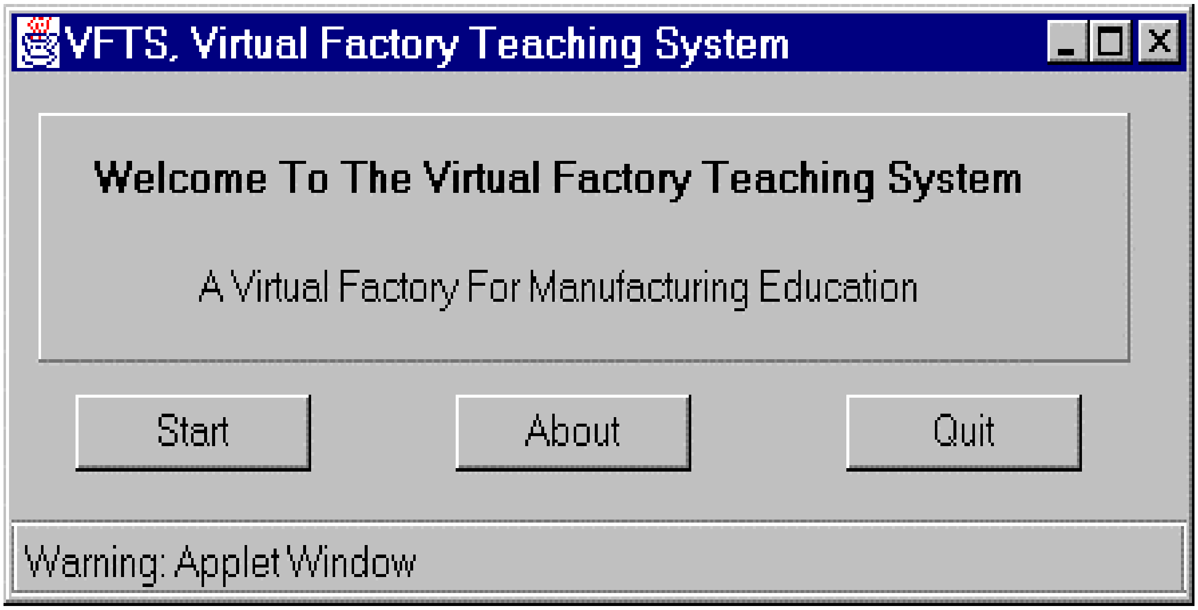


Figure 1. Architecture of Prototype

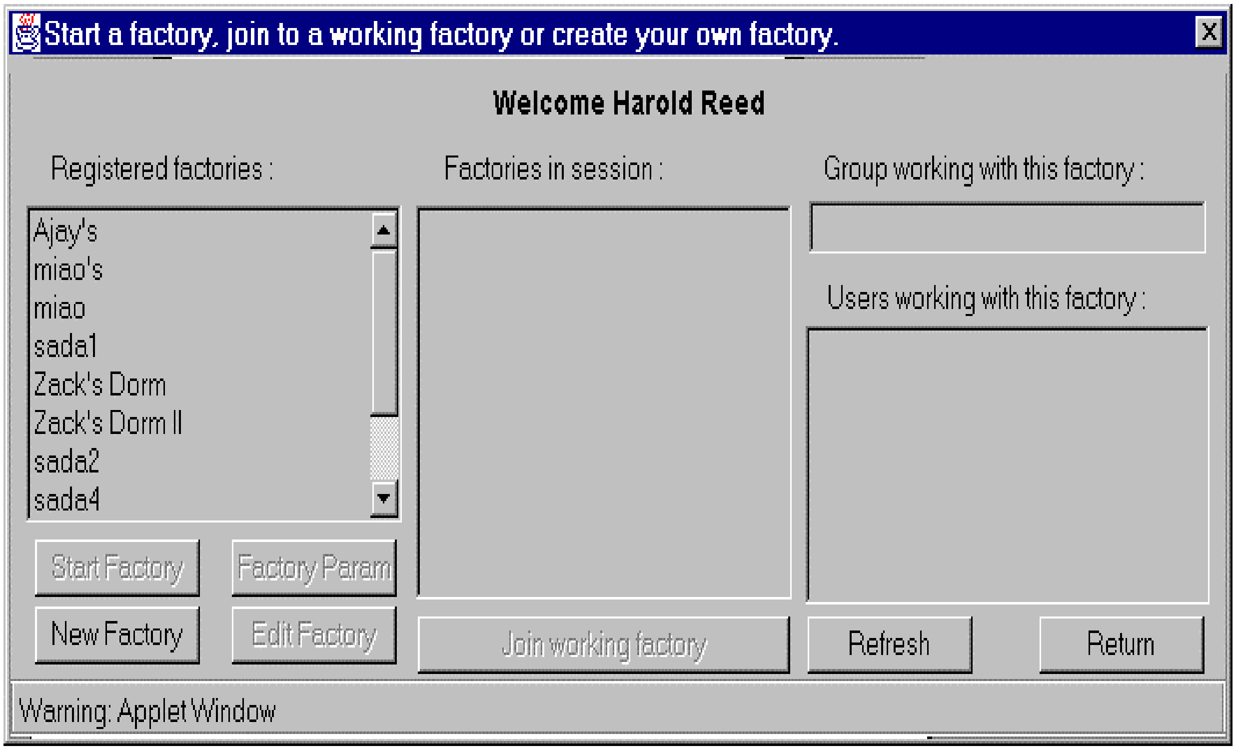


VFTS, Virtual Factory Teaching System

Welcome To The Virtual Factory Teaching System

A Virtual Factory For Manufacturing Education

Warning: Applet Window



Start a factory, join to a working factory or create your own factory.

Welcome Harold Reed

Registered factories :

Ajay's
miao's
miao
sada1
Zack's Dorm
Zack's Dorm II
sada2
sada4

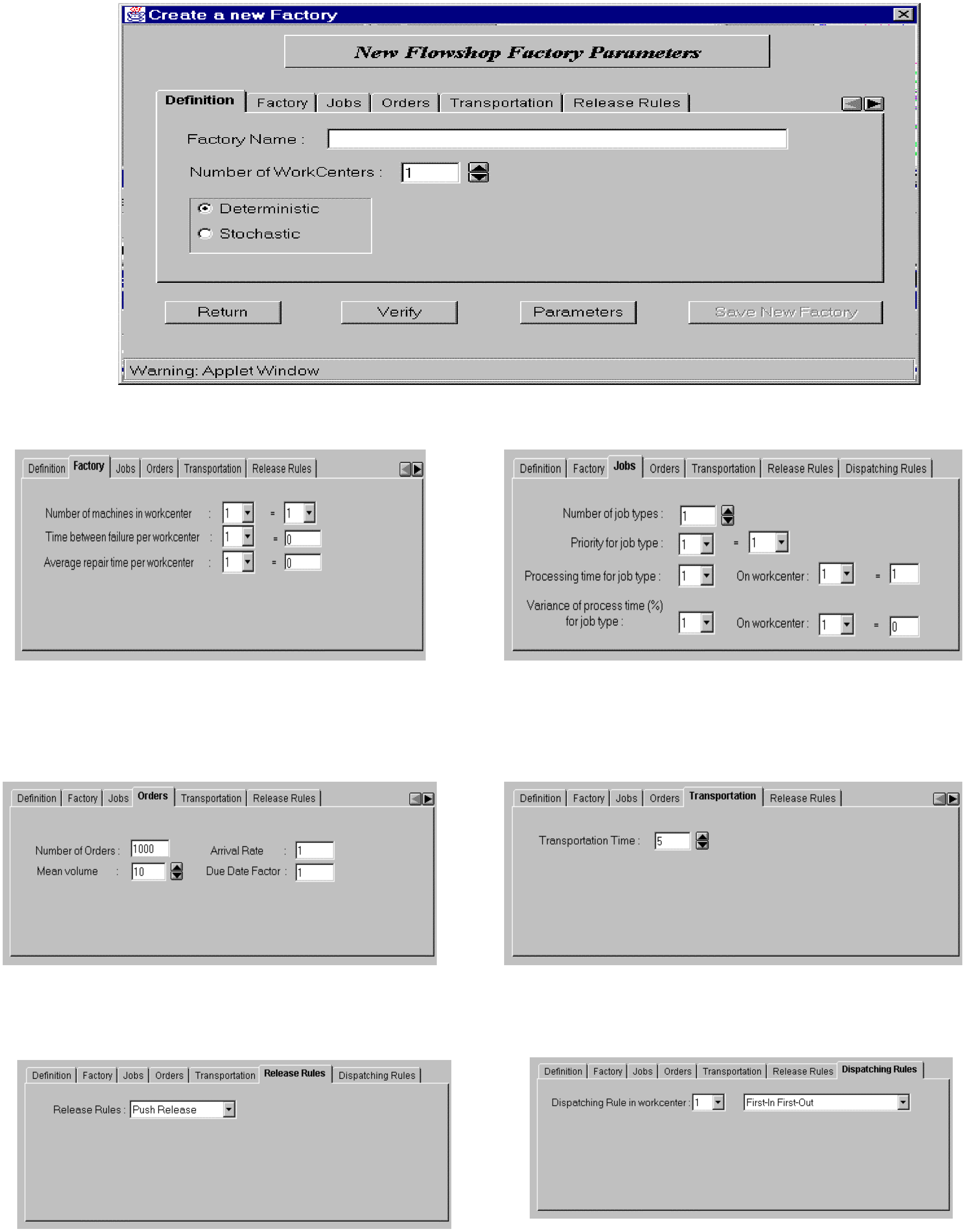
Factories in session :

Group working with this factory :

Users working with this factory :

Warning: Applet Window

Figure 2. Main Windows of the Prototype VFTS



New Flowshop Factory Parameters

Factory Name :
Number of WorkCenters : 1
● Deterministic
○ Stochastic

Number of machines in workcenter : 1 = 1
Time between failure per workcenter : 1 = 0
Average repair time per workcenter : 1 = 0

Number of job types : 1
Priority for job type : 1 = 1
Processing time for job type : 1 On workcenter : 1 = 1
Variance of process time (%) for job type : 1 On workcenter : 1 = 0

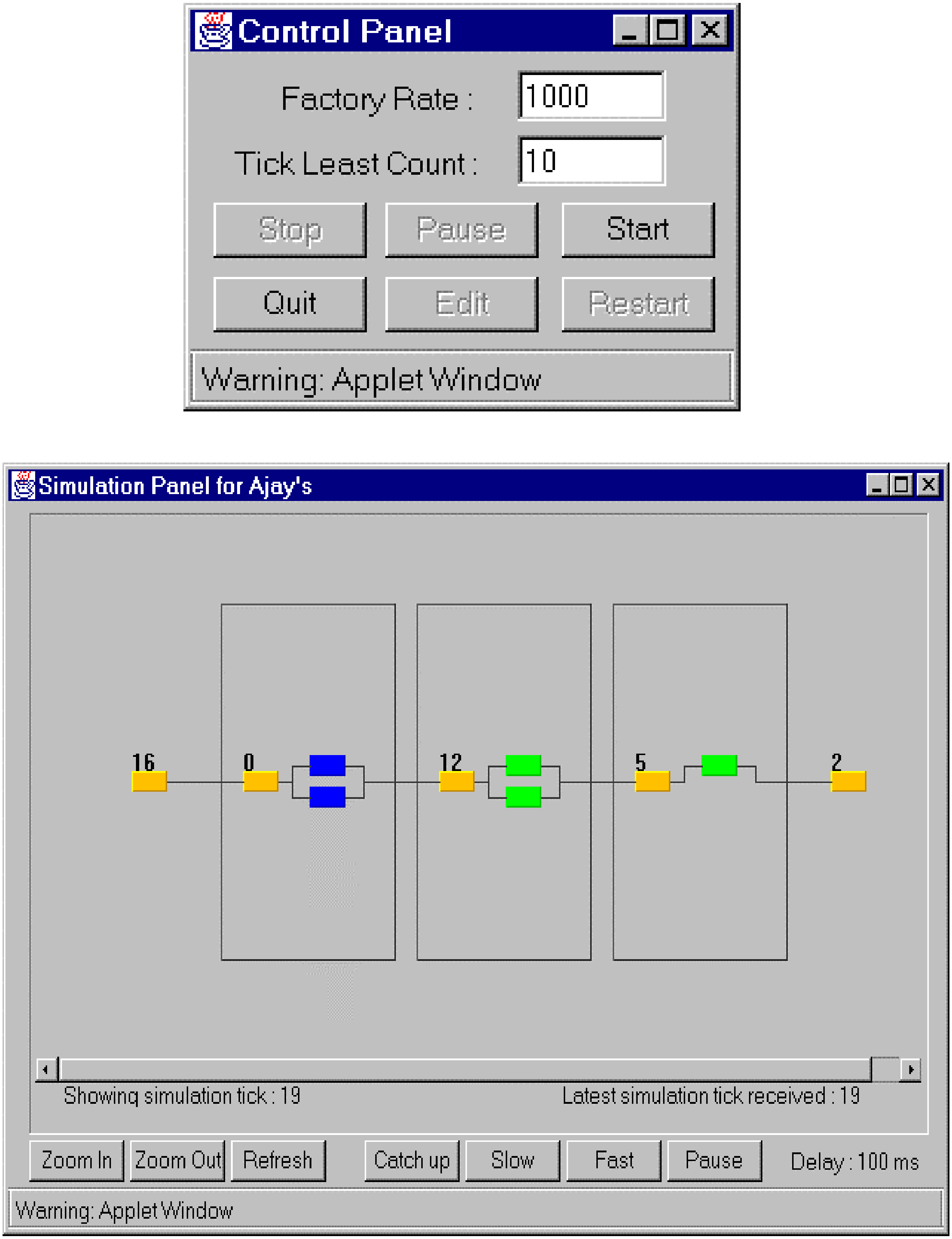
Number of Orders : 1000
Arrival Rate : 1
Mean volume : 10
Due Date Factor : 1

Transportation Time : 5

Release Rules : Push Release

Dispatching Rule in workcenter : 1 First-In First-Out

Figure 3. Prototype VFTS Factory Creation Windows



Factory Rate : 1000

Tick Least Count : 10

Warning: Applet Window

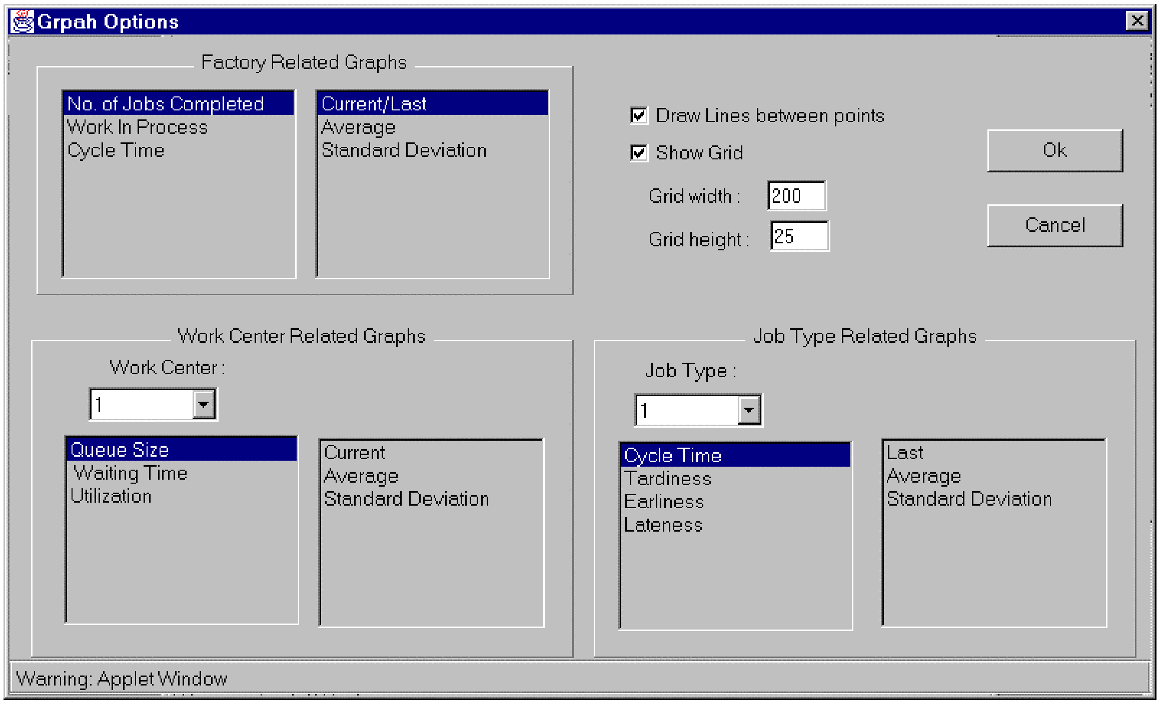
Showing simulation tick : 19

Latest simulation tick received : 19

Delay : 100 ms

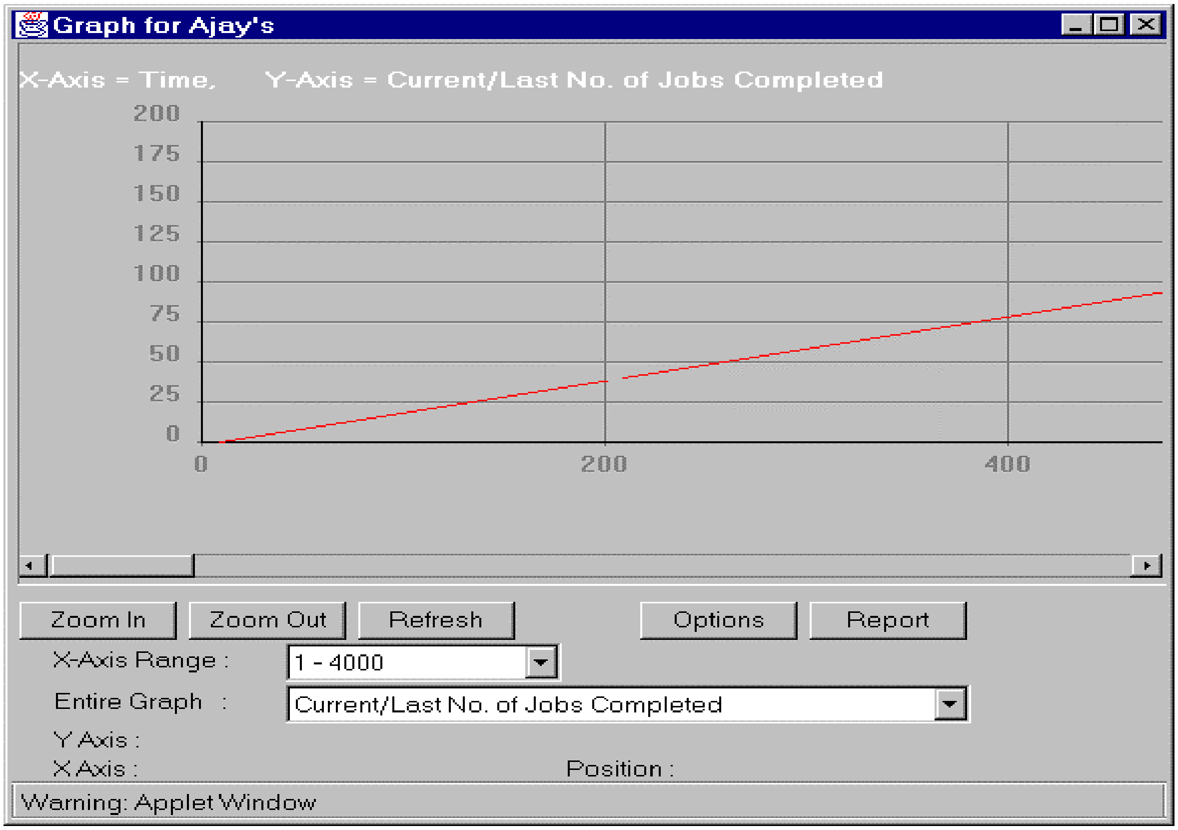
Warning: Applet Window

Figure 4. Sample Simulation Windows



☑ Draw Lines between points
☑ Show Grid
Grid width : 200
Grid height : 25
Work Center : 1
Job Type : 1

Warning: Applet Window



X-Axis Range : 1 - 4000
Entire Graph : Current/Last No. of Jobs Completed

Warning: Applet Window

Figure 5. Sample Dynamic Graph Windows

BIOGRAPHICAL SKETCHES

Sadashiv Adiga is a Software Consultant at a Silicon Valley based start-up company. Prior to becoming a Software Consultant, Dr. Adiga was on the faculty at the University of California, Berkeley. Dr. Adiga received his Ph.D. in Industrial Engineering at Arizona State University. His research interests include simulation, object-oriented programming, and software design.

Diane E. Bailey is an Assistant Professor in the Industrial and Systems Engineering department at the University of Southern California. She was awarded the Ph.D. degree in Industrial Engineering and Operations Research in 1994 from the University of California, Berkeley, where she also earned her B.S. and M.S. degrees. Her dissertation won the 1995 Doctoral Dissertation Award from the Institute of Industrial Engineers. Dr. Bailey's research interests are in the area of work organization, with a particular focus on semiconductor manufacturers. Her work has been published in engineering and business journals.

George A. Bekey is Professor of Computer Science and Director of the Robotics Research Laboratory at USC. His research concerns theory and applications of autonomous robotic systems. He has published some 200 papers in the areas of robotics, biomedical engineering, computer simulation, control systems, and human-machine systems. Dr. Bekey is a Fellow of the IEEE and a Member of the National Academy of Engineering. During 1996-97 he served as President of the IEEE Robotics and Automation Society.

Maged M. Dessouky is an Assistant Professor of Industrial and Systems Engineering at the University of Southern California. He received his Ph.D. in Industrial Engineering from University of California, Berkeley, M.S.I.E. and B.S.I.E. from Purdue University. Prior to joining the faculty at USC, Dr. Dessouky was employed at Hewlett-Packard (Systems Analyst), Bellcore (Member of Technical Staff), and Pritsker Corporation (Senior Systems Analyst). His research interests include production and operations management, modeling of manufacturing processes and systems, simulation, and operations research applications to industrial systems.

Edward John Kazlauskas is Professor, School of Education, University of Southern California, where his areas of teaching and research are instructional and human performance technology, and information systems. He is the author of over 70 publications and is currently consultant to the United Nations and the U.S. Department fo Agriculture. He is Co-Principal Investigator for a National Endownment for the Humanities (NEH) funded project entiled, Learning with ISLA: Information System for Los Angeles.

Sushil Verma received a B.Tech. degree in mechanical engineering from Indian Institute of Technology at New Delhi (INDIA) in 1987. He finished his Ph.D. in operations research from University of California at Berkeley in 1994. Soon after graduation, he joined the faculty of University of Southern California as a visiting assistant professor. There he was involved in an active research program as well as undergraduate teaching. He has published in refereed journals like *Mathematical Programming* and *Mathematics of Operations Research*. He is currently working as a Senior Operations Researcher at Advanced Micro Devices in Sunnyvale.