2006-2116: MANUFACTURING SIMULATION FOR INDUSTRIAL PROJECTS

Paul Nutter, Ohio Northern University

Paul Nutter, CMfgE, is an Associate Professor in the Department of Technological Studies at Ohio Northern University. He has been teaching industrial technology for six years, and has 26 years experience in manufacturing and industrial engineering. Paul is active in the Society of Manufacturing Engineers, serving as chair of the Student Relations Subcommittee for 2005, and on the Member Council for 2006.
Abstract

Manufacturing simulation is a major component of the technology program at our university, and has provided opportunities for numerous industrial projects. This software application is being used extensively by many major corporations to model, analyze, and optimize complex manufacturing operations, including Boeing, Lockheed-Martin, Daimler-Chrysler and Toyota. Companies are utilizing these advanced 3D digital manufacturing tools as a component of their product life-cycle management to optimize and continuously improve the manufacturing processes. In many cases simulations are mandatory prior to implementation of any significant new operation, project or process. Manufacturing technologists and engineers need to be familiar with these modern tools and their applications, and to understand when and how to effectively utilize them. At our university these applications are being taught under the title of virtual simulation (VS). This paper explains how VS has been integrated into our curriculum, and has been used to establish effective partnerships with major manufacturing companies.

Introduction

We are in our eighth year of a curriculum utilizing advanced industrial computer simulation software. The virtual simulation classes are offered in a sequence of three quarters, earning four credits per quarter. Students learn specific simulation applications from tutorials and online course materials. Teams of students then work with local companies to create simulation models of actual manufacturing operations. Each student team prepares PowerPoint materials which are presented to representatives of the company. Recent projects included work with major automotive original equipment manufacturers (OEMs) and suppliers, along with a major defense industry company. This paper and presentation includes examples of simulations and the results of the students’ analysis of the operations.

The simulation applications used in these industrial projects include robotic workcell processing, ergonomics analysis, and discrete event materials/process flow studies. This curriculum has also provided an opportunity for integration of several technologies and manufacturing management aspects into application-based environments, including 3-D CAD modelling, robotics, and production system design. Students gain skills and experience in teamwork, project planning, problem solving, and formal multi-media presentations in industrial environments. Benefits include exposure to in-plant manufacturing operations, and the opportunity to personally deal with company professionals. Current students have obtained coop/internship positions, and graduates are finding simulation jobs in the fields of manufacturing and applications engineering.

Program Background

A grant from the Society of Manufacturing Engineers in 1997 permitted the initial offering of virtual simulation (VS) as a senior capstone project for technology majors. By the summer of 1999, simulation internships had placed 12 of 17 students after running full-scale simulation
Internship placements included NASA-Johnson Space Center, a Navistar truck plant, Deneb Robotics, DaimlerChrysler, and General Motors. By 2000 graduates with these skills received the following successful job placements: Applied Manufacturing Technologies (Systems Engineer); Argus & Associates (Simulation Engineer); Delphi Corp. (Simulation Engineer); Delmia (7 Interns); Detroit Central Tool (Robotics Simulator); General Motors (Simulation Engineer); and HRU Corp. (Project/Simulation Engineer). Based on these successes, and demand by students, virtual simulation is now a principle component of the Advanced Manufacturing option in the Department of Technological Studies, and is offered as three distinct courses.

Simulation Curriculum Overview

Virtual simulation courses are taught in the Department of Technological Studies as a significant component of the Advanced Manufacturing concentration, and also as a Virtual Simulation minor for students in other majors. These courses are for junior and senior level students, and currently have no specific pre-requisites. (Beginning next year a programming course will be a pre-requisite for the final class.) All students in the technological studies major have had previous CAD/CAM coursework, which provides them with experience using similar applications. The course materials use a combination of the tutorials, simulation exercises, application quizzes, and reality-based projects.

The Technological Studies Department is currently utilizing the manufacturing simulation software offered by Delmia Corp. of Auburn Hills, MI, providing access to a variety of applications. The specific Delmia products used during 2005-2006 included IGRIP (robotics simulation), V5 DPM Envision Assembly (assembly/disassembly sequencing), V5 Human Modeling (ergonomics analysis), and QUEST (discrete event material and process flow analysis). An educational partnership with Delmia provides major software discounts, support, and training materials at costs that are practical for our program. For example, the educational for pricing the software licensing for the 2005-2006 year was under $15,000; the quoted annual “commercial value” was nearly $6,000,000. Licensing is purchased each year on a per product, per seat basis, with the flexibility to select the specific applications needed. The software licensing may be loaded to specific machines, or onto a network server.

An advantage of utilizing the Delmia suite of products is the common interfaces between their various applications. The parent company for Delmia is Dassault Systemes, which also owns the CATIA CAD/CAM product for parametric/solid modeling. Due to this common ownership, the simulation software is being revised and developed for incorporation into the CATIA interface environment. These two applications then work together seamlessly, with the ability to switch between various “workbenches” for each application while working on the same model. Students utilizing the new Delmia V5 products gain proficiencies in the use of the CATIA CAD application during their course work. The high visual and graphical results have also proven effective in stimulating student interest in the Technological Studies program, countering some public negativism for industrial/manufacturing occupations.

In the past five years, 21-31 students enrolled in the Advanced Manufacturing option, which includes the VS classes. We have averaged 23% of all students in the department, which is by far the most popular option. The lab facilities for these classes include 10 high-end computer workstations equipped with dual monitors. The students learn the various simulation applications
through tutorials, and then create independent projects to demonstrate and develop basic competencies. Student teams are then formed to complete industrial company projects. The teams visit local manufacturing operations to observe their processes, create simulations of the projects, and present the results at the company facility upon completion, including digital videos of the simulations and PowerPoint presentations.

At the beginning of each quarter, new projects are identified at local companies that apply the specific software applications for the quarter. Student teams are formed based on expressed interest to work with a specific company or convenience for some to work together. Efforts are made to change team members each quarter. At the completion of the three VS courses, each student creates and presents a portfolio CD to the class summarizing all of their VS work. In addition, significant benefits have resulted from application of coursework from other classes in the technology major into this curriculum.

Specific benefits to our students and our program include the following:

- Practical application of an advanced technology
- Generates student enthusiasm for manufacturing
- Excellent project coordination tool for concurrent engineering
- Teamwork activities
- Project planning
- Problem solving
- Industrial exposure
- Co-op/Internship opportunities
- Job Placement contacts
- CAD/CAM systems experience
- Application of other industrial technology applications and curricula

Other industrial technology applications incorporated into the classes include the following:

- 3-D solid modeling and data translation
- Robotics construction, kinematics, robot programming
- Ergonomics analysis
- Assembly sequencing
- Production layout & material flow optimization
- Formal multi-media presentations to industrial professionals
- Creation of personal portfolio and CD

An additional incentive has been the extensive use of this specific simulation software by major companies in our geographical region (Honda, DaimlerChrysler, General Dynamics, and Toyota), and significant opportunities for internships, co-ops and jobs using this software at automotive OEMs and major defense industries. Also the opportunity to incorporate such “high-tech” advanced computer applications into a basic industrial technology program served to differentiate our program from others.

Initial problems in the program implementation included the high initial cost of the lab facilities, and the annual expenses for software (initially $25,000/year). A grant and from the Society of Manufacturing Engineers assisted in the initial investments and course development. The
university has consistently sponsored this curricula as a distinctive and appropriate component that supports the mission of the institution.

Specific Simulation Coursework

The following are descriptions of the three simulation courses, with explanation of the industrial project applications.

TECH 321 - Basics of Virtual Simulation (robotic offline programming): Using Delmia IGRIP robotics simulation software, students follow a short tutorial to create a 3D model their own hand, applying motion control kinematics and writing a basic program. Students then use robotics libraries and the Delmia software to work through distance learning tutorials and videos provided by Immersive Engineering, Inc. Online quizzes for each chapter and a final exam verifies student comprehension, and exercises are submitted electronically and graded to ensure active student involvement. The final tutorial includes creation and generation of an off-line robotics program, which can be sent to a working robot in another location. All students work independently on their assignments, but frequently assist one another to overcome problems they encounter.

Approximately midway through the ten-week quarter the students are split into teams of three to five persons for assignment to a company project. Based on individual preferences or company restrictions (e.g.; US citizenship) the project is designated and arrangements made for a plant visit. Typically, a 1-2 hour meeting with the company includes an explanation of their business, a general description of the operation(s) to be simulated, and a tour of the plant and specific operation(s). Data is provided then and upon request, including pictures and videos if available. The team observes the plant operations, discuss the issues and company expectations, gather relevant data and information, and begin creation of the simulation. Additional plant visits and company communications are the responsibility of the students. A Gantt chart from Microsoft Project is submitted weekly, and the professor monitors project progress. Technical support at Delmia is solicited for especially complex, unique or unusual applications, along with software issues. During the tenth week of the quarter, the team presents the results of the simulation and analysis to representatives of the company, along with basic suggestions; typically thirty minutes to an hour. A comprehensive PowerPoint presentation of each student’s work for the quarter, including video files of the project, is made to the class and submitted on a CD.

TECH 322 - Virtual Simulation of Systems (ergonomic analysis and assembly sequencing): Students are introduced to new CATIA based applications through tutorials and training materials provided by Delmia and CATIA. Each student works independently to create a unique assembly sequence of a complex 3D CAD model using the V5 DPM Envision Assembly software, and then presents the results to the class. Students projects have included assembly of engines, guns, industrial machines, and even human dissections.

The V5 Human Modeling ergonomics simulation curriculum is then provided with Immersive Engineering tutorials, similar to those used in the previous course, along with Delmia materials. Each student creates and presents a unique ergonomic simulation of their own, with an emphasis on use of the ergonomic analysis tools. They are encouraged to be creative and imaginative. Recent project examples have included gymnastics, fighting, and running through a maze. Student teams are again formed at the middle of the term and assigned to a company project,
which is completed and presented to the company with recommendations. PowerPoint presentations of all the coursework for the quarter and a final CD are again submitted.

**TECH 423 - Virtual Simulation-Production & Management (material and process flow analysis):** Quest tutorials from Delmia are used for the student training, with specific exercises at the end of each chapter that are submitted electronically for grading. Each student creates and presents a unique, complex manufacturing system of their own design or personal experience utilizing most of the standard components of the software. Following this the classes are again divided into teams who go into manufacturing companies and create a simulation of a specific operation or process. Team presentations and suggestions are presented to company officials.

At the end of the full sequence of courses each student formally presents to the class a final comprehensive portfolio of their VS projects. These portfolios are intended to be suitable for presentation to a perspective employer, and are graded as their final exam.

**Company Simulation Project Examples and Descriptions**

Following are descriptions of sample simulation projects completed during the past three academic years.

**Fall Quarter:**

**IGRIP (robotics simulation)**

A simulation was created at the Lima, OH, General Dynamics Joint Systems Manufacturing Center (JSMC). A military component mounted on a tilt/rotate fixture is repositioned and welded by an articulated robot with dual weld torches. The proposed robotic process was evaluated for throughput, reach capacity and workspace requirements. See Figure 1.

Two other projects were completed simulating complex robotic spotwelding cells at the Honda automotive assembly plant in Marysville, OH. Existing and new equipment was being consolidated into significantly smaller workspace; clearances and accessibility for operators and parts handling were in question. Some of the equipment geometry was available from Honda’s IGRIP models, with others created by the students in Pro-Engineer and imported into the simulation. All weld points and motions were programmed into the simulations and run to verify reaches and clearances. In one of the models the opportunity to eliminate a robot from the cell was identified by the students. Figures 2 and 3 are other examples of recent robotics projects.
An ergonomic analysis was completed for the installation of exhaust systems at an automotive assembly plant. This study identified opportunities for fatigue and repetitive motion stress reduction. See Figure 4.

In figures 5 and 6, at a Ford engine plant two operations were video taped and simulated for ergonomic evaluation. Numerous postures and activities were analyzed and presented to the plant’s safety committee. Some opportunities were identified and implemented immediately.
Spring Quarter:  
QUEST Material/Process Flow Analysis

A simulation of miscellaneous machining operations for 104 different parts for a proposed military product was analyzed for throughput at the General Dynamics Joint Systems Manufacturing Center. See Figure 7.

A study for the Ford Lima Engine Plant involved analysis of the machining and assembly operations on a new engine. In this scenario engine cylinder heads are received at a dock and delivered either to a machining line, or if pre-machined to an assembly line. Parts for machining have process times before going to assembly. A principle component of the analysis was evaluation of whether multiple lift trucks could keep up, or if a trailer train with multiple carts would be more effective. The logistics and throughput for a cylinder head line was simulated with alternative material handling equipment, including lift trucks, AGVs and trailer trains. The visualization and recommendations of the simulation led to layout revisions for the installation currently in progress. See Figure 8.

Company Collaborations

The issue of getting company involvement required some persistence. The cooperation was gained largely by offering the opportunity for company representatives and management to influence students to pursue manufacturing jobs (appealing to their personal interests, and “parenting” emotions), plus opportunities for employees to demonstrate community service. Now there is very good acceptance and support. The essential component in achieving successful company projects has been the establishment of a working relationship with individuals in the company who had the authority, interest, and willingness to get involved. All companies have been supportive and cooperative once the relationship was established, although it sometimes took patience, perseverance and repeated communications to achieve this cooperation.
All contacts were very busy, but were receptive to the idea of providing the opportunity for students to gain first hand real world experience in dealing with manufacturing issues. The expectations of both parties and the deliverables are identified in the initial meeting between the students and the company representatives. When the projects were underway, and they found our needs were not very demanding, the willingness to provide support and even encouragement grew. The companies have expressed high satisfaction with the results of the students’ work, with offers to provide future projects. They have also expressed a willingness to pursue opportunities for financial grants and other partnership activities.

Student Issues, Successes and Satisfaction

Students have struggled with real life project management, division of responsibility, and on-time project completion issues, but have usually come through with results well received by companies. The virtual simulation curriculum continues to provide graduates with excellent internship and job opportunities. Recent placements using VS included Dassault Systemes, Delmia, General Dynamics, Honda and Lockheed-Martin, along with several tier 2 and tier 3 supplier companies and system integration/simulation development companies.

A salary survey of placements for student graduates from 2003-2005 substantiates the benefits of this program. The average initial compensation reported for all graduates of the technology program for the three years is $39,689. The average during the same period for graduates that took the advanced manufacturing option or the virtual simulation minor and took jobs in a related field is $45,214, which is 14% higher than the overall average.

A survey taken spring quarter of 2006 of current students in their third quarter of the sequence provided the following insights into their perceived value of the company projects.

1. **How much value do the company projects add to these classes?**
   - I believe they are a very important factor of the Virtual Simulation class. By visiting different companies and having the opportunity to show a project presentation students learn more about the industry and professional environment.
   - The company projects make the virt. sim. class. I have learned the most from those projects to gain real time experience. The tutorials lay out the basic functions and the company projects allow us to apply those functions to real time applications that we may deal with in the future.
   - They directly show what we are capable of doing with the knowledge we gained from the class.
   - I think the company projects have lots of value; it gives us the opportunity to go into a company and see how a real company works and develops ideas and solutions to a problem. As long as you have a simulation class I believe you need to have the company projects because otherwise everything is abstract and really has no real-world application.
   - I feel that they add a great deal of value to the class not only through the experience of working with the software, but also working with an actual company in a real-world setting.
2. Do the company projects significantly improve your learning and education?
   - Yes, because we learned to work in teams, improve our computer simulation skills, and be more involved with an industrial environment.
   - Yes, the company projects enable us to gain insight to a real manufacturing setting.
   - They provide the majority of the learning through creating new challenges within the programs.
   - They help show the real world applications were this software is actually used.

Class Evaluation Comments:

Students have been attracted by, and demonstrated enthusiasm for, working with the visual computer-oriented nature of simulations, but have been impatient working through the details and complexity of the applications. A trainer of the IGRIP product at Delmia made the comment that it takes two years using the products full time in industrial applications to achieve 90% proficiency; this statement has been used to assure the students that they should not get frustrated, and that they should plan on extended usage to achieve high competency levels. Although basic proficiencies are desired, the more important objective is an understanding of how these tools are used. Further training is expected at the employer in the specific applications the company utilizes. Manufacturing simulation programs are being used at other universities, include several using Delmia in limited applications or graduate work, but no others are believed to have the number of courses or with the number of industrial projects achieved at our school.

Simulation Significance and Opportunities

A study sponsored by the National Science Foundation identified “synthesis, modeling, and simulation for all manufacturing operations” as one of the top ten technology areas for meeting the challenges of manufacturing in the year 2020 [2]. The report also identifies significant opportunities in workforce education and training: “Educational and training methods that would enable workers to assimilate knowledge to improve their effectiveness are priority technologies.”

“Research opportunities include the development of tools that are not language or culturally dependent; technologies that can capitalize on advances in the cognitive sciences; interactive techniques, including simulation and virtual reality; and learning modules that can be adapted and tailored to meet individualized educational needs.”

Modern manufacturing operations are increasingly dependent upon the synergies of employees, vendors and customers to achieve excellent performance. Creation of a common vision for project proposals and process improvements are essential for effective and efficient project and program implementations, and to stimulate best ideas and practices. The ability to communicate and capture ideas and proposals that can be shared across a broad cross section of personnel are integral components of concurrent engineering, cross-functional teams, lean manufacturing, and self-directed work teams. These are the mechanisms that have permitted Japanese and Asian companies to dominate in many industries, and which are being embraced by the most successful American manufacturers.
The original math based simulation applications of several years ago were primarily the domain of industrial and systems engineers for analysis and interpretation. The high visual nature of the newer object based simulations lends themselves particularly well to current management trends utilizing cross-functional teams and concurrent engineering. As illustrated in Figure 10, the use of the animation functionalities provides workers, technicians and management better understanding and conceptualization of new layouts and processes before they are built, permitting improved brainstorming and idea generation.

### Table 1: Simulation Spectrum of Comprehension

| Math based simulations (Objective, Analytical) | Industrial/Systems Engineers |
| Object based simulations (Visual, Intuitive) | Mechanical Engineers |
| | Manufacturing Engineers |
| | Management |
| | Technicians |
| | Workers |

**Figure 10: Simulation Spectrum of Comprehension.**

At our school additional simulation applications are planned or under evaluation for incorporation into the technology curriculum. These include Delmia’s V5 DPM Powertrain, Process Engineer, and Workload Linebalance, along with other applications in demand by industry. Planning is also in progress for integration of the Delmia simulation applications into other University courses, including PLC’s and Industrial Robotics, CAD/CAM and Automation Systems, and Advanced Robotics and Automation.

The following VS opportunities are also under consideration:

- Summer technology camps for high school and middle school students.
- Commercial industrial training both on site and with distance learning.
- Creation of a Center for Advanced Manufacturing to integrate Technological Studies, the our College of Engineering, the College of Business Administration, and industrial companies in new partnerships.

**Summary**

Manufacturing companies are pushing the envelope to gain competitive advantages through rapid development of new products, processes and production systems in lean environments that emphasize continuous improvement. Companies are embracing digital manufacturing, product lifecycle management and simulation analysis as tools to achieve their goals. Boeing, General Motors, the United States military, and others are mandating that simulations of major projects are completed prior to implementation. Graduates of engineering and technology programs who have an understanding and ability to apply these tools will find many opportunities as our economy continues to grow.

During the 2005-2006 school year requests for graduates, co-ops and internships with simulation experience significantly exceeded our supply of students choosing to follow this career path. The virtual simulation program is a distinctive component of the Department of Technological Studies, and provides excellent opportunities for student field experiences and applications of advanced computer technologies. The curriculum provides the opportunity for real-world projects, internships and jobs for our students, and is providing modern industrial companies with effective management and manufacturing engineering professionals. The local industrial companies have been very receptive and supportive of the partnerships which improve the quality of the students’ education and better prepares them for future opportunities in manufacturing.
Bibliography
