AC 2008-708: DIGITAL MANUFACTURING AND SIMULATION CURRICULUM

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Digital Manufacturing and Simulation Curriculum

Introduction

Ohio Northern University is in the tenth 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, assembly sequencing, 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. Students have obtained coop/internship positions, and graduates are finding simulation jobs in the fields of manufacturing and applications engineering.

Defining Digital Manufacturing and Simulation

Digital manufacturing (DM) encompasses a variety of computer applications and processes that are being embraced by companies of all sizes to remain competitive in the global market. Boeing is recognized for its design of the entire 777 airliner without using a single 2-D drawing—only 3D models were used. [1]

One definition is "Digital manufacturing is the ability to describe every aspect of the design-to-manufacture process digitally—using tools that include digital design, CAD, Office documents, PLM systems, analysis software, simulation, CAM software and so on." [2]

"Digital Manufacturing provides manufacturing and design engineers the benefit of enhanced visualization. In product design, powerful tools are frequently available for developing electronic product mockups, allowing engineers and non-engineers alike the ability to interact with a product before the design has been committed. Tools that allow 3D visualization replace sketches and drawings with something that comes much closer to the real world. By simulating the actual product that will be produced, countless mistakes are avoided and many improvements made.

Time and expense have been reduced by reducing the number of physical prototypes that must be created in order to validate a product design in the physical world." [3]

Simulation is one of the growing applications within the DM realm. The Society of Manufacturing Engineers (SME) has created a technical group to provide reference information and networking opportunities within this field. This group has designated four areas of simulation related to manufacturing operations: [4]

1. Virtual product design
2. Physical prototype validation
3. Production/operations analysis
4. Enterprise analysis

The principle applications used in our curriculum fall within the production/operations domain.

Curriculum Background at Ohio Northern University

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 classes [5]. 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 can be part of a Technology minor for students in other majors. These courses are for junior and senior level students, and have a programming course pre-requisite. 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, exercises, and individual and team reality-based projects.

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 supported this curriculum as a distinctive and appropriate component that supports the mission of the institution.

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 2007-2008 include V5 DPM Envision

Assembly (assembly/disassembly sequencing), V5 Human Modeling (ergonomics analysis), V5 Robotics, 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 for ten seats of the simulation software licensing for the 2006-2007 year was approximately $16,000. New two year pricing options reduced the 2007-2008 cost to just over $5,000, bringing our average cost per year to approximately $10,500. This includes nearly their entire suite of simulation software, and has an additional seat for a laptop computer. The quoted annual "commercial value" for all of these is well over $4,000,000.

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.

An additional incentive has been the extensive use of this specific simulation software by major companies in our geographical region (Honda, Chrysler, 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 advanced computer applications into a basic industrial technology program served to differentiate our program.

During the spring of 2007 the author was the primary recipient of the Engineering VISION 2007 Grant awarded by Engineering.Com, Inc. The award included the following: 30 seats of CATIA education licenses, 30 CATIA training manuals by Ascent Corp., five days of CATIA training by Rand International, a Dell XPS 1710 laptop computer, and a cash honorarium of $2,000. (Note: According to Engineering.com, each CATIA V5 Academic license has a commercial value in excess of $1.25 million, putting the total commercial value for the lab of 30 CATIA V5 licenses awarded through this grant in excess of $35 million.) This grant was the result of the author's submission of a student team project from a previous simulation class that was revised to demonstrate the 3D visualization capabilities of the CATIA V5 software, which is the same platform as the DELMIA V5 applications.

Due to the benefits gained from the Engineering VISION 2007 Grant, the pre-existing association with the CATIA software, and the high demand for CATIA applications by several of our local companies (including Honda their suppliers) the curriculum for the simulation sequence has been revised, as will be explained later in this paper.

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 individual or team projects to demonstrate and develop basic competencies.

During the winter and spring quarters 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 these quarters, new projects are identified at local companies that apply the specific software applications for the quarter. Student teams are formed based on their 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 these three courses each student creates and presents a portfolio CD to the class summarizing all of their work during this course sequence.

This curriculum has benefited our program in many ways as identified below.

Incorporation of other industrial technology applications into these classes:

- 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

General benefits and opportunities for our students and our program:

- 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

Specific Simulation Coursework

The sequence for these courses may be summarized as follows:

- Fall Quarter
    - Digital Manufacturing Design and Applications
- Winter Quarter
    - DELMIA V5 Simulation
    - Industrial Team Project
- Spring Quarter
    - DELMIA D5 and Process Engineer
    - Industrial Team Project

TECH 321 - Digital Manufacturing Design and Applications: Covers the design of 3D CAD solid models for manufacture of mechanical parts and products, with simulation and analysis of assembly processes. Includes an overview of digital manufacturing systems, including manufacturing simulation applications, product lifecycle management, and use of resource planning/database systems. Training materials included the CATIA Intro to Modeling manual (by Ascent/RAND from Engineering.Com grant), DELMIA tutorials and training materials, professional webinars by Dassault, RAND, professional organizations and Dassault resellers, reference materials from the Society of manufacturing Engineers (SME) Simulation Technical Group, and IMMERSIVE Engineering's internet-based digital-manufacturing learning mgt. system. Upon completion of CATIA training the students were assigned to complete a team project and present the results in a PowerPoint presentation.

TECH 322 - Virtual Simulation of Systems (advanced assembly sequencing, ergonomic analysis, and robotics): Students continue the CATIA based applications through tutorials and training materials provided by Delmia. Student teams to create a unique projects applying each of the principle applications and then create PowerPoint presentations summarizing the project.

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.

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: Digital Manufacturing Design and Applications:
Upon completion of CATIA training the students were assigned to complete a team project from an existing product that included "waku-waku," which results from a presentation at the 2007 DELMIA User Conference where a Honda manager emphasized this as a core component of the Honda philosophy and products. His interpretation of "waku-waku" is that their product should be "sexy. To satisfy this requirement the students modeled a radio controlled car completely in CATIA, including most of the components as illustrated in Figure 1. This proved to be an assignment that generated high student motivation, work effort and satisfaction.

Figure 1: Examples of CATIA Design Project

Winter Quarter:
V5 Human Solutions
(ergonomics analysis):
An ergonomic analysis was completed for the installation of exhaust systems at a Honda automotive assembly plant. This study identified opportunities for fatigue and repetitive motion stress reduction.
See Figure 2.

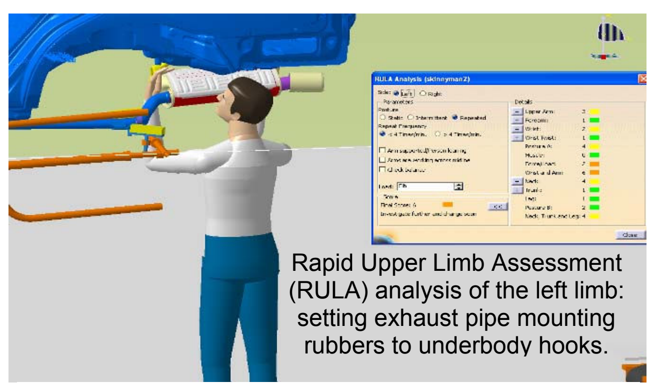

Figure 2: Ergonomic Analysis of Exhaust System Installation

Winter Quarter 2007-2008:
V5 Robotics and Human Solutions ergonomics analysis:
Figures 3 shows one of two robotic workcell simulations for the spotwelding of automotive body panels for a Chrysler/Jeep facility. The operations were videotaped and then simulated with the inclusion of an operation previously performed independently to demonstrate the viability of consolidating the operations. An ergonomic analysis was also completed of the affected operator.

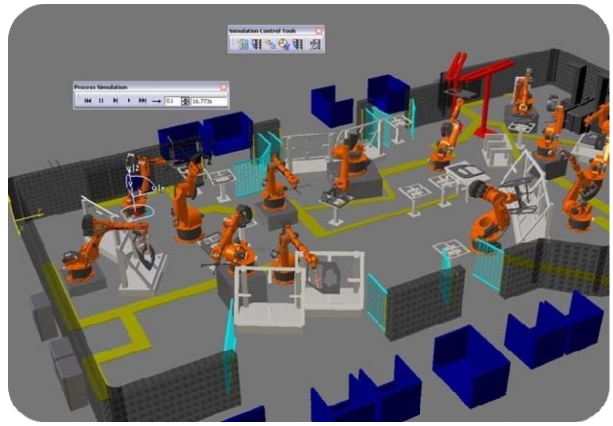

Figure 3: Robotic and Ergonomic Analysis of Automotive Body Spotwelding

Spring Quarter:
QUEST Discrete event Material and Process Flow Analysis:
A simulation of miscellaneous machining operations for 104 different parts for a proposed military product was analyzed for throughput at a General Dynamics manufacturing plant. See Figure 4.

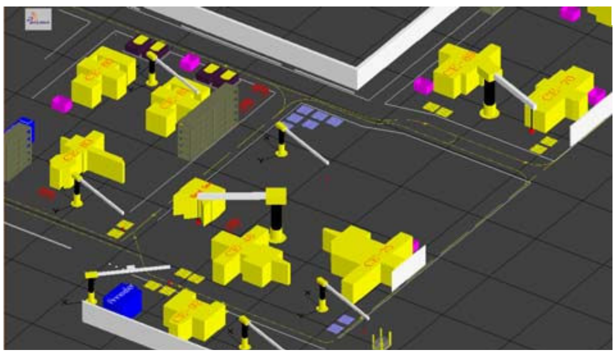

Figure 4: Discrete Event Material Flow Analysis

Another discrete event simulation study was completed at a Ford engine plant involving analysis of the machining and assembly operations on a new V6 engine. In this scenario engine cylinder heads were to be received at a dock and delivered either to a machining line, or if pre-machined were to be sent directly to an assembly line. Parts for machining had specified processing times prior 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 factory layout revisions.

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. <u>How much value do the company projects add to these classes?</u>
    - 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 virtual simulation 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.
    - 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. <u>Do the company projects significantly improve your learning and education?</u>
    - 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, including 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 as at our school.

Simulation Significance and Opportunities

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 5, 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.

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

Figure 5: 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.

State of the Art of Digital Manufacturing

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 [6]. 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." [ibid.] (Italics added)

Many of the opportunities relate to new visualization and documentation applications using 3D graphics and convenient annotations. New products by Adobe Systems (Adobe Acrobat 3D), Dassault Systemes (3DVIA), and others, along with new developments in virtual reality technologies, will permit communications and collaborations that are not language or geometry based, but visually convey information in forms that humans easily understand. These are already being integrated into Product Lifecycle Management (PLM) systems in some companies.

"Digital manufacturing solutions are part of collaborative PLM systems and make up the manufacturing element of PLM, including integrated solutions supporting manufacturing process design, tool design, and powerful 3-D visualization simulation tools. The integration of digital manufacturing into PLM solutions is providing a critical link between design and manufacturing engineering, according to market researcher ARC Advisory Group (Dedham, MA), enabling the collaborative environment that is essential to successfully implementing concurrent engineering practices." [7]

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 with an understanding and ability to apply these tools will find many opportunities as our economy continues to grow.

During the 2006-2007 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.

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