

## **Incorporating Descriptive Simulation of Integrated Manufacturing Systems to an Engineering Technology Capstone Course**

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Dr. Littell is an accomplished manager with more than 10 years of experience providing results-oriented leadership. His previous positions include the PLM Coordinator at the Center for Advanced Vehicular Systems at Mississippi State University from 2004-2008. He was Director at Large for COE, the World's largest users group of Dassault Systemès PLM products from 2008 to 2012, where he was acknowledged with the BJ Fries Award of Merit for making balanced contributions to the organization's activities and growth. His most recent position was as the Engineering Program Manager and CAD/PLM Administrator at Viking Range LLC, located in Greenwood, Mississippi from 2008 to May 2014.

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## Introduction

Manufacturing systems are becoming more autonomous, requiring less operator intervention in daily operations. This is a consequence of today's market conditions, characterized by global competition, a strong pressure for better quality at lower prices, and products defined in part by the end-user. Manufacturing engineers need to integrate isolated manufacturing operations with the objective of extracting from them the most flexibility and productivity they can offer by using various technologies. There is a need to introduce the principles and practice of integrated manufacturing systems into an Engineering Technology Program which has most of the students pursuing their future careers in manufacturing industry.

The Engineering and Technology department at Ohio University hosts a senior capstone course, which operates within a team centric manufacturing environment. This course couples an operations management course with an opportunity for the students to apply the skills they have acquired through partial completion of the program to pursue the design, development, and manufacturing launch of a new product. Course requirements dictate that the students create a functional physical prototype. As part of the class, students are required to design, build and validate all of the required manufacturing documentation and fixturing for use during the production of their product. The student design teams execute a pilot production run to validate documentation and fixtures and then they refine the manufacturing and production process to efficiently produce the products. The capstone course ends with a six-hour production run, where the students lead a group of their peers to build between 15 and 21 products. To incorporate the practice of integrated manufacturing systems into this course, students are also required to design, simulate and analyze a fully automated production line for their products which includes production stations, material handling systems, storage systems, motion controllers, sensors, and robots. The system will be simulated and analyzed using Simulmatik3D software. At the same time, this project will also explore the possibility of incorporating a real CIM cell for student product run based on hardware and software requirements.

This paper will demonstrate the design of the new capstone course activities, scheduling, and assessment. This project will provide a strategy and case study in incorporating manufacturing automation and integration to Engineering Technology programs for students to gain hands-on and software simulation and modeling experiences.

## The ETM capstone course

The capstone course within the engineering technology and management department at Ohio University exists as a comprehensive manufacturing experience. The course exists as a problem based learning (PBL) environment, and as such it focuses on the five primary characteristics of such an environment: Problem-focused, student-centered, self-directed, self-reflective and having a facilitator instructor [1]. This environment is intentional to allow

the students to synthesize what is actually required within the context of their project. Schwering supports this methodology and defines the act of providing an open-ended project based project as one of the hallmarks of a superior capstone experience [2].

Students enrolled in the capstone course divided into groups of five or six members. The class typically has between four and six of these groups. One of the group member will take the role of a project manager, and then each member of a group will take a different role as in a manufacturing industry, such as design engineer, production engineer, etc. The students are responsible for purchasing the raw material for the products that they will be building. The products that they design do have a few design constraints. They must be comprised of more than seven fabricated (not purchased) parts. The products must have at least one moving part, such as a door or drawer. Example products include a mantle clock, a diploma display case and a dart board case. Also, students are required to build an inventory system for their production. The inventory control system that the students design, build and implement is required to be able to track each of their parts from inventory, through WIP and as built into a finished good. This is a basic but typical inventory workflow[3].

While the lectures for the course provide a foundation in operations management, the students are required to leverage the competencies they have achieved in past courses to design a product as well as the required engineering and manufacturing documentation. The students are also required to build production tooling, work instructions and conduct pilot builds which lead to a production run. During their production run, the students will manage a group of their peers who will build one product for each student enrolled in their section of the course, plus one product that the department keeps as reference for future capstone groups. The production run duration is six hours, and the students typically build between fourteen and twenty-one products.

The production design and operation of the capstone projects utilizes one CNC router, two CNC mills, one laser cutter, several band saws, table saws, and drill press. Each manufacturing process has been operated separately on different machines, and all the material and parts transportation and handling are manually completed. The product final assembly and sub-assembly are all done manually. It is realized that introducing automated manufacturing systems into this capstone course becomes more and more important in order to prepare students for current and future manufacturing industry.

#### Introduction of automated production modules

The Automated Production Systems Modules are designed to help students study and practice the technology associated with automated production systems. The modules include an overview of production systems, automated production lines, automated assembly systems, group technology, and flexible manufacturing systems [4]. After the study of these modules, students will be able to design, simulate and analyze automated production systems. The learning outcomes of the automated production modules are aligned with the learning outcomes of the ETM program, and are described as below:

1. Discuss manufacturing operations and processes and activities that support these processes. And explore the influence of several production parameters have on manufacturing systems.
2. Explain the importance of automated manufacturing systems to support upper level business operations in the enterprise integration for manufacturing industry.
3. Develop and modify ladder logic programs for PLCs to enhance the functionality of the program.
4. Design the movements of an industrial robot, and simulate the robot to complete a specific series of operations for an automated material handling process.
5. Understand the concepts and major elements (sensors, controllers, robots, and other smart machines) of an automated production system, along with the application to practical situations.
6. Apply knowledge and skills to the crucial aspects of integrating design with planning activities through simulation and by designing integrated system.
7. Write a personal perspective on the principle and applications of automated manufacturing systems.
8. Use resources of information on manufacturing issues from books, magazines, and electronic media to supplement learning and practicing.
9. Demonstrate ability to communicate professionally through written and oral reports and be an effective team leader/member.

Considering the workload of the capstone projects, only production managers from groups are required to study these modules. These modules are created and posted on Blackboard, therefore, students can access and study the materials on their own time. Not only production managers can learn from these modules, all capstone students have access to these online modules. Also, production managers will meet and discuss their learning experience with a faculty in their weekly meeting. They will bring their production design and discussion back to the group, and get feedback for their production system design and configuration.

The content of the learning modules are described briefly in Table 1 as below.

Table 1:

Module 1: An Overview of Production Systems	Introduce different types of production systems, and discuss the key parameters to evaluate the performance of production systems.
Module 2: Automated Production Lines	Discuss the major components, part transportation, storage buffers, and control of automated production lines.
Module 3: Automated Assembly Systems	Study the different layout configuration, part delivery, and control of automated assembly systems.
Module 4: Group Technology	Learn the principle of group technology, and the implementation of group technology in the design of automated production lines.
Module 5: Flexible Manufacturing Systems	Introduce the definition, configuration, layout design, control systems, and performance evaluation of flexible manufacturing systems.

## Simumatik3D simulation with CoDeSys PLC

Simumatik3D is a new simulation environment for industry automation simulations with controllers and robots. It provides a professional and convenient way for students to simulate their design and configuration of automated production systems. The software interface is shown as below in Figure 1.

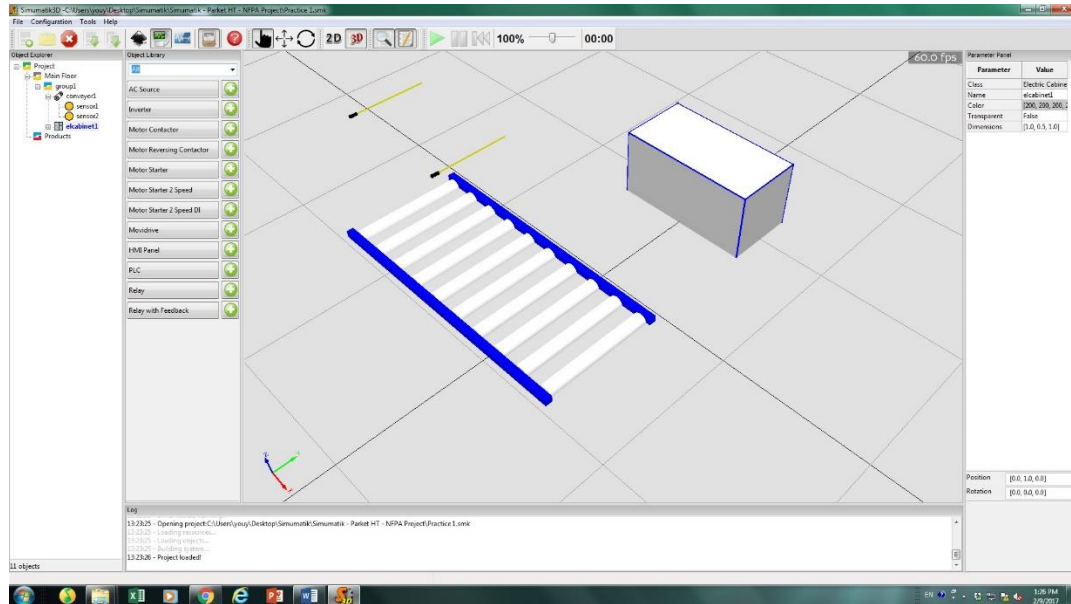


Figure 1. Simumatik3D Interface

Simumatik3D provides a user library which contains various objects that users can add to their systems. The major categories of the objects are elements, vision objects, electric devices, programmable logic controllers, base, 3D models, products, and human-machine interfaces. Users can design their own objects and imported to the library, such as industrial robots with various axis configurations. For each object added to the system, users can set/change properties of that object, including sizes, name, location, orientation, and other configuration parameters based on the specific type of the object. In the Simumatik3D environment, students can design and build their automated production lines with the objects from the library. Most objects are available from the library, such as conveyors, sensors, motors, motor contactors, programmable logic controllers (PLCs), electric devices, industrial robots, and sensors. To accurately simulate the production operation, students can import their designed parts into Simumatik3D environment and save them as 3D models in the library. The actual machining processes cannot be simulated at this time, but the machine setup and machining time could be integrated into the process through programming.

Once the physical setup of the production line has been completed in the simulation environment, students need to design the automation process and program controllers to integrate all the devices into the automation. CoDeSys, a Controlled Development System, is used to run as a virtual PLC controller, to support Simumatik3D for the simulation of the integrated automation process.

CoDeSys contains the interface, objects, data tags, visualizations, and programming languages to design, program, and run a virtual PLC controller in its development environment. Students can program the PLCs that will be used for their production simulation in CoDeSys environment. The development environment is demonstrated in Figure 2.

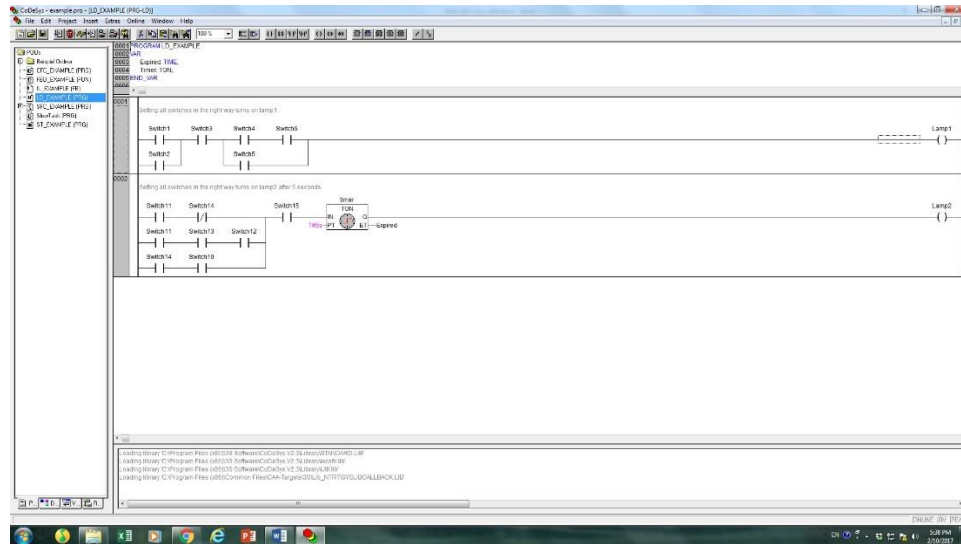


Figure 2. CoDeSys development system

For the virtual PLC controllers to run in Simumatik3D, the communication between CoDeSys and Simumatik3D needs to be established through data tag communication. All the input and output variables are specified and named consistently to be used on data tags that sent back and forth between these two software. With the virtual PLC running at CoDeSys, input variables are read from input devices in Simumatik3D, and output variables are sent to control output devices in Simumatik3D at a real time manner. An example of the global variable declaration at CoDeSys is shown in Figure 3.

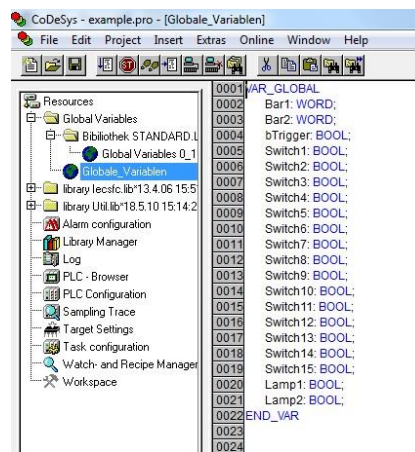


Figure 3. Globele variable declaration at CoDeSys

The requirements for students' production simulation are:

1. Design the layout of the automated production system that can be used for the mass production of their product.
2. The production system must be flexible and fully automated without any manual process.
3. Program all the PLC controllers and industrial robots used in the system.
4. Specify the machining/production and material transportation time in the simulation system.
5. Simulate the operation of the whole production system, and determine the manufacturing lead time and production rate for the system to produce their products.

### Project implementation and future considerations

This automated production system module started to be implemented in the Capstone project in this Spring semester of 2017. There are six groups in this Capstone project, each group has assigned a production engineer to work on this simulation. The production engineers work with their groups to design the automated production system that produces their products. Then, the production engineers create and simulate part of the automated production system in the Simumatik environment. The physical objects of the system has been created in the Simumatick environment, and the 3D model of parts and the robot are imported to Simumatik. After the physical setup has been created, programming codes for PLCs and the robot are developed in the CoDesys. Through the connection of data tags with global variables, the programs in CoDesys are able to drive the PLCs and the robot in the Simumatik setup. Therefore, the simulation can demonstrate the production system operation close to a real world situation. In Figure 4, a production workcell is simulated with three conveyors, a six-axis robot, sensors, and a programmable logic controller. Figure 5 simulates a workcell with five smart conveyors, two turning tables, and a machine workstation.

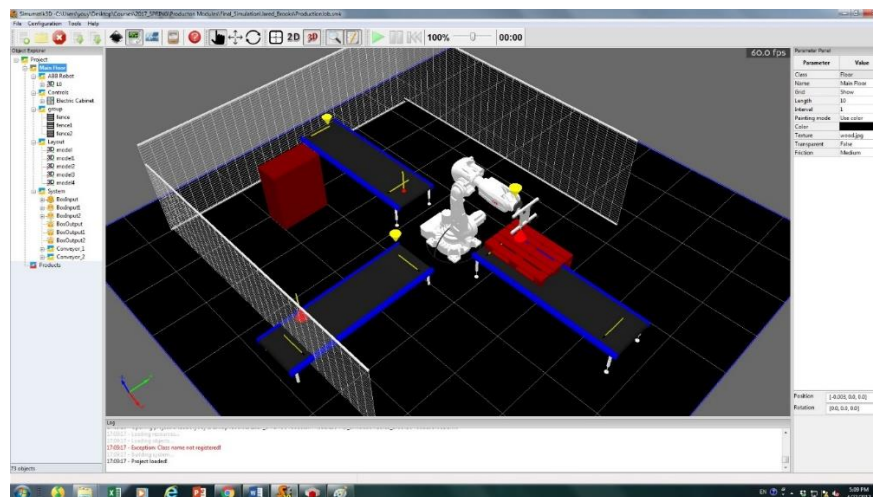


Figure 4. Simulation of a robot workcell

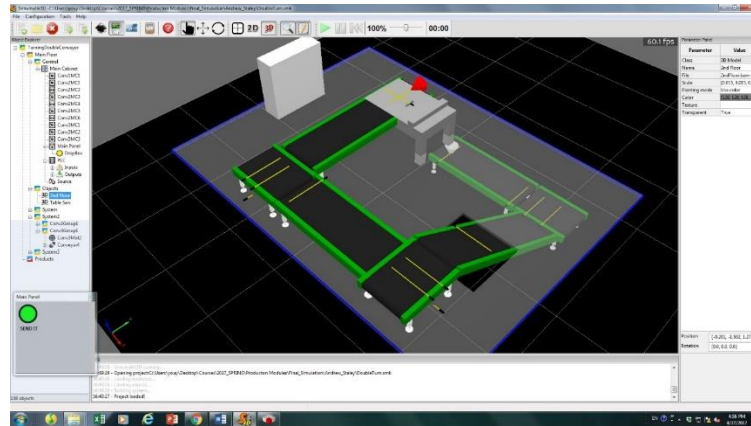


Figure 5. Simulation of an automated conveyor system

By the end of this semester, the outcome of the learning modules will be assessed through the evaluation of the simulated production systems. Also, students' feedback on the integration of automated production system design and simulation into the Capstone project will be collected and analyzed for future development.

The Engineering Technology and Management students acquire many diverse skills through the successful completion of many competencies within the program. Because the capstone course currently exists as one five credit hour course taken during one semester, the course is very compressed with respect to the deliverables expected of the students. Several students expressed frustration that they wanted to pursue more within the course to push their projects further but were constrained by time. From the Fall semester of 2017, the course will split into a two semester experience where the student focus on the Operation Management portion of the class and the second class focuses on their production run. By spreading the course over two semesters, the students would have more time to design and simulate a more robust automated production system.

One additional opportunity would be for the students to further extend the system design and simulation to a real system implementation with the available equipment in the manufacturing lab. The ETM Department just purchased six new robots, conveyors and PLC controllers. With this extension, students who are interested in the area of manufacturing automation will be able to practice what they have learned in previous courses into a real system integration project. This interaction would provide a deeper level of assessment of the student competencies related to control systems, material handling, industrial robots, and systems integration within the modern manufacturing environment.



## References

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