COLLABORATIVE DEVELOPMENT AND INTEGRATION
OF LABORATORY MATERIAL UTILIZING
A FLEXIBLE MANUFACTURING CELL

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Abstract

This paper presents the design and implementation of laboratory material that integrates two traditionally independent courses in the industrial engineering curriculum, manufacturing, and simulation, utilizing an flexible manufacturing cell. This collaborative project incorporates a team-based learn-by-doing approach to the theoretical knowledge in these subject areas. This dynamic environment gives the students the opportunity to design an automated system for manufacturing a product and analyze the production methods. Furthermore, the students have the opportunity implement their system design and contrast the design against the working system. The results of this project are discussed along with the anticipated impact on the curriculum.

1. Introduction

Curriculum integration and multidisciplinary studies have become key issues in improving engineering education. However, the areas of manufacturing and computer simulation are traditionally treated independently both from a research and teaching perspective.

Current courses in manufacturing, especially those with a laboratory component, assume that a given manufacturing process or assembly operation is in place and that the system configuration is permanent. In general, when placed on this arena, the student proceeds to observe, collect data, analyze, and draw conclusions based on the current configuration. Consequently, an important aspect dealing with the design of the system and operation is often neglected. Ideally, the student should be able to question the current configuration, design several alternatives, evaluate them according to appropriate metrics and choose the best, instead of being forced to observe a pre-determined setup. The design and evaluation process mentioned above can be approached with computer simulation techniques that are currently taught in a separate course and fall outside the area of expertise characteristic of an instructor in manufacturing. Similarly, teaching the simulation course centers primarily around written descriptions of systems. Since many undergraduate students do not have experience with the behavior of industrial systems (or at least not common experiences), the problem descriptions are often simplified to promote understanding or are derived from common, non-technical systems such as bank operations, car
washes, etc. Although these types of problems adequately illustrate simulation concepts, they do not provide practical engineering applications of simulation.

The objective of this work is to develop and implement a hands-on case study on a flexible manufacturing cell to serve as a common basis to illustrate the manufacturing and simulation concepts in the respective courses. Under this scenario, the students are exposed to the same experiential setup from two different perspectives. This allows for stronger continuity and breadth of understanding across these two core subjects in the curriculum.

2. Motivation

The basic motivation for undertaking this project was to strengthen the industrial engineering curriculum at Rochester Institute of Technology (RIT). In order to achieve this, a more integrated approach to teaching courses such as manufacturing and simulation, which are traditionally thought of as independent topics, is provided. Furthermore, the experiential setup will allow the incorporation of a team-based learn-by-doing approach to the theoretical knowledge in the areas of manufacturing and simulation and their interrelationship by being exposed to all the different facets of manufacturing systems engineering.

Typically, a graduate from an industrial engineering program is expected to perform and contribute in all the areas mentioned above, sometimes in a common arena. However, the instruction provided to the students is usually isolated by course and without a strong and explicit connection across courses. This approach will provide the student with the opportunity of looking at the same process from two different perspectives, thus imitating real working environments. Additionally, the hands-on approach and open-ended nature of this experience could result in a more effective way of communicating and instructing, as well as improved student’s knowledge retention and assimilation. A higher level of student motivation and involvement is one of the expected outcomes since this interactive approach tends to be more appealing to the student.

It is important to note that, along with this project, other similar types of activities are taking place within the Industrial and Systems Engineering Department at RIT. In particular, a manual assembly system is being utilized to integrate courses on manufacturing, ergonomics, and simulation (Carrano, Kuhl, and Marshall, 2003).

3. The Flexible Manufacturing Cell

The flexible manufacturing cell shown used in the development of the laboratory material is shown in Figure 1. The cell consists of a conveyor system on which pallets can travel around in a closed loop configuration to three stations. At each station, sensors are used to detect the arrival of pallets. Two of the stations are equipped with robots that are capable of performing pick and place and assembly operations. In addition, a numerically controlled milling machine is contained within the cell and can be loaded and unloaded by the robots within the cell. All of the stand-alone components of the cell were integrated for the purposes of this project and can be programmed and controlled through ladder logic on a computer terminal.
One of the products that has been developed to utilize all of the operations within the cell and to demonstrate its operation is an engraved pen holder (Olney et al. 2003). The finished product is shown in Figure 2. The components of the product include a black anodized blank aluminum plate and the pen holder on a swivel base. The holder is fastened to the base with an adhesive and the base is engraved with the RIT logo and tiger paw print. Figure 3(a) shows the CNC milling machine performing the engraving process. The machine is loaded and unloaded by a robot and sensors are used to determine the placement of the aluminum plate and to activate the milling machine. Figure 3(b) shows the robot performing a pick and place assembly process to place the holder assembly onto the plate. For this operation, a special gripper was designed for the robot to grasp and place the holder.
The workstations on the manufacturing system are capable of being reconfigured and reprogrammed to accommodate different products and different system designs. Under this environment, the students are able to study the product (dissection and reverse engineering), study the manufacturing and assembly processes (task division and precedence, time study, workstation design, computer simulation, etc), design several alternatives of the entire process (line layout, number and type of workstations, pace of assembly, etc), implement the best design, and conclude the activity with a real pilot run on the cell.

4. Laboratory Modules

Each of the two laboratory modules have been developed to be used in the manufacturing and simulation courses. Each of these modules is described separately below.

4.1 Manufacturing

The manufacturing portion of this study is conducted as part of the undergraduate mandatory course “Manufacturing Engineering” for all ISE students. During this course, the students are walked through the manufacturing sequence of such product as shown in the following schematic

![Manufacturing Sequence Diagram]
The proposed experiential activity fits within the automated fabrication and assembly portions of the sequence that constitutes the backbone of the course. At the stage of fabrication and assembly, the students were sufficiently familiar with the individual parts composing the assembly and the issues around them (i.e. manufacturing processes, materials, etc). The students worked in teams and were assigned the general task of designing the assembly line for this product. This required subdividing the assembly tasks down to the smallest work elements, familiarizing themselves with the assembly operations, developing and capturing tool and fixture requirements, performing time studies on the tasks, performing capacity and throughput analysis from this data, designing the macro configuration of the line (i.e. general flow configuration) as well as designing micro aspects of the system (raw workstation design, tooling, fixtures and component storage) and performing line balancing and task allocation by using LOB algorithms. An important portion of the work is devoted to programming the cell elements, such as the benchtop milling machine via CNC codes, the scara robots, as well as the belt conveyor via PLC ladder logic. At this point, the students had proposed a full design of the assembly line based on their analyses. They also had projections and estimates of the performance of the proposed system.

The final experience was to perform a one-half hour pilot run with the students running the flexible manufacturing cell with the configuration and design they proposed. Data recorded on a continuous basis included throughput and number of defective assemblies. Data on the status of the system was collected every 5 minutes. This included the state of the line such as workstation utilization, accumulations on queue, starving workstations, blocked workstations and WIP in system. A discussion at the end of the experience reflected upon the discrepancies between the theoretical and actual performance.

4.2 Simulation

The simulation component of this project includes all aspects of a simulation study. The students are shown the flexible manufacturing cell and shown its capabilities and limitations. For a given product, the students are given the very general task of designing an efficient manufacturing system. The assignment of this project will be given approximately half-way through the course so that the students have enough background in the simulation concepts to approach the problem and yet there is enough time remaining in the quarter to adequately complete the modeling, analysis and implementation.

The following steps of the simulation study are taught in the lecture and applied to the design and analysis of the flexible manufacturing cell. The first step is to define the problem, its scope, and measures of performance. That is, the students define what they consider to be an efficient manufacturing system for the given product. For example, the students may define an efficient system as one that results in high throughput, low cycles times, low work-in-process inventory, and low cost. The next step is to apply techniques taught in the manufacturing class to break down the assembly process into individual tasks and collect data on the time to perform each task. Using distribution fitting software, probability distributions are fit to the processing times for each task to be used as input to the simulation model. Using simulation software, a simulation model of the system is constructed for each alternative system configuration that the students identify. The simulation models are verified and validated using techniques such as traces,
structured walkthroughs of the model, etc. After designing a set of experiments (determining the number of replications, length of replications, etc.), the simulation models are run and the output of the simulation runs are analyzed by constructing confidence intervals on the output performance measures. The system configurations are compared both from a statistical point of view and from a practical, engineering perspective. The students then make a recommendation for the most efficient manufacturing system design.

The entire simulation study can then be documented. One method that has been used to document the study has been to construct a web-page which allows for the inclusion of the simulation models, data files, etc. as part of the final report and allows other students to view and learn from the project. Finally, as discussed further in the next section, the students in the simulation course give a presentation to the students in the manufacturing course, who in turn, implement the recommended system configuration in a pilot production run.

5. Implementation and Integration

This project enables students to learn and apply the various industrial engineering techniques of manufacturing and simulation in a common setting with the goal of educating the students not only in the specific engineering methods but also in the integration and interdependence of these methods and their impact on decisions about system design and implementation.

Specifically, the integration of the laboratory modules for the two courses using the flexible manufacturing cell includes the industrial engineering techniques of dividing the assembly process into individual tasks, collecting data on the time required to perform each task, fitting probability distributions to the observed data, utilizing the distribution as input to the simulation models, and evaluating alternative system configurations, to completely design the manufacturing system. Perhaps the most important aspect of project is the ability to fully implement the recommended system configuration and perform a pilot production run using the actual system to manufacture the products.

6. Results and Observations

At this point, the laboratory material for each course has been developed, and the material is in the process of being formally documented. During the last academic year, a pilot study that utilized a group of students from the simulation course developed a simulation model of flexible manufacturing cell. Further, during the last academic year, the flexible manufacturing system itself was fully integrated by students into a central computerized control center so that the capability now exists to fully implement the laboratory modules in both courses.

In order to evaluate the effectiveness of this project, surveys will be distributed to the courses to determine the student’s perspective on this integrated, hands-on teaching method. Based on the pilot study conducted during the last academic year, there are several outcomes that were observed and realized:

♦ Students actively participated (with enthusiasm) in all aspects of the laboratory;
The interrelationships among manufacturing and simulation issues were emphasized which has not been the case in prior offerings of the courses; Having been exposed to the assembly system in one class, time can be saved by not needing to reorient or introduce the students to the system; and The use of the flexible manufacturing system can also being integrated into other courses such as an introductory course to IE to introduce student to automated flexible manufacturing systems.

As we continue to utilize and implement these laboratory modules we expect that other benefits will be realized. Additionally, we will use additional surveys to assess the effectiveness of the laboratory modules.

7. Conclusion

In summary, the implementation of the flexible manufacturing system has fostered the integration of two traditionally independent areas of industrial engineering, manufacturing and simulation. Through the development of these laboratory modules, students are provided with a hand-on approach to these subjects where they can fully, and actively participate in all aspects of the design and implementation of the flexible manufacturing system. Further, the interrelationships among manufacturing and simulation in terms of their impact on design and implementation can be integrated in a common arena. Finally, this project can serve as a template for the integration of curriculum topics of other disciplines.

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References


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