

Shockerphant Aerospace: Towards a sustainable model for teaching production system concepts

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Abstract

Understanding cause-and-effect relationships is key to evaluating and designing a production system. Traditional instruction methods including textbook study and lectures introduce students to concepts, theories, and formulas involved in manufacturing systems. Developments in simulation technology have enabled educators to give students a "real-world" model to apply the theories and techniques learned in the classroom. Simulation has proven to be effective at enhancing student's education by complementing the lecture and textbook material. This paper presents a simulation-based project for various Production Systems/Operations Management courses. The challenge is to develop a simulation that is flexible to cover basic course content as well as recent industry trends involving theory of constraints and the lean enterprise. This proves challenging for instructors, because many of these concepts are counterintuitive to traditional manufacturing logic. The developed simulation model meets the challenge faced by instructors and students as they try to expand current curriculum and get the most out of the simulation experience. The paper compares other production system projects, presents the project itself, describes the application of modern production systems and the integration of sustainability, and concludes with student project experiences.

Introduction and motivation

Textbook and lecture methods are much more effective when complemented with a computer simulation. Simulation allows students to make decisions in dynamic real-world environments. The output from the simulation allows the student to evaluate the impacts of decisions and make necessary adjustments while learning new problem solving strategies. The manufacturing environment provides an excellent application of computer simulation. The complexity, uncertainty, and interdependencies are hard to convey from a textbook alone. Therefore, faculty use simulation to enhance their teaching effectiveness.

Studies show that the use of computer simulation can complement and improve the traditional textbook methods. In addition to teaching concepts and theories presented in the textbooks, simulation can also stimulate group interaction and enable critical thinking, decision-making, and problem solving. A study by

Gokhale (1996) shows that students remember only 10% of what they read and 20% of what they hear. However, students remember 90% of what they learn from simulation. The study goes on to suggest that properly designed and implemented computer simulations could revolutionize education. Results show that "...effective integration of computer simulation into traditional lecture-lab activities enhances the performance of the students" (Gokhale, 1996). Student feedback from simulation projects indicates that they appreciate the relationship between real-world and course concepts, as well as the complexity of the decision making process (Bringelson et al., 1995).

A study conducted with a senior-level course at Bentley College showed that students consistently rated the simulation part of the course very highly with regards to usefulness, making the course more interesting, and helping them apply theory learned in class (Chapman and Sorge, 1999). There are many factors that can influence the effectiveness of simulation in education including student level of involvement in the simulation, instructor level of enthusiasm, emphasis on the value of the simulation, and the weight of the grade given to the simulation (Chapman and Sorge, 1999).

Students sometimes understand course concepts in a disconnected, isolated manner. Reciting theory and definitions are not of much use unless students can use that knowledge to make meaningful decisions. Students will be required to make use of this method in a project environment to make business decisions based on uncertain and ambiguous information. Decision-making ability is a critical tool sought by employers. During the simulation, decisions occur simultaneously and interactively, rather than sequentially (Chapman and Sorge, 1999). Allowing the student to practice decision-making in this environment is the primary objective of simulation. Traditional textbook and lecture methods normally have exercises designed around individual concepts. "This instructional method, while somewhat attributable to the usual trend to compartmentalize course material into homogeneous blocks, is more often due to an attempt to model traditional manufacturing organizations in which the product design function, manufacturing engineering, and production planning are separate corporate entities" (Randhawa and West, 1994).

This paper reports on the use of simulation to enhance learning in a production systems course at Wichita State University. Production systems have become more complex due to technology as well as capital investment and the increase in the number and variety of products manufactured (Khan et al., 1999). The factory is a complex environment and most students have difficulty understanding its complexities. The simulation presented here requires students to synthesize multiple class concepts in order to run an entire factory.

One fundamental skill required of an industrial engineer is the ability to run a factory. Many graduates of the Industrial and Manufacturing Engineering Department (IMfgE) at WSU are placed in a manufacturing factory environment.

It is estimated that 30% of the general aviation workforce in Wichita, Kansas are WSU engineering graduates (total employment: Boeing/Spirit – 12,565; Cessna Aircraft – 9,200; Raytheon – 7,000; Bombardier – 2,600 along with many suppliers. Based on 2003 statistics). We believe that the use of simulation in the IMfgE's Production Systems course better prepares our students to enter the aviation manufacturing job market. It is clear from teaching this class that students really begin to grasp the material during the activities of the existing project. The current class project reinforces the fundamental concepts of forecasting, scheduling, Bill of Materials, capacity analysis, workforce analysis, holding costs and backorder costs. Students have commented that they have "really learned" the course content through the simulation. Through the existing project the students develop a more thorough understanding of traditional production systems concepts. The existing class project uses a simple, non-trivial factory as shown in figure 1.

Appendix B. Shockerplant Aerospace Production Sequence Diagram

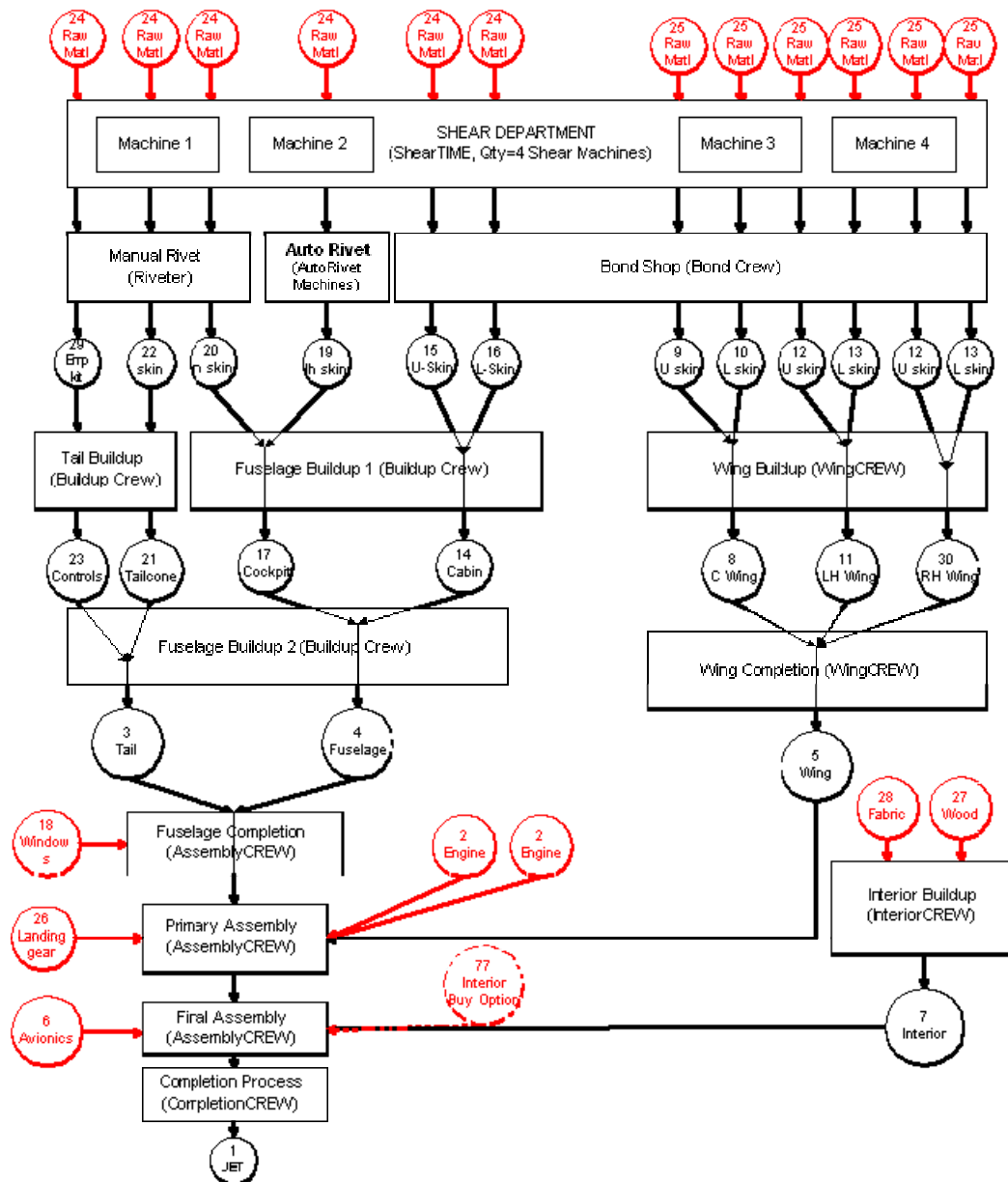


Figure 1. Factory Flow

Many students are unaware of issues beyond typical classroom lectures. The example used here is related to the idea of lean and green. The basic concept of lean and green manufacturing is for production systems to view pollution as a quality “defect,” then lean technologies will be pursued as “zero defect and zero emission” manufacturing strategies. In this sense, lean and green relationship can transform the factory from traditional production/environment tradeoff to more innovative approaches such as environmentally conscious manufacturing which can optimize the manufacturing process in ways that simultaneously improve

environmental and industry performance and reduce environmental cost and risks (Buxton and Nielsen 1995, Florida 1996). However, students must be made aware of many tradeoffs concerning lean and green. To this end, through an NSF funded project, we are extending the existing simulation based model to focus on the economic and environmental sustainability constraints and the broad education to understand the impact of engineering solutions in an economic, environmental and societal context.

The primary intent of this effort is to foster learning of class concepts and to impact the breadth of student learning (in terms of ABET outcomes “(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability” and (h) “the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context”).

Proposed project impact

The primary impact of this project will be exemplary materials both on how to incorporate lean and green concepts into student learning. All our seniors are given an exit survey where they rate their level of confidence in areas such as engineering design principles, teamwork, and socio-economic context in which engineering is practiced. We will add an additional question to this survey where students are asked about their confidence in knowledge about sustainability issues. This will provide a baseline of existing student confidence to compare with students who have taken the production systems course with the new project. As previously mentioned, traditional teaching methods cause the key concepts to be studied individually making it difficult to emphasize the important interactions between these concepts. Case studies can help bridge the gap between the textbook and the real world by providing students with an analysis of real-world supply chains. While these methods are effective to an extent, the use of a simulated network of production systems can complement these traditional approaches and remediate many of the deficiencies of traditional teaching methods. More specifically, the simulated system presents instructors with the following advantages:

- a) The dynamic nature of production systems environments so the effect of variability can be presented more clearly;
- b) Interactions between system components and their effect on the overall system are more evident;
- c) The regular decisions that must be made in a production system are experienced requiring the students to consider the important tradeoffs within the system during the process;
- d) The simulation provides feedback and prompts the use of appropriate corrective action allowing students to learn and adjust problem solving strategies; and

- e) Teambuilding lessons are worked into the curriculum when students must work together to make decisions.

For these reasons, simulation is becoming standard in most production systems courses to teach Industrial Engineers key concepts related to manufacturing. This method usually consists of students working in teams competing to meet customer demand while minimizing cost. The students are presented with a hypothetical production system and the necessary details about that system. The students must then forecast for demand of the final product and release necessary production and purchase orders to deliver the goods to the customer in the most cost-effective manner.

Simulation design

Many different production simulation products are available to instructors. However, most current products do not provide enough flexibility for the instructor. While the instructor can modify different parameters or variables, the design of the production system cannot be changed. By changing the basic model, instructors could present more concepts such as lean manufacturing, the differences between push and pull based systems, and the theory of constraints. Another deficiency in current simulation packages is the usability it provides to students and instructors. Some simulations require decisions to be documented by the students on a '.txt' file and transferred to the instructor on floppy disk. This provides for a high probability of error in the data entry process, and makes the instructor's duties more time consuming. The evolution of PC and web technology has provided a means to enhance these products by streamlining and standardizing the data entry process.

The existing production systems project uses traditional production system techniques and does not allow students to incorporate many of the concepts taught in the class such as lean techniques and variability reduction. The existing system used for semester projects in the production systems class at WSU has four main requirements. First, the simulation must represent a realistic production system (i.e. Aircraft Manufacturing). Second, the simulation must have differing degrees of variability that can be controlled by the instructor. Third, the simulation must give the instructor the flexibility to change the variables in order to make the system different for each semester, as well as change the system to illustrate different subject matter. And fourth, the student input has to be submitted by an Excel spreadsheet. Arena is the simulation software engine due to its current use for Simulation Modeling courses at WSU and many other universities as part of their Industrial Engineering programs as well as by local aircraft industry.

In order to simulate a real-world production system, this class project presents a fictional production system that builds a jet aircraft. This is an appropriate simulation since Wichita, the "Air Capital of the World", is home to the major manufacturing facilities of Spirit Aerosystems, Boeing, Cessna, LearJet and

Hawker Beechcraft Aircraft Companies. The production system starts with raw materials and has an output of a completed business jet called the ShockerJet. The bill of material had to be large enough to represent the different components of the aircraft, but was limited to about 30 part numbers in order to keep the magnitude of the production system simple enough for the students to handle. This bill of material also includes raw material and purchased parts that must be ordered from a supplier. This requires the students to consider lead times when planning their production plans.

The ShockerJet production system is designed in order to incorporate the variability and complexity of a real production system. The system includes batch processing, one-piece-flow processing, resources shared by more than one workstation, purchased parts, make versus buy decision, scrap, rework, and scoring based on revenue and cost measures.

There are fourteen workstations in the Shockerphant production system and nine types of resources used at the different workstations. The system starts with two different types of raw material, aluminum sheets and other raw material; it then processes the raw material into other components of the aircraft. These components are then assembled in other workstations where they are combined with purchased goods as well as other manufactured assemblies. The first two levels of workstations are batch processes. Parts are processed and transferred according to the batch size indicated by the production order quantity. Parts in the other workstations are processed individually. Each workstation has a specific processing time for each part as well as a resource that is required to process the part. The correct material, resources and production order are required before processing can begin at the workstation. Initial parameters for processing times, lead times, scrap and rework rates were determined and the simulation was tested using those values. Figure 1 shows the existing factory flow. Raw materials begin the process through the first two operations. These processes occur in a batch environment and incur quality reject rates. The remaining processes are assembly operations which incur rework for any defective assemblies. The student teams determine the number of each resource (machines and workers), the batch size, order quantities, and whether to make or buy the interior.

For more details concerning the Shockerphant factory and the project itself, please see the web site at: <http://models.wichita.edu/shockersim/> which includes a user's manual, web lectures on its use, an assessment rubric, a virtual reality model file of the factory, a flash movie file describing the factory, the production sequence diagram, and the bill of material. The simulation-based factory has been tested and improved and then used for eleven semesters at WSU (Spring and Fall of 2002 through Spring 2007) with each class having four to nine teams.

Project modification

In order to improve the project to incorporate additional course concepts as well as to add the concept of sustainable, a modification to the existing project is underway. The proposed effort modifies the airplane production student project by improving the infrastructure, adding lean manufacturing techniques, incorporating sustainability issues, and providing faculty assessment tools.

To improve the infrastructure:

- a web-based interface will be developed (currently students are required to submit an Excel spreadsheet containing their inputs).
- faculty configuration files will be implemented (currently the system allows the instructor to modify the demand via a spreadsheet).
- the simulation will be modified to provide costs for hiring and firing of workers.

To add lean manufacturing techniques:

- the simulation will be modified to incorporate lean concepts. The initial plan for lean concepts includes setup reduction, quality improvement, Kanban (one piece flow), automation (Jidoka), and cross training.
- the cost parameters of each lean improvement. Each of the lean improvements must have an associated cost and the appropriate value will be determined through consultation with industry (to provide realism) and through testing with the simulation (to provide system feasibility).

To add green manufacturing criteria:

- the simulation will be modified to incorporate environmental costs and benefits. The initial plan for lean concepts includes material reduction and substitution, the selection of environmentally benign manufacturing processes, the selection of processes with lower energy consumption, the elimination of wastes, and recycling of water and materials in process (Sutherland 2001).

A widely held operational strategy that has been recognized to mitigate environmental impacts within the manufacturing enterprise is lean manufacturing principles (EPA 2003). This project seeks to demonstrate that “lean and green” can be a cost effective strategy. As lean has been defined as “the relentless elimination of waste” (Womack and Jones, 1996), lean and green seem to naturally complement each other. The Environmental Protection Agency has funded several efforts in lean manufacturing hoping to leverage the environmental benefits of lean while creating greater economic benefits. Table 1 provides a list of what lean considers to be manufacturing ‘wastes’ with associated environmental impacts (adapted from (EPA 2003). In this project the concepts in table 1 will be integrated into the project simulation model. This will introduce students to concepts of environmentally sustainable manufacturing through the application of lean concepts in a production setting. Students will be made aware

that some lean concepts tend toward improving the sustainability of the product and some concepts negatively affect the sustainability of the production system.

Table 1 The relationship between lean concepts and green production

Wastes Type	Examples	Environmental Impacts
Waiting	Stock-out, lot processing delays, equipment down time, capacity bottle necks	<ul style="list-style-type: none"> • Potential material spoilage or component damage causing waste • Wasted energy from heating, cooling, and lighting during production down time
Inventory	Excess raw materials	<ul style="list-style-type: none"> • More packing to store work in process • More material to replace damaged WIP • More energy to heat and light inventory space
Over production	Excess raw materials, WIP, or finished good	<ul style="list-style-type: none"> • More raw materials used in making unneeded goods • Extra products may spoil or become obsolete
Movement	Human motions that are unnecessary or straining, carrying work in process, long distances, transport	<ul style="list-style-type: none"> • More energy used for transport • Emissions from transport • More space required for WIP movement, increasing lighting heating, cooling and light for inventory space

The two primary learning objectives of this project are to:

1. Design a production system that meets customer demand while maximizing profit both now and in the future.
2. Evaluate the impact of differing techniques of addressing sustainability concerns to determine how they affect short term and long term decisions and results.

Additional assessment tools will be provided to faculty. Many faculty are intimidated by these types of projects and team course work due to confusion on assessing individual student performance and learning. Project and problem based assessment strategies such as rubrics will provide standards and guidelines for rating student performance and learning.

Conclusion

This paper presented an overview of the existing simulation based virtual factory used by student to exercise the techniques they learn in production systems. Results of the analysis of student's feedback indicate a positive attitude towards

this project. The current system lacks other contemporary issues such as green manufacturing. The paper also presents current plans for the implementation of lean and green manufacturing concepts within this project.

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