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SIMULATE TO ELEVATE: AN EML APPROACH TO TEACHING FACILITIES DESIGN

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ABSTRACT

Simulation can be an effective tool to convey concepts and promote comprehension in courses at all levels of education. In this paper, we present an entrepreneurial mindset learning (EML) activity that utilizes discrete-event simulation to elevate the depth of understanding of manufacturing systems and layout design in a facilities planning course. This active learning module compels students to simultaneously consider manufacturing activities, capacity, and layout design using a dynamic simulation environment. We demonstrate the use of robust, data-driven, simulation objects that can be manipulated by students to meet design objectives. This allows students to focus on the facilities planning learning outcomes without the need for in-depth simulation modeling knowledge or programming skills. We present the results and lessons learned from implementing the simulation activity in a facilities planning course.

1 INTRODUCTION

Simulation has a wide range of applications ranging including commercial applications; study/research of complex systems; entertainment and gaming; and education, among others. Within education, simulation has proven to be an effective tool for conveying concepts and promoting comprehension. To that end, we present a simulation-based entrepreneurial mindset learning (EML) activity to elevate the depth of understanding of manufacturing systems and facilities layout design. The EML activity is integrated into an undergraduate facilities planning course. Through the activity, students simultaneously consider manufacturing activities, capacity analysis, and layout design in a dynamic simulation environment.

The facilities planning course focuses on gaining knowledge of how the configuration of physical spaces helps optimize productivity and efficiency of fixed assets that best support the business objectives of an organization. The course objectives center on learning quantitative methods for facility planning including the principles, practices, and tools for planning, designing, evaluating, selecting, and implementing products and processes associated with facility layout, material handling, storage, warehousing, and facility location. In the current state, production system concepts as related to facilities layout are presented via class lectures. The desired state is to provide a higher level of student engagement in learning about production systems through an interactive, simulation-based, EML activity. The intent is that the simulation exercises will support and reinforce the theoretical concepts and enhance system analysis capability.

The EML approach is used to help develop an entrepreneurial mindset in engineers by promoting curiosity, making connections, and creating extraordinary value. That is, to go beyond the analytical solutions to foster the engagement of students to ask questions and critically evaluate their solution in term of broader impacts. The simulation-based EML activity focuses on the system and layout design for a laptop computer production facility that involves analyzing production system performance of a product (laptop) for which students are very familiar.

The remainder of the paper is organized as follows. In Section 2 we provide additional details about EML and related work. In Section 3, we demonstrate the development of the data-driven discrete-event simulation model framework for the laptop production system. A discussion of how the activity has been implemented in the course is presented in Section 4. Assessment of the activity is presented in Section 5. Finally, our conclusions and lessons learned are discussed in Section 6.

2 RELATED WORK

The entrepreneurial mindset (EM) concept is described by Bosman and Fernhaber (2018) as "the inclination to discover, evaluate, and exploit opportunities". Although often associated with people starting their own company (entrepreneurs), these are also the qualities of many highly successful engineers. As such, fostering the growth of EM characteristics in engineering education has become a growing trend. The Kern Entrepreneurial Engineering Network (KEEN) has developed a framework around educating engineers with an EM. The KEEN framework centers on the characteristics of curiosity (being inquisitive), connections (integrating information) from multiple sources, and creating value (identifying opportunity and broader impacts) (Kern Entrepreneurial Engineering Network 2025).

Entrepreneurial mindset learning activities are designed to help students grow and develop an EM. Examples of EML activities in courses include a design project for assistive devices (Gargac 2024); EML activities in an introductory engineering course (Korach and Gargac 2019); on-line discussions to develop EM (Bosman, Duval-Couetil, Mayer, and McNamara 2019); and project-based learning in a statistics course (Vignola, London, Ayala, and Huang 2017).

Simulation has also been demonstrated to aid in the understanding of concepts at all levels of education. One of the most well know is the "Beer Game" (Goodwin and Franklin 1994) which not only aids in the learning of simulation concepts, it has been demonstrated to improve the engagement of students as well as improve student learning outcomes (Padilla, Lynch, Diallo, Gore, Barraco, Kavak, and Jenkins 2016). In addition, the EM concept has been applied to a series of EML activities in a simulation course to enhance traditional instructional methods (Kuhl 2020; Kuhl 2022; Kuhl 2023; Kuhl 2024).

In the next sections, an EML activity is developed that illustrates how simulation can be used in engineering courses to help students develop an EM.

3 SIMULATION-BASED EML FACILITIES PLANNING ACTIVITY

The simulation-based EML activity for the facilities planning course centers around production system design and developing the corresponding facility layout. The expected value of the activity to students includes the following:

- Allows students to engage in hands-on learning, creating and manipulating models that simulate real-world production scenarios.
- Provides a visual representation of production systems, making it easier for students to grasp complex concepts. This visual aid helps in illustrating the differences between alternative systems, enhancing conceptual clarity.
- Creates a dynamic learning environment where students can observe changes in real-time. This dynamic nature allows for the exploration of various scenarios, helping students understand how different factors impact production systems.
- Enables students to experiment with different production configurations and strategies without real-world consequences.
- Requires students to think critically and solve problems related to production systems.
- Enables students to explore how production systems adapt to changes in demand, product specifications, or other external factors. These changes can be linked to the process of designing the layout of a factory or service organization.

Our goal is to develop a simulation-based activity that will meet these desired outcomes and contribute in a meaningful way toward fostering an EM by the developing curiosity, making connections, and recognizing extraordinary value. Next, we discuss the laptop production facility design scenario that is the focus of the EML activity.

3.1 Laptop Production Facility Design Scenario

The facility design scenario focuses on a laptop computer manufacturing and assembly facility. We select this scenario as laptops are very familiar to students which enables an immediate connection to the activity. Yet the scenario challenges students to become curious and think about/question the manufacturing processes, resources, and associated facility layout needed to produce laptops to meet a target demand.

An overview of the laptop production process is shown in Figure 1. The primary laptop electronic boards are produced on surface mount technology (SMT) lines. These include motherboards, solid state hard drives, graphics cards, sound cards, and wireless (communication) cards. The boards are stored in inventory and used to feed the laptop base assembly line. In parallel to the base assembly, laptop screens are produced on the screen assembly line. The base and screen inventories feed laptop assembly stations to complete the final assembly of the laptop. Each laptop is then tested at the unit test station and reworked as needed. After passing the unit test, laptops are sent to packaging, and finally sent to the finished goods laptop inventory to await shipment. Although somewhat simplified, this scenario includes the key components one would expect to encounter in an actual production system.

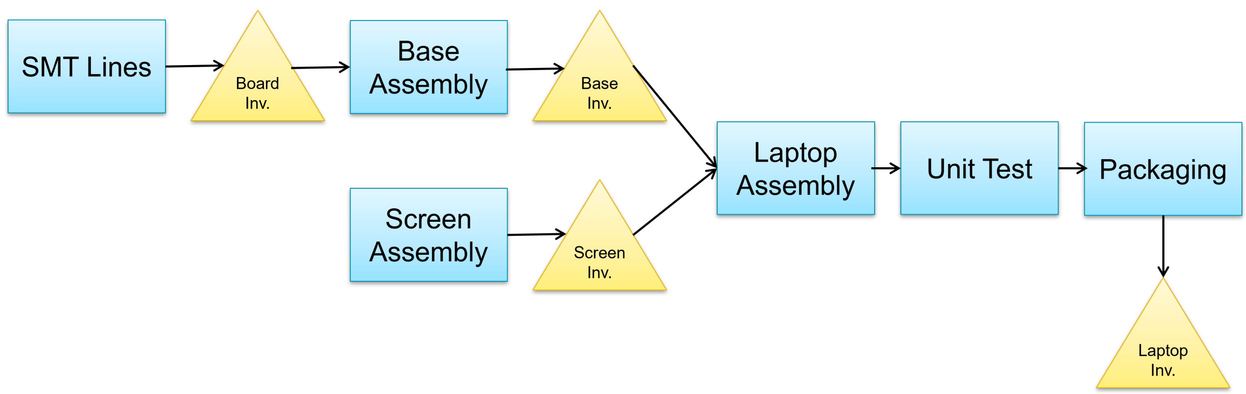

Figure 1: Laptop production process overview.

To design and compare alternative systems configurations of the production process and layout, a data-driven, discrete-event simulation modeling framework is constructed. The simulation framework consists of a set of objects that encapsulate the operational behavior of each system component. (We elaborate on the simulation modeling approach in Section 3.2.) Through interactive data tables, system components (SMT Lines, Assembly Lines, etc.) can be added along with their functional specifications. Within the facility (system) view of the simulation, the system components can be moved/arranged to create a layout for the facility. By executing the simulation, the dynamic behavior of the system can be observed. The simulation produces performance metrics can be used to analyze the effectiveness of the system configuration to efficiently meet the target demand. By identifying bottlenecks, analyzing utilization and product flow, etc. changes can be made to improve system performance. The simulation can be rerun to compare the trade-offs of alternative systems configurations and support a system/layout recommendation.

3.2 Simulation Modeling Approach

The goal of the simulation approach is to create an interactive simulation framework that students can use to specify the resources, production parameters, and layout of a manufacturing facility. In particular, the modeling framework needs to be robust and accessible to students with little or no experience with constructing and analyzing simulation models. To that end, we develop a data-driven, discrete-event simulation modeling framework. For this exercise, we utilize the Simio simulation software (Simio 2025). In addition to the capability of the software, we selected Simio because we want to make connections between courses within the curriculum, and Simio is the software students will use in their undergraduate simulation course in the following semester.

The approach that we take to creating the simulation framework is to construct custom object classes that can be instantiated and parameterized through the use of data tables. We create a custom object and corresponding data table for each component of the laptop production system including the SMT Line, Base Assembly Line, Screen Assembly Line, Laptop Assembly Station, Unit Test Station, and Packaging Station. Next, we will briefly discuss the functionality and operational specifications of these objects.

SMT Line: As displayed in Figure 2, the SMT Line is a flow line that starts with a board loader that feeds blank boards into the line, followed by a screen printing machine that distributes solder paste onto the board, and a solder paste inspection (SPI) machine. If the board fails the SPI, the board is remove from the line, the solder paste is removed, and the board is sent back to the start of the line. Boards passing SPI, then proceed through three pick and place machines that place chips or other electronic components onto the boards. Then a inspection machine inspects the chip placement. Boards failing this inspection are reworked, and boards that pass inspection are sent though a reflow oven which uses thermal cycles to solder the chip/components to the board. Boards then go through an optical inspection and a performance test. If either of these inspections fail, the board is reworked. Good boards leave this SMT Line object and are sent to the board inventory. The SMT Line can be used to produce one or more of the five board types (motherboard, hard drive, graphics card, sound card, or wireless card.) For each SMT Line object the production rate can be specified for each board type along with the failure rate at each inspection/test station and the changeover time between board types. For each SMT Line placed in the model, the user can specify the board types, batch sizes, and production sequence.

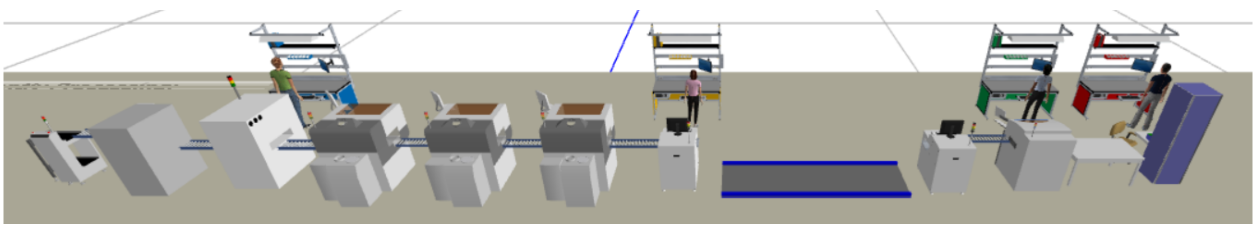

Figure 2: SMT Line object.

Base Assembly Line: The Base Assembly Line object consists of five serial workstations (see Figure 3). Station 1 represents the installation of the motherboard, hard drive, and CPU. At Station 2, the RAM, graphics card, sound card, and wireless card are installed. At Station 3, the fan, power supply, AC adapter, and USB ports are installed. The keyboard and touch pad are installed at Station 4. Finally, at Station 5, the battery and base cover are installed. The processing time distribution for each station is specified within the object. Stations 1 and 2 utilize boards from the board inventory. An inventory worker is used to bring a user-specified replenishment quantity from the board inventory to the station point of use inventory as needed. Each Base Assembly Line has a user-specified maximum work in process inventory. Once complete, the base is transferred to the base inventory.

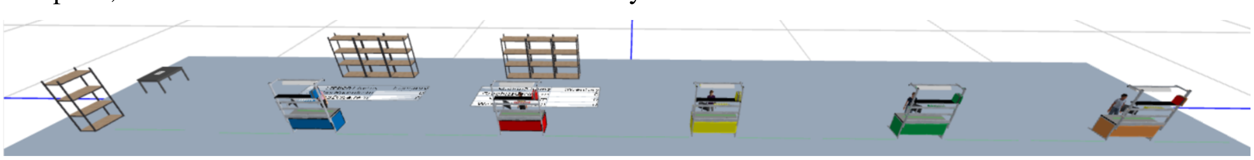

Figure 3: Base Assembly Line object.

Screen Assembly Line: Figure 4 displays the Screen Assembly Line object which consists of three serial workstations. At Station 1, the camera and screen are installed. At Station 2, the speakers and hinges are installed. And, at Station 3, the LCD and screen bezel are installed. The processing time distributions at each workstation are specified within the object. There is also a user-specified work in process quantity for each Screen Assembly Line. The completed screens are transferred to the screen inventory.

Figure 4: Screen Assembly Line object.

Laptop Assembly: The Laptop Assembly object, displayed in Figure 5, utilizes a base from the base inventory and a screen from the screen inventory to assemble a laptop. Each laptop assembly station has a capacity of 1. The processing time distribution is specified within the object. The completed laptop is sent to the Unit Test station.

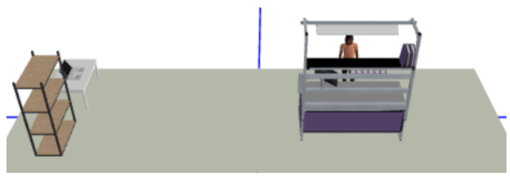

Figure 5: Laptop Assembly Station object.

Unit Test: The Unit Test object, displayed in Figure 6, includes a testing station and a rework station. At the testing station laptops are tested. Laptops that fail are sent to the rework station to be repaired and then sent back to the testing station to be tested again. There is a single Unit Test location with a user-specified capacity for the laptop test station and the rework station. The distributions of processing times for the laptop test and rework stations are specified within the object along with the probability of a failed laptop test. After passing the unit test, the laptop is sent to the Packaging station.

Packaging: The Packaging object displayed in Figure 6 represents the location where laptops are packaged for shipping. There is a single packaging location with a user-specified capacity. The distribution of processing time for packaging is specified within the object. After being packaged, the laptop is sent to the laptop finished goods inventory to await shipping.

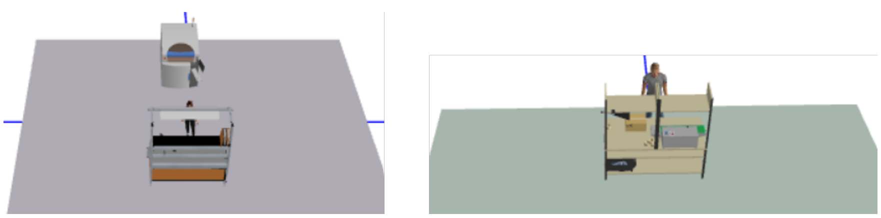

Figure 6: Unit Test object (left) and Packaging object (right).

In addition to the custom objects described above, Inventory elements are defined for each of the inventory locations. The inventory locations themselves are represented by Sink objects. Using Sink objects and tracking the component inventory reduces the number of entities in the system at any point in time and allows the simulation to run faster.

To create a system configuration and layout, the user specifies the name of the object they want to create in the corresponding object's data table. The row for that new object is then populated with the object's default values. The user can then change the default parameters as desired. The newly created object will then appear in the facility window at the origin, (0,0,0), and can be moved (by dragging the object) to the desired layout location within the facility. Once the system configuration has been specified, the simulation model can be run to evaluate system performance.

4 IMPLEMENTATION OF THE EML ACTIVITY IN THE FACILITIES PLANNING COURSE

The simulation-based EML activity was first implemented in the facilities planning course near the end spring semester of 2025. Thus, student had already received instruction on the various aspects of facilities layout and design. The new aspect was the introduction of simulation as a tool to help inform production system design and performance along with facilities layout design decisions. The activity was conducted during a two-hour period in a computer lab, and students were divided into groups of two.

As the student have had very limited (if any) exposure to simulation, a brief (≈15 minutes) introduction to simulation was provided. The discussion is intended provide some background on simulation as well as to raise the curiosity of the students about the capabilities of simulation and establish connections between the simulation and facilities planning courses. Next, the laptop assembly problem and hands-on simulation framework were introduced. The activity was split into two parts. In the first part, a production target for the current system was provided. In the second part, an increased production target was proposed. These simulation-based activities are aimed at exploring the value (cost/benefit tradeoffs) of alternative system configurations and layouts. A worksheet was provided to guide the students through the activity.

We provided the scenario as discussed in Section 3.1 where the production target for the current system was given to be 15,000 laptops in a 10 day period. A simulation model of the current system was provided which included 3 SMT Lines, 3 Base Assembly Lines, 1 Screen Assembly Line, 4 Laptop Assembly stations, Unit Test with a test capacity of 10, and a rework capacity of 1, and Packaging with a capacity of 10. The instructor and the students then ran the simulation of the current system to determine the ability of the current system to meet the production target. As the current production rate fell short, the group discussed potential causes (bottlenecks, etc.) Then the students were shown how to change the configuration by adding resources, changing parameters etc. Finally, the students were asked to make their own changes and recommend a system configuration for the current system.

The second part of the activity involved providing a proposed new target production rate of 20,000 laptops in a 10 day period. Students then evaluated the current system to determine what could be changed to increase production to the desired level. Thus, student iteratively made changes to the simulation model, changing the configuration, and evaluating the performance of alterative systems. In addition, the students were asked to design and recommend a facility layout for their final production system configuration.

The instructions for the deliverables of the activity included the following:

1. Submit the simulation models and complete the worksheet for each of the two (current and proposed) scenarios.
   - Run the simulation model to evaluate the performance of the production system.
   - Record what you observed. Provide evidence of your findings.
   - Identify changes to make to the simulation model and rerun model. Discuss what you changed and why? Record / provide simulation results as evidence of your findings.
2. Layout of the facility
   - Develop and submit a recommended layout of your final simulation model.
   - Discuss how this maintains good material flow.
   - Include locations for spaces that may be needed but are not directly part of the simulation objects such as aisles, storage locations, etc.
3. Lessons Learned
   - How did the simulation model help identify the optimal layout for the facility to handle increased demand?
   - What were the key factors considered when designing the facility layout, and how did the simulation validate these considerations?

For the most part, the students were able to complete the simulation modeling and analysis and most of the layout during the lab period, however, students were given one week to complete and submit their final models and completed worksheets.

Although this paper provides a detailed overview, additional details about this simulation-based EML activity including the activity narrative, presentation, worksheets, survey, and rubrics are available from KEEN Card 4830, Simulate to Elevate: Manufacturing System Layout Design (Kuhl and DiVasta 2025). (Note that this educational material is freely available, but the website requires users to register for an account.)

5 ASSESSMENT OF THE EML ACTIVITY

For the simulation-based EML activity, we want to assess both the technical concepts related to production systems design and facility layout as well as opportunities that activity provided for fostering curiosity, connection, and creating value.

To assess technical content the deliverables including the simulation models with the recommended configuration, the worksheet, the facility layout, and the lessons learned are graded using a rubric. Overall, the students performed very well in their demonstrating their technical comprehension and their ability to complete the task. In particular, through this type of activity we were able to see more clearly the student's depth of understanding of the concepts versus the level of detailed that was traditionally obtained from a question or two on an exam.

To assess, the opportunities to engage in EM related student development, students completed a short survey. The survey questions and student responses are summarized in Table 1. Students responded to the five questions on a 5-point Likert scale with five (5) corresponding to strongly agree, and one (1) corresponding to strongly disagree. A total of 24 (out of 24) students responded to the survey. The survey indicates that students overwhelmingly agreed with the statements. Although the results only provide

Table 1: EML simulation activity student survey ($n = 24$).

Activity Survey Questions (5-Strongly Agree; 4-Agree; 3-Neutral; 2-Disagree; 1-Strongly Disagree)	**Responses Avg. (SD)**	**Percent > 3**
The simulation-based activity:		
1) Aided me in learning to identify key features that differentiate intermittent and continuous production, such as production volume, product variety, and process flow. (Connections)	4.0 (0.8)	79%
2) Enabled me to use simulation model to evaluate the dynamic nature of production processes. (Connections)	4.3 (0.5)	96%
3) Prompted me to analyze how resources are utilized in production systems and assess their efficiency. (Curiosity)	4.4 (0.6)	96%
4) Prompted me to think critically and solve problems related to production systems including to analyze data, interpret results, make informed decisions, and develop essential problem-solving skills. (Creating Value)	4.2 (0.5)	96%
5) Provided me with a better understanding of the integration of facilities planning and simulation concepts/methods and their application to production systems. (Curiosity, Connections, Creating Value)	4.4 (0.6)	92%

empirical evidence, the student responses demonstrate that the activity provided support and opportunity for developing the EM characteristics of curiosity, connection, and creating value.

6 CONCLUSION

The simulation-based EML activity that we presented for the laptop production system design and layout is an example of how simulation can be used to convey concepts in courses such as facilities planning. As the survey results (and our own observations) indicate, the activity sparked curiosity in the subjects of both facility layout and simulation. Furthermore, exposing the students to using simulation software in a meaningful way established a connection between the facilities planning course and the simulation course. In addition, students were able to see and analyze the value created by designing a right-sized production system and corresponding layout.

Some lessons learned and challenges encountered along the way were many. In particular, the time required to construct a robust set of objects took more time than expected. Another challenge was limiting the scope of parameters that we wanted the students to experiment with to create their system recommendation. The primary concern here was not to overwhelm the students with options as the number of possible system configurations grows exponentially as the number of control parameters increase. In the end, we settled on a small set of production parameters, but these could be expanded to others such as inventory control policies, production schedules, worker shift schedules, etc. Finally, after developing this activity for the facilities planning course, we see how similar simulation-based actives could be applied in other courses. We are currently considering the development of a simulation-based EML activity for our introduction to industrial engineering course to give students exposure to simulation early in their degree program.

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