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Hands-On Simulations to Demonstrate Manufacturing Paradigms

Milinda McCorkle and John Wingerter
Erie High School
Erie, PA

Patricia Thompson
Community College of Allegheny County,
Pittsburgh, PA

Faisal Aqlan
The Pennsylvania State University, The Behrend College
Erie, PA

Abstract

With the rise in manufacturing jobs in the United States, companies are having a difficult time filling the job openings for skilled production workers. It takes an average of two months to fill these positions. This study is designed to introduce the fundamental concepts of manufacturing and demonstrate these concepts through hands-on simulation of the different manufacturing paradigms. The paper is the result of the authors' participation in a six-week NSF RET program at Penn State Behrend where high school and community college educators worked together to develop curriculum for high school students. Lesson plans, handouts, and required material lists were developed and tested. Surveys conducted after the simulation experiment provided improvements for the exercise. The simulations were then implemented in high school classrooms to improve the awareness of manufacturing among high school students and develop their technical and professional skills. By understanding the evolution of manufacturing and becoming aware of the need to gain advanced skills required for today, students will be encouraged to consider pursuing careers in manufacturing.

Keywords

Manufacturing Paradigms, Simulation, Hands-on, Manufacturing Education

1. Background

Manufacturing can be defined as the application of machines, tools, and labor to transform raw materials into finished goods for sale or use. Manufacturing has evolved through several revolutionary models, known as paradigms, that are induced by new market and economy conditions, technology advancement, and social needs [1]. Five main paradigms have evolved: craft production, mass production, lean manufacturing, mass customization, and personalized production. Manufacturing is an important contributor to the economy because it supports most of the other sectors of the economy as well as provides a wide variety of jobs. The U.S. manufacturing is facing multiple challenges including globalization and lack of skills. Today's manufacturing relies on advanced technologies and it requires specialized science, technology, and engineering skillsets. According to the Manufacturing Institute, the U.S. manufacturing workforce is older and less educated compared to the other sectors. Moreover, the U.S. dominance in product innovation is now in question [2]. Studies also show that relatively few Americans are choosing manufacturing education and careers today [3]. In addition, the skills gap in U.S. manufacturing is widening due to several factors including retirement, economic expansion, and ineffective manufacturing education [4]. It is estimated that over the next decade nearly 3.5 million manufacturing jobs likely need to be filled and the skills gap is expected to result in 2 million of those jobs going unfilled [2].

The success of today's manufacturing requires public, private, and civic partnerships as well as an emphasis on skills education supported by private industry and private and public institutions. There is also a need to have constant practical innovations that promote and support entrepreneurship at young ages to keep up with this fast-paced market change of the 21st century. Studies show that increased quality of product variation is a linear result of qualification of workers [5]. The future of U.S. manufacturing will be based, in part, on educating the new generations in manufacturing-related STEM skills to prepare them for the skill-intensive jobs [6]. To perform better in the industry field, students need practical training in addition to academic education to close this gap. By introducing manufacturing processes and techniques at the high school level, students will become more aware of world demand, and by the time they are in college, they will be goal oriented and have a better decision for their careers.

An effective method to teach engineering concepts and manufacturing paradigms is through simulation and hands-on experimentation. Simulation allows participants to experiment with various systems in a realistic setting. Simulation has been used in a variety of business sectors; it is the second most popular used technique in the field of operations management [7-8]. Simulation, which is the process of imitating the behavior of a real system, has been widely used in many different applications including manufacturing, healthcare, and the service industry. There are two main types of simulations: computer simulation and physical simulation. Both simulation types require building a model for the system being simulated. Computer simulations involve the development of a computer program and usually require specialty skills. Physical simulations require hands-on experiments using a prototype of the real system.

Using hands-on simulations to teach manufacturing systems is an effective tool to convey the concepts to learners. Both technical and non-technical skills can be integrated with the simulations. The use of hands-on simulations can improve the student's understanding of the interrelationship between manufacturing concepts. It also provides a means to engage students in classrooms allowing students to become active and interested in the topic [5]. Studies found that hands-on simulations can improve student attendance by 50% [9]. In manufacturing education, hand-on simulations can be used for teaching students the principles of manufacturing systems and processes. A limited number of studies in the literature discussed the development of hands-on simulations for manufacturing systems and processes. For example, a study developed hands-on activities to compare craft production and mass production in the classroom [10]. In a similar study, a simulation game was developed to educate students and industry professionals on lean manufacturing principles [11]. A summary of the use of simulation games in manufacturing was discussed in Aqlan and Walters [12]. This study discusses the development and use of hands-on simulations of producing car toys to teach manufacturing concepts to high school students. The students worked in groups and their understanding of manufacturing concepts is evaluated through observations and surveys. A simulation task is allocated to each group member such as supplier, customer, assembly, inspection, and test. The performance of each student group is evaluated based on the number of car toys produced per unit time, number of defects, and total production cost. Data pertaining to student performance and learning is collected and analyzed.

2. Development of the Hands-on Simulation

This section discusses the development of the simulation games for the manufacturing systems. Car toys made of plastic bricks are used for the simulation activities because they are cheap and easy to assemble and disassemble. In this paper, we will discuss the simulation of mass production, one of the main manufacturing paradigms. The simulations were developed and then implemented by high school and community college educators as part of a summer research program. In a previous study, we developed a simulation game for the craft production paradigm. In mass production, large quantities of standardized products are produced by various techniques: division of labor, assembly lines, and automation machinery. Mass production was utilized by Henry Ford in the 1910's with the manufacture of cars, which resulted in the most dominant form of manufacturing around the world. Many manufacturers began using mass production because it was an efficient and cheap way to produce goods. Figure 1 shows the process flow for mass production. The developed game was used to teach high school students the concepts of mass production. The production strategy for mass production is based on a push system; manufacturers designed products and pushed them to the customer with only limited inputs. The advantage of mass production is the decrease in labor costs from the increased assembly rate of production from automated processes. The disadvantage is that workers are not motivated due to repetitive procedures while the production line is not flexible and can cause ceased production from broken equipment or disturbances within the line [1]. Mass production may produce products at a high-volume rate; however, quality may decrease. This simulation requires the total of seven participants. Five participants are involved at the tables to build the assemblies; the two other participants will be acting as an inspector and tester. All participants will work together in an assembly line to produce a standardized product. The simulation game design for each job assignment is shown in Figure 2.

The simulation demonstrates how one standardized product is assembled and tested through a production line and delivered to inventory. The simulation begins with students receiving instructions for a standardized assembly of a basic car toy design. The assembly is divided into five sub-assembly steps, one per station. Each of the five stations begins with enough components to build five cars. The worker at each station will repetitively build the same assembly for the duration of the simulation game. Each builder will also record the time the sub assembly is delivered to inspection. Once a station has depleted their component stock they may proceed to the supply/inventory area to gather components for five cars. An inspector will inspect each sub assembly after each station to move sub-assemblies down the production line. A tester will test finished product, perform final inspection and deliver to inventory.

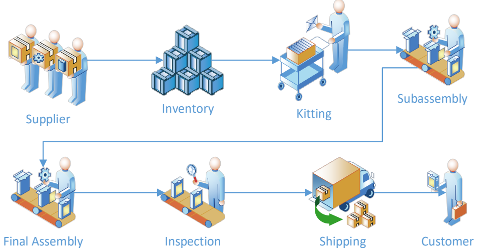


Figure 1: Mass Production Layout

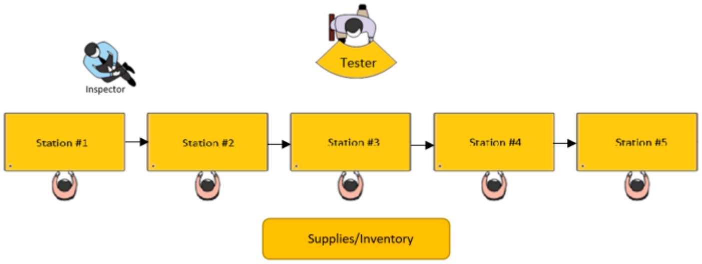


Figure 2: Mass Production Simulation Set-up

A randomly generated customer demand (by rolling dice) is implemented at the end of the simulation to determine how much is sold and what is left in inventory. The simulation game is conducted for 15 minutes. Sample instructions for Stations 3 and 6 are shown in Figures 3 and 4, respectively.

STATION #3	Step 1: Front End Components	Step 2: Front End Layer Assembly	Step 3: Front End Windsield Assembly	Step 4: Front End to Base/Wheel Assembly
Small Soft Wheels				
Medium Hard Wheels				
Medium Soft Wheels				

Figure 3: Visual instructions for Station 3

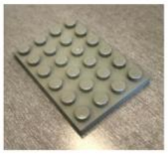
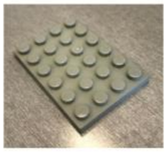
STATION #6	Small Soft Wheels	Medium Hard Wheels	Medium Soft Wheels
Step 1: Roof Components			
Step 2: Roof Assembly			

Figure 4: Visual instructions for Station 6

Upon simulation completion, all assemblies and sub-assemblies at each station should be observed and recorded for cost analysis. A randomly generated customer order should be produced using dice to determine total sales. Figure 5 shows samples pictures from the hands-on simulation activities. The research team bought plastic bricks and build dedicated kits for the simulations. One kit can be used by seven students at a time and it costs less than $50.

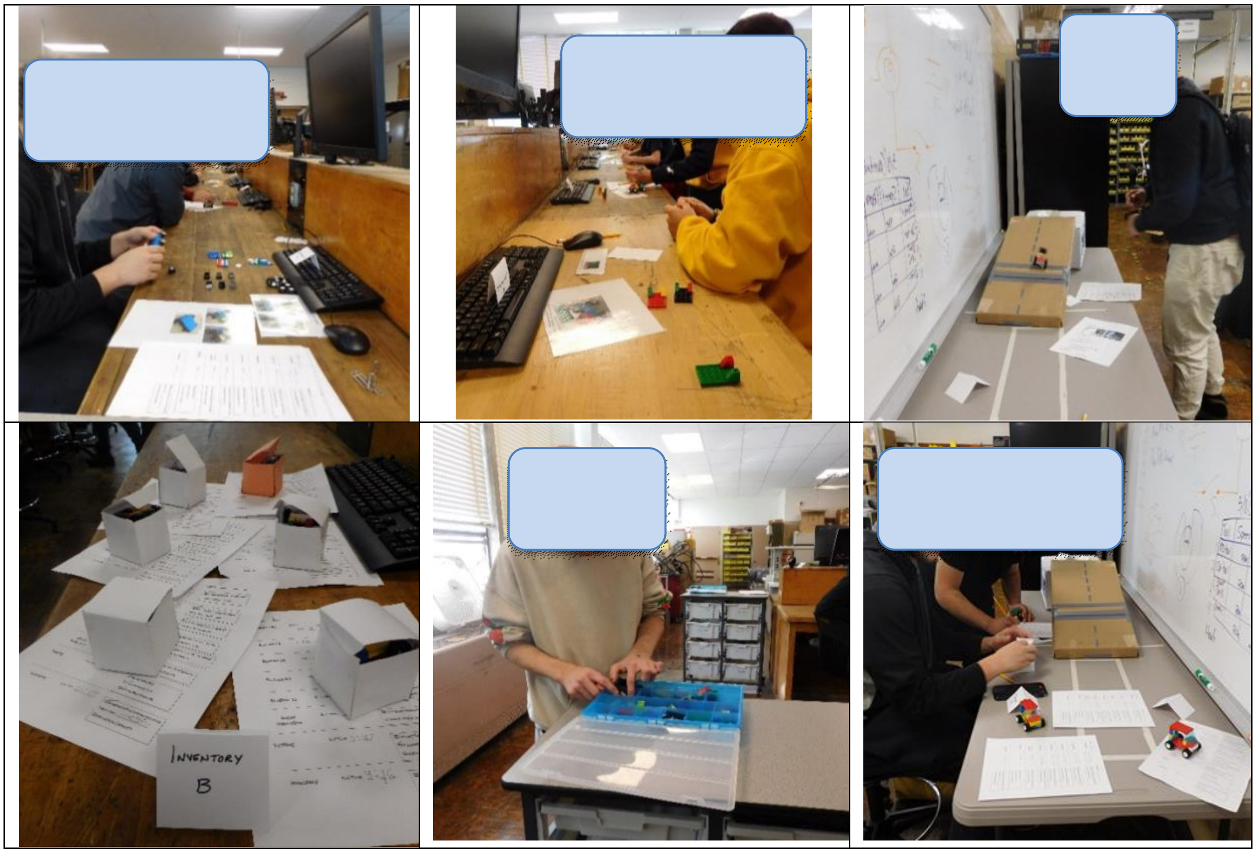


Figure 5: Sample pictures from the simulation activities

3. Results and Analysis

The simulation activities were conducted as part of the pre-engineering course (CTE Course Number: Engineering Technologies CIP-15.9999). The simulation involved 11th graders with 28 students participated in 4 groups. The mass production simulation game was evaluated based on four student groups performing the simulation twice. Each simulation consisted of 5 assembly operators, 1 inspector, and 1 tester per group. All job assignments were randomly chosen for each group. Students were able to produce an average of 11 finished cars in about 15 minutes. Table 1 shows the results for each test run and trial for the four groups (A, B, C, and D).

Table 1: Final simulation results

Performance Measure	Group A1	Group A2	Group B1	Group B2	Group C1	Group C2	Group D1	Group D2
Total Cars Built	12	11	11	15	10	13	10	6
Average Time/Car	2.17	2.95	2.97	1.75	3.74	3.02	3.13	6.22
Cars Reworked	0	0	0	0	0	0	0	0
Cars in Production	1	4	4	1	1	1	2	6
Customer Order	**20**		**22**		**13**		**14**	
Cars in Inventory	**4**		**4**		**10**		**2**	

The simulation was also designed to observe the flow of the production line. All build times were recorded (using a stop watch) after each subassembly. Figure 6 illustrates the average build times for each station. It is observed that the most time to assemble the car is at Station #1 with 18% and Station #2 with 28% of the time. In these two stations, students assemble the tires with axles and the base of the cars. The teams were provided with standard forms to conduct the cost analysis after the customer sales was generated. In all trials the manufacturer did make a profit from the customer order. The average production rate was 0.73 cars/min. Figure 7 illustrates that there is more cost associated with the cost of goods sold in combination with the capital charges which decreases the amount of profit. Therefore, improvements could be made to the production line to decrease work in progress and labor costs which would then increase the equivalent work added. (Note: COGS = cost of goods sold, EAV = equivalent added value).

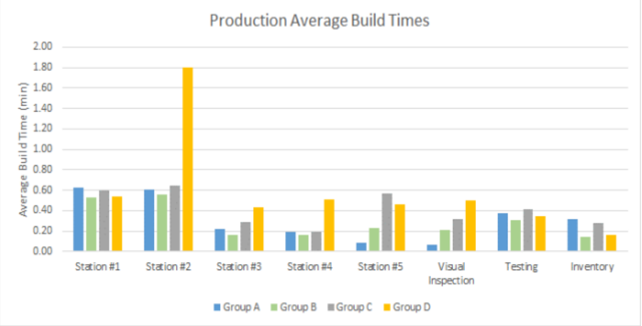


Figure 6: Production Average Build Times

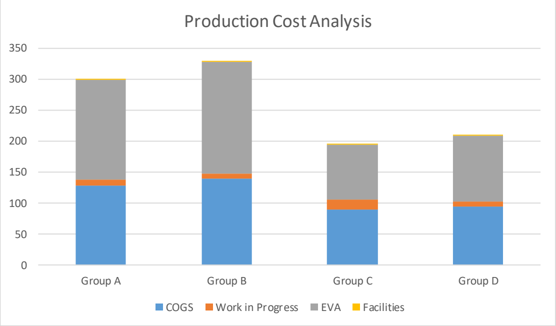


Figure 7: Production Cost Analysis

The students completed a questionnaire (developed by the researchers) to present feedback on the understanding of mass production. Table 2 lists the questions that each participant answered. For questions 1 and 3 all students agreed that the production style focused on quantity and the customer interaction occurring at the end of the process. For question 2, most students felt that they would produce more cars as they became a better assembler (Figure 8).

Table 2: Mass production quantitative questions

Number	Question	Answer
Q1	Did the style of production focus on quality or quantity?	(Quality) 5 4 3 2 1 (Quantity)
Q2	The output of product would increase as I become a better Assembler?	(Agree) 5 4 3 2 1 (Disagree)
Q3	When was the customer involved in the process?	(Beginning) 5 4 3 2 1 (End)

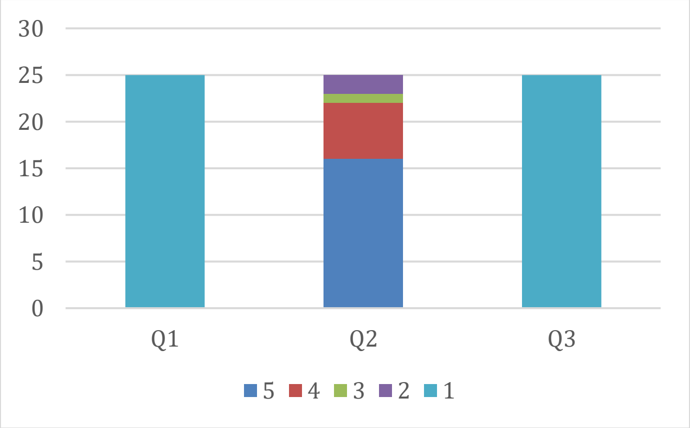


Figure 8: Mass production questionnaire results

Qualitative questions were considered to additionally gather feedback on further understanding of mass production. The questions are: Q1: Define Mass Production based on the activity performed? Q2: What is the benefit of mass production? Q3: What part of the assembly process could have been improved? The participants' answers were analyzed using word clustering as shown in Figure 9. The responses to these questions indicate that the benefit for mass production is that the process is ***faster*** and produced ***quantity***. The assembly process improvements were a combination of various responses including improving the inspection station. It is worth noted that the high school students who participated in the manufacturing simulations have reported that the simulations helped them understand manufacturing concepts and increased their awareness of manufacturing. Moreover, several of our high school grduates who participated in the program were hired by local manufacturing companies as full time employees.

Figure 9: Word clouds for mass production questions

4. Conclusions and Future Work

In this paper, we discussed the development and use of simulation games to teach manufacturing systems concepts to high school students. Specifically, we focused on the mass production paradigm. Results from the simulation activities indicated that high school students were able to learn the basics of the mass production paradigms and associated concepts such as cycle time, production cost, and work-in-process. Students were exposed to these terms during the simulation activities and their answers to the qualitative questions conducted at the end of the simulation activities reflected the characteristics of the mass production paradigm. Future work will focus on extending the simulations to mass customization and Industry 4.0. We will also develop virtual reality simulations for the manufacturing paradigms and compare them with the physical simulations. Moreover, the professional skills of the student groups such as communication, leadership, and teamwork will also be considered.

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