Development of a Simulation Game for the Craft Production Paradigm

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Abstract

Simulation is an effective and practical tool for teaching manufacturing systems; it allows students to experiment with various systems in a realistic setting. This paper develops a simulation game for the craft production paradigm using Lego blocks. The role of participants is to understand the craft production paradigm and learn how to engage in a team-work and manage time. The simulation game consists of hands-on activities that will be used to teach high school students the concepts of manufacturing systems with the focus on the craft production paradigm. The hands-on activities discussed in this paper were performed by a group of high school teachers who served as suppliers, customers, and assembly operators. Two groups of six teachers conducted the simulation experiments and results on both system performance and learning outcomes were analyzed.

Keywords
Manufacturing paradigms, craft production, Legos, simulation, manufacturing education.

1. Background

In the recent few years, the job market has become more competitive due to globalization and rapid technology advancements. There is 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. The quality of product variation is a linear result of the qualifications of workers. To perform better in the industry field, students need practical training in addition to the academic education. The rapid change and complex competition encourage companies to recruit multi-skilled engineers and technicians with enough knowledge and expertise.

Manufacturing is the application of machines, tools and labor to transform raw materials to finished goods for sale or use. It is an important contributor to the economy as it supports all the other sectors of the economy and provides a wide variety of jobs. Over the years, manufacturing has evolved through a number of production models known as paradigm. The common manufacturing paradigms that characterized significant periods of time include: craft production, mass production, Lean production, mass customization, and personalized production. According to Koren (2010), a manufacturing paradigm is defined as “A revolutionary integrated production model that arises in response to changing societal and market imperatives, and is enabled by the creation of a new type of manufacturing system”. The evolution of the manufacturing paradigms is illustrated in Figure 1. The main drivers for these manufacturing paradigms include globalization, technology advancements, and societal needs. Understanding the different manufacturing paradigms can allow extrapolation of future trends through analysis and specification of the key drivers behind the changes (Mehrabi et al., 2000).

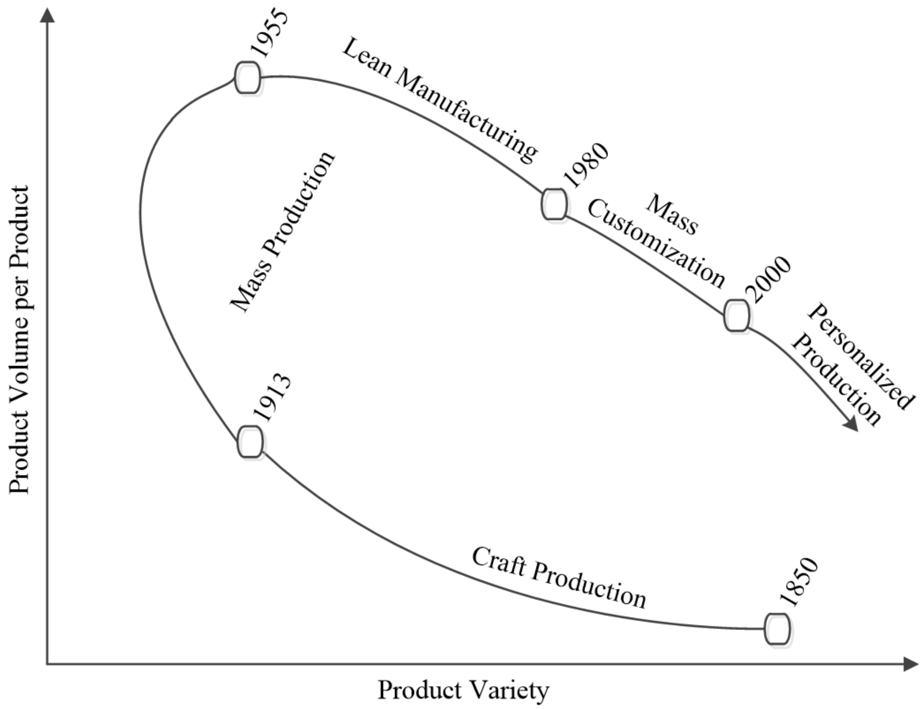


Figure 1. Evolution of manufacturing paradigms (adapted from Hu, 2013)

The future of U.S. manufacturing will be based, in part, on educating the new generations in manufacturing-related skills to prepare them for the skill-intensive jobs. However, most of high school teachers do not have training in engineering concepts and there is a dearth of programs and curricular content in this area (Kimmel et al., 2006). An effective way to teach engineering concepts and manufacturing paradigms is through simulation hands-on experimentation.

Simulation games and hand on activities provide a means to engage students in classrooms allowing students to become active and interested in the topic (Ammar and Wright, 1998). According to literature, hands-on simulations can improve student attendance by 50% (Kresta, 1998). In manufacturing education, simulation games and hand-on activities can be an effective method for teaching students the principles of manufacturing systems and processes. Several studies in the literature have developed physical simulations for manufacturing systems and processes. For example, Simpson (2003) developed hands-on activities to compare and contrast craft production and mass production in the classroom. A paper airplane activity was used to demonstrate the benefits and drawbacks of craft and mass production. In a similar study, Ozelkan and Galambosi (2009) developed a simulation game that can be used to educate students and industry professionals on lean manufacturing principles. Aqlan and Walters (2017) also discussed the use of simulation games to teach Lean manufacturing principles.

Manufacturing simulation games are effective tools for teaching the several steps of manufacturing development techniques that have been practiced in the history. This simulation teaches the young generation, starting from high school, with the manufacturing process such as machinery, workforce, market demand, benefits and drawbacks of each step. The educational purpose of manufacturing simulation is helping students to learn different methods of the manufacturing process and familiarize them with the actual practice in the real world. Allowing students to explore unknowns is a major key factor in entrepreneurship, which this simulation motivates students to focus on critical thinking, problem-solving and find the alternatives solutions and techniques for producing a better product. As high school students learn more about manufacturing processes and techniques, they will become more aware of manufacturing, and by the time they are in college, they will be goal oriented and have a better decision for their careers. This simulation teaches science teachers to get their students involved in several different manufacturing processes and their integration in the practical world.

3. The Craft Production Paradigm

Craft production was a method to produce goods before industrialization; this method was a simple way to transform raw materials into a final high quality products in a workshop where one skilled worker fulfills a custom order. In craft production, skilled workers use general purpose machines and tools to produce exactly what the customer paid for; one product at a time (Koren, 2010). Every unique product is produced separately in a small machine shop supported by limited technology aids and general purpose machines. Craft production focuses on producing high quality products, usually at high costs and without any standardization (Modark, 2014). In craft production, not two products are exactly the same and there is a trade-off between process efficiency and product-process flexibility. Some craft production firms are still operating today such as Aston Martin. The company has only made 15,000 craft produced cars since its establishment in 1913 (www.astonmartin.com). Figure 2 shows a process flow for the craft production paradigm.

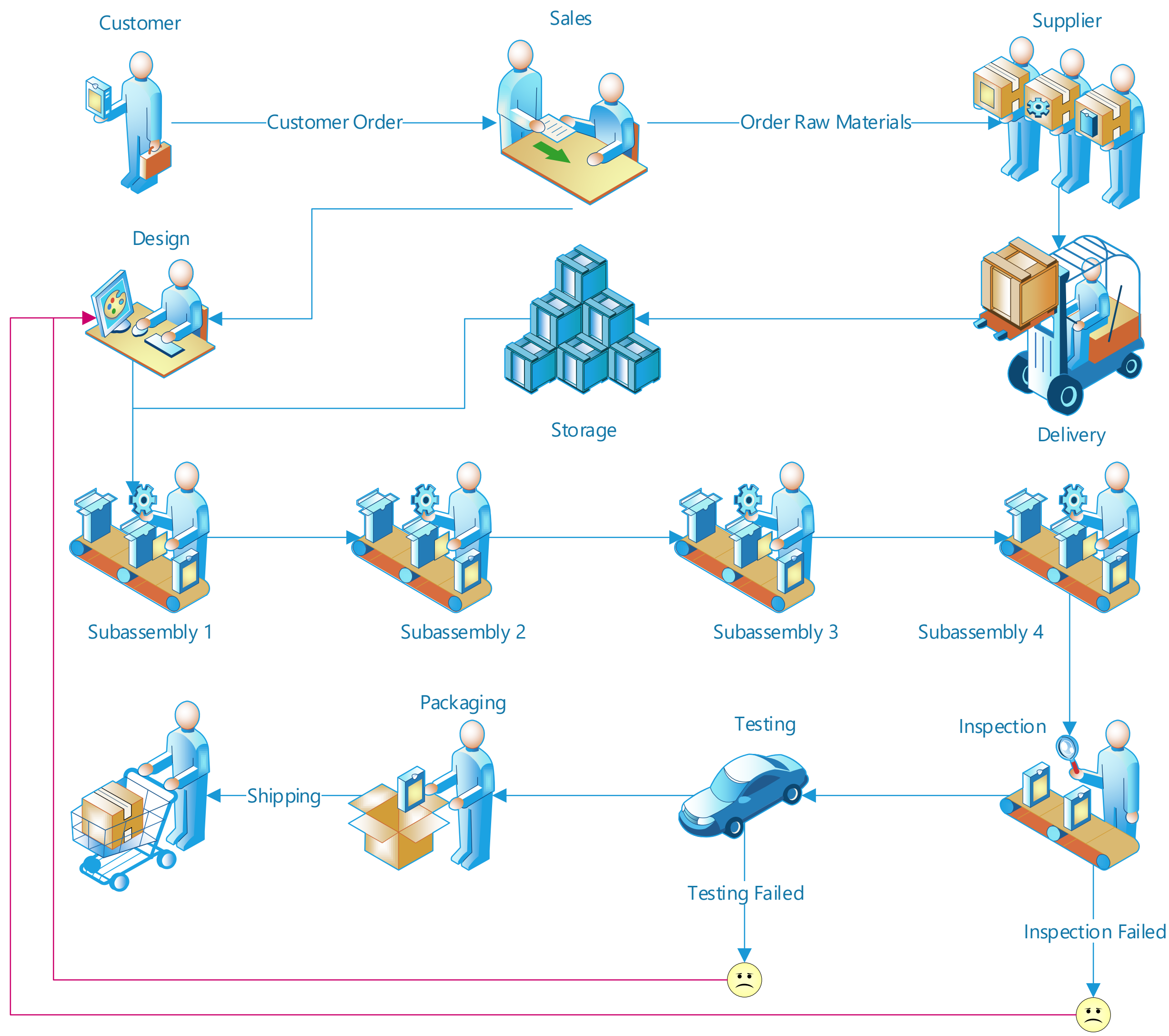


Figure 2. Process Flow for Craft Production

2. Development of the Simulation Game

This Sections discusses the development of a simulation game for the craft production paradigm. We will use Lego blocks because they are cheap and easy to assemble and disassemble. The developed game is conducted by a group of high school teachers and will be used to teach high school students the concepts of craft production. The production strategy for craft production is based on a pull system; after a customer's order is placed, the production will start by designing and then making the product. Craft production requires a very skilled worker who has full knowledge of all steps of the process. The advantage of craft production is the high variety of work, which avoids any boredom. The disadvantage is that one person is in charge of the full process. Therefore, that single person must be highly qualified to get the job alone, which may slow down the speed of the production. Also, this method of production is based on a small economical scale and producing high-quality, low volume products.

2.1 Set Up and Preparation

The craft production simulation game requires a total of 6-7 participants. 4-5 participants are involved at the tables to build the crafts; the 2 other participants will be acting as supplier and customer. Because the production is craft method, all participants will work individually. The simulation game design for each job assignment is shown in Figure 3.

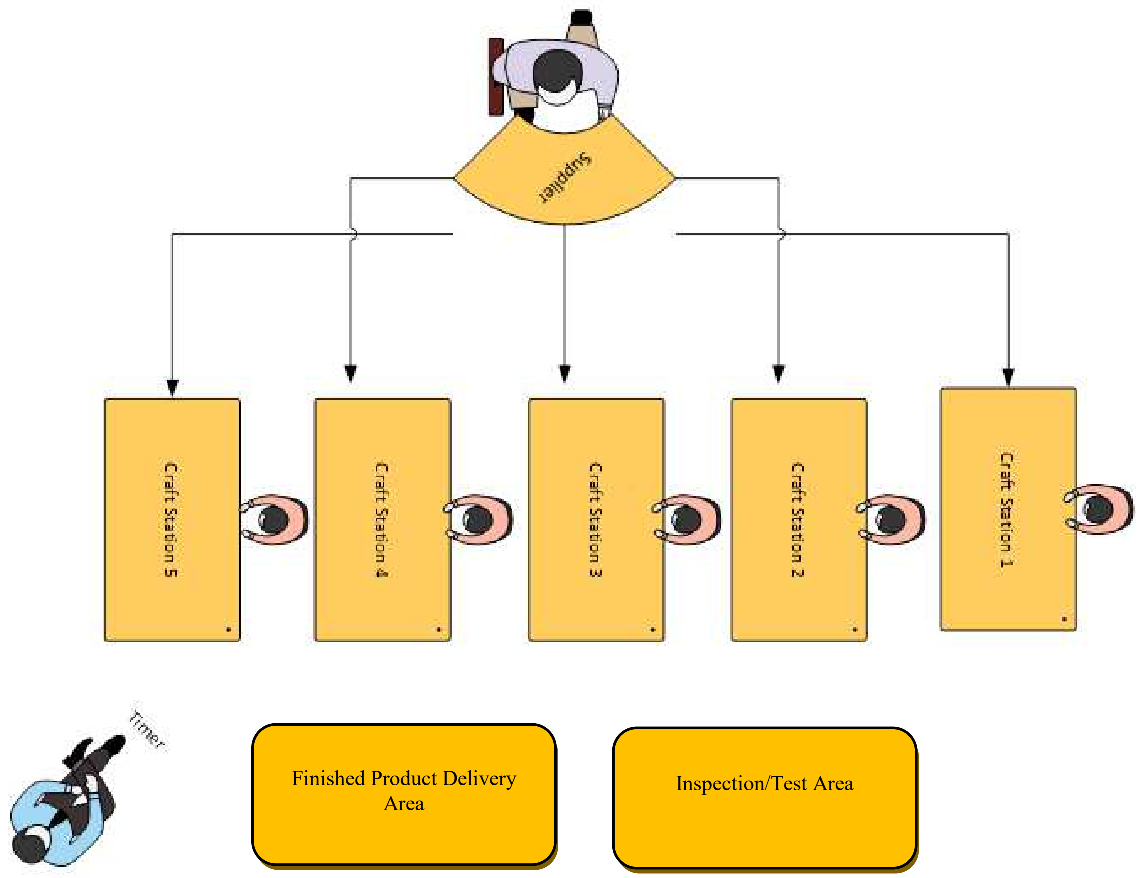


Figure 3. Layout for the craft production simulation

2.2 Simulation Procedure

The simulation hands-on activities demonstrate how one person (craftsman) conducts the processes from initial customer order to final delivery. The process begins when a customer places an order to the builder for a customized design. An order for the raw material is generated from the builder and placed with a supplier. After the components are received, production starts and assembly of the product is in process. After completion of the product, the final inspection and testing is also performed by the builder at which this craftsman must be fully knowledgeable and skilled to make sure the final product meets customer specifications. The finished product is then delivered to the customer. The simulation game is played for 30 minutes at which the timer will begin and end the simulation as well as record the process times and number of products produced.

Step 1: Generate Customer Order (Items needed: <u>Customer Order Form</u>, 6-sided die*)
**All data for customer order forms will be randomly generated with dice*

1. Write your Builder Number on your <u>Customer Order Form</u> (Figure 4).

2. Roll Die to Choose ***<u>Car Design</u>***
   a. Even Number – Choose Option A
   b. Odd Number – Choose Option B

3. Roll Die to Choose ***<u>Wheel Options</u>***
   a. Roll a 1 or 2 – Choose Large Wheels
   b. Roll a 3 or 4 – Choose Small Wheels
   c. Roll a 5 and 6 – Choose Hard Wheels

4. Roll Die to Choose ***<u>Roof Color Options</u>***
   a. Roll 1 – Black Roof
   b. Roll 2 – Red Roof
   c. Roll 3 – Blue Roof
   d. Roll 4 – Green Roof
   e. Roll 5 or 6 – Roll Again

5. Roll Die to choose ***<u>Packaging/Delivery Options</u>***
   a. Even Number – Choose Standard
   b. Odd Number – Choose Premium

Customer Order Form   Builder #

<u>Car Design Options</u>

☐ Option A: Car w/ Windshield

Car Features: 1 x 1 Tall (6), 1 x 3 Tall (2), 1 x 4 Tall (2), 2 x 2 Slant (2), Axle (4), 2 x 2 Flat (4), Spoiler (2), Wheels (4), Steering Wheel (1), Windshield (1), 4 x 6 Flat (1), 2 x 8 Flat (2) **Cost: $3.87**

☐ Option B: Car w/o Windshield

Car Features: 1 x 1 Tall (10), 1 x 3 Tall (2), 1 x 4 Tall (2), 2 x 2 Slant (2), Axle (4), 2 x 2 Flat (4), 1 x2 Slant (2), Wheels (4), Steering Wheel (1), 4 x 6 Flat (1), 2 x 8 Flat (2), **Cost: $3.73**

<u>Additional Options</u>
(Additional charges applied to design cost)

Wheel Options
☐ Large Wheels ($0.39 / wheel)
☐ Small Wheels ($0.23 / wheel)
☐ Hard Wheel ($0.24 / wheel)

Roof Color Options
☐ Black Roof ($0.19)
☐ Red Roof ($0.25)
☐ Blue Roof ($0.25)
☐ Green Roof ($0.25)

Packaging/Delivery
☐ Standard ($0.15)
☐ Premium ($0.25)

Figure 4. Customer order form

Step 2: Complete Supply Order (Items Needed: Customer Order Form, Supplier Order Form/Inventory Checklist)

Builders will generate a component order form (Figure 4) from the generated customer order form and proceed to the supplier to receive Lego™ components. Once components are received the builder will verify that all components are supplied using the inventory check list (Figure 5). If components are missing the order form should be resubmitted to the supplier. This order form represents the wait time it takes the builder to receive supplies once a customer order is generated. It is typically during this time that a craftsman may develop a design or make improvements to a defined design to meet the new specifications of the customer.

Builder #			Trial #							
Catalog Item		**Size/Cost**		**Customer Order**		**Inventory Check List / Car**				
				Quantity	**Total Cost**					
Flats 4 x 6 R G B		2 x 2	0.11							
		2 x 6	0.18							
		2 x 8	0.25							
		4 x 6 (Black/Color)	0.19/0.25							
		4 x 8	0.25							
Axle		0.18								
Tires (wheel hubs required with small and large tires)		Small	0.15							
		Large	0.29							
		Hard	0.24							
Wheel Hub		Small	0.08							
		Large	0.10							
Spoiler		0.13								
Talls		1 x 1	0.07							
		1 x 3	0.14							
		1 x 4	0.15							
Slants		1 x 2	0.11							
		2 x 2	0.14							
Steering Wheel		0.29								
Windshield		With	0.38							
		Without	0.00							
Packaging		Standard	0.15							
		Premium	0.25							
				Overall Total Cost:						

Figure 5. Supplier Order Form and Inventory Checklist

Step 3: Assemble Design (Items Needed: Lego™ Blocks, Assembly Procedure)

Builders can begin to assemble their customer driven design after confirming inventory of all components were received from the supplier. Any components not received would require a resubmittal to the supplier. All components received allowed the builder to begin the assembly procedure. The builder would build the design generated from the customer. This simulation had two possible build designs with some various options for wheels and roof color. Figure 6 shows the assembly procedure.

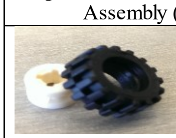
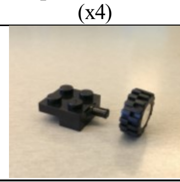
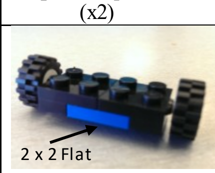
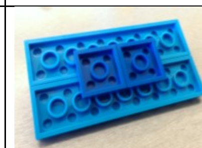
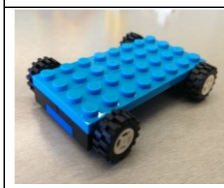
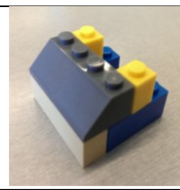
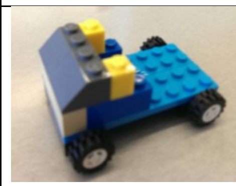
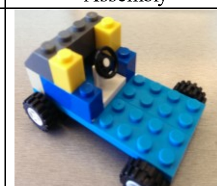
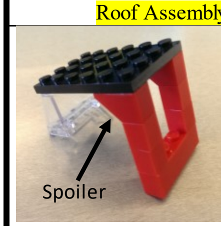
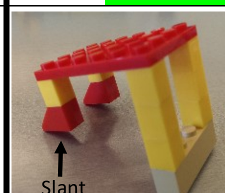
Assembly Procedure			
Step 1: Tire and Wheel Hub Assembly (x4)	**Step 2:** Wheel/Axle Assembly (x4)	**Step 3:** Coupled Axle Assembly (x2)	**Step 4:** Frame Assembly
 * If required			
Step 5: Chassis Assembly	**Step 6:** Front Cab Assembly	**Step 7:** Cab to Chassis Assembly	**Step 8:** Steering Wheel Assembly
	 1 x 1 Tall (2) 1 x 3 Tall (2) 1 x 4 Tall (1) 2 x 2 Slant (2)		
Option A: (with Windshield) Roof Assembly	Roof to Frame Assembly	**Option B:** (w/o Windshield) Roof Assembly	Roof to Frame Assembly
 1 x 1 Tall (2) 1 x 3 Tall (2) 1 x 4 Tall (1) Spoiler (2) 4 x 6 Flat (1)		 1 x 1 Tall (8) 1 x 4 Tall (1) 1 x 2 Slant (2) 4 x 6 Flat (1)	

Figure 6. Assembly procedure

Step 4: Inspection and Performance (Items needed: Assembled Design, Quality Control Sheet, Test Track)

Builders would proceed to the inspection and drive performance area to evaluate their designs. The builder would partake in their own visual inspection to observe if the design was to customer specifications and had no design flaws. The performance criteria consisted of evaluating on a flat surface to verify all 4 wheels rotating freely and on a one bump ramp to confirm all components, including an added driver, would remain intact. (Figure 6)

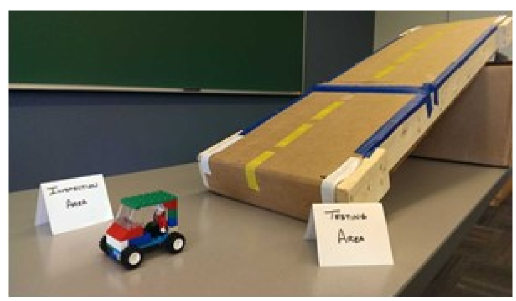


Figure 7. Test area

Step 5: Customer Delivery (Items Needed: Assembled Design w/ Packaging, Stop Watch, Timer Recording Sheet)

Builders would deliver all acceptable designs to the customer at the assigned customer delivery area. The timer would record the delivery time for each design for every individual builder for the duration of 30 minutes. Builders would continue to assemble additional builds (identical customer order) after each delivery was made.

Figure 8 below shows pictures of some activities of the simulation runs where twelve teachers were divided into two groups, each group consists of a supplier, a customer, and four individual assembly operators.

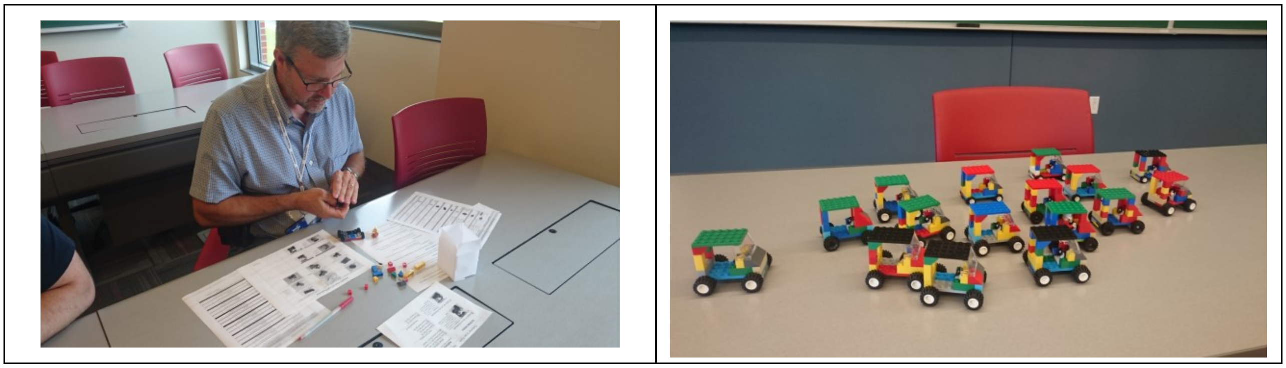


Figure 8. Some pictures for the hands-on activities

3. Results and Analysis

The craft production simulation game was evaluated based on a test run and two group trial runs. Each simulation consisted of 4 builders, 1 supplier, and 1 timer per group. The timer serves as a customer as well. There were two simulation groups (A & B) for each trial but only one group for the test run. All job assignments were randomly chosen for each test run and trial.

The test run was generated to establish any discrepancies in the simulation procedure for the 30 minute duration. There were no significant process disruptions, therefore the data will be used for analysis. See Figure 9.

		Test Run			Trial 1A			Trial 1B			Trial 2A			Trial 2B		
Builder	Cars Built	Start	Finish	Total	Start	Finish	Total	Start	Finish	Total	Start	Finish	Total	Start	Finish	Total
	1	0	19.3	19.3	0	22.47	22.47	0	16.2	16.2	0	11.09	11.09	0	15.38	15.38
	2	-	-	-	22.47	28.34	5.87	16.2	21.4	5.2	11.09	18.44	7.35	15.38	21.32	5.94
1	3	-	-	-	-	-	-	21.4	27.4	6	-	-	-	21.32	26.44	5.12
	1	0	17.14	17.14	0	25.28	25.28	0	16.2	16.2	0	14.18	14.18	0	19.55	19.55
	2	17.14	25.42	8.28	-	-	-	16.2	23.45	7.25	14.18	23.32	9.14	-	-	-
2	3	-	-	-	-	-	-	23.45	29.3	5.85	-	-	-	-	-	-
	1	0	23.54	23.54	0	24.24	24.24	0	14.45	14.45	0	21.03	21.03	0	10.08	10.08
	2	-	-	-	24.24	29.58	5.34	14.45	19.4	4.95	21.03	26.44	5.41	10.08	15.56	5.48
	3	-	-	-	-	-	-	19.4	27.4	8	-	-	-	15.56	23.05	7.49
3	4	-	-	-	-	-	-				-	-	-	23.05	26.49	3.44
	1	0	24	24	-	-	-	0	15.4	15.4	0	9.05	9.05	0	15.25	15.25
	2	-	-	-	-	-	-	15.4	19.4	4	9.05	15.28	6.23	15.25	23.28	8.03
4	3	-	-	-	-	-	-	19.4	24.58	5.18	15.28	20.33	5.05	23.28	29.24	5.96

Figure 9. Simulation Timer Recorded Data (min)

All timed data was recorded by the timer for each group (see Figure 10). The average time (supplier + build) per car was calculated from the supplier order submittal to customer delivery. This data represents the entire time it would take to order/receive supplies, assemble the car, inspect and test, and delivery to the customer. This would all occur after the craftsman had met with a customer and generalized a conceptual design. The average customer generation/order form time was calculated to simulate the craftsman meeting with the customer and creating the design concept.

Referring to Figures 9 and 10, the average time it took to receive supplies, assemble, inspect/test, and deliver one car to the customer is approximately 6.45 minutes. The test run and all trials are comparable and consistent with the longest time to deliver a car was the test run. The test run was the first time the simulation was initiated and the process was not completely explained to all participants. In the trials, there was a brief introduction about the process prior to simulation which may have resulted in less confusion and quicker output. This is apparent with the number of total cars built during the simulation (Figure 11).

	Test Run	Trial 1A	Trial 1B	Trial 2A	Trial 2B
Total Cars Built	5	5	12	9	11
Average Time (Supplier + Build)	8.28	5.61	5.8	6.64	5.92
Average Customer Generation/Order Form Time	12.72	18.39	9.76	7.2	9.14

Figure 10. Total cars built and average time (min)

Figure 11 represents the total number of cars completed during simulation for each group during the simulation. In the test run the cars produced is extremely low. This is when all participants are unfamiliar with the process and are assigned job assignments with no training. In Trial 1 the groups show a difference of output of cars manufactured. This is not unexpected for some craftsman who become extremely efficient with their craft while others that are just beginning would take longer to perfect. Those familiar with Lego^{TM} building may assemble and/or supply components faster. In Trial 2, where the trial is repeated both groups begin to close the gap of output. The participants are aware of the process and some have become expert builders. The overall total cars manufactured was 17 for Trial 1 and 20 for Trial 2.

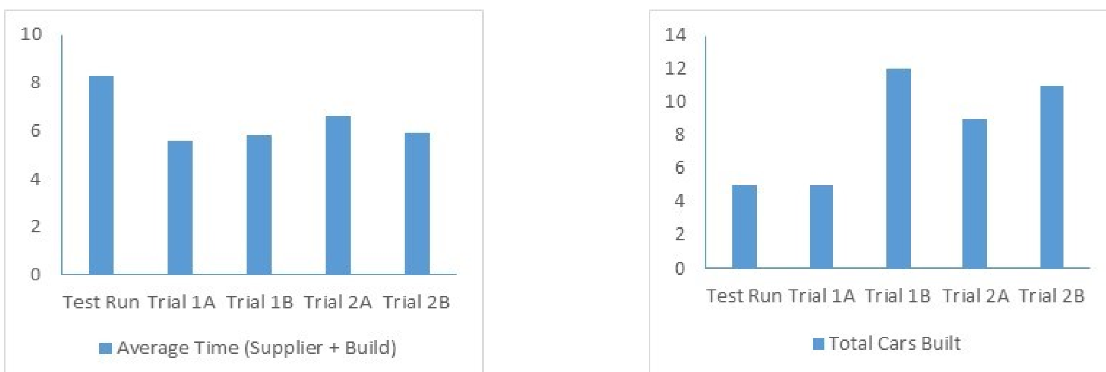


Figure 11. Average time (left) and total cars built (right)

Participants were asked to define craft production based on the simulation and determine if the style of production focused on quality, efficiency, or quantity. The answers provided from the participants were used as an assessment to verify if the simulation was representative of craft production. The results confirm that in craft production, quality is most prevalent followed by one person. Figure 12 represents the definition of craft production after performing the simulation.

Figure 12: Simulation survey results

4. Conclusions

Simulation is an effective method of teaching manufacturing systems because the manufacturing processes to produce a finished product are impractical for the classroom. Simulation provides a basis to understand the manufacturing production methods without the use of tools and machinery. The craft production simulation game developed in this study will provide participants the ability to visualize the process a craftsman executes to deliver a finished product to a customer.

The randomized customer order generation simulates the craftsman meeting with the customer to conceptualize a customized design. The supplier gathering and shipping orders to the craftsman simulates the wait time from design to assembly. During this simulation, it was apparent to see from generating the customer order to receiving the first shipment of components was the most time consuming, approximately 38% of the 30 minute duration. The duration of the simulation was assembly, inspection/testing, and delivery which amounted to 22% of the process to complete one car. This would only allow a craftsman to build 3-4 cars respectively which represented that the process was slow and finished product output was at a minimum. However, as the craftsman became more trained and an expert at the process the time to produce the finished product improved.

The simulation emulated the progression of craft production. The output was a unique quality product that required a highly skilled professional to perform all phases of the manufacturing process. The process was slow and resulted in low finished product output. The simulation game created using the Lego™ blocks is an inexpensive plan that will proved teachers a guaranteed method to represent the manufacturing paradigm – craft production. Future work will focus on developing simulation games and hands-on activities for the other manufacturing paradigms.

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References

Ammar, S.H., and Wright, R.H., Introduction to operations management: The MBA in-class experience, *Decision Lines*, vol. 29, no. 5, pp. 3-6, 1998.

Aqlan, F., and Walters, E.G., Teaching Lean principles using simulation games, *American Society for Engineering Education (ASEE) Conference*, pp. 1-13, 2017.

Hu, S.J., Evolving paradigms of manufacturing: From mass production to mass customization and personalization, *Proceida CIRP*, vol. 7, pp. 3-8, 2013.

Kimmel, H., Carpinelli, J., Burr-Alexander, L., and Rockland, R., Bringing engineering into K-12 schools: A problem looking for solutions, *American Society for Engineering Education Annual (ASEE) Conference*, 2006

Koren, Y., *The global manufacturing evolution*, New York, NY: Wiley, pp. 23, 2009.

Kresta, S.M., Hands-on demonstrations: An alternative to full scale lab experiments, *Journal of Engineering Education*, vol. 87, no. 1, pp. 7-9, 1998.

Mehrabi, M.G., Ulsoy, A.G., and Koren, Y., Reconfigurable manufacturing systems: Key to future manufacturing, *Journal of Intelligent Manufacturing*, vol. 11, pp. 403-419, 2000.

Modark, V., *Handbook of research on design and management of Lean production systems*, Hershey, PA: IGI Global, 2014.

Ozelkan, E., and Galambosi, A., Lampshade game for lean manufacturing, *Production Planning and Control*, vol. 20, no. 5, pp. 385-402, 2009.

Simpson, T.W., Experiences with a hands-on activity to contrast craft production and mass production in the classroom, *International Journal of Engineering Education*, vol. 19, no. 2, pp. 297-304, 2003.

Biographies

John Wingerter is a CTE instructor at Erie High School in the Erie School District in Pennsylvania. John's field of instruction is defined by CIP code 15.9999 (Engineering Technologies). His career encompasses 25+ years in the areas of engineering and manufacturing spanning the industries of Oil and Gas, Medical Sterilization, Transportation, Electronic Signage, and Steel Products and Services. John holds an Associate degree in Electrical Engineering Technology, Bachelors in Business, and an MBA with specialization in Project Management. He has held leadership positions in several organizations and was active with Pennsylvania's Workforce Development Board. John believes in our youth and his passions drive him to transfer his experiences into his teaching to prepare students for the future.

Milinda McCorkle has been a CTE Pre-Engineering/Math teacher at Erie High School for the past 6 years. She obtained her Bachelor of Science in Chemistry and Mechanical Engineering from Gannon University and her Master's in Education at Edinboro University. She began her career of 12 years at Lord Corporation as a process engineer for their Materials and Process Development Team at which she had developed an interest in engineering and manufacturing. She is currently teaching Pre-Engineering at Erie High School with the focus on Engineering design and 3D modeling and is an advisor for their Battlebot competition teams. Milinda enjoys teaching and bringing creativity in design to many of her students with hopes to encourage more young women to pursue a career in engineering.

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