**IE Paper Airplane Activity**

**Objective**

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| **Objectives**  1.) Understand that industrial and manufacturing engineering focuses on process improvement.  2.) Learn the key differences between traditional (push) and lean (pull) manufacturing.  3.) Learn how bottleneck operations limit production capabilities.  4.) Learn the types of waste present in traditional manufacturing. |

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| **Skill Level:** This activity is targeted for middle school age level. | **Prep time:** 15 minutes **Class time:** Approximately 50 minutes |

**Materials**

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| * Minimum 80 sheets of white paper for each team of 5 students * At least 2 sheets of colored paper per team (For optional run listen in procedure) * 1 stopwatch per team of 5 students (For optional runs listed in procedure) * 1 writing utensil per group |

**Standards**

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| **Disciplinary Core Idea:** ETS1.C: Optimizing the Design Solution  **Performance Expectations:**  MS-ETS1-3 Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.  MS-ETS1-4 Develop a model to generate data for iterative testing and modification of a proposed object, tool, or process such that an optimal design can be achieved. | |
| **Practices** Asking questions / defining problems Developing / using models Planning / carrying out investigations Analyzing / interpreting data Math / computational thinking Constructing explanations / design solutions Engaging in argument from evidence Obtaining / evaluate / communicate | **Crosscutting Concepts**  Short/Long term Consequences  Positive/Negative Consequences  Society Driven Technology Systems and system models |

**Background Information**

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| **Introduction:**  Industrial and manufacturing engineering is the study and application of process development and improvement through the use of analysis and engineering methodologies. In a manufacturing environment there are two main types of production systems; the traditional, and the lean system. The traditional model relies on large inventories of finished goods and expected customer demand for products. The lean methodology is just the opposite, products are produced based on customer orders, i.e. a product would only be made after someone orders it, creating very little inventory quantities. Each of these methodologies is explained in detail below.  **Background Information:**  In the traditional manufacturing world, products are scheduled for production based on expected customer demand for a product; this is called a sales forecast. For example, if the forecast predicts that the *Peanut Butter Jelly Company* (PBJ Inc.*)* will sell 25 peanut butter and jelly sandwiches in a day, the manufacturing plant would make 25 sandwiches ahead of time and store them as finished goods. Manufacturers build and store large inventories of products in expectation that they will eventually be sold to customers. This type of manufacturing is called a “push” system. The forecast triggers the beginning of manufacturing a product regardless of if it has been ordered yet or not.  A product is made by going through a series of process steps. Each step adds a component or performs an operation. At the end of the last process a finished product is completed and stored. This cycle repeats for the total amount of products estimated by the forecast. It is defined as a push system because the forecast drives the first operation to build as many products as they can and push them forward to the next operation. The first process only stops production after the sales forecast has been filled. The traditional system as represented by the *Peanut Butter Jelly Company* is shown below.  *Figure 1: Traditional manufacturing flowchart for PBJ Inc.*  At first this sounds like a reasonable production methodology, but in reality there are many problems with this. First and foremost, forecasts are always estimates and are rarely completely accurate. In many cases this means that companies will overproduce the amount of products they need, leading to reduced profits or an overabundance of products that can’t be sold. In the case of PBJ Inc., if they predicted 25 sandwiches would be sold and in reality they only sold 15, what would the company do? They would be forced to offer the sandwiches at discount or simply throw them away. In both scenarios this causes the company to lose money.  Additionally, since this is a push system, production begins at the first operation. The operator will continue to apply peanut butter to sandwiches until his quota, as determined by the forecast, is met. Many times this causes imbalances in the flow of products through the facility. In the flowchart above, it is shown that the first two operations take 30 seconds each. These operations are what is called balanced, as they take the same amount of time to complete. The third operation takes 45 seconds, the slowest operation in the factory, and is called the “bottleneck” operation. In the 25 sandwich order the peanut butter operator starts a sandwich every 30 seconds this is no problem for the jelly operator as they can keep up an even production pace. The sandwich assembler however takes an extra 15 seconds to do the final steps. In the push system the peanut butter operator and the jelly operator are blissfully unaware of this time difference and continue to perform their operations at a pace taking 30 seconds. Imagine what happens to the assembler. The assembler is unable to keep up so a steady amount of sandwiches build up in front of this work station. This is called “Work-In-Process” (WIP). By having an abundance of WIP by the assembler, a large inventory of nearly finished products must be stored. This creates excess waste by creating a need to have a storage location for the WIP. 25 sandwiches can still be made but the flow through the factory is uneven. The pace is quick to start but then halts at the assembler, who ultimately creates the speed at which a finished sandwich can be completed. Any manufacturing process can only move as fast as the slowest component, which is the bottleneck.  On the other hand, in a lean manufacturing system, the number of products made are directly related to the orders purchased by customers, not the forecast. A good everyday example of this is *Subway Sandwiches;* they only make a sandwich after it is ordered instead of trying to predict what kind of sandwich will be ordered. This is known as a Pull System (opposite of the Push System described above).  To demonstrate the lean production system (pull system) with the PBJ Inc. example, the manufacturing process will begin when 25 sandwiches are ordered by customers. Since no completed sandwiches are in inventory, the sandwich assembler will be notified that a sandwich is needed. At this point, the assembler has no product to assemble and will then pass the message back to the jelly application operator who in turn will pass this information to the peanut butter operator, who begins production. This is referred to as a “pull” system because the information flow (the orders) begins at the end and flows backwards through the facility. The peanut butter applicator only makes sandwiches based on the jelly operator asking them to make another one. In this system, the production stops when the final order has been filled. The assembler no longer asks the jelly operator for more products and the jelly operator no longer requests any more from the peanut butter operator so they will have no more work to do. For the last step in the process to have material, the next-to-last step in the manufacturing process must be triggered, and so on down the line from the end to the beginning. All orders have been successfully “pulled” through the factory.*Figure 2: Lean manufacturing flowchart for PBJ Inc.*  With a pull manufacturing system, a large buildup of inventory before the bottleneck is avoided. The amount of WIP at each manufacturing step can be preset and held constant; whenever the set amount of inventory is depleted, the previous step produces more product until the desired level is met. This means the company will have less inventory holding costs. Besides reducing waste, another advantage of the pull system is the reduction of labor. Since there is no need to build up a large amount of WIP within the process, the workers do not need to make as much product at the beginning of the line. This reduces the amount of labor required as well as conserves the amount of unneeded resources in the production line.  In a pull production system, the 25 sandwiches that were produced only replaced the 25 sandwiches that were sold. This reduces the amount of sandwiches that might go bad due to being stuck in the line for a long period of time. In comparison, a push system might have a pb&j sandwich stuck in the production line waiting to be placed in a bag for a long time, decreasing the amount of time the customer can have the sandwich before it gets moldy or stale. Most modern production companies are utilizing the pull system to produce products in a more efficient manner. |

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| **Engage** |
| If you were working for the paper airplane company, why would you want to make the airplanes faster? Why would you want to reduce waste in the process of making the paper airplanes? What different kinds of wastes can be reduced? Think of the paper airplanes as money; the more airplanes that are produced, the more money the factory line can make. What are some of the costs of making an airplane? What happens if too many airplanes are produced? |

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| **Explore** |
| **Experiment Questions**:  How can we make everyone work the same amount?  Which production method had more WIP (work in process: the amount of paper plane started, but not finished)?  Why is the pull system preferred?  What are the advantages of having less WIP?  **Procedure: Paper Airplanes Production Line**  **Before First Run**  1. Divide Class into groups of 4 or 5 students.  2. 4 students represent the different work centers identified in step 4.  3. The 5th student is an optional “Quality Assurance” Person that ensures the other students “work at a comfortable pace”. (**Do not rush** to the point where the performance of tasks suffers). The quality assurance inspector observes the process during each run and checks that each finished airplane meets the quality outlines below (exact quality to be up for interpretation) :   * The tip of the airplane must be sharply pointed, not blunt. * When the wings are folded down together, they must be the same length (Poor quality example shown below)     4. The following images show the Assembly of a Paper Airplane and the responsibilities of each Work Center.  **Work Center 1:**    The work center 1 operator folds a paper in half hot-dog style, and passes it to work center 2.  **Work Center 2:**    Work center two folds the top left and top right ear to the middle line, refolds in half, and passes to work center 3.  **Work Center 3:**    Work Center 3 has two steps; they are to fold each wing from the inside to the outside edge, and then write the team name neatly on one side of the airplane before passing it to work center 4 (or write something, i.e. draw a star).  **Work Center 4:**    Work center 4 folds each outer wing from the inside opening down to the outer edge. The operator then inspects the plane and places it in the finished location.  5. Practice manufacturing paper airplanes: Each student should be given one or two pieces of paper to practice making an entire paper airplane per the instructions previously listed. Once students are comfortable making their own airplanes, reiterate the role of each work center and continue on.  6. Each team’s production line should be set up according to Figure 3 shown below for the first run. The blue boxes represent the work center folding areas, and the green boxes represent the area where each work center places an airplane after they have completed their fold. The next work center then pulls from this area for their operation.  *Figure 3 Push Production Line Set-up:*    Product Flow  7. Each assembly team will make one practice paper airplane according to the work center instructions to ensure students all know which folds they are responsible for.  **Run 1: Push System**  8. For the Push run, each student is to make their fold as fast as they can while still meeting quality expectations and “push” to the next work center.  9. Each work center must fold the paper that has been waiting the longest (First In First Out).  10. Begin the Push run.  11. Continue the Push run for all work centers until 12 airplanes have been completed.  12. Count the amount of WIP (unfinished airplanes) in the line.  13. Gather and clean up all airplanes to avoid distraction.  14. *Prompt Group Discussion*:  a. What worked well during the run? What didn’t work well?  Answer: Should identify that work center 3 is the slowest (bottleneck).  b. Did it seem like everyone was working equally hard? How does each member of the team  feel about their job?  Answer: Work center 3 should feel busier than everyone else. Work center 4 had more  free time (idle time).  c. Did it seem like large amounts of WIP was building up anywhere? Why? How might this  affect a real life manufacturing plant?  Answer: Work center 3 has a lot of WIP buildup because this operation takes more time.  WIP buildup causes storage issues, increased labor due to over-production, causes  excess storage costs.    d. What pros and cons for the push system can you think of?  Answer: Pros: Simple process  Cons: A lot of WIP, takes more time to get a plane through the system (has to go  Through first in first out inventory piles), excess labor.  **Before Pull Run**  15. Place 1 unit of WIP in front of work centers 2, 3 and 4 (in the green in/out boxes shown below). The work centers should look like figure 4 below.  *Figure 4: Pull System Assembly Line Setup*    Product Flow  16. For this run indicate that one worker’s “inbox” is another worker’s “outbox”.  17. Discuss that a worker can start work at their work center only when:  a. There is 1 unit in the incoming area (except work center 1) &  b. When their outbox is empty. If the outbox is not empty, halt production until it is. (When these conditions are met, the empty outbox is considered to be a signal that more production is needed from the prior work center).  **Run 2: Pull System**  18. Each work center must fold the paper that has been waiting the longest (First In First Out).  19. Begin the Pull run.  20. Continue the Pull run until 12 airplanes have been completed.  21. Count the amount of WIP (unfinished airplanes) in the line.  22. Gather and clean up all airplanes to avoid distraction.  23. *Prompt Group Discussion*:  a. What worked well during the run? What didn’t work well?  Answer: Should identify that work center 3 is still the slowest (bottleneck).  b. Did it seem like everyone was working equally hard? How does each member of the team  feel about their job?  Answer: Work center 3 should feel busier than everyone else. All other work centers  should feel like they had free time.  c. Did it seem like large amounts of WIP was building up anywhere? Why? How is this an  improvement?  Answer: No, all the work centers are producing at the same rate as the bottleneck.    d. What pros and cons for the pull system can you think of?  Answer: Pros: Consistent production speed, less WIP, faster time from order to delivery.  easier to find other production flaws (un-balanced jobs)  Cons: More complex system, requires coordination  **Run 3: Optional Time Component.**  Repeat both the push and pull runs as listed above. This time add a colored piece of paper as the 8th paper at the beginning work center. Have the quality inspector begin timing the colored paper as it begins the first operation. Stop timing when the colored airplane is fully finished. This will demonstrate the total time it takes 1 airplane to go through the production line (Time in system).  Discussion: Compare the time in system for the push versus pull runs. It should be shown that the push system has a much larger time in system due to the WIP that is built up in the system. |

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| **Explain** |
| 1. What might switching from a push style system to a pull style system do to improve a manufacturing facility?  A. Less WIP is in the process. It is easier to adapt to orders because inventory is made to order.  2. How does the pull manufacturing system help a factory save money (compared to the push methodology)?  A. Less WIP means less waste. Waste is money lost.  3. What are the limiting factors in both the traditional and lean style manufacturing systems?  A. The bottleneck is always the limiting factor. The manufacturing process is only as fast as its  slowest part.  4. Which system (traditional or lean) would be desired in a manufacturing environment that produces products in low volume?  A. For low volume, the PULL system is desired because one WIP is a large percentage of the  products made. Low volume usually means each product is expensive. The business will want  to be able to make each product with as little waste as possible to save money.  5. Will more, less, or the same amount of workers be needed in a lean versus traditional style manufacturing system? Use examples from the paper airplane activity.  A. The same number of workers can be used, but the workers have more free time, so they could  use that time to do other things (help the bottleneck), or less workers could be used.  6. What are the main differences between a push and pull (traditional and lean) system?  A. In a push system, each person does their job to make products as fast as possible, no matter  what is happening in the other work centers. In a pull system, a signal is sent from the back  end of the process to each work center to begin working.  7. What products might be made using a pull system? A push system? Why?  A. A pull system is better for highly customizable or low volume products such as a luxury sports car. Products made using a push system are high volume with little customization such as toilet paper.  8. If every worker is doing their job quickly and efficiently, does that always mean the product will be produced quickly?  A. NO. The product can only be made as fast as the bottleneck work center can produce. If the  other steps in the process work fast, they could just be creating more WIP and wasting their  own time that could be spent doing other things (for example cleaning or working on other projects.) |

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| **Elaborate** |
| 1.) What else could we do to the production line to increase finished planes?  Answers:   * Line balancing, i.e. distribute some of the work from the bottleneck operation to other workers. For example, allow the 4th worker write the team name on the side. * Redesign the airplane, make it simpler to make (less folds) * Increase the amount of workers (more production lines) * Move some of the faster workers to help the bottleneck operation.   2.) If the airplane production plant was spread out across a large area, how could you signal the previous operation that you need more products? What kinds of devices could accomplish this?  Answer:   * Lights, Sounds, Cards, Hand signals (waving), emails, phone calls.   3.) How would making more than one airplane design change the manufacturing process?  Answer:   * Lead Discussion: Possible answers could include that the amount and type of worker duties could change. The amount of workers for each workstation could change. Another option would be to have a separate production line for each style of airplane. |

**Resources**

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| **Additional Resources:**  2 min. video of Lean Manufacturing Principles (Baking cakes)  <http://www.youtube.com/watch?v=wfsRAZUnonI>  Introduction to Lean Manufacturing  <http://owic.oregonstate.edu/sites/default/files/EC1636.pdf>  Lean Manufacturing FAQ’s  <http://www.lean.org/WhatsLean/CommonLeanQuestions.cfm>  **Resources Referenced:**  <http://www.shmula.com/paper-airplane-game-pull-systems-push-systems/8280/> |