MANUFACTURE YOUR PATH

LEAN MANUFACTURING

Topic(s): Lean manufacturing, 5S, Kaizen

Grade level(s): 9th – 12th grades

Time: 45-60 minutes

TEKS Alignment: PRINMAN.2.A, PRINMAN.7.A, PRINMAN.7.B, DIMANU1.1.B, DIMANU1.6.A, DIMANU1.6.B, DIMANU1.7.B, DIMANU1.9.A, PREMMAN2.1.G, PRACMAN.2.C

ACTIVITY OVERVIEW

In this activity, students are challenged to improve an out-of-date airplane assembly process. Students participate at workstations within the airplane assembly plant and have specific job roles from assembly to resource management, to quality control. At the start, the process is inefficient- the assembly flow is convoluted, the resource management is limited, and the process from start to finish is lengthy. Students will identify the process wastes and provide solutions to improve. Through multiple iterations, students will collect data about the number of planes produced and if they met customer demand as well as production time and amount of work in progress items.

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ALIGNMENT TO STANDARDS

Texas Essential Knowledge and Skills (TEKS):

Principles of Manufacturing

PRINMAN.2.A: Demonstrate communication techniques consistent with industry standards
PRINMAN.7.A: Investigate an area of interest in manufacturing
PRINMAN.7.B: Analyze the various specializations in manufacturing

Diversified Manufacturing I

DIMANU1.1.B: Interpret engineering drawings, charts, diagrams, and welding symbols
DIMANU1.6.A: Participate in the manufacturing of a mass produced project
DIMANU1.6.B: Develop a method to check and maintain quality control throughout the manufacturing process
DIMANU1.7.B: Determine the most effective strategies to minimize costs.
DIMANU1.9.A: Demonstrate communication techniques consistent with industry standards.

Precision Metal Manufacturing I

PREMMAN2.1.G: Evaluate systems and operations; identify causes, problems, patterns, or issues; and explore workable solutions or remedies to improve situations

Practicum in Manufacturing

PRACMAN.2.C Demonstrate teamwork processes such as promoting team building, consensus, continuous improvement, respect for the opinions of others, cooperation, adaptability, and conflict resolution

LEARNING OBJECTIVES

Students will know:

- The terms lean, 5S, and kaizen.
- Examples of waste in manufacturing.

Students will understand:

- The difference between push and pull assembly processes.
- The effect of work in progress and inventory on manufacturing cost.
- Process inefficiency does not equate to employee laziness.

Students will be able to:

- Work as a team to problem solve and build Lego airplanes.
- Interpret and use visual work instructions.
- Identify wastes within the process and propose solutions.

CAREER CONNECTIONS

Industrial Production Managers

Industrial production managers oversee the operations of manufacturing and related plants.

Work Environment: Industrial production managers spend some of their time in an office and some of it in the production area. When they are in the production area, they may need to wear protective equipment, such as a helmet, hearing protection, or safety goggles.

Duties: Professionals in these jobs have the following duties and more: decide how best to use a plant's workers and equipment to meet production goals, streamline the production process, and lead staff in resolving problems or improving production.

Median US Salary: $121,440 (US Bureau of Labor, 2024)

Source: https://www.bls.gov/ooh/management/industrial-production-managers.htm

Industrial Engineers

Industrial engineers design, develop, and test integrated systems for managing industrial production processes.

Work Environment: Industrial engineers work in a variety of settings, such as offices and manufacturing plants. Industrial engineers work in a variety of settings. For example, they may observe workers assembling parts in a factory or spend time in an office analyzing data.

Duties: Professionals in these jobs have the following duties and more: evaluate manufacturing, delivery, customer experience, or other systems and identify ways to improve productivity and quality, design processes, systems, or enhancements to maximize productivity, efficiency, or space, and analyze data to identify trends and areas for improvement.

Median US Salary: $101,140 (US Bureau of Labor, 2024)

Source: https://www.bls.gov/ooh/architecture-and-engineering/industrial-engineers.htm#tab-1

Operations Research Analyst

Operations research analysts use mathematics and logic to help solve complex issues.

Work Environment: Operations research analysts generally work in offices. Some operations research analysts in the federal government work for the Department of Defense, which also employs analysts through

private consulting firms. Operations research analysts spend much of their time in office settings. They may travel to gather information, observe business processes, work with clients, or attend conferences.

Duties: Professionals in these jobs have the following duties and more: identify problems in areas such as business, logistics, healthcare, or other fields, analyze collected data and extract information relevant to the problem being addressed, and gather input from workers or subject matter experts.

Median US Salary: $91,290 (US Bureau of Labor, 2024)

Source: https://www.bls.gov/ooh/math/operations-research-analysts.htm

BACKGROUND INFORMATION

In this activity, students will have the opportunity to see assembly line processes in live time and see hands on how small changes to the process can vastly improve production.

This activity can be used to present advanced manufacturing concepts or to introduce the concept of change as a positive force. Throughout the activity, students will compare cellular manufacturing, pull/push systems, batch size, work in progress as a manageable asset, inventory risks, independent cross training, and the effects of rapid throughput with traditional manufacturing.

This activity dramatically demonstrates the advantages of advanced production techniques over traditional production methods still practiced by many companies today. The activity consists of four different phases. By working through the four basic phases, students quickly understand the dynamics necessary to maximize throughput, minimize losses, and minimize inventory.

Utilizing a hands-on approach, students operate workstations (WS) along the assembly line in a fictional aircraft plant. For simplicity, the actual construction materials and components are represented with Lego blocks. Labor skills, deadlines, quality control and other real-life situations have been incorporated into each phase of the simulation. Each phase of the simulation runs approximately 6 minutes.

Glossary:

Term	Definition
Assembly	Two or more integrated components.
Cellular	A design where workstations are positioned so that sequential operations are next to one another.
Component	A subassembly comprised of one or more blocks.
Intake Area	A holding area for WIP between each workstation.
One-Piece Flow	The smallest logical batch size. In this simulation it is one assembly.
Pull System	Utilizing intake areas to control the production of work in progress (WIP). WIP Is only produced to fill an empty intake area.
Raw Materials	All unused blocks.
Rework	Any improperly constructed components, assemblies, or airplanes.
WIP	Work in progress.
WS	A workstation. The area directly in front of each working for assembly.

Additional Resources

Understanding Lean Manufacturing

- https://kaizen.com/insights/understanding-lean-manufacturing-guide/

Lean Thinking and Methods- 5S

- https://www.epa.gov/sustainability/lean-thinking-and-methods-5s#:~:text=5S%20is%20a%20cyclical%20methodology,This%20results%20in%20continuous%20improvement.

Lean Simulations

- https://www.leansimulations.org/p/huge-list-of-free-lean-games.html

PRE-ACTIVITY RECOMMENDATIONS

Students can begin to think about time wastes and how organization decreases that waste with a 5S activity.

5S Numbers Game by St. Andrews Lean (https://www.standrewslean.com/wp-content/uploads/2024/06/st-andrews-5s-numbers-game-v2.3.1.pdf)

O'Peep's 5S Game by eLearning Factory (https://ex.elearningfactory.com/5s-game/)

POST-ACTIVITY RECOMMENDATIONS

Students can further explore lean and how to best solve problems related to bottlenecks with another simulated manufacturing experience.

The Bottleneck Game (https://www.agilecoach.net/coach-tools/bottleneck-game/)

ACTIVITY FILES AND MATERIALS

The Manufacture Your Path classroom activity set includes all of the materials needed for 5 assembly plants. In the case that you would need to create more of the items or replenish other materials, the descriptions of what is included is described below. The files referenced below can be downloaded from our website.

1. WS 1-5 Work Instruction Sheets
    a. This is a file intended to be printed **landscape** and **double sided**.
    b. This includes the visual instructions for workstations 1-5.
2. Workstation Designations, Airplane Staging Area, and WS6 Work Instructions
    a. This file is intended to be printed **landscape** and **single sided.**
    b. This includes the sheets to mark the working area for each workstation and the airplane stating area as well as the work instructions for WS-6.
3. Workstation Intake Areas
    a. This file is intended to be printed **portrait** and **single sided.**
    b. This includes the sheets to mark the intake area between workstations.
4. 2x2 Lego Bricks
    a. There are 1000 2x2 bricks included in the kit, 500 of each color (red and blue). These supply all of the necessary bricks for 5 assembly plants
5. 2x4 Lego Bricks
    a. There are 1350 2x4 bricks included in the kit, 675 of each color (red and blue). These supply all of the necessary bricks for 5 assembly plants
6. 2x8 Lego Bricks
    a. There are 500 2x8 bricks included in the kit, 250 of each color (red and blue). These supply all of the necessary bricks for 5 assembly plants
7. Feeler Gauge
    a. This is a 0.15cm feeler gauge used to check thickness. To make the gauge heavier to hold, it has been attached to a small keychain.
8. Dry Erase Markers
    a. These are used to write on some of the laminated sheets. Erasers are included on the cap of the provided markers, but additional erasers or paper towels can be provided.
9. Collapsible, divided cloth containers
    a. These are used to hold the Lego blocks needed at the student stations. It is recommended to set up the divider so students can have an area for each colored block (red and blue).
10. Dice
    a. There is one standard die and one custom labeled die for each station. These are used to populate the customer orders randomly throughout each phase of the activity.
11. Stopwatch/Timer
    a. This is included to time each phase of the activity.

PLANT SET-UP

Each assembly plant requires 6 students. An additional 1-2 students can be assigned to a plant in supplementary roles. The classroom activity set includes materials for 5 separate assembly plants.

Student Roles

Student Number	Station	Role	Responsibilities
1	WS-1	Assembly Worker	To build the components/assemblies
2	WS-2	Assembly Worker	To build the components/assemblies
3	WS-3	Assembly Worker	To build the components/assemblies
4	WS-4	Assembly Worker	To build the components/assemblies
5	WS-5	Quality Inspector	Perform quality control tests
6	WS-6	Teardown and Data Collector	Teardown assemblies from previous phases, announce incoming customer orders, and tabulate production results
7	n/a	Forklift Operator	Move materials from one WS to another upon request or resupply raw materials upon request. Can assist with WS-6 tasks as needed.
8	n/a	Forklift Operator	Move materials from one WS to another upon request or resupply raw materials upon request. Can assist with WS-6 tasks as needed.

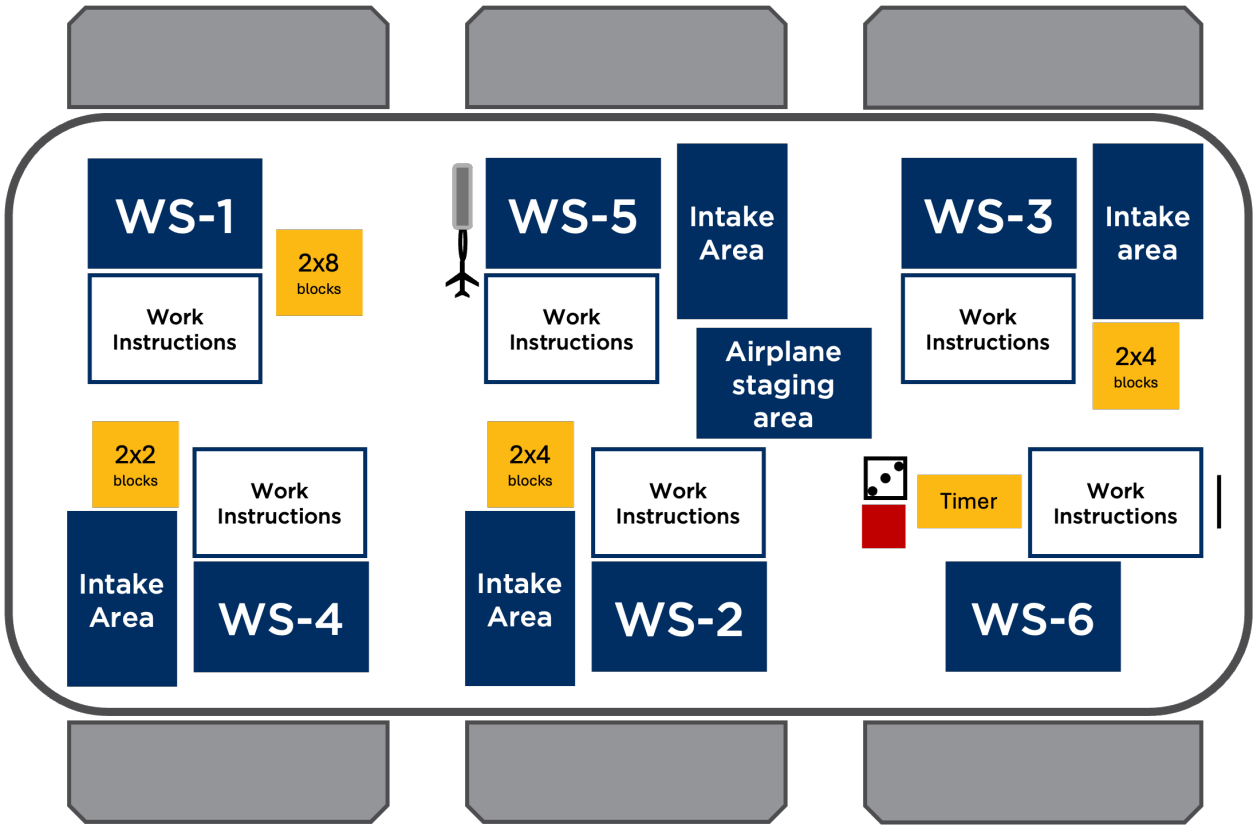
Materials Required (Per Plant)

1. (6) Workstation designations (laminated)
2. (4) Workstation Intake Area designations (laminated)
3. (6) Workstation instruction sheets (laminated, WS1-5 are double sided)
4. (1) Airplane Staging Area (laminated)
5. (1) Feeler Gauge (0.15 cm thickness checking device)
6. (1) Dry erase marker with eraser
7. (4) Collapsible, divided cloth containers
8. (2) Dice (one labeled with red/blue, and one standard die)
9. (1) Stopwatch/timer

Initial Set Up

Prior to student arrival, place the two-sided work instruction sheets in position on the table/ group of desks with the Phase-4 side down.

WS-2 through WS-5 require an intake area. WS1 through WS4 require a divided bin for raw materials. Each bin can start with one handful of each color Lego. The larger boxes with the remaining Lego should remain accessible to the groups at the front or back of the room.



Since Phase-1 simulates the traditional facility, one whose layout has been designed around departments or over time growth, production should be as difficult and cumbersome as possible. Additional obstacles may be placed in the room (size permitting) to further inhibit the workers' efficiency.

LESSON PLAN

Introduction and Practice Round (5-10 min)

- Welcome students to the classroom and direct them to take a seat.
- Explain to students that they will be acting as employees at an airplane assembly plant. Explain that everyone will have a different role in the assembly process and their goal will be to produce as many planes as possible to sell to customers. Throughout our simulation students will be looking to work lean.
- Ask students if they know what it means to work lean or to use lean manufacturing?
    - If students are unfamiliar, slides 2 and 3 of the accompanying Powerpoint can be used to introduce students to lean manufacturing and the different types of wastes.
    - Explain that lean manufacturing is a process meant to maximize value for customers by eliminating wastes and improving processes.
    - Ask students what kinds of wastes might we see in manufacturing?
        - Students may mention poor supply use (not using a whole metal sheet to its fullest), creating parts with defects, and more.
        - Explain that in lean we look to reduce 8 wastes: transportation, inventory, motion, waiting, overprocessing, overproduction, defects, and skills. This can easily be remembered with the acronym TIM WOODS.
        - Walk through some of the wastes to explain how it causes an increase in costs for the manufacturer and a worse product for the customer.
- Explain that throughout the simulation, they will need to evaluate the production process for wastes to improve the number of planes produced, as well as the quality of those planes and the time to produce them.
- Explain that in this simulation, they will be using Lego bricks to create their airplane. Explain that before we begin any full-scale assembly, we will first begin with a practice round so that everyone understands how to read and interpret their work instructions.
- Direct WS-1 workers to make one blue plane using their instructions. Then have them pass their assembly to the WS-2 workers to add their components. Continue to pass the one plane all the way through the stations until all workers have had a chance to use their instructions to add their assembly components.
    - *Teacher's Note:* Ensure students are passing to the next **numbered** workstation and not the station next to them. If possible, demonstrate the specific procedure for each workstation as it is passed along. Ensure they are fulling pressing the blocks together so the airplanes will pass inspection. Explain how to hold the assembly to reference each of the views (top, side, front).
- Once the plane has reached WS-5, ensure the Inspector at that station understands the configuration of the final product. Explain that completed airplanes will fail inspection if they are improperly assembled (components missing or in the wrong place) or poorly constructed (horizontal gaps between two or more blocks). Explain that if the feeler gauge slides easily between the blocks, the airplane is defective. The feeler gauge should **not** be forced between blocks.
- Once all students are familiar with their instructions, the final place can be handed to WS-6 for teardown and the raw materials are replenished to the divided bins.

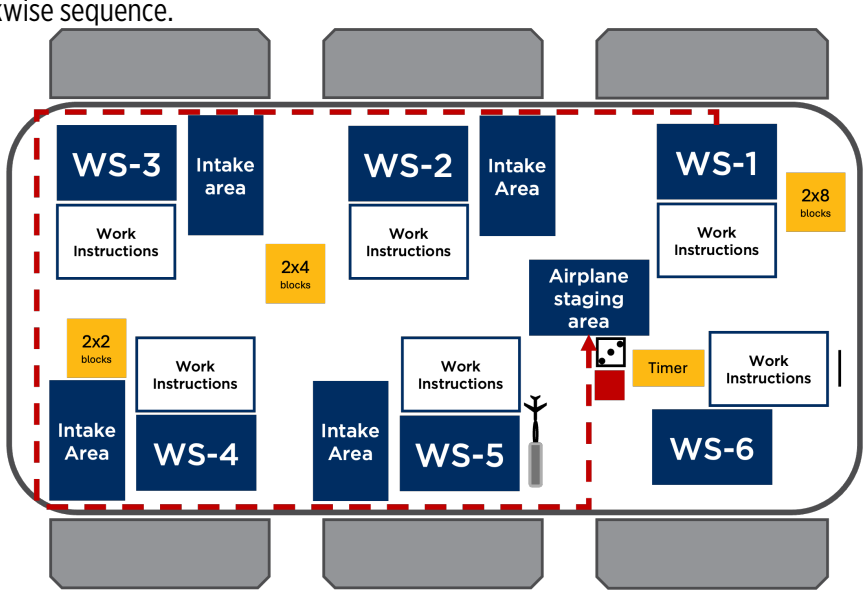
Part 2: Phase-1 Traditional Production (15 min)

- Explain to students the evolution of traditional production practices in the United States. For example, a small manufacturer builds a facility placing heavy fabricating machinery on the ground floor as far away from the offices due to noise. Raw material is stored near the loading docks, and assembly is in between the office space and the heavy machinery. When an order comes in, the entire job is entered into the production pipeline and work begins.
- Explain that as the company grows, additional fabrication machinery is added in the same heavy production area of the facility due to the availability of power, water, etc. Assembly, now short on space, is expanded and moved up to the second floor. As business improves, an additional warehouse is constructed on the premises away from the main facility and a new shipping area is constructed next to the warehouse. Explain that this process is usually slow, occurring over years, if not decades, until the entire production flow becomes so convoluted as to be nearly unworkable. Or, perhaps, the plant was designed with the emphasis on departmental proximity. As new technologies were added, or the product line changed, the production flow slowly became more and more encumbered and convoluted. While the process of the business seemed efficient, the product took increasingly longer to get out the door.
- Explain that for these reasons, Phase-1 of the simulation, workers must physically go to a distant supply area for raw materials, get up and carry the batch to the next workstation and refrain from communicating production problems to anyone. This round is a "don't think, work!" model. In addition, the Inspector is not communicating defects as a form of job security.
- Explain the production rules for phase-1.
    - Aircraft must be assembled in batches of 5. Explain that this means a worker must make 5 assemblies, walk to pass them into the intake area of the subsequent station, then walk back and start making another batch of 5. **Explain that all planes within a batch must be the same color (red/blue).**
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator move the batch to the next station. This request can only be made when the batch has been completed.
    - Each worker is responsible for refilling raw materials and raw materials can only be restocked once their current supply is fully empty. Explain that when they run out of bricks of a certain color completely, they must get up to get **one handful** of the needed bricks from the resupply bin.
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator to get their materials and bring them back. But this request can only be made when the requested bricks have been completely depleted from their bin.
    - Workers must only perform their assigned jobs. They cannot help their teammates or do other functions. They can only do the jobs outlined on their work instructions.
    - All QC structural problems must be set aside for rework. If an assembly gets to their station and the bricks are not in the correct configuration, the assembly is set off the side of their workspace and turned upside down. This includes if any assemblies fall apart while you are working with them. If an aircraft is set aside, the rest of the batch travels through production with the remaining planes. For example, if one plane in the batch is incorrectly put together, it would be set aside for rework and the batch would continue with only 4 planes.

    - QC problems can only be detected by the Inspector. If students notice that some blocks in an assembly are not pressed all the way, they cannot fix that. They can only add their components and pass it along. If the inspector uses their gauge and finds those gaps, they will mark it for rework by placing it upside down.
- Explain that the groups will have 6 minutes or until the first good plane is finished to test their production method. Remind them that as they are working or waiting, they should be looking for different wastes that could be reduced.
- Once all groups are ready, have WS-6 start the stopwatch and roll the dice to announce the first customer order (number of planes and what color was ordered).
    - Remind WS-1 to consider the orders coming in as they decide what color each batch should be. For example, if there is an order for 6 red planes, they might want to consider doing two red batches before starting another color.
    - Remind WS-6 to continue announcing customer orders every minute or once an order has been completed (reached the airplane staging area), whichever is faster. These customer orders should be marked on their work instructions under customer orders with a tally mark.
- As the production beings, walk around the room and help to enforce the rules in place. Remind them that once a batch is complete, they must deliver it to the next workstation then return to their station to make another batch. **There is a tendency for WS-1 to stop working after the first batch is delivered to WS-2. WS-1 should continue filling the WS-2 intake area with as many components as possible in the time allotted.**
- WS-3 through WS-5 will remain idle until the first batch of assemblies is delivered to them. Depending on the group dynamics, the facilitator can make comments such as "Why aren't you working?" or "What am I paying you for?" and "QC sure has a posh job!" Use this time to comment on the problems inherent in the traditional production method.
    - A perfect scheduling system is necessary to keep all workstations busy when using large batches.
    - Batch-oriented plants stack large quantities of WIP in front of each workstation to prevent waiting.
    - Large batches of WIP carry risks with them: investment in inventory, you are forced to run a job regardless of changing customer demands, and any quality problems from the last operation can be detected only as you being to use WIP.
- All production is halted at 6 minutes or when the first good airplane is completed, whichever takes longer. The Inspector should tell WS-6 when the first airplane (not the first batch) has passed inspection. At this time, WS-6 should stop the stopwatch and record the time it took to complete the airplane. WS-6 along with the other workers will then count and record the number of good airplanes, rework, and WIP.
    - WS-6 will mark the total completed planes and then break that number into sold or inventory according to the customer orders. If one red plane is produced but there are orders for 5 red planes and 6 blue planes, they would mark that there was 1 completed plane, 1 sold plane, 0 inventoried, and 10 backordered.
- All completed planes, WIP, and rework are passed to WS-6 for teardown. WS-6 disassembles all planes and assemblies, placing the blocks in their appropriate boxes for use in the next simulation. This can continue as the next phase begins.
- Discuss with students as a group the pitfalls of this production process and ideas to improve.

Part 3: Phase-2 Cellular Layout (10 minutes)

- Explain that, in Phase-2, students will rearrange their stations to a cellular layout. This means that the workstations are repositioned so that the production operations are next to each other and in a counterclockwise sequence.



- Help students to rearrange their groups, ensuring that they take their work instructions with them. Remind students that they will only need 3 of the supply bins now (WS-2 and WS-3 can now share the same bin). The bins can be filled with 2 handfuls of each Lego color to start.
- Review the production rules for Phase-2.
    - Aircraft must be assembled in batches of 5. Explain that this means a worker must make 5 assemblies, pass them into the intake area of the subsequent station, start making another batch of 5. **Explain that all planes within a batch must be the same color (red/blue).**
        - *Teachers Note:* Students no longer need to walk from one workstation to another but can simply pass the batch into the intake area which should be directly to their right.
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator move the batch to the next station. This request can only be made when the batch has been completed.
    - Each worker is responsible for refilling raw materials and raw materials can be restocked at any time. Explain that when they restock, they must get up to get **two handfuls** of the needed bricks from the resupply bin.
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator to get their materials and bring them back. This can be done at any point.
    - Workers must only perform their assigned jobs. They cannot help their teammates or do other functions. They can only do the jobs outlined on their work instructions.
    - All QC problems must be set aside for rework. If an assembly gets to their station and the bricks are not in the correct configuration, the assembly is set off the side of their workspace and turned upside down. This includes if any assemblies fall apart while you are working with them. If an aircraft is set aside, the rest of the batch travels through production with the

remaining planes. For example, if one plane in the batch is incorrectly put together, it would be set aside for rework and the batch would continue with only 4 planes.
    - The Inspector verbalizes QC problems. If the Inspector notices an issue, they can inform their teammates in an effort to reduce those errors going forward.
    - The Inspector will announce the completion of the first good airplane. This will be the time that we compare to Phase-1 but this phase will last 6 minutes total.
- Explain that the groups will have 6 minutes to test their production method. Remind them that as they are working or waiting, they should be looking for different wastes that could be reduced.
- Once all groups are ready, have WS-6 start the stopwatch and roll the dice to announce the first customer order (number of planes and what color was ordered).
    - Remind WS-1 to consider the orders coming in as they decide what color each batch should be. They don't have to follow customer orders exactly, but they should try to get some of each order completed across multiple batches if possible. For example, if there is an order for 6 red planes, they might want to consider doing two red batches before starting another color.
    - Remind WS-6 to continue announcing customer orders every minute or once an order has been completed (reached the airplane staging area), whichever is faster. These customer orders should be marked on their work instructions under customer orders with a tally mark.
- As the production beings, walk around the room and help to enforce the rules in place. Ensure that they are still working in batches of five.
    - While significant changes have been made, there is still a lag as the assemblies move down the production line. Workload comments are still appropriate. Some workers will not be doing anything for a few minutes, and the Inspector still has little to do (which may be why everyone wants to be in quality control!).
- Once the first good airplane enters the Airplane Staging Area, the Inspector announces it and WS-6 records the time at that point. Production continues until 6 minutes have passed since the start of the phase.
- All production is halted at 6 minutes. WS-6 along with the other workers will then count and record the number of good airplanes, rework, and WIP.
    - WS-6 will mark the total completed planes and then break that number into sold or inventory according to the customer orders.
- All completed planes, WIP, and rework are passed to WS-6 for teardown. WS-6 disassembles all planes and assemblies, placing the blocks in their appropriate boxes for use in the next simulation.
- Discuss with students as a group the successes and pitfalls of this production process and ideas to improve.
    - While significant changes have been made, there is still a lag as the assemblies move down the production line. Of course, once the ball gets rolling, the picture changes: significantly more airplanes are being built, although workers still wait for the batches to arrive at their workstations.
    - By removing obstacles (walking around) and changing the flow of the assembly line, production is up dramatically. However, WIP is also up since there was an increase in production. Greater amounts of WIP increase the inventory investment and raise the risk of loss if anything needs to be scrapped (this may happen if there is a material defect in a product given to us by a vendor).

- In this phase, there is more raw materials accessible to the workers and they have the freedom to get more when they feel they need it. The workers could build more airplanes because they had more time to build them. Time spent in Phase-1 to restock raw materials could be used more productively.
- WS2 and WS-4 are still constraints- work slows down at these workstations due to their workload. Changes were made to the production layout, not to the workload. High WIP accumulates in front of the constraint workstation. Also, waiting on batches slows down the flow.

Part 4: Phase-3 One-Piece Flow with Pull System (10 minutes)

- Explain that, in Phase-3, students will remain in their cellular layout, but we will now be working with one-piece batches in a pull system.
- Explain that the system we've used up to this point is called a push system. We have been pushing product out regardless of customer needs. In a pull system, we only start production once we know what a customer wants. This helps to reduce inventory and WIP.
- To set up for this phase, have each worker make two assemblies that can go into their intake area (one in red and one in blue). Students will have to borrow blocks from other stations to assemble these or you can have WS-1 make 4 of each color, then have WS-2 add their components to 3 of each color while keeping 2 assemblies in their intake area and so on. By the end every intake area should have 2 assemblies, one red and one blue.
- Explain that once an order is announced, WS-5 is going to select a plane based on the customer needs (ie if 4 red planes are ordered, they will only select red planes until the order is complete). When there is an empty area for an assembly in an intake area, the workstation down the line works to replenish it. For example, WS-5 picks up a red plane to start inspecting, WS-4 pick up their red plane and starts adding components so they can refill the WS-5 intake area. WS-3 begins adding components to their red assembly and so on. The advancement of an airplane along the production line pulls the next assembly into the system. Point out that another assembly cannot be placed in the intake area until the assembly is removed.
- The facilitator should also warn the Inspector that production will increase dramatically, that the staging area will need be needed to store the completed planes prior to shipment, and to watch for that first good airplane. It's easy to miss!
- Review the production rules for Phase-3.
    - Aircraft must be assembled in batches of 1. Explain that this means a worker must make 1 assembly, pass them into the intake area of the subsequent station.
        - *Teachers Note:* Students no longer need to walk from one workstation to another but can simply pass the batch into the intake area which should be directly to their right.
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator move the batch to the next station.
    - Workers can have only 1 assembly of each color in their intake area. There can be only one red and one blue assembly in each intake area. When one is removed, one is made to replace it.
    - Each worker is responsible for refilling raw materials and raw materials can be restocked at any time. Explain that when they restock, they must get up to get two handfuls of the needed bricks from the resupply bin.
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator to get their materials and bring them back. This can be done at any point.
    - Workers must only perform their assigned jobs. They cannot help their teammates or do other functions. They can only do the jobs outlined on their work instructions.
    - All QC problems must be set aside for rework. If an assembly gets to their station and the bricks are not in the correct configuration, the assembly is set off the side of their workspace

and turned upside down. This includes if any assemblies fall apart while you are working with them.
    - Any worker can verbalize QC problems. If a worker notices an issue, they can inform their teammates in an effort to reduce those errors going forward.
    - The Inspector will announce the completion of the first good airplane. This will be the time that we compare to Phase-1 but this phase will last 6 minutes total.
- Explain that the groups will have 6 minutes to test their production method. Remind them that as they are working or waiting, they should be looking for different wastes that could be reduced.
- Once all groups are ready, have WS-6 start the stopwatch and roll the dice to announce the first customer order (number of planes and what color was ordered).
    - Remind WS-6 to continue announcing customer orders every minute or once an order has been completed (reached the airplane staging area), whichever is faster. These customer orders should be marked on their work instructions under customer orders with a tally mark.
        - *Teacher's Note:* Watch for that first good airplane! It's usually finished in a minute or less!
- As the production beings, walk around the room and help to enforce the rules in place. Help students if they struggle to switch to the pull system rules.
    - Assemblies will be moving much more quickly along the production line. Keep the energy and excitement up. Encourage and praise the students for their excellent productivity. Be especially aware of the time it takes to build the first good airplane (usually less than a minute!) and let everyone know what a great job they're doing.
- Once the first good airplane enters the Airplane Staging Area, the Inspector announces it and WS-6 records the time at that point. Production continues until 6 minutes have passed since the start of the phase.
- All production is halted at 6 minutes. WS-6 along with the other workers will then count and record the number of good airplanes, rework, and WIP.
    - WS-6 will mark the total completed planes and then break that number into sold or inventory according to the customer orders.
- All completed planes, WIP, and rework are passed to WS-6 for teardown. WS-6 disassembles all planes and assemblies, placing the blocks in their appropriate boxes for use in the next simulation.
- Discuss with students as a group the successes and pitfalls of this production process and ideas to improve.
    - The first airplane goes to the customer in record time! Finding sufficient space to park all of the completed airplanes may have presented the largest challenge. This raises and interesting question: does the customer actually need all of the order all at once? Would it not be more efficient to build and immediately deliver a few airplanes every month, thereby freeing the production line for other orders.
    - What are the costs to store the completed but not shipped inventory? Traditional thinking says that the larger the order, the lower the unit cost. However, by reducing the cost of storing inventory for weeks or even months prior to shipment, wouldn't the same (or greater) savings be realized? If the producer communicated this situation to the customer, both could benefit.
    - WIP risk is also greatly reduced by this method of production, due to the reduced batch size. The average WIP reduction from Phase-1 to Phase-3 is 66%. If the WIP for a company was

$100,000, that translates into a $66,000 investment recovery for the company implementing this type of system.
    - The pull system allows a maximum of 18 WIP aircraft along the assembly line. There are 5 workstations with 4 intake areas between them. A reduction in WIP reduces the risk of loss due to defective product or midstream specification changes, dramatically reducing scrap.
    - With the workers now involved in the inspection process, rework loss was also reduced. And, with the increased throughput, QC is finally earning its keep. Working interaction also builds interdependency. They start helping each other. They begin to get a clearer picture of their individual place in the overall production process and may develop a better work ethic with an improved attitude and less absenteeism.
    - Due to their more involved workload, workstations 2 and 4 are slowing the process somewhat. Even with all of the advantages of this production method, there is still room for improvement.
- *Teacher's Note:* 45-minute classes may not have enough time to complete all four phases. It is recommended to stop at the end of a phase if there is not enough time to complete the next one.

Part 5: Phase-4 Flexible Workforce (10-15 minutes)

- Explain that, in Phase-4, students will remain in their cellular layout and will maintain the one piece pull system, but that their work instructions will change to balance the workload and hopefully reduce bottlenecks.
- Direct students to flip over their work instructions to see their role for Phase-4. Explain that the changes to their work should help to balance the workload among the workstations. Not only have their tasks changed, but each worker also can take on additional tasks as necessary. Generally, this means to help the station identified (usually the one next to them) to help with their task or to provide help in a more freestyle form.
- Make sure to review each of the new production steps so that each worker understands their new task. Also direct students to rearrange their divided bins so that the workers can access their components they need. We recommend:
    - Next to WS-1: 1 bin of 2x8 and 1 bin of 2x4
    - Between WS-2 and WS-3: 1 bin of 2x4
    - Next to WS-3: a small pile of 2x2 in each color
    - Between WS-4 and WS-5: 1 bin of 2x2
- Explain that in an effort to reduce WIP, we will remove all intake areas. In this pull system, a worker can have two assemblies in front of them (one of each color). When a slot is opened, a new assembly can be passed directly to their workstation.
- Because this phase will also use the pull system, have each worker make two assemblies that will fill the two available spots at their workstation. Students will have to borrow blocks from other stations to assemble these or you can have WS-1 make 4 of each color, then have WS-2 add their components to 3 of each color while keeping 2 assemblies in their intake area and so on. By the end every workstation should have 2 assemblies, one red and one blue.
- Explain that once an order is announced, WS-5 is going to select a plane based on the customer needs (ie if 4 red planes are ordered, they will only select red planes until the order is complete). When there is an empty area for an assembly, the workstation down the line works to replenish it. Point out that another assembly cannot be placed in the workstation area until the assembly is removed.
- The facilitator should also warn the Inspector that production will increase dramatically, that the staging area will need be needed to store the completed planes prior to shipment, and to **watch for that first good airplane. It's easy to miss!**
- Review the production rules for Phase-4.
    - Aircraft must be assembled in batches of 1. Explain that this means a worker must make 1 assembly, pass them into the intake area of the subsequent station.
    - Workers can have only 1 assembly of each color in their intake area. There can be only one red and one blue assembly in each intake area. When one is removed, one is made to replace it.
    - Each worker is responsible for refilling raw materials and raw materials can be restocked at any time. Explain that when they restock, they must get up to get **two handfuls** of the needed bricks from the resupply bin.
        - *Teachers Note:* If forklift operators are in use, a worker would need to raise their hand to request a forklift operator to get their materials and bring them back. This can be done at any point.

    - Workers can now do their Phase-4 instructions as well as help any other team member on the line.
    - QC problems can be detected and repaired by any worker. If an assembly gets to their station and the bricks are not in the correct configuration, the worker can fix the mistake and continue with the assembly. If the worker cannot fix the issue, it is set aside for rework.
    - The Inspector will announce the completion of the first good airplane. This will be the time that we compare to Phase-1 but this phase will last 6 minutes total.
- Explain that the groups will have 6 minutes to test their production method. Remind them that as they are working or waiting, they should be looking for different wastes that could be reduced.
- Once all groups are ready, have WS-6 start the stopwatch and roll the dice to announce the first customer order (number of planes and what color was ordered).
    - Remind WS-6 to continue announcing customer orders every minute or once an order has been completed (reached the airplane staging area), whichever is faster. These customer orders should be marked on their work instructions under customer orders with a tally mark.
        - *Teacher's Note:* Watch for that first good airplane! It's usually finished in a minute or less!
- As the production beings, walk around the room and help to enforce the rules in place. Help students if they struggle to switch to their new instructions.
- Once the first good airplane enters the Airplane Staging Area, the Inspector announces it and WS-6 records the time at that point. Production continues until 6 minutes have passed since the start of the phase.
- All production is halted at 6 minutes. WS-6 along with the other workers will then count and record the number of good airplanes, rework, and WIP.
    - WS-6 will mark the total completed planes and then break that number into sold or inventory according to the customer orders.
- All completed planes, WIP, and rework are passed to WS-6 for teardown. WS-6 disassembles all planes and assemblies, placing the blocks in their appropriate boxes for use in the next simulation.
- Discuss with students as a group the successes and pitfalls of this production process and ideas to improve.
    - Balancing the workload and empowering workers should result in a production increase with a very low amount of rework. WIP should be further reduced due to the elimination of intake areas.
    - From the recorded data, the facilitator can compare the results (effectiveness) of the four production methods, and moderate a discussion comparing the impact of relatively small changes. The resulting plant efficiency and improved employee attitude make an excellent case for contemporary production methodologies.