Introduction

This paper airplane folding exercise demonstrates the push vs. pull aspect of lean manufacturing.

The goals of this exercise are to illustrate the significant reduction in WIP and throughput time using the pull system, to explain and illustrate the concepts of push, pull, kanban, bottleneck, cycle time, idle time, line balance, and to illustrate worker behaviour in an operational setting.

This exercise utilizes four assembly operators in an assembly line to build a paper airplane. The work centre tasks are assigned in such a way as to place the bottleneck at the third workstation. The students first work in a standard push approach: each student works at their own comfortable pace as long as inventory is available, and they do not worry about inventory build-up.

The second run requires a pull of one unit at a time. The reduction in inventory and throughput time is readily evident to all, providing a powerful learning experience. In addition, student discussion of a multitude of lean concepts and behavioural issues is easily elicited.

This exercise can be completed in about 20 minutes, using 100 sheets of blank, standard A4 paper and 2 coloured sheets of Coloured Paper. A white board / flip chart can be used to record key data.

The basic folds are easily explained, as shown in Figure 1.

The four work centres are set up as below:

Figure 2 Push Production Line Set-ups

Table length ~12 feet

	Student		Student		Student		Student	
Raw	Work Centre		Work Centre		Work Centre		Work Centre	Finished goods
Material		WIP		WIP		WIP		
	1		2		3		4	(Airplanes)
(Paper)								

Material Flow

Participants

Personnel required are as follows:
4 Assembly Operators
1 QA Person

Since the objective of this exercise is the push and pull concepts, the quality is monitored by the QA person to insure that the operators are not rushing improperly to try to balance the line. Workers need to be instructed to "work at a comfortable pace, this is not a contest for maximum output, but quality will be monitored by the QA person," students will work accordingly.

The objective is to complete 20 airplanes at the Finished Goods Station. The Instructor monitors the time it takes to complete the 20 units. Dividing by 20 will give the average cycle time

The remaining participants should gather around and be instructed to keep an eye on the workers and the action, with knowledge that they are to provide insightful discussion at the conclusion.

Exercise

PUSH RUN

The first run is the push run: let them make inventory as fast as they want and push to the next work centre.

At an opportune time, insert the coloured sheet onto the top of the raw material paper. Insist on a FIFO type of process between work centres so that the plane with the coloured paper doesn't jump ahead of the queue. The Instructors tracks the throughput time: the time from when the first worker takes the sheet from the raw material pile, to the time when the last worker completes the plane and places it in the finished goods inventory. This throughput time is recorded. The task is completed once 20 planes are placed in finished goods.

A discussion at this point should result in the identification of the bottleneck, the piles of inventory, and observation that work centre 4 is idle some of the time while the other work centres worked continuously. This is a good time to reinforce the concepts of bottleneck, cycle time, throughput time, push, line balance and worker behaviour.

PULL RUN

The second run is a pull system. Designate a space between each work centre as an imaginary kanban box where inventory will be held as shown in Figure 3.

Place 1 unit of WIP in each of the 3 kanban areas. Indicate that one worker's in box is the previous worker's out box.

A worker can start work at their work centre only when

1) there is 1 unit in the incoming Kanban area (except for work centre 1, which is pulling from the raw material area).
2) When they are done they place the unit in the Kanban out box and wait until the box is empty again.

When these conditions are met, the empty out box is considered a kanban signal that more production is needed.

Figure 3

Pull Production Line Setup

Table length ~12 feet

	Student		Student		Student		Student	
Raw	Work Centre	Kanban Area	Work Centre	Kanban Area	Work Centre	Kanban Area	Work Centre	Finished goods
Material	1		2		3		4	(Airplanes)
(Paper)								

Material Flow

After a few trials to make sure the pull is working, start the run. Repeat the insertion of the colour sheet, and time the throughput. During the pull run, an instructor can have some fun asking the bottleneck worker what the problem is since this is holding up the output, while also asking the idle workers why they are sitting around doing little work.

The pull system requires 3 of the 4 work centres to be idle part of each cycle, a process that is counter to our usual thinking. It is actually good, in this case, to be idle! The alternative is a build-up of inventory

The following are Discussion topics:

Participants may be astounded to discover that as the inventory is reduced, the throughput time is also reduced. In addition, three workers are idle. How can this be?

Work centre 3 has the longest task time and is the bottleneck. The bottleneck worker can be asked how he or she felt as the only one working all the time while the other three workers had idle time.

If this is a work team, how will they go about resolving the obvious imbalance in workloads?

In the pull system, inventory build-up hid the fact that the first two work centres were out of balance with the bottleneck.

The line can be balanced in a variety of ways. Use the task times to determine how to combine tasks to balance the line.

Work centres 1 and 2 were often idle in the pull runs, but not the push system.

Workers often do not communicate with one another. Worker communication must be enabled if this team is to improve the production process.

The concept of pull is readily apparent

Figure 1 Assembly of a Paper Airplane

Work Centre 1

Fold up in half long way.

Work Centre 2

Fold first corner down on each side

Work Centre 3

Second Fold of wing in each side

Draw a Star with a coloured marker on one side

Work Centre 4

Third fold of each wing on each side.

Place in finished goods Inventory.