Converting from Assembly Line to Cellular Manufacturing with the PJ1500

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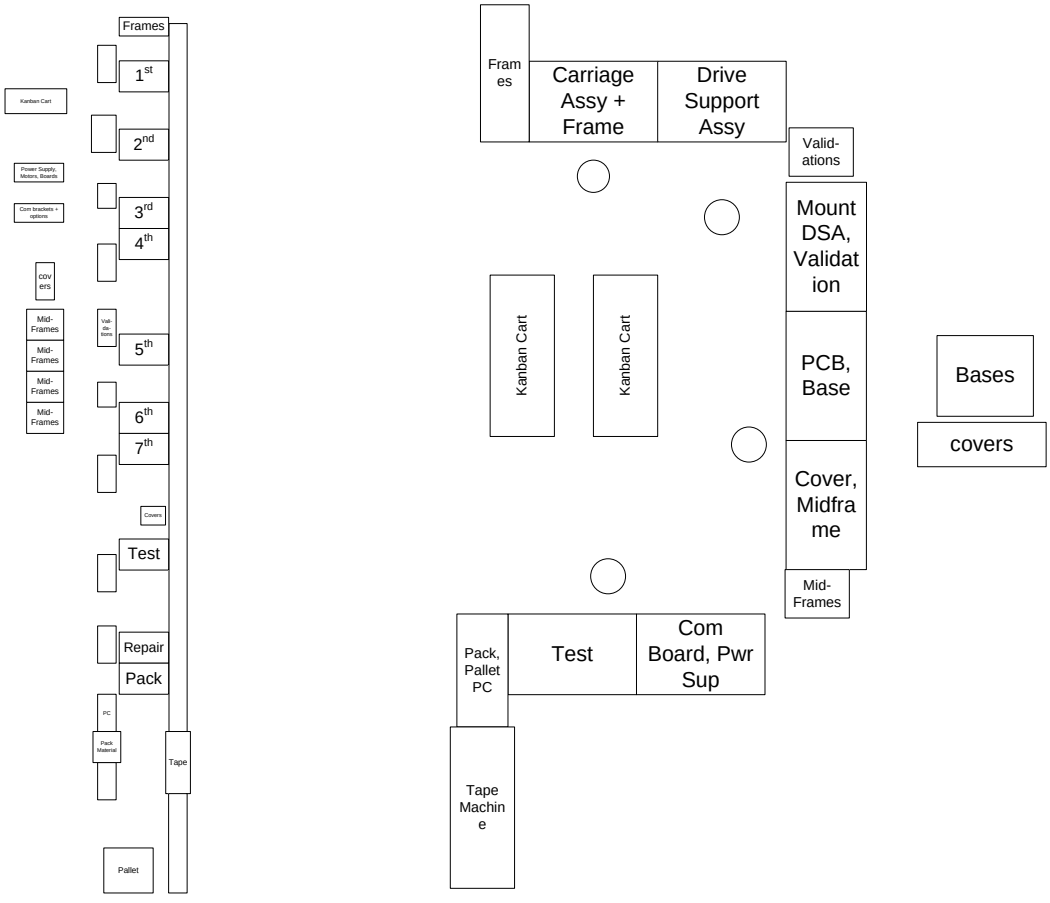
Background

The PJ1500 is an inkjet POS printer that has been produced on an Assembly Line at Transact Technologies' Ithaca, NY factory for over 10 years. The goal of this project was to redesign this Assembly Line into an "Assembly Cell" using the principles of Cellular Manufacturing. Cellular Manufacturing is a technique used to design manufacturing processes based on the ideas of the Toyota Production System alternatively known as Lean Manufacturing. The goals of Cellular Manufacturing are decreased floor space, increased efficiency, and fewer defects. In addition, *the Line is designed to run with a fixed number of operators (8) whereas the Cell is designed to run efficiently with 1, 2, 3, or 4 operators*; since there are fewer employees trained to build the PJ1500, this is a major reason for the conversion. This report describes the process of converting the PJ1500 Assembly Line into an Assembly Cell.



Assembly Line Cycle Time Audit

The first step in the process was auditing build cycle times on the Line. I did this with a stopwatch and a template for recording the times at each step of the build. As opposed to using a video camera or other timing system, this was the ideal way of surveying the Line for a few reasons:

1) The operators get involved with the conversion discussion as early as possible.

2) There are fewer measured cycles that have to be discarded since the operator will avoid distractions until the measurement cycle is complete.

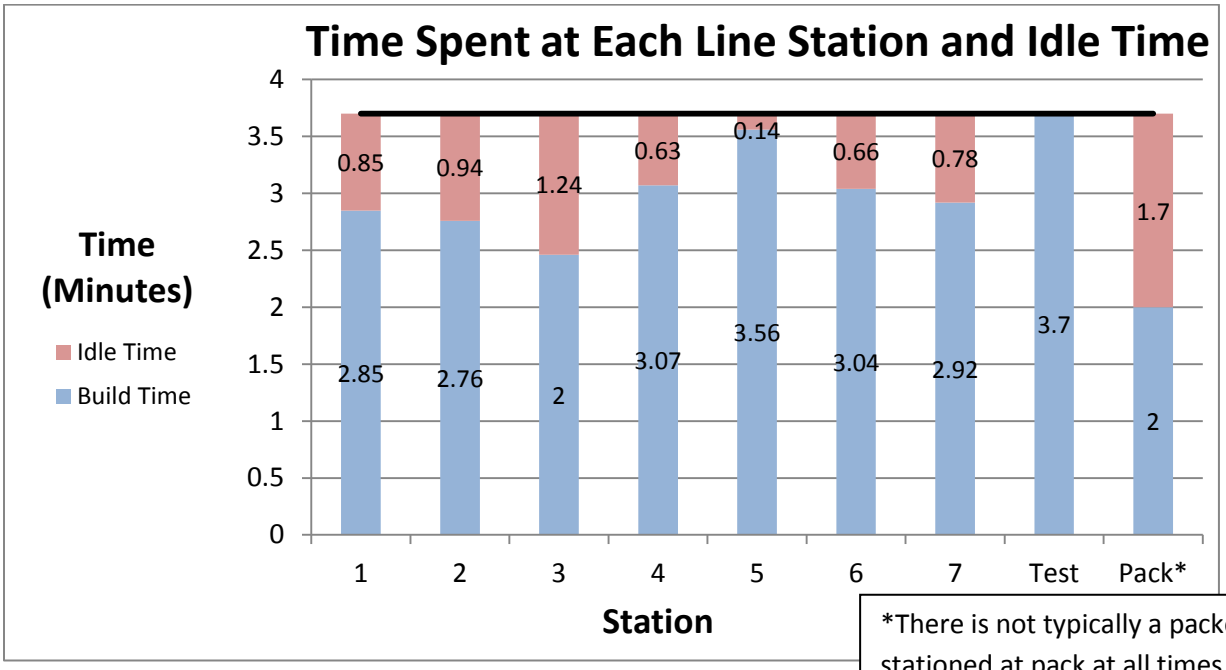
3) When a rare event occurs that alters the cycle time to be out of the ordinary, the operator can discuss what is happening so the cycle time can be explained.

The result of this audit is the cycle time table shown below. The original goal was to observe 10 cycles, but after 5 cycles the repeatable time is usually apparent. The repeatable time was chosen to be approximately the second fastest time, considering the fastest time might have been an outlier. I located all of the current work instructions for each step in the process and put a link to them in the left column. The units in the table are 1/100ths of minute.

Process Study	Process: 1500 Build	Product: 1500				Observer: Ethan Suttner						Date: 7/10-7/12	
Process Steps	Work Element	Observed Times											
		1	2	3	4	5	6	7	8	9	10	Repeatable	Sum
1st Station	Communications Board	80	74	83	86	87	87	60	78	77	85	76	
W20-03407 - Mechanism Frame 1st Station / W20-03416e - Cabinet Base 1st Station Assembly -	Assemble Frame	92	89	101	88	91	76	99	85	102	102	87	
	Prepare Base	152	124	134	125	130	150	114	121	127	120	121	285
2nd Station	Insert 2 Head Retainers	133	157	169	196	179	198	242	165	202	151	156	
W20-03411G - MODEL PJ1500 2ND STATION	Put in fixture, Insert Felt Washers, Ensure Shaft slides loose	79	100	83	110	111	68	94	111	51	65	67	
	Install Belt, 2 latches, and Pin	55	56	54	94	37	61	73	46	62	65	52	276
3rd Station	Assemble Belt Tensioner	65	76	46	80	63	61	62	60	50		56	
W20-03414 REV. H 3rd Mount Carriage Assembly -	Mount Carriage Assembly	72	60	102	86	92	86	99	76			74	
	Inspect Assembly	110	155	134	140	115	123	126	130	117		116	246
4th Station	Spittoons and Wiper Arm w/ Cal Gauge	40	50	50	54	55	54					50	
W20-03413 REV V - MODEL PJ1500 4TH STATION	Assemble Drive Support in Fixture	267	272	257	253	261	277					257	307
	Mount Drive Support in Fixture	96	90	106	104	95						94	
	Install Gears	108	114	110	131	88						104	
5th Station													
W20-03415 REV. O 5th Station Drive Support Mount	Remove from Fixture, Power button, Rubber Feet	55	53		60	61						54	
	Install Validation	110	107		105	101						103	356
6th Station	Assemble Keypad	36	48	44	37	33						35	
W20-03418 REV. I Mount PCB 6th Station Assembly -	Install PCB and Mount Keypad	113	133	126	146	136						123	
	Attach Cables	97	96	94	98	114						96	
	Insert Frame into Base	18	17	24	21	27						18	
	Install Communications Board	20	16	18	16	18						16	
	Install Power Supply	17	16	15	18	17						16	304
7th Station	Paper Cover	94	98	120	97	104	103	102	88	96	93	94	
W20-03419 REV AC PJ 1500 7th Station Printer	Assemble Midframe	138	135	137	161	143	141	131	133	129	135	133	
	Assemble onto Base	72	69	54	66	64	71	74	66	67		65	292
Test Station	Test	386	398	393	369	523	370					370	370

Assembly Line Cycle Time Audit (continued…)

The right column of the cycle time table shows how much build time is required at each station.



*There is not typically a packer stationed at pack at all times.

Using this data we can calculate a few values that summarize the build when operators are stationed at every workstation on the Line:

- The total time required to build one printer is calculated by summing each time in the right hand column of the table.
- The time required to build each subsequent printer is the largest value in the column.
- The time difference between the most time consuming station and every other station contributes to idleness and, therefore, inefficiency.
- The calculated efficiency of the Line is the printer build time divided by the idle time plus the printer build time: $\frac{24.4\ minutes}{5.2\ minutes+24.4\ minutes} = 82.4\%$

Theoretical Values for PJ1500 Line Build Based on Cycle Time Audit

	Line with Designated Packer	Line with Consolidated Pack
Number of Operators Required	8 plus packer	8 plus packer
Time Required for First Printer	26.4 minutes	26.4 minutes
Time Required for Each Subsequent Printer	3.7 minutes	3.7 minutes
Idle Time for Each Subsequent Printer	6.94 minutes	5.24 minutes
Calculated Efficiency	79.2%	82.4%

If printers were consolidated and packed by batch, there is less idle time and higher efficiency

Assembly Line Structure

WIP stored on trays slides down the rollers. WIP capacity was loosely defined by how many trays could fit on the rollers in between stations.

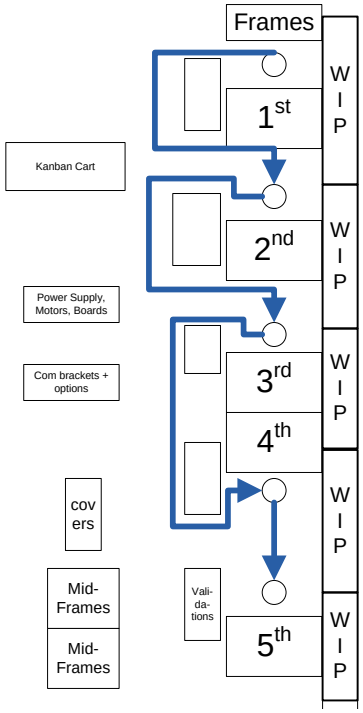
The defining characteristic of the Line's structure is the use of the metal rollers shown above. The rollers enable material to be placed on trays and moved between stations. This is convenient when more than one item needs to move between stations; however, much of the material put on the trays wasn't used until many stations later. Specifically, the Communications Board and the Printer Base would be prepared at the first station but not used until the sixth station. The result is extra WIP which necessitates the use of large trays and rollers and therefore requires additional floor space.

Process Steps	Material Flow									Repeatable	Sum
1st Station		Comm Board								76	285
			Frame							87	
	Base									121	
2nd Station										156	276
				1-3	Carriage					67	
					2-3					52	
3rd Station										56	246
			Frame	Carriage						74	
										116	
4th Station						Drive Support				50	307
	1-6		1-6		3-5		4-5			257	
5th Station										94	356
			Frame	Carriage		Drive Support	Validation			104	
										54	
										103	
6th Station										35	304
										123	
	Base	Comm Board	Frame	Carriage		Drive Support	Validation	Power Supply	PCB	96	
										18	
										16	
										16	
7th Station										94	292
	Base	Comm Board	Frame	Carriage		Drive Support	Validation	Power Supply	PCB	Midframe	133
										65	
Test Station	Base	Comm Board	Frame	Carriage		Drive Support	Validation	Power Supply	PCB	Midframe	370	370

The prepared Communications Board and Printer Base travelled an excess amount on the rollers

Assembly Line Structure (continued…)

Although the Line is designed for 8 operators, often the Line was staffed with one to four operators. In order for the Line to run with fewer people, the operators would have to move from station to station building up work-in-progress (WIP) on the rollers until they either ran out of work to do at the station or ran out of room to put their completed WIP. The problems with this scenario are a) the overproduction of WIP is encouraged so less movement is needed and b) the movement between stations was excessive since the stations were not immediately adjacent to one another. Both of these problems are considered "waste" in the Toyota Production System and must be eliminated in order optimize production.



Wasteful motion is required to move between stations on the Line. The process is even worse when, for example, a new employee that has only been trained on the first and fifth stations must move back and forth between these two stations in order to contribute to the build.

Summary Values for PJ1500 Line Structure

Number of Workbenches	10 benches
Overall Width	14 feet
Overall Length	74 feet
Total Footprint	1036 square feet

Additional photographs and a diagram of the Line are included in the Appendix

Designing the Assembly Cell: Requirements

With the overall goal of converting the Line into a Cell, some Lean Manufacturing-based requirements were put forth in order to define the structure of the Cell:

1. One piece of material shall move between stations wherever possible.
2. The new Cell structure shall eliminate the need for the rollers.
3. The use of side-carts shall be minimized.
4. The Cell shall have a "U" shape to minimize the distance and walking time between each station.
5. The amount of WIP shall be defined using visual indicators called "WIP squares."
6. The work performed at each station shall remain as unchanged as possible in order to avoid retraining.
7. 3 foot wide exit paths shall be maintained for insurance purposes.

Designing the Assembly Cell: Cycle Times

The simplest starting point involved moving the preparation of the Communications Board and Printer Base from 1st Station further down in the process such that they get prepared immediately before they are installed into the assembly.

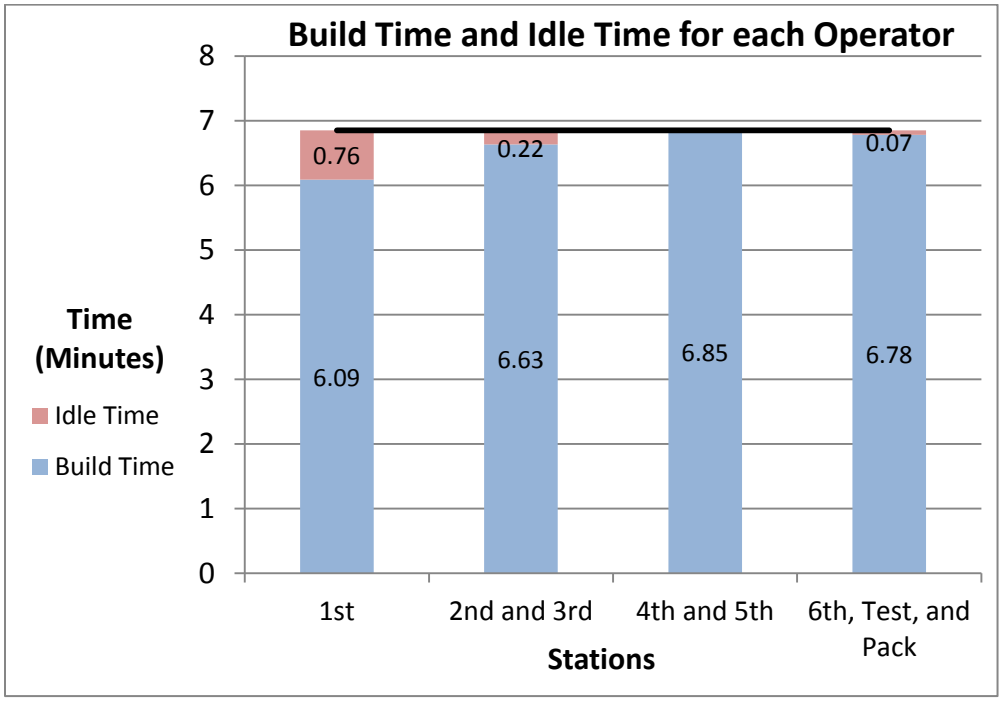
Process Steps	Material Flow									Process Step Time	Total	Sum
1st			Frame							87	609	609
										156		
				Carriage						67		
										52		
										56		
			Frame	Carriage						74		
										116		
2nd					Drive Support					50	307	663
										257		
3rd										94	356	
			Frame	Carriage	Drive Support	Validation				104		
										54		
										103		
4th										35	393	685
										123		
										96		
		Base	Frame	Carriage	Drive Support	Validation	PCB			121		
										18		
5th										94	292	
		Base	Frame	Carriage	Drive Support	Validation	PCB	Midframe		133		
										65		
6th										76	108	678
										16		
	Comm Board	Base	Frame	Carriage	Drive Support	Validation	PCB	Midframe	Power Supply	16		
Test										370	370	
Pack										200	200	

Except for the 1st and 2nd Stations, each item is prepared as it is needed in the Cell

Designing the Assembly Cell: Cycle Times (continued...)

By removing the Printer Base and Communications Board preparation from 1st Station, only 0.87 minutes worth of work remained at 1st Station. After removing the Base and Com Board material from this station, the space created on the workbench allowed for the 2nd and 3rd station to be combined with this station.

With 4 operators working at 1st; 2nd and 3rd; 4th and 5th; and 6th, Test, and Pack, the Cell efficiency is improved over the Line efficiency.



In theory, the Cell has an improved efficiency over the Line and can run with fewer people, however the overall output of the Cell will be reduced since each printer after the first will take 3.15 minutes longer to build. Since the Line would never run with 8 people any way, this was not a realistic concern.

Theoretical Cycle Time Values for PJ1500 Line vs. Cell

	Line	Cell
Number of Operators	8 plus packer	4
Time Required for First Printer	26.36 minutes	26.36 minutes
Time Required for Each Subsequent Printer	3.7 minutes	6.85 minutes
Idle Time for Each Subsequent Printer	6.94 minutes	1.05 minutes
Calculated Efficiency	79.2%	96.2%

Designing the Assembly Cell: Floor Layout

To design the floor layout, I used Microsoft Visio to create a rough draft that had a U-shape and no rollers. I cut large sheets of paper from rolls used for packaging in order to represent workbenches; it is easier to move sheets of paper instead of workbenches to adjust the floor layout. We met with the operators for about an hour per day for 5 days in order to refine the design. Once we were confident with the design, we immediately began converting the Line into the Cell.

Sheets of paper represent workbenches in the design process

One of the major challenges of the Cell design was eliminating the need for side carts. In the Line configuration, each workbench could have a side cart to hold additional material that was typically too large to stage on the work surface. 3 techniques were used to solve this problem:

1. Chutes were designed to stage the side cart material above or below the work surface.
2. The amount of material on the side cart was reduced to an amount that fits on the work surface.
3. The side carts were reduced in size and modified to have an optimal number of shelves. Also, the tops of these side carts were designated for WIP.

Summary Values for PJ1500 Line Structure vs. Cell Structure:

	Line	Cell
Number of Workbenches	10 benches	7 benches
Overall Width	14 feet	18 feet
Overall Length	74 feet	36 feet
Total Footprint	1036 square feet	648 square feet

Photographs and a diagram of the Cell are included in the Appendix

Designing the Assembly Cell: Benefits

Besides increased efficiency, decreased floor space, and fewer operators required to build the PJ1500, there are some additional advantages to be expected with the Cell conversion.

Better Production Control Definition

By designating "WIP squares" which are taped off areas to store up to 4 pieces of WIP in between workstations, the operators are better able to manage what work needs to be done at any given time. When the WIP squares are filled, it is the signal that the operator needs to move to a different station in the Cell and can return when the WIP squares begin to empty; this prevents over-production. Over-production is considered waste because it does not contribute to the value-adding work. For instance, if at the end of the day an order is not completed in time yet WIP has been started for the next day, then the missed shipment may have been able to be completed had time not been wasted producing WIP that was not needed that day. Also, large amounts of WIP mask defects until testing at which point the defects can be discovered and large amounts of rework will be required.

Labor Flexibility

The Cell is able to run with 1, 2, 3, or 4 operators before a decrease in efficiency begins. Using the WIP as the signal to perform work, the operators can distribute themselves throughout the Cell in a way that is as balanced as possible - such as the 4 person situation described earlier. If the operator is needed elsewhere in the factory and needs to leave the Cell, the other operators can easily adapt and transition to a different division of labor.

The other way to run the Cell is called a "Rabbit Chase" where each operator builds an entire printer by moving from the first station through to the last station at which point they will pack the printer and begin again from the first station with the next printer. This represents one-piece flow manufacturing and results in zero WIP. As long as no one has to wait for anyone else in the Cell, there should be no idle time and therefore a theoretical efficiency of 100%.

Nearby Experts, On the Job Training

Since benches are close to one another, it is much easier to conduct on the job training in which one operator trains another. For example, an operator who only has been trained on one or two stations can watch another station build during idle time. Since some operators have more experience than others, when a problem arises no one has to travel too far to discuss how to correct the problem.

No Repair Bench Needed

When a defective printer is identified, the operator can go to any station to fix the problem instead of letting the defective printers accumulate at a repair bench which would need to be stocked with all the tools that might be required for a repair.

Fewer Injuries from Repetitive Hand Motions, Improved Morale

Since there are only 4 WIP squares available, the operators are forced to move throughout the Cell and so it is rare to perform repetitive hand motions at one station many times in a row. This is in contrast to the Line scenario in which an operator could work at the same station for many days in a row.

Pack Station in the Cell

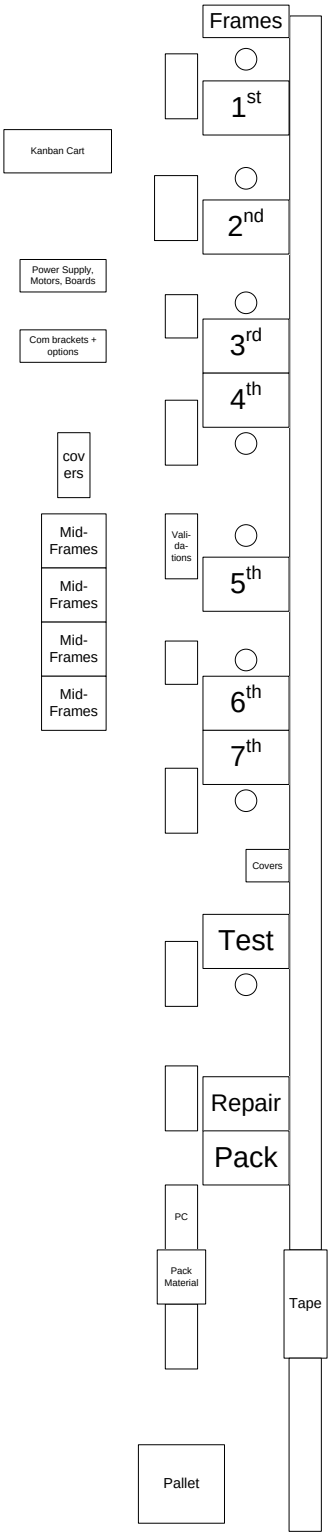
Once the material is delivered to the Cell's staging areas, nothing built is staged on a cart and needlessly moved throughout the factory. This action of loading, moving, and unloading carts is wasteful and is something to avoid in Cell design. By packing the printers in the Cell, they can be moved to Outgoing Inspection (OOBA) and then to Shipping as efficiently as possible.

Conclusions

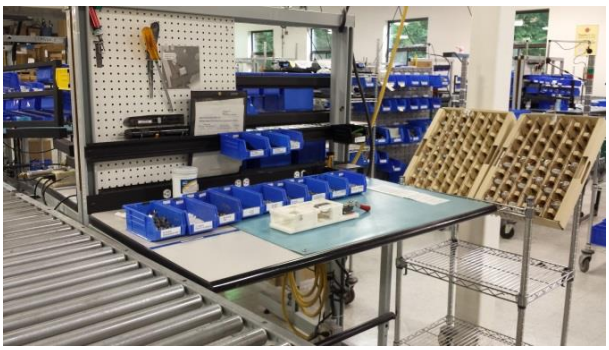
Lean/Cellular Manufacturing is a technique that can have many advantages over traditional manufacturing practices. When Transact began to do business overseas with Original Equipment Manufacturers (OEMs), we shared with them some of the modern trends in manufacturing. In a short time however, some of these OEMs such as Honortone in Guangdong Province, China advanced their manufacturing practices to the point where we could improve our operations by learning from them; our conversion of the PJ1500 Line into a Cell has been the first of many such improvements in order to advance our manufacturing towards a world class level.

Over the course of the next year, we plan to convert the production Lines for other products into Cells in order to further reap the benefits of Lean Manufacturing.

Appendix: Photos and Diagram of PJ1500 Line



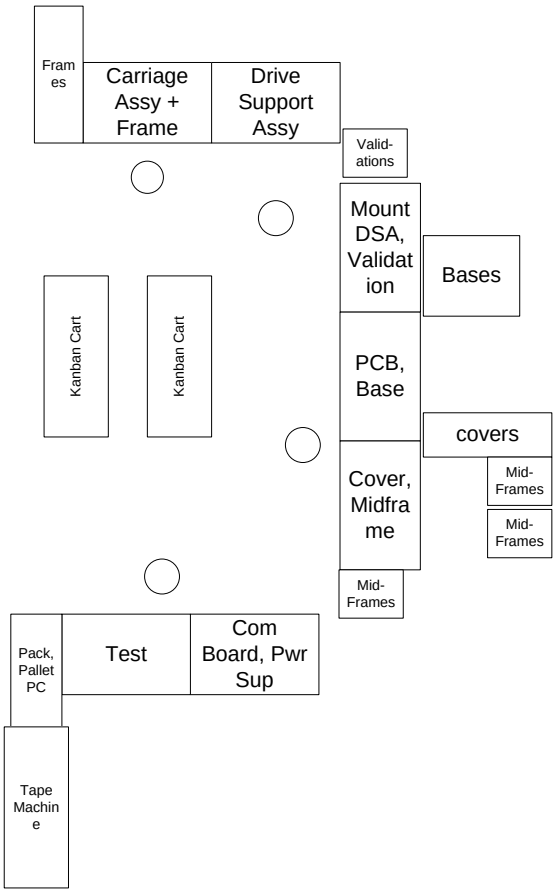
Trays stacked at the beginning of the Line



An example of inefficiently used side carts on the Line

View from the end of the Line. Communication between stations was difficult

Appendix: Photos and Diagram of PJ1500 Cell

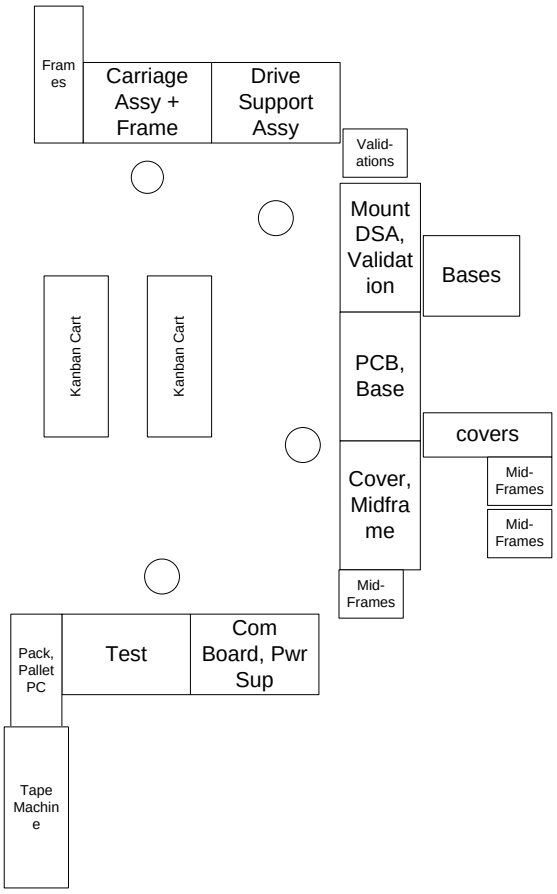


Motors and Blades are staged on angled racks instead of side carts.

4th Station to Test Station with WIP squares separating them. A smaller side cart stages midframes between 5th and 6th Stations.

Test Station and Pack Station are also adjacent in the Cell

Appendix: Photos and Diagram of PJ1500 Cell



Kanban Carts stage some of the material that had been on side carts

Chutes that present material to the operator are filled from behind. This material had been on side carts in the Line.

Printer Bases are also staged in a chute to take up less space.