JOB SHOP LEAN

Ed's Note: This is the fourth article in an eight-part "reality" series on implementing Continuous Improvement at Hoerbiger Corporation. Throughout 2013, Dr. Shahrukh Irani will report on his progress applying the job shop lean strategies he developed during his time at The Ohio State University. These lean methods focus on high-mix, low-volume, small-to-medium enterprises and can easily be applied to most gear manufacturing operations.

Dr. Shahrukh Irani, Director IE Research, Hoerbiger Corporation of America

Design of a Flexible and Lean Machining Cell (Part 1.)

Background

Group technology (GT) has been practiced around the world for many years since the 1960s as part of sound engineering practice and scientific management. S.P. Mitrofanov (1966) defined GT as "a method of manufacturing piece parts by the classification of these parts into groups and subsequently applying to each group similar technological operations." Cellular manufacturing (CM) is an application of GT to factory reconfiguration and shop floor layout design. I. Ham (1985) defined:

- a *part family* as "a collection of parts which are similar either because of geometric shape and size or because similar processing steps are required to manufacture them."
- a *manufacturing cell* as "an independent group of functionally dissimilar machines, located together on the shop floor, dedicated to the manufacture of a family of similar parts."

Although a cell is dedicated to produce a single part family, it must have the requisite equipment capabilities, routing flexibility, cross-trained employees and, to the extent possible, minimal external process dependencies. Cells are often implemented in job shops since they provide the operational benefits of flowline production.

Cells: The Foundation for Job Shop Lean

Starting in 1959, Serck Audco Valves, a U.K. manufacturer of industrial stop valves and actuators, began to implement GT and CM as a foundation for reorganizing their complete manufacturing enterprise, *even though they started with their machine shops*. In his book *Group Technology: A Foundation for Better Total Company Operation*, G.M. Ranson wrote "As a practitioner with some twelve years (of) experience of this technique (group technology), the definition which I think most clearly describes it is as follows: *The logical arrangement and sequence of all facets of company operation in order to bring the benefits of mass production to high variety, mixed quantity production.*"

Following in the footsteps of Serck Audco Valves and many other similar HMLV (high-mix low-volume) manufacturers, the starting point for implementing Job Shop Lean in any high-mix low-volume manufacturing facility is to convert their existing facility layout, usually a functional layout, into a cellular layout. The functional layout has advantages such as high machine utilization and high flexibility in allocating parts to alternative machines in any department (aka process village or workcenter) whenever any batch of parts arrives for processing. However, it has disadvantages such as high stock-to-dock order flow times, high WIP levels, poor quality control and difficulty in locating orders. In direct contrast, the cellular layout has advantages such as short stock-to-dock order flow times, lower WIP levels and effective quality control.

Table 1 Routings and Production Data for a Sample of Parts

			Routing (Sequence of Operations)						
Part No.	Qty	Revenue	Op 1	Op 2	Op 3	Op 4	Op 5	Op 6	Op 7
Part 1	10642	31336	1	4	8	9			
Part 2	4270	21300	1	4	7	4	8	7	
Part 3	1471	10901	1	2	4	7	8	9	
Part 4	4364	25774	1	4	7	9			
Part 5	5013	1580	1	6	10	7	9		
Part 6	4679	36069	6	10	7	8	9		
Part 7	5448	47776	6	4	8	9			
Part 8	5339	50339	3	5	2	6	4	8	9
Part 9	9117	48784	3	5	6	4	8	9	
Part 10	8935	37774	4	7	4	8			
Part 11	7100	68153	6						
Part 12	8611	60272	11	7	12				
Part 13	9933	39903	11	12					
Part 14	3824	19258	11	7	10				
Part 15	1359	7800	1	7	11	10	11	12	
Part 16	1235	8562	1	7	11	10	11	12	
Part 17	8581	44074	11	7	12				
Part 18	3963	23137	6	7	10				
Part 19	2309	3012	12						

Gear Up Your Quality Control

Robot systems for quality control of surface treatment such as grinding and shot peening by Barkhausen Noise and X-ray stress measurements.

RoboScan system

- *automated inspection*
- *all surfaces with one set-up*
- *safe, fast and easy measuring, also on large and complicated parts*
- *instant feedback*
- *quantitative results for production control*
- *environmentally friendly*

For residual stress testing by X-ray diffraction

Xstress Robot

- *reaches hard-to-reach areas*
- *handles complicated and large parts easily*
- *provides maximum flexibility and easy positioning*
- *is fast and precise*

stresstech group

www.stresstechgroup.com

Table 2	Information about Machines in the Different Departments			
Machine No.	**Area Requirements**	**No. available**	**Purchase Price**	**Mobility**
1	2000	2	N/A	N/A
2	1000	1	N/A	N/A
3	1000	1	N/A	N/A
4	2000	2	N/A	N/A
5	1000	1	N/A	N/A
6	2000	2	N/A	N/A
7	4000	4	N/A	N/A
8	1000	1	N/A	N/A
9	2000	2	N/A	N/A
10	4000	4	N/A	N/A
11	3000	3	N/A	N/A
12	1000	1	N/A	N/A

In this column, we will illustrate how to form the part families and machine groups that will constitute the cells which are the foundation for Job Shop Lean. Table 1 contains the P-Q-R-$ information for each of 19 parts that are produced in a hypothetical machine shop that consists of 12 machines:

1. Product Number and Name
2. Annual Production Quantity
3. Manufacturing Routing
4. Annual $ales

In addition, information about each piece of equipment used in the machine shop is needed (Table 2). The last two attributes of each machine — purchase price and mobility — are important because (1) if additional copies of that piece of equipment need to be purchased and placed in several cells, the capital expense should be affordable and (2) it could be exorbitantly expensive to relocate that piece of equipment. Figure 1 shows the existing functional layout for the shop. Figure 2 shows a cellular layout with three cells that was designed for the same shop. Each cell was designed to produce a subset of the 19 parts listed in Table 1. With reference to the cells shown in Figure 2, the existing machines in the departments 1, 6, 7, 9 and 10 in the Functional Layout have been distributed among the cells in the Cellular Layout. Finally, an up-to-date layout of the existing facility must be available along with Tables 1 and 2.

A Comprehensive Approach for Implementing Job Shop Lean

Figure 3 presents a flowchart for a comprehensive approach for implementing lean in job shops. At the core of this iterative process is the expectation that a job shop (i) will identify the stable part families in its product mix, and (ii) will implement a FLEAN cell to produce each part family. What is a FLEAN (flexible and lean) cell in a job shop? It is essentially a mini-job shop which is (a) ***flexible*** because it is designed to produce all parts in a part family, and (b) ***lean*** because its design has incorporated all the lean tools that are essential for job shops to use. In theory, each iteration of the design process shown in Figure 3 will result in the implementation of a stand-alone cell that is dedicated to producing a part family. In reality, numerous constraints will arise that could prevent implementation of any cell. Some constraints could be broken (Example: Operators could be cross-trained to operate multiple machines in a cell). Whereas, some constraints may remain unbreakable (Example:

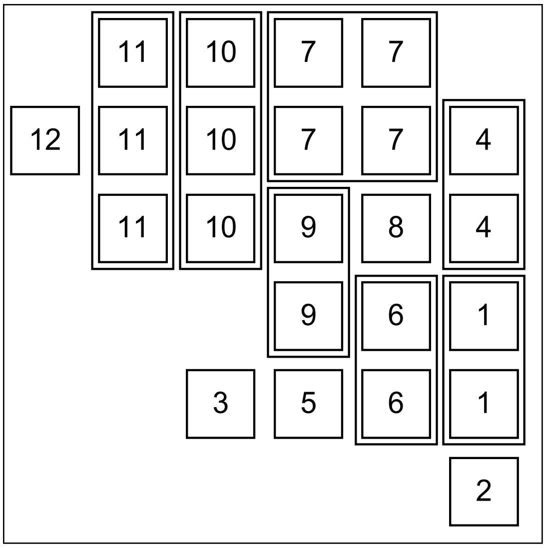

Figure 1 Functional Layout

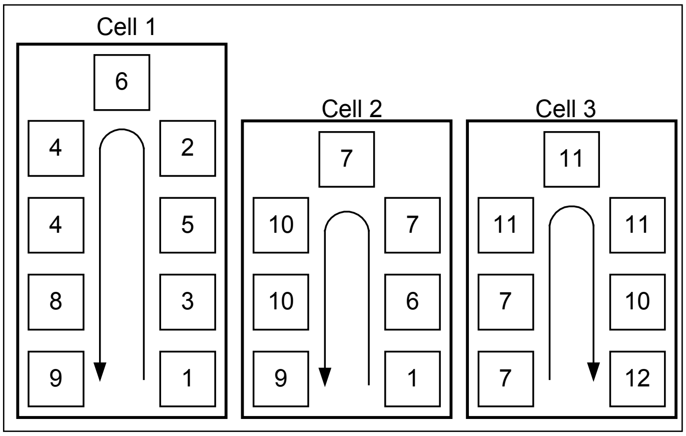

Figure 2 Cellular Layout

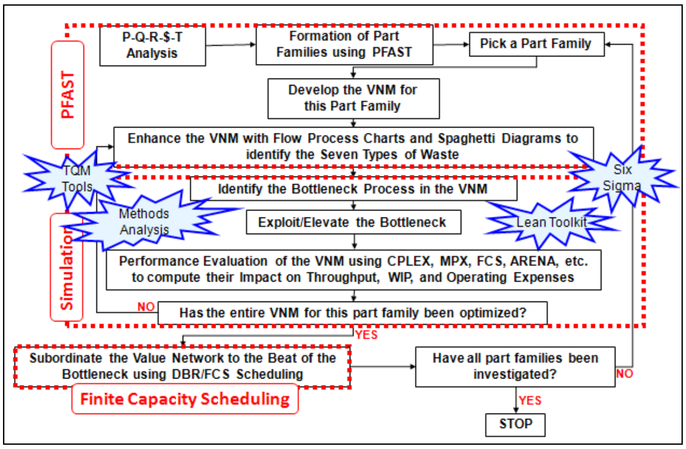

Figure 3 Comprehensive Approach for Implementing Job Shop Lean

Heat treatment furnaces cannot be placed inside a cell next to a CNC grinder).

Upon completion of this process, a job shop would typically end up being divided into at least two sections:

- Section 1: This area of the facility will consist of FLEAN cells with each cell dedicated to a product family.
- Section 2: This area of the facility is a "remainder shop" where the non-production orders (spare parts, prototypes and one-offs for new customers, rush orders) are produced.

By dividing the job shop into these two sections, two benefits are gained: (1) The cells provide unquestionable quick response, high quality, team work and order traceability and (2) A smaller portion of the entire business now needs to be managed as a complex job shop where flexible automation coexists with firefighting and overtime to fulfill orders.

An Illustrative Example to Explain the Analytics Underlying the Methodology

This section briefly describes how we analyze the data captured in Tables 1 and 2 to implement the approach shown in Figure 3 in a high-mix low-volume facility like HCA-TX. We used the *PFAST* (*Production Flow Analysis and Simplification Toolkit*) software that helps to implement Prof. John L. Burbidge's method of production flow analysis (PFA) for implementing cellular manufacturing in any complex multi-product facility.

From-To Chart: Given the routings of a sample of parts in Table 1 and the Quantity (or Revenue) for each of those parts, the From-To Chart (Table 3) captures the cumulative volume of material flow between every pair of consecutive machines that occurs in one or more of the routings listed in Table 1. Each entry in the chart represents the aggregate material flow "from" the machine listed in any row of the table "to" any machine listed in any column of the table. For example, the total number of parts flowing From Machine #1 to Machine #2 is 1,471 because only the routing of Part #3 contains that pair of consecutive machines (1→2) and Q = 1,471 pieces for this part.

Table 3 From-To Chart

		To											
	Machine	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
From	**1**		1471		19276		5013	2594					
	2				1471		5339						
	3					14456							
	4							19040	43751				
	5		5339				9117						
	6				19904			3963			9692		
	7				13205				6150	9377	7787	2594	17192
	8							4270		36696			
	9												
	10							9692				2594	
	11							21016			2594		12527
	12												

If you input the From-To Chart in Table 3 to a standard facility layout software like *Storm*, *Plantopt* or *Factoryflow*, it will produce a functional layout for the entire shop like the one shown in Figure 4 (similar to the one shown in Figure 1). The algorithm internal to any of these software tools will place departments with the highest traffic volume adjacent to each other. The same software tools could be used to design the layout of an individual cell or a shadowboard for tools used to assemble a variety of products.

***Product-Process Matrix Analysis*:** This is the method that is widely touted in the lean literature for the formation of product families and manufacturing cells. However, history will show that it was first utilized by Burbidge for identification of part families and machine groups in the fabrication shop of a crane manufacturing facility. The Initial 0-1 matrix (Table 4) converts the original part routings in Table 1 into a matrix with part numbers in the rows and machine numbers in the columns. Each cell in the matrix which contains a "1" links a part number to a particular machine number that occurs one or more times in the routing of that part. For example, the routing for Part #1 is 1→4→8→9. Therefore, in Table 4, in the row for Part #1, a "1" occurs in the columns for "m1", "m4", "m8" and "m9."

The Initial 0-1 matrix does not show potential groups of machines and parts that are the basis for implementing FLEAN cells. However, when the same matrix is manipulated by reordering the rows and columns, it produces the final 0-1 matrix in Table 5. This new matrix reveals the potential for implementing two cells provided that some machines can be duplicated in both cells. Each block in the final matrix, which is defined by a set of consecutive rows and consecutive columns, represents a family of parts that could potentially be produced by putting the appropriate group of machines into a manufacturing cell. For example, in Table 5, we can see that two cells can be formed: Cell 1 consists of machines 2, 3, 5, 4, 8, 9, 6, 1, 7 and 10 and Cell 2 consists of machines 6, 1, 7, 10, 11 and 12.

If we desire to implement two cells, then machines 1 and 6 must also be placed in Cell #2, and machines 7 and 10 must also be placed in Cell #1. Unless these machines are duplicated and assigned to both cells, inter-cell flows will occur that are not easy to coordinate and will be disruptive to operations in both cells. This is where the "Purchase Price" column in Table 2 plays a key role. Alternatively, instead of drawing the cut-off line between Part #6 and #18 in Table 5, we could have drawn it between Part #11 and #14. That would have eliminated the need to duplicate Machine #6 but it would make one part family (and its cell) much larger than the other part family. Many other strategies exist to eliminate the inter-cell flows, besides distributing the existing machines of each type among several cells or acquiring extra machines. They would be evaluated by a cross-functional team during one or more kaizens authorized by management. Interested readers who wish to obtain the two strategy maps that summarize all the strategies to eliminate or manage inter-cell flows in HMLV facilities are welcome to e-mail Dr. Shahrukh Irani at *shahrukhirani1023@yahoo.com*.

Based on Table 5, if it is desired to implement two independent cells with no inter-cell flows of parts, machines 1, 6, 7 and 10 must be duplicated in both cells. Figure 5 shows the layout that was developed for each cell. Instead, if it is desired to allow inter-cell flows between the two cells because machines 1, 6, 7 and 10 will not be duplicated, then the shop layout would be as shown in Figure 6. Both layouts were developed using the *Storm* software.

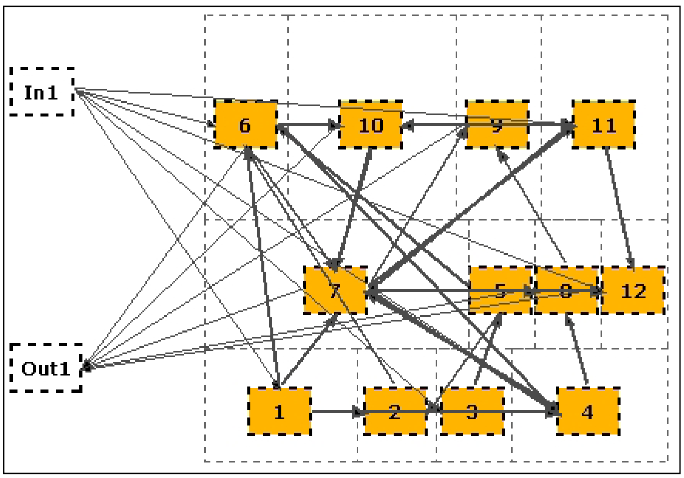

Figure 4 Functional Layout

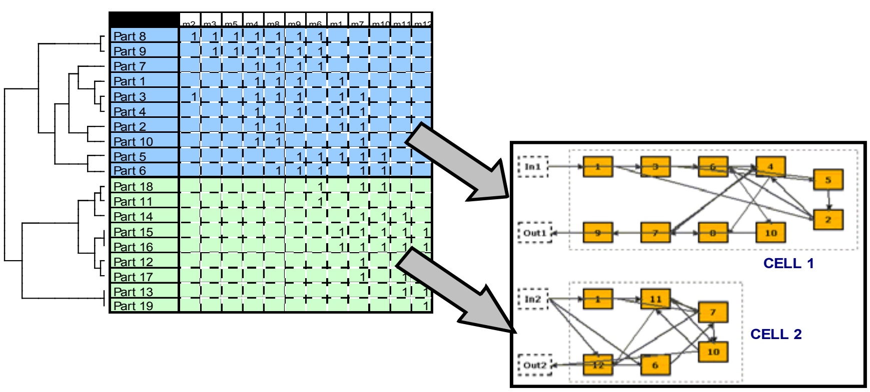

Figure 5 Cellular Layout with No Inter-cell Flows

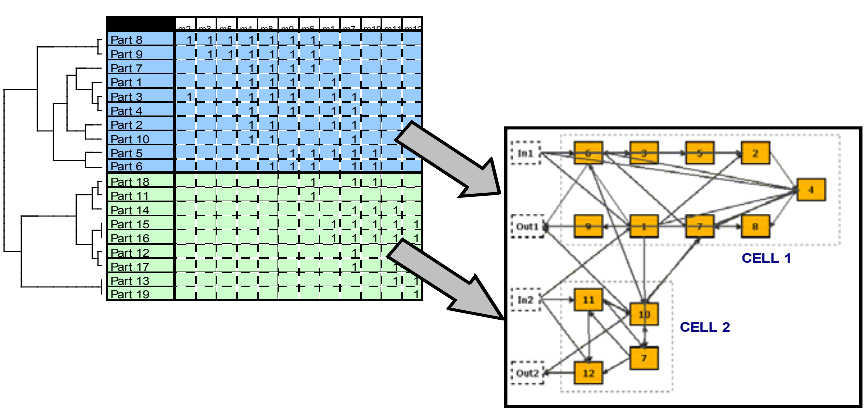

Figure 6 Cellular Layout with Inter-cell Flows

Sequence Similarity Analysis of Routings: If we use the 0-1 matrix to represent the routings in Table 1, we fail to capture the exact sequence in which machines are visited by a part. Table 6 shows results from an alternative method — sequence similarity analysis – that overcomes this major shortcoming of product-process matrix analysis. How would you put Table 6 to work? Imagine that, for each part produced in the facility, you implement a flowline cell simply by placing the machines that occur in its routing in sequence. You could not afford to buy that many machines if you had to do the same for all the parts being produced, right? Instead, what if you placed side-by-side those flowlines that produce parts with identical, or at least similar, routings? This would allow an entire part family with identical, even similar, routings to be produced on a single flexible flowline whose layout conforms with the routings of the parts in that family. For example, with reference to Table 6, you would start with just machine

Table 4 Initial 0-1 Matrix

	m1	m2	m3	m4	m5	m6	m7	m8	m9	m10	m11	m12
Part 1	1			1				1	1			
Part 2	1			1			1	1				
Part 3	1	1		1			1	1	1			
Part 4	1			1			1		1			
Part 5	1					1	1		1	1		
Part 6						1	1	1	1	1		
Part 7				1		1		1	1			
Part 8		1	1	1	1	1		1	1			
Part 9			1	1	1	1		1	1			
Part 10				1			1	1				
Part 11						1						
Part 12							1				1	1
Part 13											1	1
Part 14							1			1	1	
Part 15	1						1			1	1	1
Part 16	1						1			1	1	1
Part 17							1				1	1
Part 18						1	1			1		
Part 19												1

Table 5 Final 0-1 Matrix

	m2	m3	m5	m4	m8	m9	m6	m1	m7	m10	m11	m12
Part 8	1	1	1	1	1	1	1					
Part 9		1	1	1	1	1	1					
Part 7				1	1	1	1					
Part 1				1	1	1		1				
Part 3	1			1	1	1		1	1			
Part 4				1		1		1	1			
Part 2				1	1			1	1			
Part 10				1	1				1			
Part 5						1	1	1	1	1		
Part 6					1	1	1		1	1		
Part 18							1		1	1		
Part 11							1					
Part 14									1	1	1	
Part 15								1	1	1	1	1
Part 16								1	1	1	1	1
Part 12									1		1	1
Part 17									1		1	1
Part 13											1	1
Part 19												1

Cell 1

Cell 2

These machines will need to be duplicated in both cells

Table 6 Sequence Similarity Analysis of Routings

Part No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Part 11				6										
Part 18				6					7	10				
Part 14								11	7	10				
Part 12								11	7			12		
Part 17								11	7			12		
Part 13								11				12		
Part 19												12		
Part 15	1					7	11	10	11			12		
Part 16	1					7	11	10	11			12		
Part 5	1			6				10	7				9	
Part 6				6				10	7			8	9	
Part 10					4				7		4	8		
Part 2	1				4				7		4	8		7
Part 4	1				4				7				9	
Part 3	1		2		4				7			8	9	
Part 1	1				4							8	9	
Part 7				6	4							8	9	
Part 8	3	5	2	6	4							8	9	
Part 9	3	5		6	4							8	9	

#6 in a machining flowline on the shop floor. But then you could only make part #11. Next, you would expand this flowline with three machines sequenced as follows: 6→7→10. This flowline could now produce part #11 *and* part #18. Next, if you placed machine 11 side-by-side with machine #6 and machine #12 side-by-side with machine #10, this new flowline could also make part #s 12,17, 13 and 19. Next, add Machine #1 at the front of the flexible flowline and we could make part #s 15 and 16 too. Stop! Beyond this point, this current flowline's part family ought *not* to include any more parts (See Figure 7).

Starting with the routing for Part #5, begin building a second flexible flowline for the second part family. Actual projects have involved up to about 1,500 routings. Therefore, we have preferred to compare the part families suggested by product-process matrix analysis with those suggested by sequence similarity analysis to determine the part families and compositions of their corresponding cells.

Part No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Part 11				6										
Part 18				6					7	10				
Part 14								11	7	10				
Part 12								11	7			12		
Part 17								11	7			12		
Part 13								11				12		
Part 19												12		
Part 15	1					7	11	10	11			12		
Part 16	1					7	11	10	11			12		
Part 5	1			6				10	7				9	
Part 6				6				10	7			8	9	
Part 10					4				7		4	8		
Part 2	1				4				7		4	8		7
Part 4	1				4				7				9	
Part 3	1		2		4				7			8	9	
Part 1	1				4							8	9	
Part 7				6	4							8	9	
Part 8	3	5	2	6	4							8	9	
Part 9	3	5		6	4							8	9	

If a standard 2-cell Cellular Layout were designed, this is where the two part families would be separated.

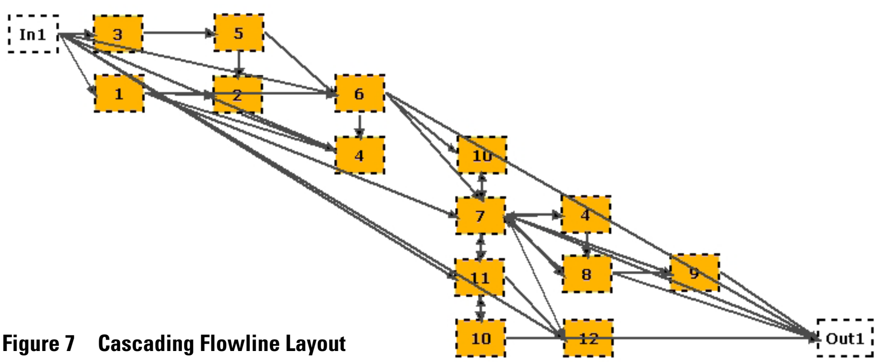

Figure 7 Cascading Flowline Layout

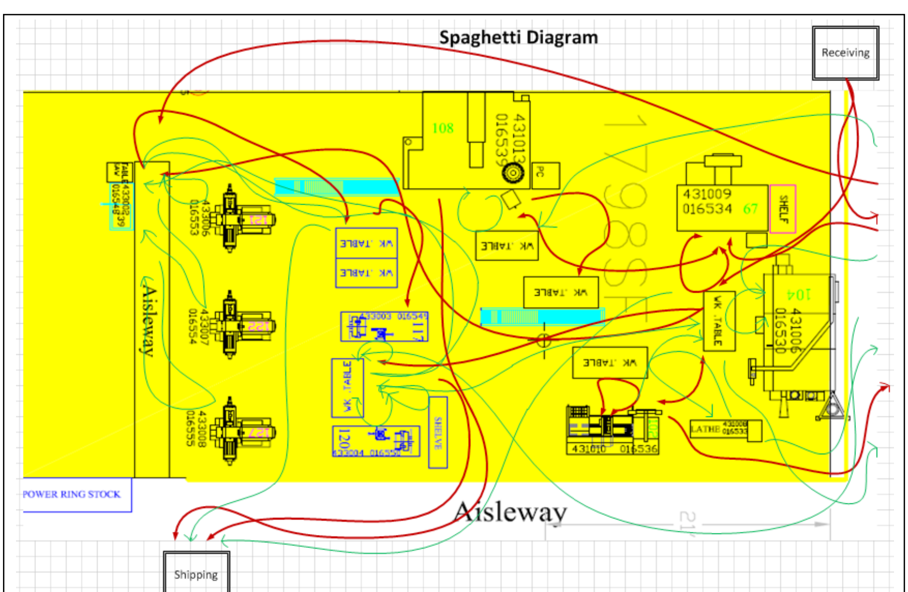

Figure 8 Material Flows in the Current Layout for the MP Cell

Application of the Theory at HCA-TX

At HCA-TX, we are already organized loosely into seven FLEAN cells — five in the machine shop and two in the molding department. While this gives us an excellent foundation for implementing Job Shop Lean, the word "loosely" describes our current state very well. Except for the QRC, the other cells are not self-contained, hence unable to function as ABUs (autonomous business units). Of the five existing machining cells in our facility, the MP Cell (MPC) was the best candidate for demonstrating the use of our computer-aided methodology for implementing Job Shop Lean, as described in Figure 3. Unlike the MPC, the other four machining cells are currently in flux for a variety of reasons, such as changes in their product mix, technology upgrades, reduction or replacement of vendors, etc.

Dhananjay Patil is a Masters student at the University of Texas-Arlington where he is pursuing his degree in Industrial Engineering (IE). He is currently working as an Industrial Engineering intern at Hoerbiger.

Dr. Shahrukh Irani is the Director of Industrial Engineering (IE) Research at Hoerbiger. In his current job, he has two concurrent responsibilities: (1) To undertake continuous improvement projects in partnership with employees as well as provide them OJT training relevant to those projects and (2) to facilitate the implementation of Job Shop Lean in HCA's U.S. plants.