SAINT-GOBAIN ABRASIVES SHANGHAI – LEAN MANUFACTURING FEASIBILITY STUDY

A Major Qualifying Project Report

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Abstract

Saint-Gobain Abrasives Shanghai is a grinding wheel manufacturing plant that intended to apply lean manufacturing principle to its manufacturing processes. This study was conducted to determine whether or not the idea of implementing lean was feasible. After thorough analysis, it was determined that the company would be able to benefit from the implementation of lean manufacturing. This report provides the company with proposed cell designs and also a method for the scheduling of manufacturing.

Acknowledgements

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1 Introduction

Saint-Gobain Abrasives Shanghai is a manufacturing plant for grinding wheels of various sizes. Currently, the plant manufactures the grinding wheels in a conveyor line. This means that for a product to be completely manufactured, it must travel the entire length of their plant. This is an archaic method from the time of Henry Ford's Model T assembly line. In this day and age where competition is the driving force for innovation and improvements, the conveyor manufacturing line just will not suffice.

Saint-Gobain wants to apply lean manufacturing to their plant. In the process, the company would like to convert their current conveyor line into multiple cells to manufacture their grinding wheels. The company already proposed a new plant layout that included the cells. The problem is that the newly proposed design had not been tested to confirm any improvements over the older conveyor design. Validation was necessary. With this validation, Saint-Gobain also wanted the team to develop a method for scheduling the manufacturing methods within the cells

Understanding Saint-Gobain's expectations of lean manufacturing is an important step to properly implementing the principles. There are five major aspects that a company wants to improve when lean manufacturing is implemented. The improvements are: increased production capacity, increased production efficiency, increased production rate, increased product quality, and increased profit margin. Laying out a set of objectives to go about doing this project is crucial in being able to implement lean manufacturing. The project team determined that the following objectives were essential: understand Saint-Gobain's current manufacturing processes, identify why there is a need to apply lean manufacturing, determine if the initial proposed design is feasible, determine the details in the cell design, evaluate the new cells targeting on the reduction of waste, and to assess the project outcomes against lean principles.

To get the final results for this project, the team had to perform four separate phases, they were: analysis phase, cell design phase, scheduling phase, and the final design phase.

The goal of this project was to assess Saint-Gobain Abrasives Shanghai's proposed lean system by following the lean procedures systematically and to provide a validated solution with details to improve its current status.

2 Background

This section shows what knowledge is necessary to completing the project. It is important to have a background on the company. Knowing what the company does is of great value because it allows the project group to have a better sense of who they are. The project becomes more personal to both the project group and Saint-Gobain. Obtaining knowledge of grinding wheels is important to this project because Saint-Gobain Abrasives Shanghai is primarily a grinding wheel manufacturing plant. To understand what materials are used and how it all comes together is a key aspect.

2.1 Saint-Gobain Abrasives Shanghai

Saint-Gobain Abrasives Shanghai is located at Minhang Economic and Development Zone in Shanghai, China. There are two plants, one is on site and the other is located in Dongguan, China. The plants manufacture grinding wheels in various sizes, with outside diameter ranging from 180 millimeters to 1100 millimeters. The plants are ISO 9001 certified. All of their products satisfy or exceed the industrial standards set by GB, JIS, and ANSI. (Saint-Gobain Abrasives Shanghai – About Us, 2006)

2.2 Lean Manufacturing Principles

To appropriately apply lean manufacturing to Saint-Gobain Abrasives Shanghai manufacturing plant, it is important to gain knowledge of the process of lean, its principles and its outcome.

Lean manufacturing is an initiative focused on eliminating waste in a manufacturing process[1]. Waste can be defined in seven ways: overproduction, inventory, waiting, transportation, motion, process, and defects. The removal of waste allows for an improvement in product quality, reduction in the cost of manufacturing the product, and an increase in the overall delivery efficiency. Essentially, the thought process behind the lean manufacturing principles is to make a company faster, cheaper, and better. The following points were taken from Michael D. Regan's The Kaizen Revolution.

- **Overproduction** becomes a problem when manufacturing a product because according to the lean ingredients, products should be produced in a just-in-time manner. Producing more product than necessary is a large waste, especially because it creates an inventory of finished product.
- **Inventory** is considered a waste because the only thing a finished product does in inventory is wait. Having an inventory means that unnecessary work had been performed.
- **Waiting** is one of the largest wastes in a manufacturing process. Anytime waiting is occurring, it means that no value is being added to the material. Non-value added steps are mostly unnecessary.
- **Transportation** is defined as a waste because moving material long distances between steps does not aid in getting it produced any faster. Setting up work cells will allow for a reduction in transportation by placing the machines at a more reasonable distance.

[1] http://www.isixsigma.com/dictionary/Lean_Manufacturing-116.htm

- **Motion** is the unnecessary movement of personnel. People moving around the plant floor will not have as much time to work on finishing a product.
- **Process** is any process that does not add value to manufacturing.
- **Defects** are considered a waste because every time a defective product is produced, it must go through the entire manufacturing process a second time. Running a process two times to get only one product is an enormous waste.

There are eight lean ingredients that must be applied to implement, correctly and fully, lean manufacturing. It is necessary to identify the current problem areas of the company to realize the faults a company has to overcome to make better their situation. The following is a list and definition of the eight lean ingredients from The Kaizen Revolution:

- **Just-in-time production** is changing the approach of the company's method of fulfilling customer orders. The point of this ingredient is to produce according to demand, meaning only manufacture products as an order comes in. Just-in-time production should eliminate overproduction. Potentially, this ingredient also allows for removing inventory of finished products and raw materials.
- **Continuous one piece flow** means when raw material to be produced into a final product enters the manufacturing plant, it is always moving through the steps to create the finalized product and it is delivered. The product will never go into stock.
- **Work cells** are a group of machines needed to produce a product family. This allows for less motion and transportation of personnel and material being

produced. After each processing step, the material can be moved almost instantly to the next step.

- **Setup reduction** is when machines are set to allow for flexibility to make more than one specific process. To apply this, it is important to fulfill orders in complete batches and then once the specific product has been produced the next one can be started.
- **Preventive maintenance** is used to keep machines from breaking down. Anytime a machine becomes disabled, it will stop the entire production process in a lean environment, therefore it is very important to keep machines in prime working order.
- **Kanban** is a compromise that has to be made to a manufacturing process. Anytime kanban is used, a non-value added step is added to the process.
- **Workplace organization and cleanliness** is an important ingredient to utilize in a manufacturing plant. This "is also known as 5S." 5S are seiri, seiton, seiso, seiketsu, and shitsuke. The English translations of the Japanese words translate into sort, straighten, scrub, schedule and score. Sort means to get rid of everything not utilized on the plant floor. Straighten means to find a place to for everything and to keep everything there. Scrub means to keep everything clean. Schedule is maintaining a set schedule to perform the other three Ss. Score means to grade how well the first three Ss are being performed. (Regan 39, 2000)
- **Standard work** is to document the best known way of doing a process and using that same method every time. If a better method of doing the process is discovered, the method can change, standard work allows for flexibility as long as

it is a standardized process. "Standard work is the highest quality, lowest cost, and fastest way to do work." (Regan 40, 2000)

- **Teams** are useful in lean manufacturing because it allows for solving problems as they become apparent.

Utilizing the ingredients above, it will be possible to remove the seven wastes.

In implementing lean manufacturing, it is imperative that the entire process for manufacturing is understood. It is useful to record the takt time, or how long each process takes. Knowing the time of every process will make it obvious to where the manufacturing process gets bogged down. It will then be possible to identify bottleneck areas. Bottleneck areas are where products wait for the next step to occur; usually it is because the following step takes more time to perform than the previous step. Bottleneck areas make it difficult to make the manufacturing process flow continuously. To allow for continuous one piece flow, the takt time must be balanced.

Another step in understanding the manufacturing process is to record all of the steps in the process. After the steps have been recorded, a value-added analysis should be performed. This will make it possible to visualize where all of the value added and non-value added steps occur. "A process step is value-added if it causes a change in the physical state of the material, in accordance with customer specifications." (Regan 15, 2000) The removal of all of the non value-added steps will cause an increase in quality, cost and delivery. Every step that is taken is a step where an error could occur. Deleting actual process steps means there are not as many steps for errors to occur. Every process step takes a certain amount of time to perform; therefore removing the unnecessary steps will increase the speed of production. Generally, there is a direct relationship between time and money. When time is reduced, less money is spent on producing the product. Profitability will increase.

It is important to note, "if you are managing a high-mix, low-volume plant, you must implement 5S, standard work, setup reduction, and preventive maintenance. However, just-in-time production, continuous one-piece flow, work cells, and kanban can actually *decrease* efficiency in a true high-mix, low volume environment because these techniques require some degree of repetitiveness." (Regan 31, 2000)

2.3 Scheduling

"Scheduling consists of planning and prioritizing activities that need to be performed in an orderly sequence of operation. It is a tool that optimized the use of available resources. Scheduling leads to increased efficiency and capacity utilization, reducing time required to complete jobs and consequently increasing the profitability of an organization. Efficient scheduling of resources such as machines, labor, and material is a must in today's extremely competitive environment." (Sule, 1997)

There are many different methods of scheduling, but for the purposes of this project, only two methods were studied and utilized. These two methods were the First Come First Serve (FCFS) method and the Longest Process Time (LPT) method.

The FCFS method of scheduling means that as orders come, the orders will queue in the order they were received. This is a very simple method for a shop to follow. The only thing the company would have to do is manufacture products as they are received.

"The longest processing time rule orders the jobs in the order of decreasing processing times. Whenever a machine is freed, the largest job ready at the time will begin processing. This algorithm is a heuristic used for finding the minimum make span of a schedule. It schedules the longest jobs first so that no one large job will 'stick out' at the end of the schedule and dramatically lengthen the completion time of the last job." (Hochbaum, 1999)

2.4 Summary of Background

Utilizing the information that was studied while compiling the background section, the following methodology can be applied to practice lean manufacturing at Saint-Gobain Abrasives. This study is necessary because it allows us to do a proper analysis of the company and also it will assist us in applying the lean manufacturing principles to the company.

3 Methodology

The objectives of this project were to assess Saint-Gobain's proposed lean system by following the lean procedures systematically and to develop a method of scheduling for their manufacturing processes. The team needed to understand Saint-Gobain's current manufacturing processes. They needed to identify why there is a need for the company to implement lean manufacturing. They needed to determine if the initial design that Saint-Gobain provided was feasible. They also needed to determine the details in the cell designs. To do these things, it was necessary for the team to collect data and then to analyze the collected data. With the data they received, they were able to design their own cells and develop a scheduling method.

3.1 Data Collection

The project team received a lot of data from the company. Most of the data the team needed to analyze the company was already recorded by the company as they were in the process of implementing lean. The information the team needed includes:

- Complete machine list with specifications
- Data from manufacturing processes according to the size of grinding wheels.
    - Cycle time
    - Machine time
- Floor layout for both current layout and multiple cell layouts

All of the information above was given to the team by the company. Other information that the team needed were obtained by taking tours of the plant.

The team needed to gain extensive knowledge about the company and how they operate. Touring the plant was an important step to becoming familiar with the manufacturing process. Being able to observe the happenings on the floor was extremely helpful. It was also nice that we were able to ask the machine operators questions during our plant tour. The questions that the team asked were general ones such as the manpower that was need to run a machine properly. From the layout of the plant floor, the team members were able to create flow charts of the manufacturing process of the grinding wheels. These flow charts helped the team to better visualize each of the process steps the grinding wheels needed to be completed. A very important point the team was able to determine was that touring the plant floor made it extremely easy to see where bottlenecking occurs. It is important to identify bottlenecks because products waiting do not add value and it increases the manufacturing time.

3.2 Data Analysis

Using the principles from lean manufacturing and the data they acquired from the company, the project team decided on performing two phases of analyzing data.

3.2.1 Primary Analysis

For the primary analysis stage, the project team decided that they would just do a surface analysis of how the company manufactures their grinding wheel and also do simple analysis on orders from customer orders. From the tours, the team was able to create flow charts for the grinding wheel manufacturing process. Flow charts were important because it allowed for a way to visualize the steps it takes to manufacture grinding wheels. We compiled a list of machines that were on the floor. We did this by going from station to station in the factory and just jotting down the machines that were present. To find areas where bottlenecking occurs, the team just observed where there was a lot of products waiting.

From the data the company provided to the team, they were able to calculate the order frequency for the various product families. Simple statistics were used to do this, such as getting average number of wheels per order and the standard deviations.

3.2.2 Secondary Analysis

The secondary analysis phase of this project was to take the knowledge gained from the primary analysis section and further analyze the data. The team created three charts, the machine utilization chart, the time chart, and the quantity variations between orders chart. The three charts helped the team visualize the data they received.

3.3 Cell Design

Saint-Gobain provided the team with two proposed designs for potential cell layouts for the manufacturing floor. The project team did an extensive analysis of the two designs. They looked for potential travel back areas, bottleneck areas, and areas of unnecessary transportation of the products.

The WPI-HUST team, after doing the analysis of the cells given to them by Saint-Gobain, designed their own cell design which was proposed to the company. The project team used data analysis to design their cells. The cells were designed with the most typical orders in mind. Any orders with significant variations were not truly included in the cell designs. Variations would have to be manufactured in a different, out of the way, route.

3.4 Scheduling

Saint-Gobain is an order oriented manufacturing company. With this being the case, the scheduling task became a course that faced two objectives, one being the due date and the other is lead time. According to the company, their current scheduling practice follows the first come first serve (FCFS) rule.

Saint-Gobain asked the WPI-HUST project team to create a method for scheduling the tool room. After some research, the team decided that the best method would be the longest process time (LPT) rule for scheduling.

4 Results

Following the methodology, the team was able to develop the following results. This section will show the data that was collected from Saint-Gobain, the data analysis, the different cell designs including a comparison among the teams design and Saint-Gobain's design, and the results of scheduling. There will also be a final design description which the team thinks is the best way to layout the plant according to the complete data analysis from the data given to them by the company and the results from scheduling.

4.1 Data Collected and Analysis

The data the company provided to the team was separated into the separate size categories that the company wanted to make their cells into. The team looked at the data to see if there would be any other way to separate the different sizes but what the company made the most sense as they did the separation according to the machines capabilities. The size categories are tool room, small room, medium room, and large room. The tools, small, medium and large are designations for the size range of the outside diameter of the grinding wheels. Table 1 shows the outside diameter of the grinding wheels according to size of the room.

Room	Outside Diameter
Tool	OD = 180mm and 205mm
Small	205mm < OD ≤ 400mm
Medium	400mm < OD ≤ 610mm
Large	OD > 610mm

Table 1: Outside diameter according to room size

Figure 1 shows the flow of the manufacturing process. The company wants the team to just concentrate on the steps highlighted by the purple box. The four process steps before this must be left the way they are.

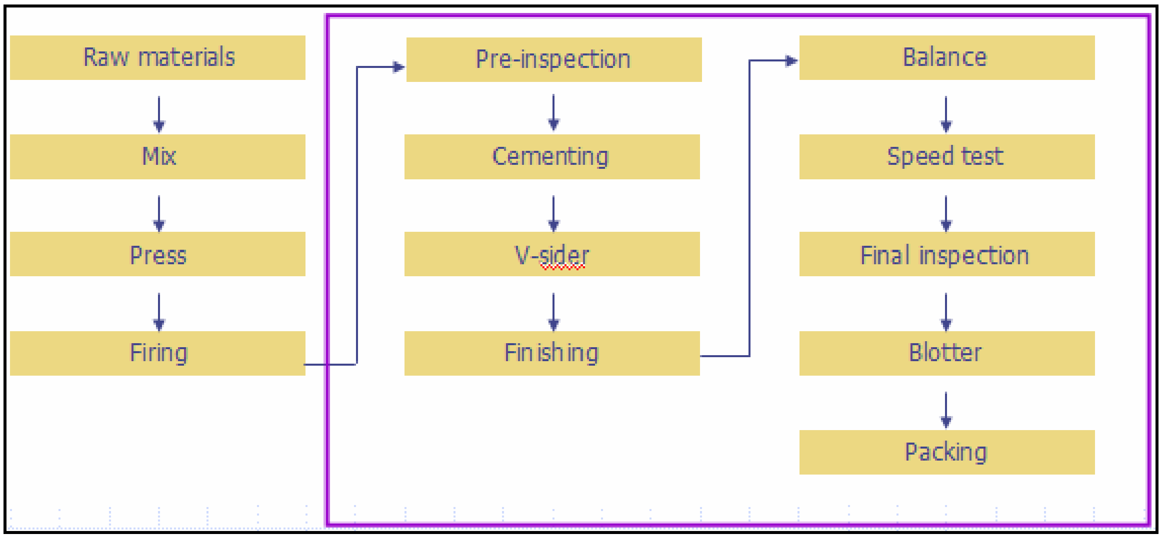

Figure 1: Flow chart of manufacturing process

Table 2 is just a part of the list of machines that Saint-Gobain provided to the team. There are a total of 86 machines on the floor of the plant.

MACHINE	NO.	FUNCTION	DIMMAX	MANPOWER
PRE-INSPECTION	YP1	PRE-INSPECION		1
PRE-INSPECTION	YP2	PRE-INSPECION		1
WEIGHT	ZL	PRE-INSPECION		1
SBP	565-01	SBP_TEST	≤1200	1
SBP	545-8	SBP_TEST	≤1200	1
SBP	562-2	SBP_TEST	≤1200	1
SBP	565-7	SBP_TEST	≤1200	1
OUTLINE-HOLE	599-31	OUTLINE-HOLE	≤610	1
REAM-HOLE	599-32	REAM-HOLE	≤405	1
CEMENT_BUSH	599-7	CEMENT_BUSH		1
CEMENT_BUSH		CEMENT_BUSH		1
CEMENT_BUSH	599-64	CEMENT_BUSH	≤610	1
CEMENT_BUSH	599-63	CEMENT_BUSH	≤610	1
CEMENT_BUSH	599-24	CEMENT_BUSH		1
CEMENT_BUSH	599-58	CEMENT_BUSH	≤610	1
ARTER	599-11	SIDES-DIAMOND	≤405	1
ARTER	599-71	SIDES-DIAMOND	≤405	1
ARTER	599-17	SIDES-DIAMOND	≤405	1
V-SIDER-FINISHING	599-67	VSIDER-FINISHING	<660	1
V-SIDER-FINISHING	J599-50	VSIDER-FINISHING	≤610	1

Table 2: Sample Machine List

Tables 3 through 6 are a sampling of the orders that we have received from the company. The tables include a calculation of cycle time, average cycle time and a standard deviation calculation. The standard deviation calculation allowed the team to see which orders had the most variation. From the company, the team received a total of 85 orders. According to the company, the orders they gave to the team was a good indicator of "typical" orders the company receives from its clients.

	101221893	101274741	…	101274077			
	order 1	order 2	…	order 11	the sum	average	stdev
PRE_INSPECTION	4.025	4.025	…	4.025	44.275	4.025	0.00
SBP	0	0	…	0	2.143	2.143	0.65
VSIDER	54.223	49.333	…	49.333	574.532	52.23018	14.38869
SIDES_S	143.589	79.829	…	79.829	835.65	75.96818	33.1225
PLASTIC_BUSH	0	102.744	…	102.744	924.696	102.744	44.25607
CEMENT_BUSH	112.944	0	…	0	166.655	83.3275	36.22
FACE	38.331	34.881	…	34.881	369.682	33.60745	3.99466
300SD	0	0	…	0	824.36	412.18	166.74
BAL_D610	73.523	66.893	…	66.893	744.466	67.67873	10.52147
JS	67.366	61.866	…	65.676	684.415	62.21955	9.632761
INSPECTION	66	42	…	42	486	44.18182	9.568889
BLOTTER	33.67	30.64	…	30.64	340.07	30.91545	4.608322
PAPER_BOX	44.6	41	…	41	454.6	41.32727	5.475233
CYCLE TIME	638.271	513.211		517.021		586.504	181.2346889

Table 3: Sampling of tool room orders with cycle time

	101255253	101275218	…	101293239			
	order 1	order 2	…	order 32	the sum	average	stdev
PRE_INSPECTION	4.025	4.025	…	4.945	125.08	3.90875	1.137831412
SBP	0	0	…	2.792	40.743	1.567038462	1.241936922
VSIDER	7.862	11.609	…	5.62	309.202	9.6625625	10.05056929
SIDES_S	21.958	43.717	…	0	251.683	7.86509375	20.94043187
PLA_BUSH	0	0	…	0	6.39	0.1996875	0.821902766
CEMENT_BUSH	6.917	13.521	…	0	232.413	7.26290625	9.53891875
GO	4.6	0	…	0	67.25	2.1015625	2.663669527
CNC2	0	0	…	3.971	28.807	0.90021875	2.507877971
CNC2	0	0	…	1.512	98.962	3.0925625	12.05456241
FACE	6.734	12.932	…	0	197.891	6.596366667	11.5564535
200S	0	0	…	0	301.3	9.415625	43.84910822
400S	0	0	…	0	31.815	0.99421875	4.042077266
300SD	0	0	…	0	72.831	2.27596875	11.850811
600SD	0	0	…	0	57.419	1.79434375	8.0637283
BAL_D610	6.962	17.192	…	3.812	176.646	5.5201875	5.524620515
JS	5.108	12.568	…	4.82	396.549	12.39215625	13.71746039
INSPECTION	6.667	7	…	8.596	238.193	7.44353125	7.436668258
BLOTTER	3.985	9.745	…	2.281	119.342	3.7294375	3.567617357
PAPER_BOX	10.2	18	…	8.2	329.42	10.294375	5.573611175
			…				
CYCLE TIME	85.018	150.309	…	46.549		96.3105	105.992656

Table 4: Sampling of small room orders with cycle time

	101214202	101262430	…	101279238			
	order 1	order 2	…	order 29	the sum	average	stdev
PRE_INSPECTION	4.945	3.361	…	6.633	112.49	3.878965517	1.704105934
CON_SBP	2.792	0	…	4.851	48.543	1.673896552	1.799827022
VSIDER	2.789	2.952	…	0	186.825	6.442241379	9.868133992
SIDES_S	12.851	0	…	33.266	360.499	12.431	17.46382393
GO	0	6.129	…	0	77.104	2.658758621	3.157622723
CNC2	1.854	2.119	…	14.004	197.117	6.797137931	8.597411079
CNC2	0.605	0.718	…	5.812	78.974	2.723241379	3.684655893
400S	0	0	…	0	13.912	0.479724138	2.583393545
600S	0	0	…	0	177.761	6.129689655	24.92598434
600SD	15.313	0	…	0	54.599	1.882724138	5.75366819
BAL610	4.006	2.118	…	14.727	269.408	9.289931034	10.83231472
JS	6.02	4.82	…	27.475	459.842	15.85662069	16.86093793
INSPECTION	8.596	4.586	…	6.656	232.764	8.026344828	9.545420549
PAKSPRAY	0	0	…	0	46.732	1.611448276	3.241183245
BLOTTER	2.053	1.321	…	4.73	89.35	3.081034483	3.442356434
PAPER_BOX	7.4	6.6	…	23	314.25	10.8362069	6.38174876
			…				
CYCLE TIME	69.224	34.724	…	141.154		93.79896552	87.049452

Table 5: Sampling of medium room orders with cycle time

	101285522	101285521	…	101282129			
	order 1	order 2	…	order 13	the sum	average	stdev
PRE_INSPECTION	8.877	8.877	…	13.197	132.681	10.20623077	3.69295379
SBP	2.663	2.663	…	3.959	39.803	3.061769231	1.107886137
SIDES_L	58.045	58.045	…	354.052	6026.506	463.5773846	512.6343342
OUTLINE_HOLE	0	0	…	0	69.456	5.342769231	19.26362841
CNC1	10.359	10.359	…	12.249	349.812	26.90861538	34.4639309
CNC1	7.695	7.695	…	4.86	157.681	12.12930769	14.36771125
1200SD	0	0	…	0	132.724	10.20953846	29.09175527
BAL_D1200	18.203	18.203	…	49.144	932.408	71.72369231	89.80134841
JS1200	21.879	21.879	…	59.755	1307.584	100.5833846	110.698111
INSPECTION	27.409	27.409	…	51.409	1256.317	96.63976923	104.5164691
SPRAY	8.029	8.029	…	15.029	366.877	28.22130769	30.48397015
BLOTTER	22.506	22.506	…	43.506	1080.078	83.08292308	91.45191044
PAPER_BOX	25	25	…	101	2136	164.3076923	199.4293461
			…				
CYCLE TIME	210.665	210.665	…	708.16		1075.994385	1168.89587959

Table 6: Sampling of large room orders with cycle time

Figures 2 through 4 show the various charts that were created during the analysis of the data for the tool size orders. Figure 2 shows how the machines in the tool room would be utilized when following the manufacturing process steps from Figure 1. The yellow line on the chart shows the sum of the amount of time each of the machines is used. The charts make it much easier to visualize the manufacturing process. The best attribute of the chart is that it allows you to see the variations between the orders. Figures 2 and 3 show that orders 8 and 9 are both significant variations and will create waiting time and bottlenecking. For the orders where there is no variation, the takt time can be approximately 150 minutes. This time represents the longest process step in the process. Figure 4 shows that there is very little variation in quantity between orders for the tool room. The average number of grinding wheels per order is 302.7. Only orders 3 and 10 significant variation. They are more than 2 standard deviations (45.6) away from the average number of wheels that were produced. The following are some of the important points to take away from Figures 2, 3 and 4:

- Orders 8 and 9 have the most variation. These orders can take a longer route towards completion.
- The 300SD operation acts as a bottleneck, taking almost an entire shift (420 minutes).
- Plastic Bush's machine utilization, 924 minutes, is the highest.
- BAL_D610 and JS also have high machine utilization rate at 744 minutes and 684 minutes respectively
- The average cycle time for the optimum operation line would be 586.504 minutes, with a standard deviation of 181.23

The analysis for the other size categories was done in the same method as in the tool room. The following charts will be for the other size categories with analysis descriptions.

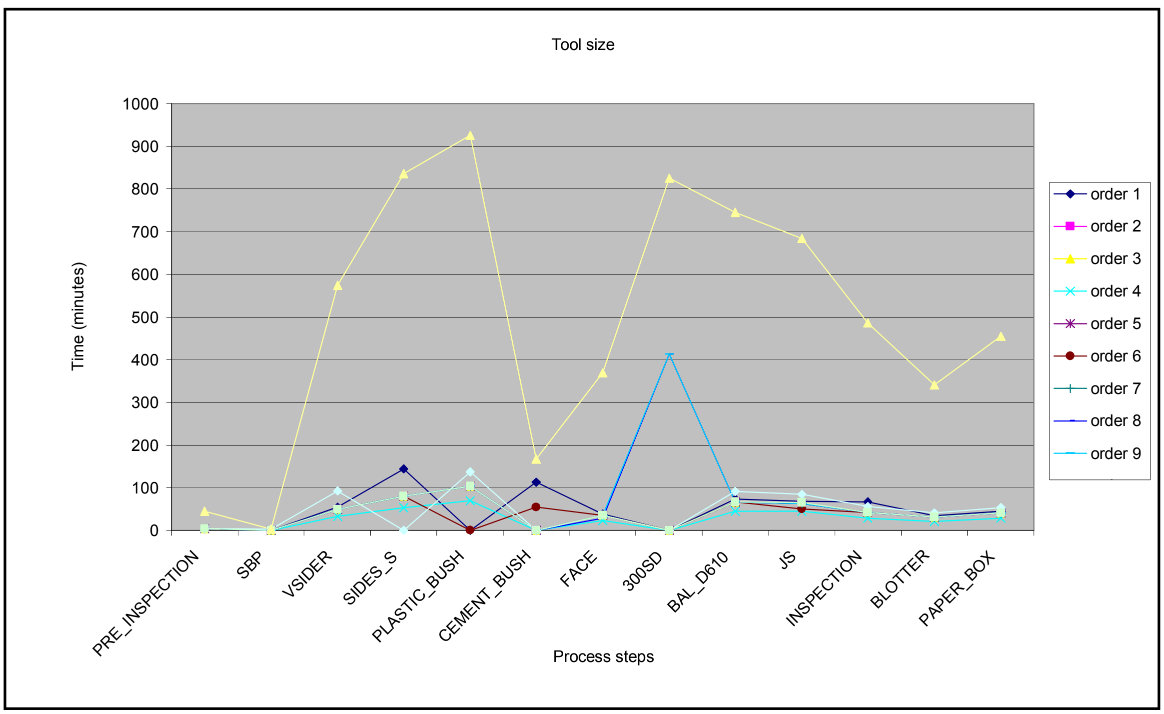

Figure 2: Tool room machine utilization chart

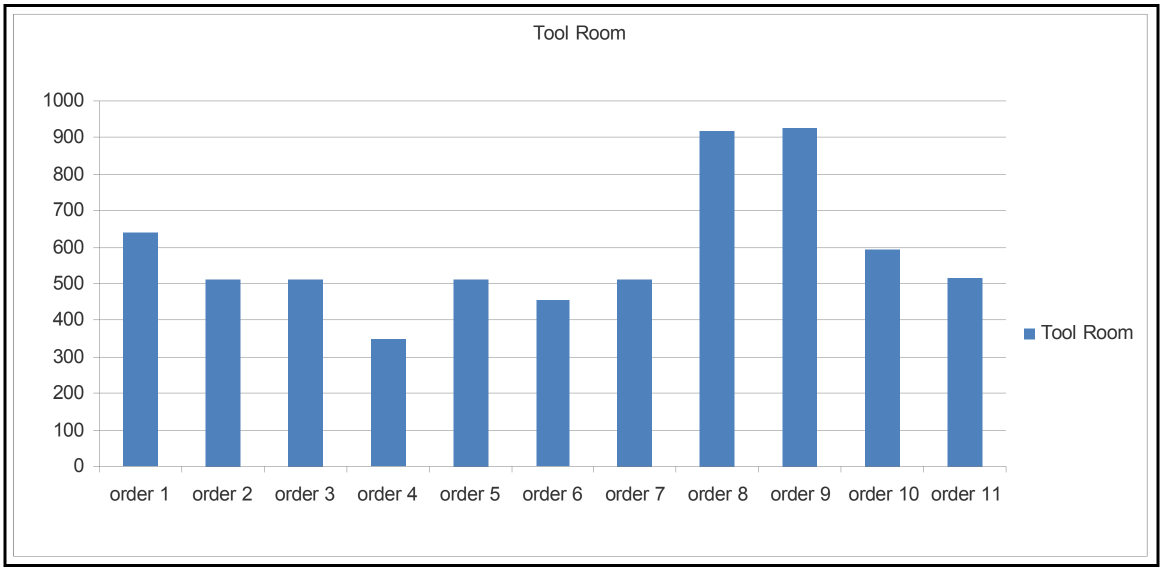

Figure 3: Tool room process cycle time chart

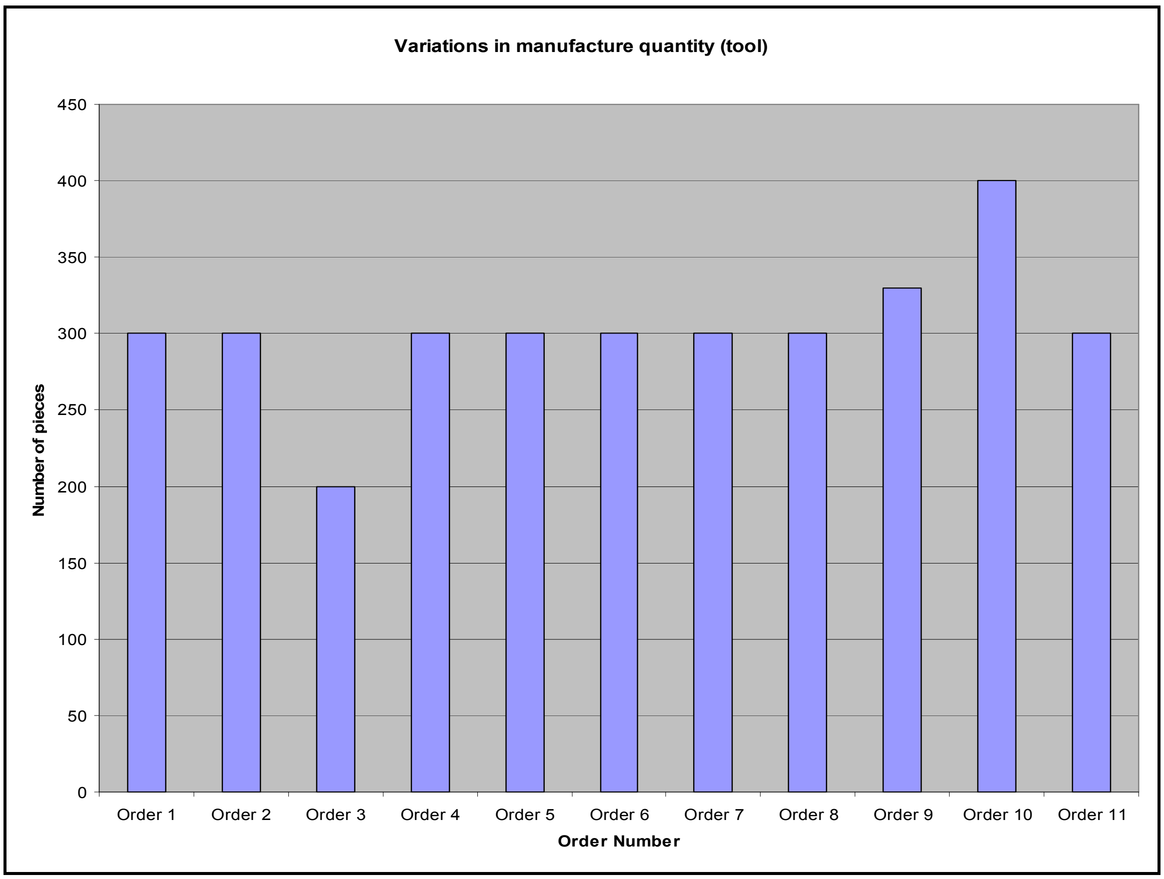

Figure 4: Tool room variations in quantity between orders

The team received a lot of data from the company for the small room. The total number of orders for the small room was 32. Figures 5 through 7 are charts from the analysis of this size. The following are the important points learned from analyzing the small room data:

- 87.5% of the orders can go for a takt time of 95 minutes.
- Orders 9, 13, 17, 21 have the most variation. These orders will take a longer route towards completion.
- The 200SD operation acts as a bottleneck in one of the orders, taking 248 minutes
- 300SD occurs only on two orders.
- Plastic bush step only occurs 2 times out of 32 total products (6.25%) for this size range.
- Sides_S, Vsider and JS have relatively high machine utilization rate and are potential bottleneck areas.
- PLA_BUSH has the lowest utilization frequency of 1/32 (3.125%).
- The average cycle time for the optimum operation line would be 96.31 mins, with a standard deviation of 105.99

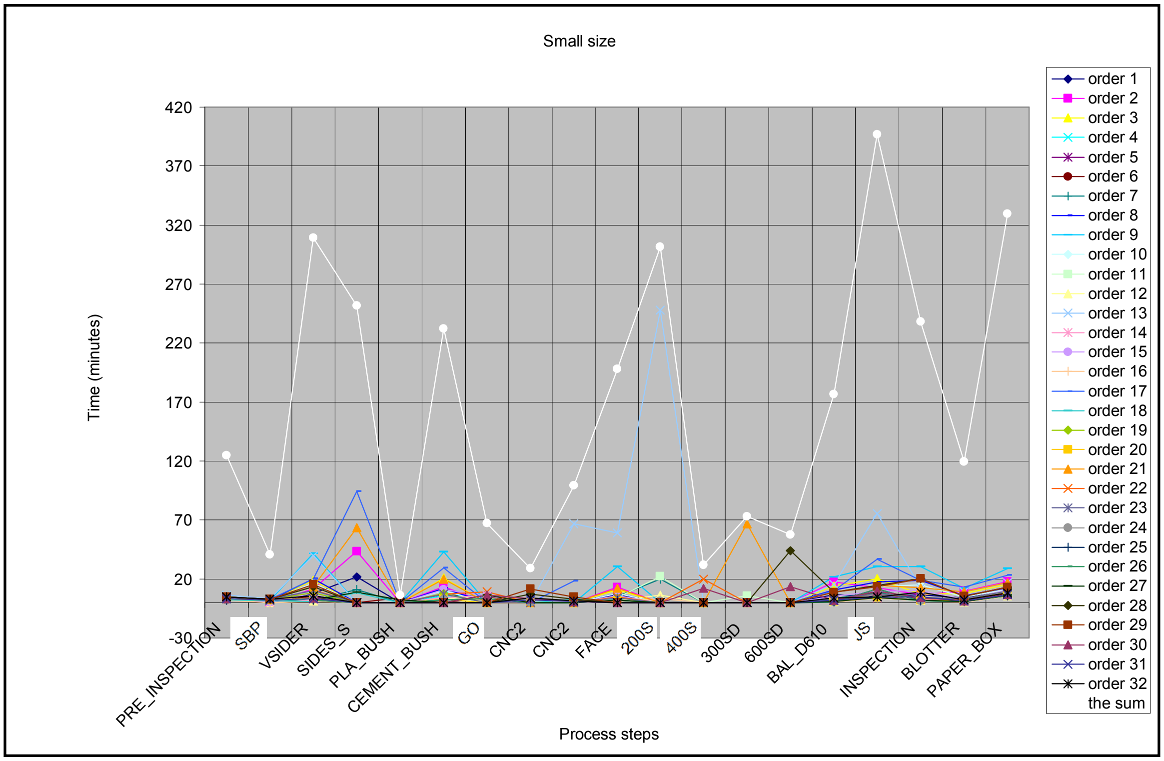

Figure 5: Small room machine utilization chart

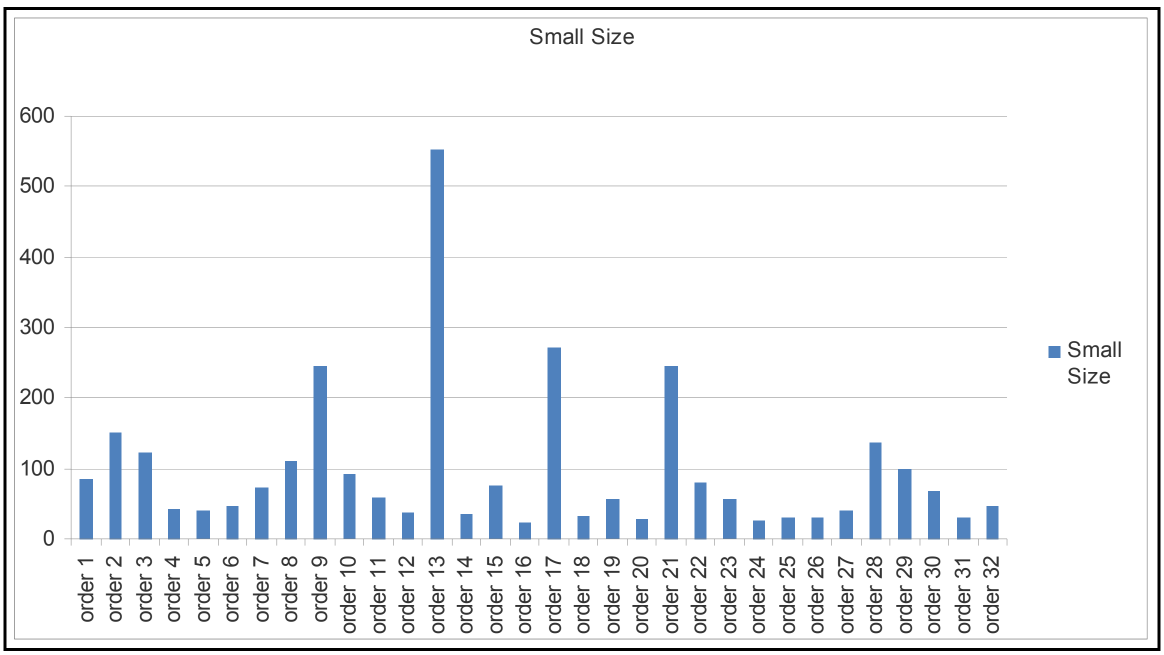

Figure 6: Small room process cycle time chart

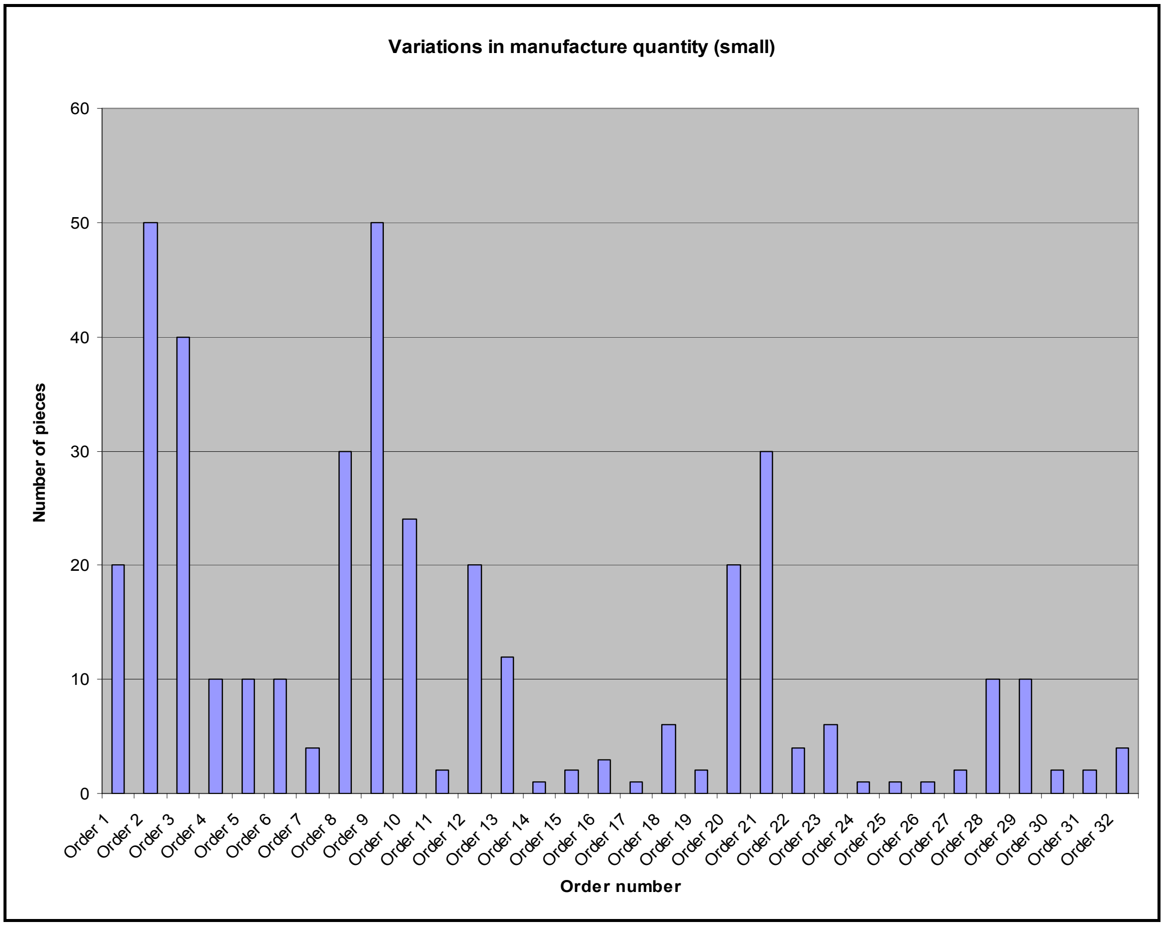

Figure 7: Small room variations in quantity between orders

For the medium room, the company provided the group with 29 orders. The charts for the medium room are shown in Figures 8 through 10. The following points are the important aspects realized from the analysis of the data:

- 86.2% of the orders can go for a takt time of 63.3 minutes.
- Orders 11, 13, 14, and 15 have the most variation. These orders can take a longer route towards completion.
- The Sides_S, BAL610, 600S and JS operations act as bottleneck areas.
- There is one product (order 11) with a large variation from rest of products. 600S and JS process steps take significantly more time than for the other orders going through the same steps.

- PAKSPRAY process step occurs only two times. This step can occur out of cell.
- 400S process step is necessary only in 1 of 29 (3.4%) products.
- Plastic Bush's machine utilization, 924 minutes is the highest.
- Sides_S and JS also have high machine utilization rate for 360.5 minutes and 459.8 minutes respectively
- The average cycle time for the optimum operation line would be 93.79 minutes, with a standard deviation of 87.049

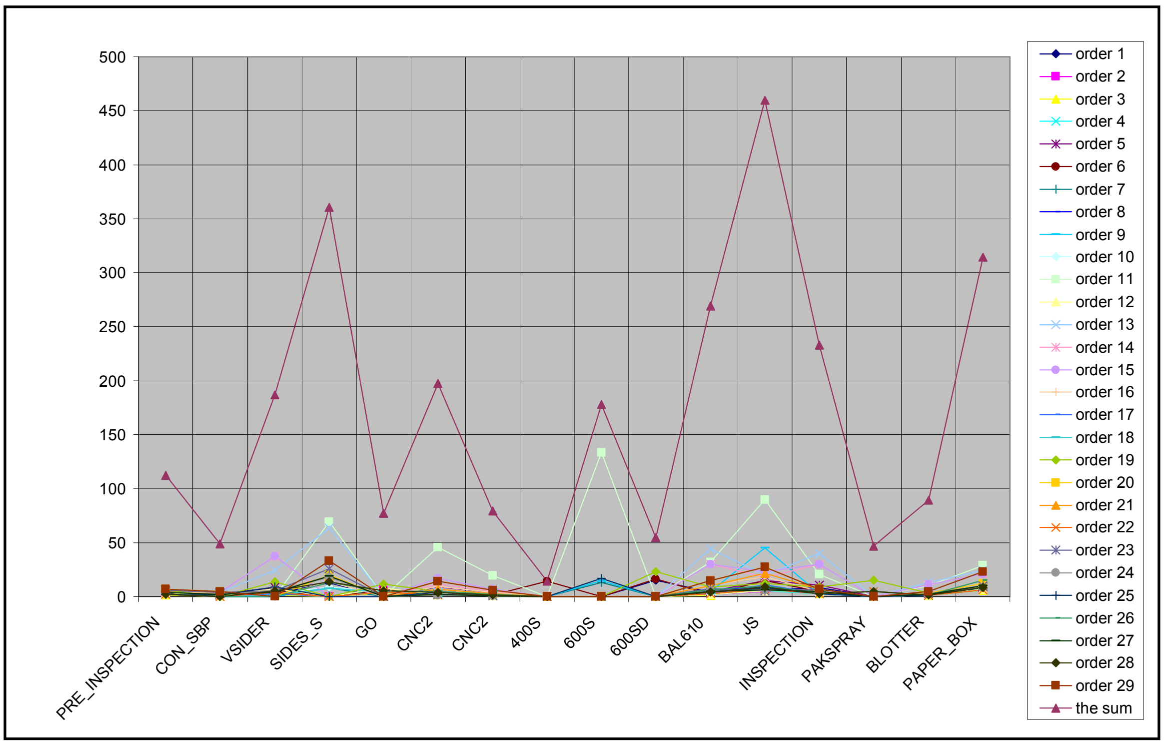

Figure 8: Medium room machine utilization chart

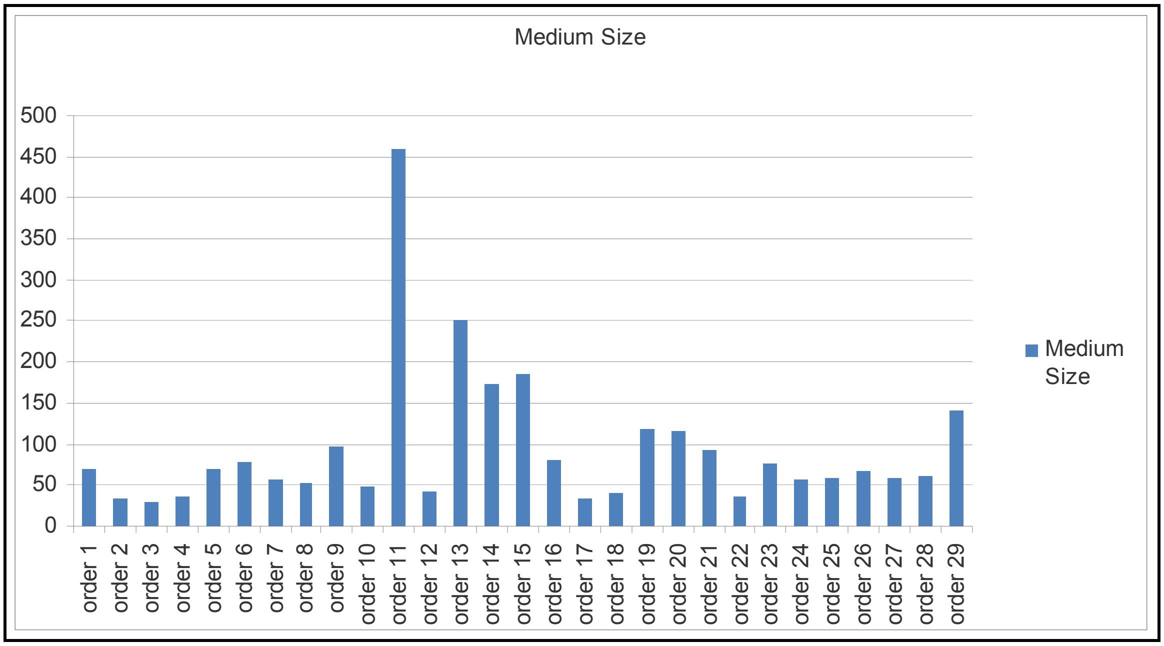

Figure 9: Medium room process cycle time chart

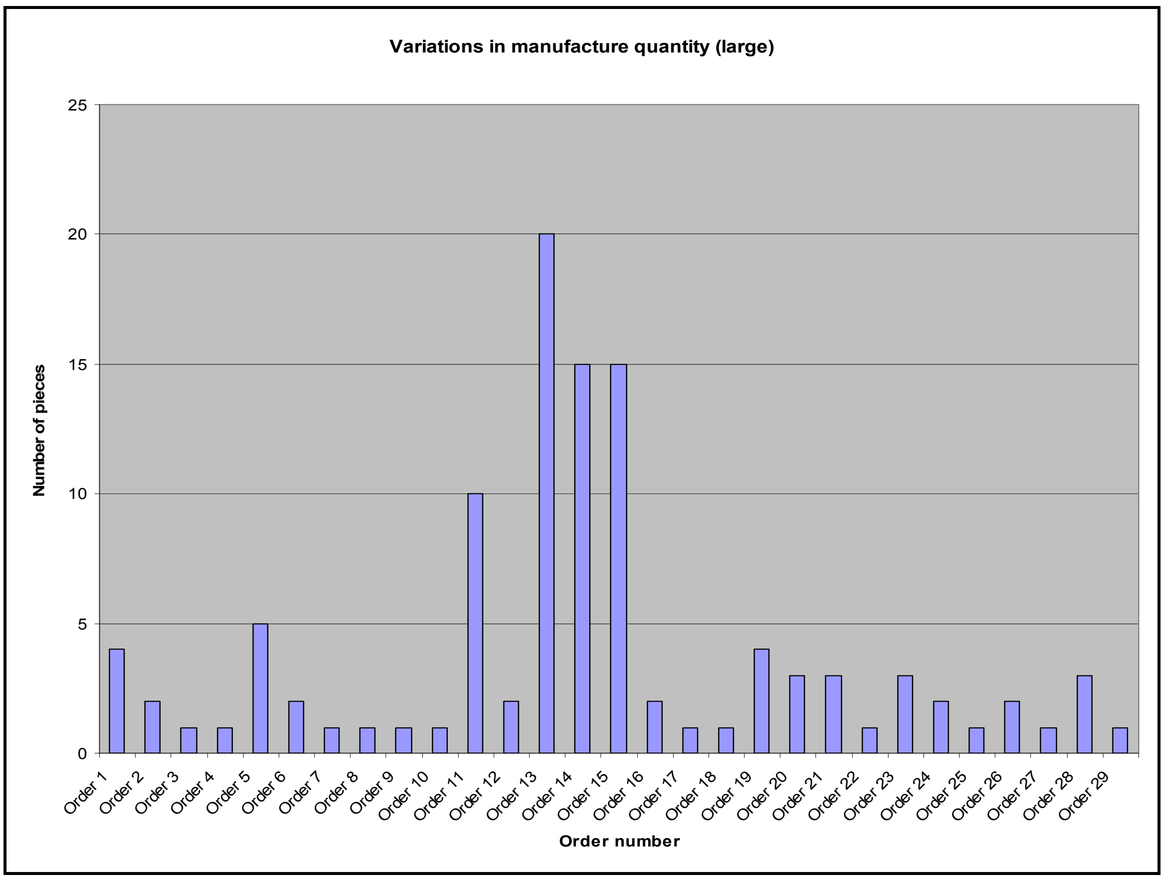

Figure 10: Medium room variations in quantity between orders

For the large room, the company provided the team with 13 orders of data. The charts for the large room are shown in Figures 11 through 13. Some of the important points from analyzing the charts are:

- The average cycle time for the optimum operation line would be 1075.944 minutes, with a standard deviation of 1168.896.
- There is a lot of variation happens in this 13 orders most likely due to the large difference in the order sizes.
- The variations are a direct result of the number of grinding wheels in an order.

The data analysis provides the group with information that they feel is important for determining developing and comparing cell designs and for doing scheduling.

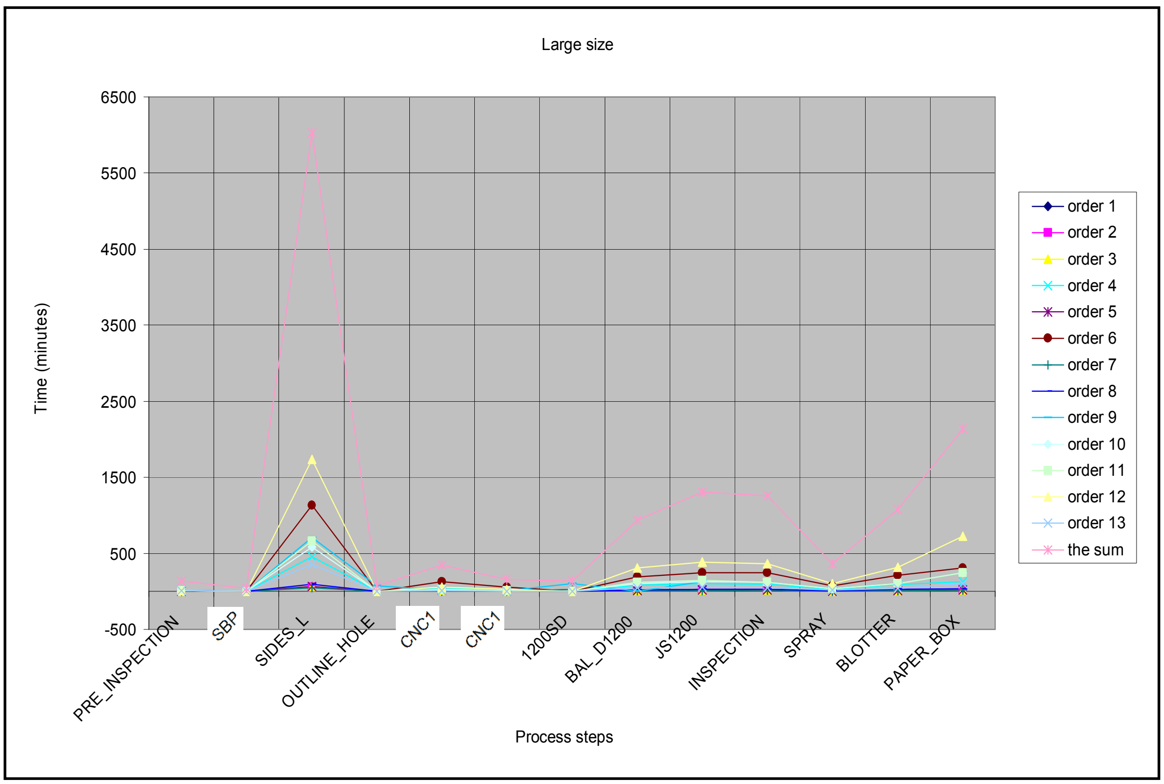

Figure 11: Large room machine utilization chart

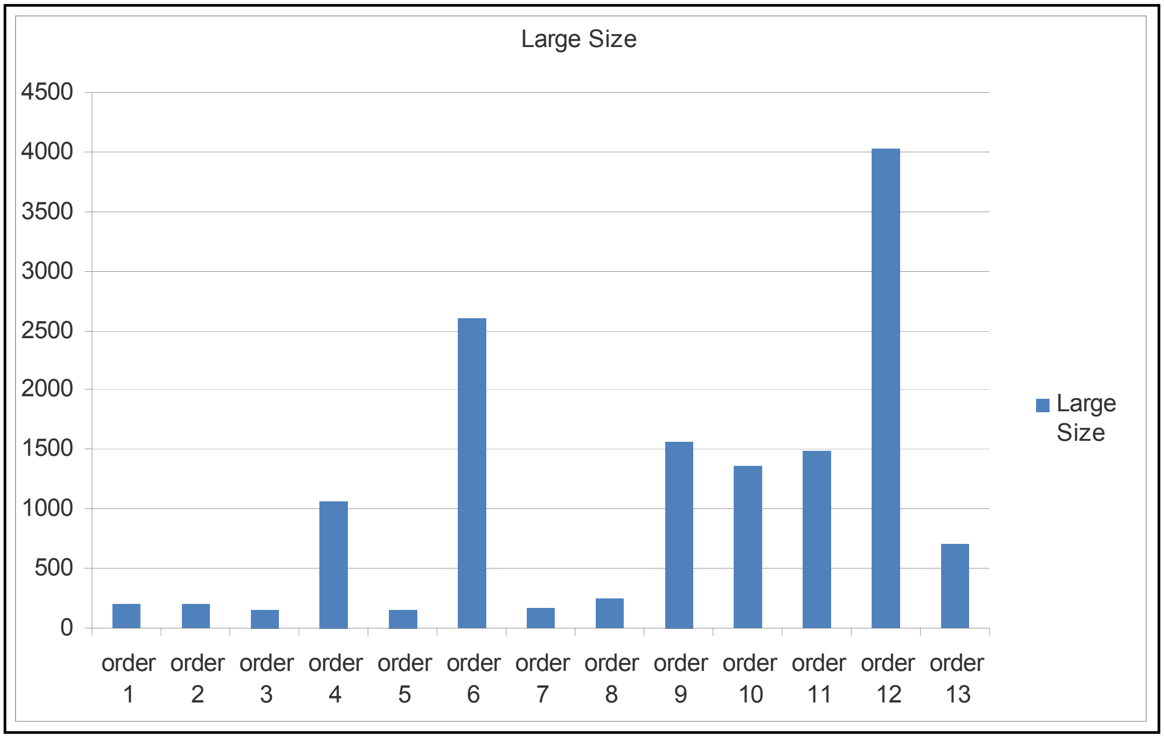

Figure 12: Large room process cycle time chart

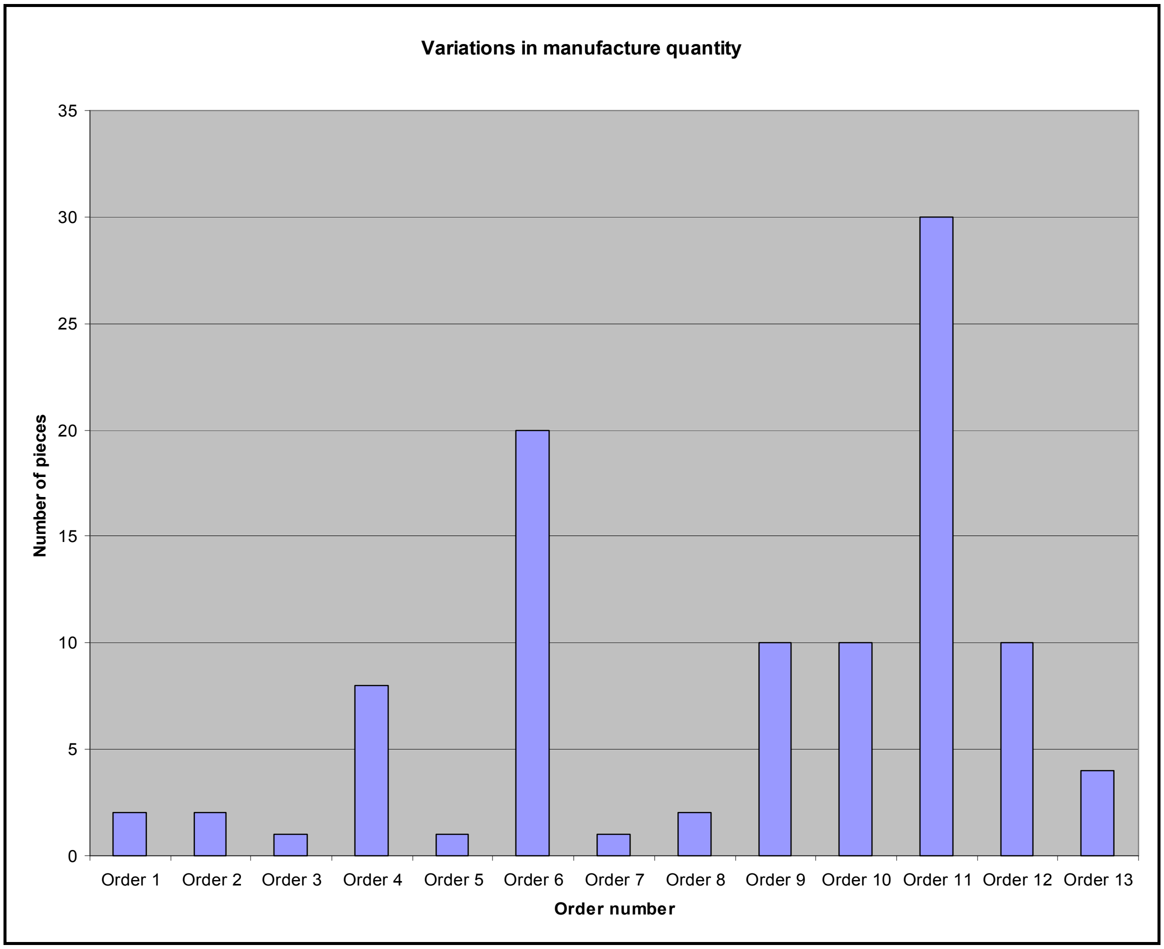

Figure 13: Large room variations in quantity between orders

4.2 Cell Designs

Saint-Gobain provided the team with the layouts for their current floor plan and their proposed lean cells. The group analyzed both of these designs. The group also designed their own floor plan for converting the conveyor layout into cell layout.

Figure 14 shows Saint-Gobain's current layout of their floor plan. After doing an analysis of this layout, the team realized the following points:

- The large room has its' own room on the left hand side of the plant.
- The other sizes are all worked on to the right of the large area.
- There is some travel back in this layout.

- There are many machines not being used.
- If a defect is discovered after inspection, bringing the defect back to the machine to be reworked is far away.

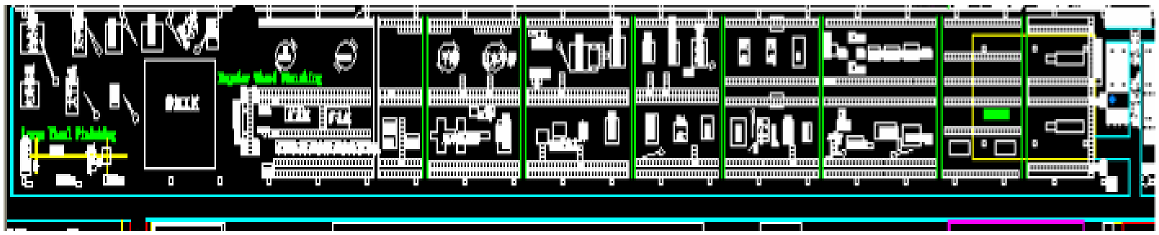

Figure 14: Saint-Gobain's current layout

Figures 15, 16 and 17 show three different cell layouts for Saint-Gobain. Figures 15 and 17 were developed by Saint-Gobain, while the cell layout in Figure 16 was designed by the project team. The following is a list of general observations and comparisons the team was able to make:

- All three of the designs divided the entire work area into four cells to separate the products by weight, transportation, and machines outside diameter size capacity.
- The cells of each size category are in a “U” shape as to reduce the time for transporting of the products to get reworked after inspection if defects are found.
- The WPI-HUST proposed design uses less manpower than either one of Saint-Gobain’s proposed and modified cell designs.

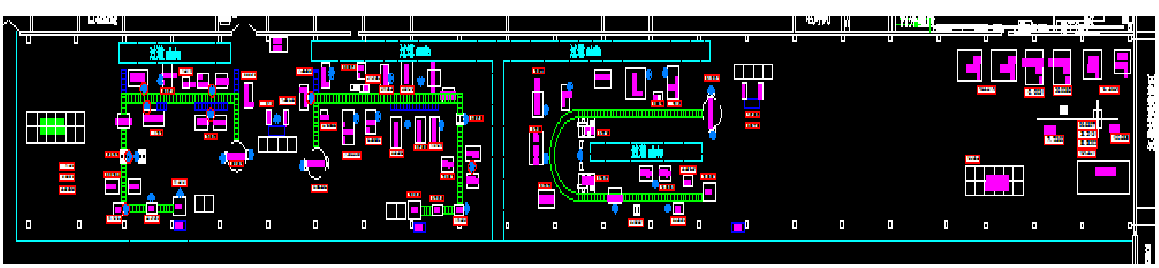

Figure 15: Saint-Gobain's proposed cell layout

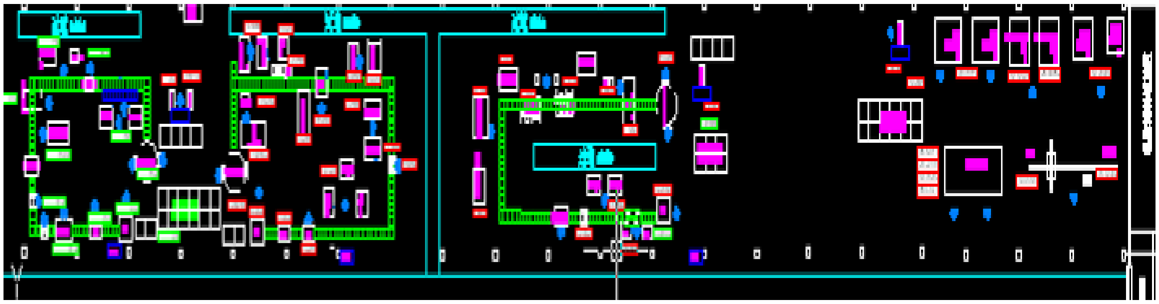

Figure 16: WPI-HUST proposed cell layout

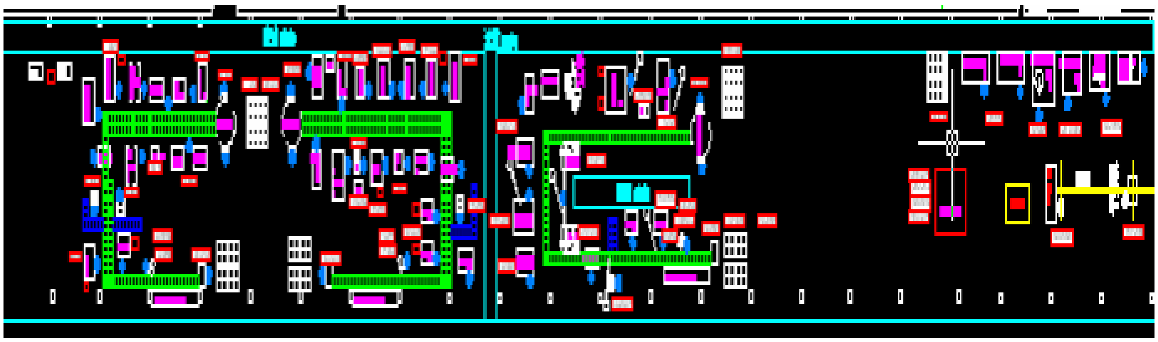

Figure 17: Saint-Gobain's modified proposed cell layout

Figures 18 and 19 show the tool room in much greater detail. After analyzing the two layouts, many things became apparent:

- The WPI-HUST design has one less ARTER. The reason for this is because having an additional ARTER will not reduce the takt time very much.
- The driller and face machines are in a different location. They have been moved to the main transportation line to enhance the flow speed.
- The cement bush and CNC 300 machines are moved closer to the worker who will operate these two machines. This will shorten the amount the worker has to move, which will improve time.
- Cement bush and driller will share one worker, face and CNC 300 machines will share one worker, and JS and blotter will share one worker. This allows for a reduction in manpower without reducing output.

- One worker has been added to each driller because according to the data analysis, the driller’s machine utilization time is relatively high.

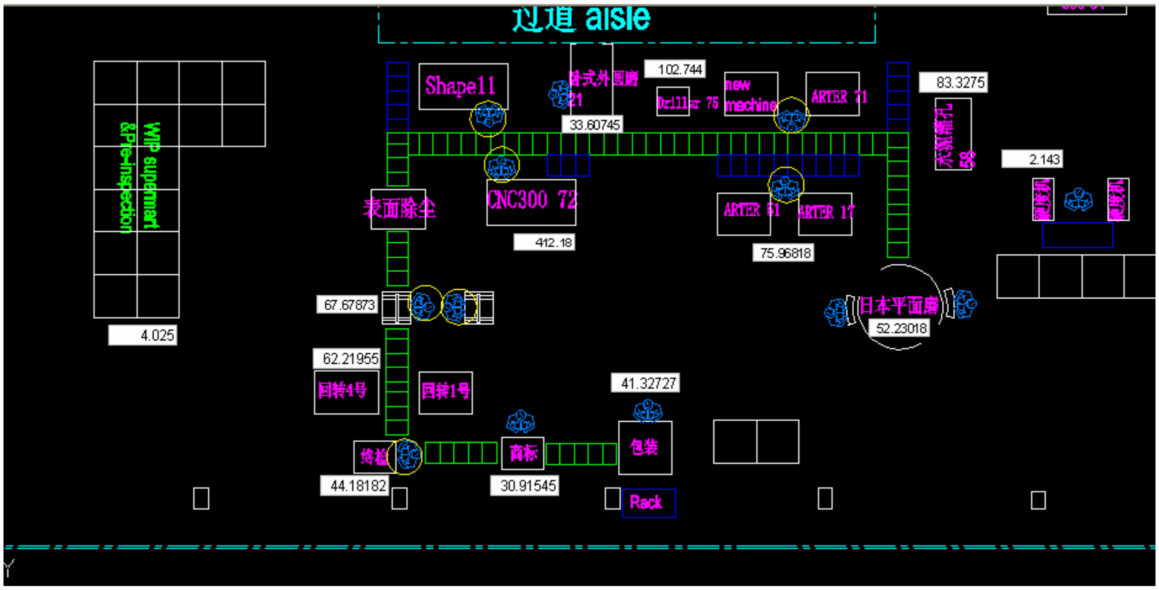

Figure 18: Saint-Gobain's proposed tool room design

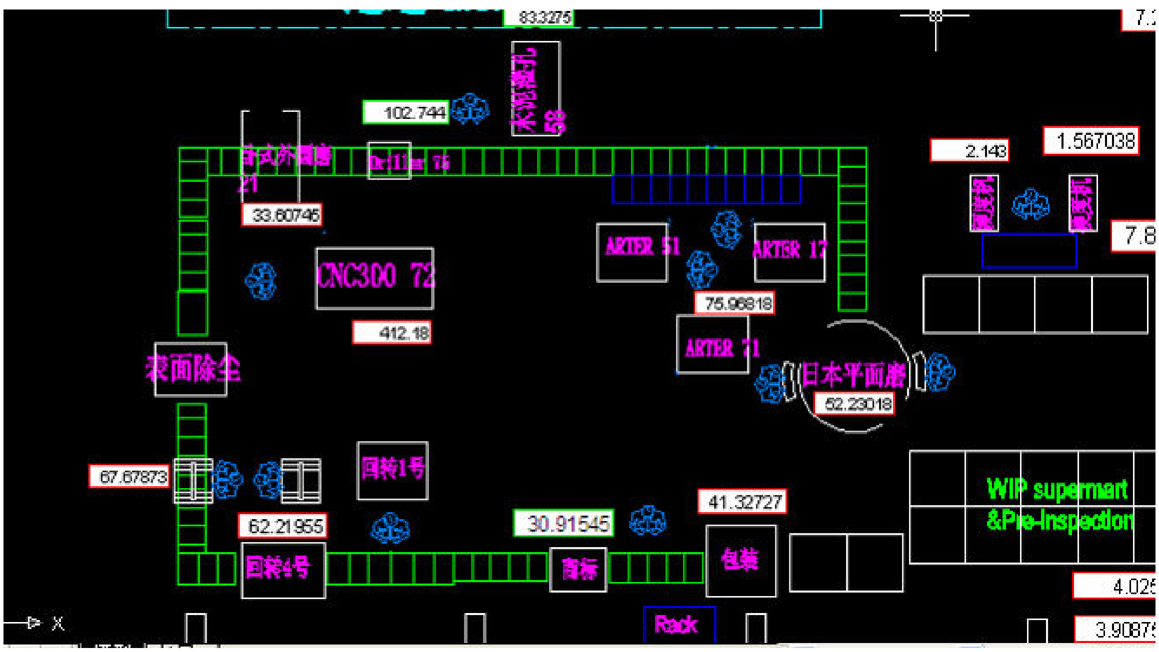

Figure 19: WPI-HUST proposed tool room design

Saint-Gobain had two proposed designs. The company presented, to the project team, the modified design. They saw some flaws in their initial design after the team did some analysis on the initial proposed design. The differences between the initial proposed design and the modified design is as follows:

- The modified design has a separate pre-inspection area. It is a good idea to move the pre-inspection but in the modified design; it is in the way of the shipping channel.
- The cement bush has been moved but there is still travel back. It should be relocated according to the process steps.
- Two workers were added, one to the cement bush and another to the dust remover. The operation times of each machine are different. This will cause an unbalanced flow causing WIP. Sometimes a worker will be left with nothing to do while other processes get completed. It is possible to reduce the number of workers in the modified design.
- A second transportation line has been added to the modified design. The company probably added this line to try to increase the product flow. It actually creates more difficulty in that it will be more difficult for the workers to get the wheels further away from them.
- CNC 300 was moved.

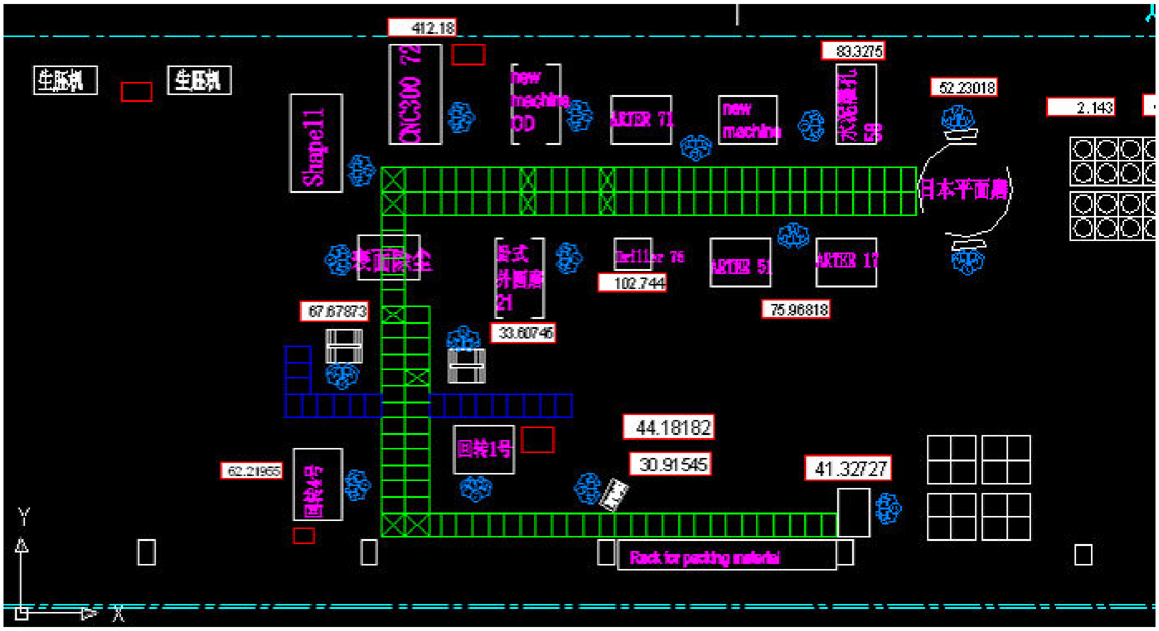

Figure 20: Saint-Gobain's modified proposed tool room design

The following is a list of differences with comments between Figures 21 and 22:

- The Face operation should be moved to the main transportation line because according to the data analysis, 25 out of 32 orders need this step. Moving it to the main line will enhance the product flow and there will be less transportation and workers movement.
- Sides_S, driller, 200S, 400S, and shape outside operations are all moved. It is possible to reduce waste by moving the process steps by reducing travel back and transportation time.
- One JS machine was moved so that it will be in a more convenient location for the worker using the machine.
- CNC 360 and face operations share one worker and the two cement bush operations can share one worker. Doing so will allow for a more balanced product flow and allowing for a worker to always have work instead of just waiting.

- One worker has been added to packing. This will enhance the product flow from inspection to packing, allowing for an improvement in cycle time.
- The packing area is moved to shorten the distance between the packing and shipping areas. The packing area can be shared with the tool room.
- The pre-inspection step has been moved and it interferes with the shipping area. It should be moved closer to the SBP machines. This will also shorten the distance between the two process steps.

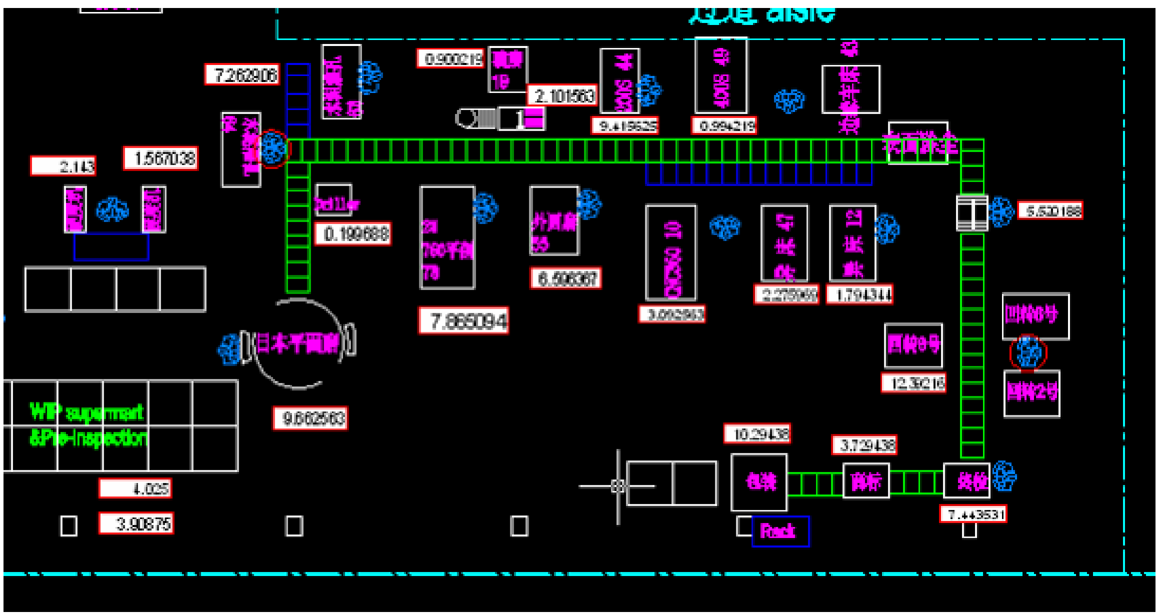

Figure 21: Saint-Gobain's proposed design for the small room

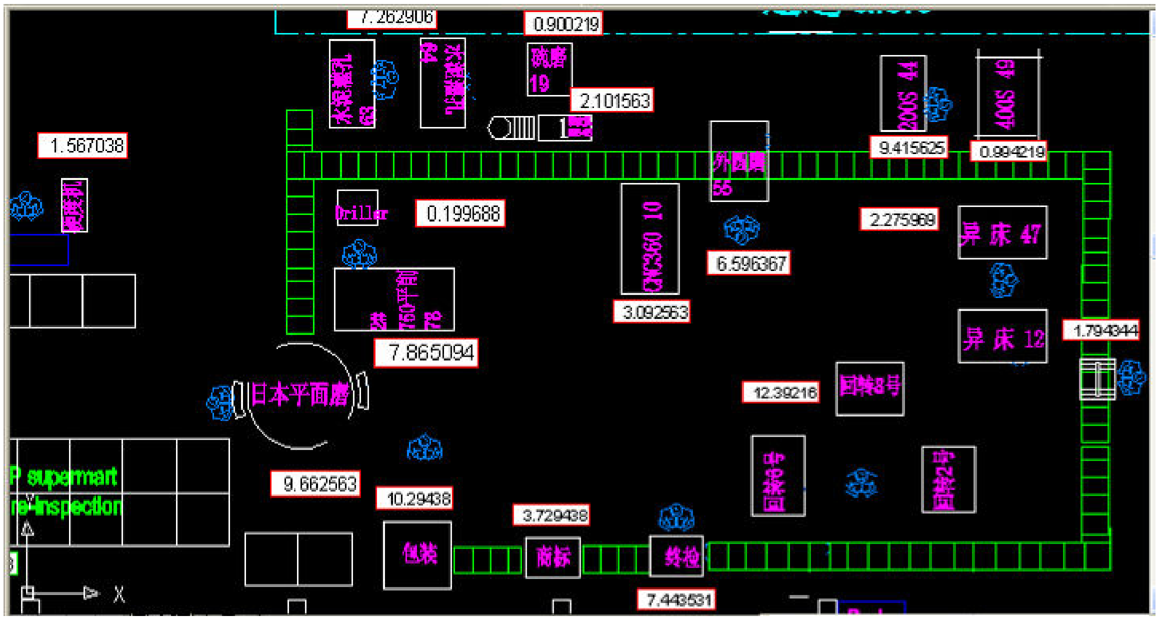

Figure 22: WPI-HUST proposed design for the small room

Figure 23 shows Saint-Gobain's modified design for the small room in detail. The following list will point out the differences between the two designs Saint-Gobain proposed:

- A separate pre-inspection area has been added. This is unnecessary since the tool room and small room have very similar products. Pre-inspection can be shared by the two rooms.
- The balance machine has been moved. This is a common step in the manufacturing process and moving it out of line does not make sense.
- A second transportation line has been added, but this is not ideal as moving the product from one line to the other is waste.
- Each machine has one worker. Having a worker for each machine will not help balance the flow and workers will not always be working, resulting in salary for workers who are doing nothing.

- The machines sequence has been changed. There is no evidence to show that the manufacturing process has been modified therefore it is not necessary to change the order the machines are in.

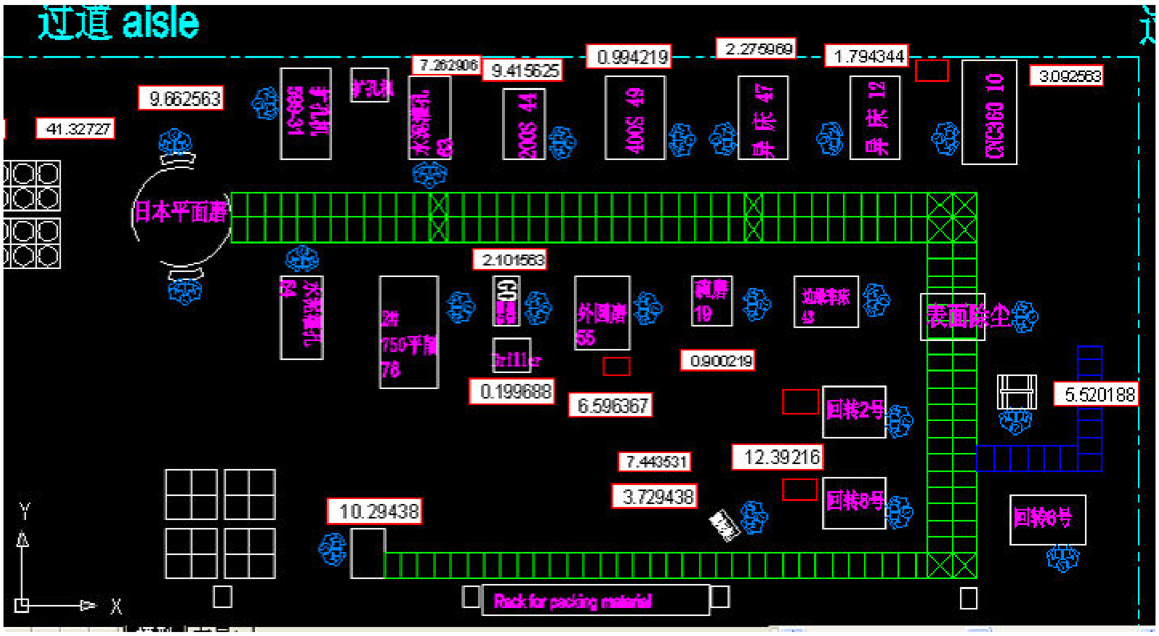

Figure 23: Saint-Gobain's modified design for small room

Figures 24 and 25 are the two designs for the middle room. The following are the differences between the Saint-Gobain and WPI-HUST designs:

- A pre-inspection area was added.
- An SBP machine was removed. The operation time is short so it will not improve the takt time.
- The Sides_S, CNC 600, CNC 700, and balance machines can be added to the transportation line as the majority of the orders for the medium room require the process steps. Including the steps into the main line will improve flow.

- The 400S and shape outside machines are moved. According to the data the company provided to the team, moving the machines will reduce travel back.
- 600SD, 400S and shape outside machines can share one worker. Due to the unbalanced flow, one worker can handle the three machines.
- One worker has been added to the packing area. This areas total operation time is long because of the lack of manpower. Adding this worker should improve the overall flow.

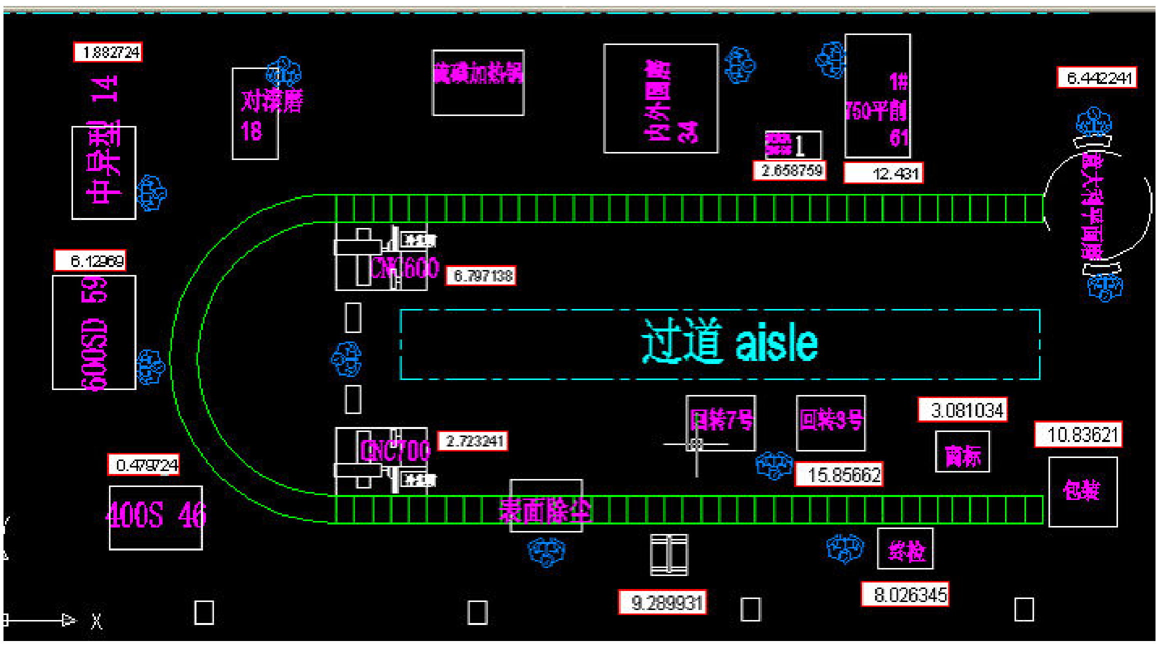

Figure 24: Saint-Gobain's proposed design for middle room

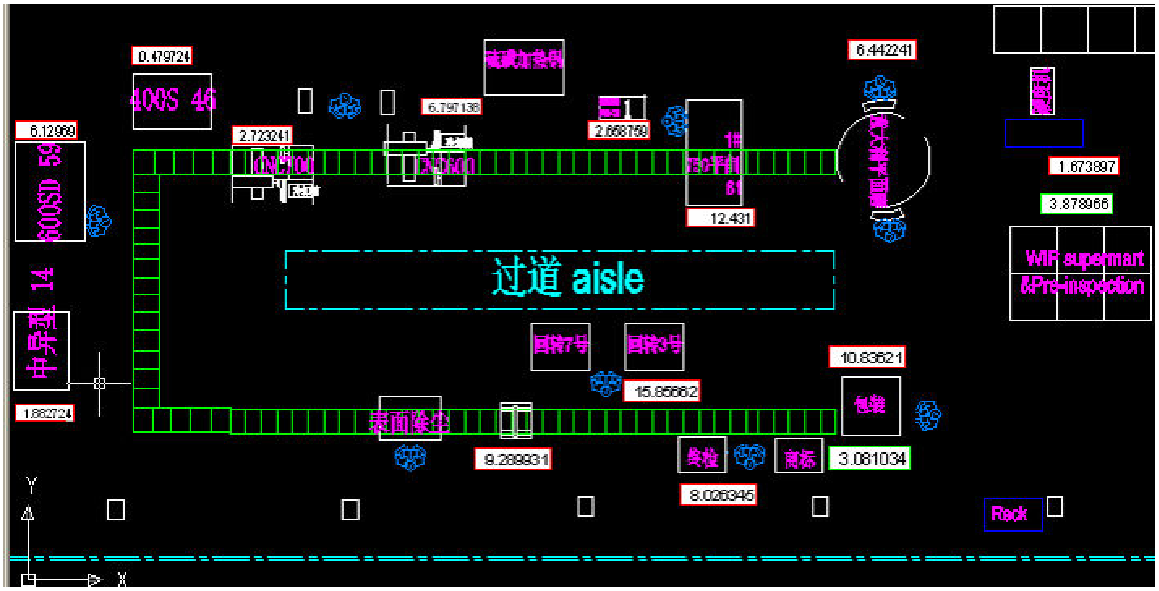

Figure 25: WPI-HUST proposed design for middle room

The following points will show the differences between Figure 24 and 26:

- A new pre-inspection area has been added. In the initial design, the pre-inspection was far from the SBP machine. Having a pre-inspection area close by will reduce transportation of the product being manufactured.
- One worker was added to the 400S machine. This is unnecessary because the product flow will be too fast and will create bottle necks and unbalanced flow.

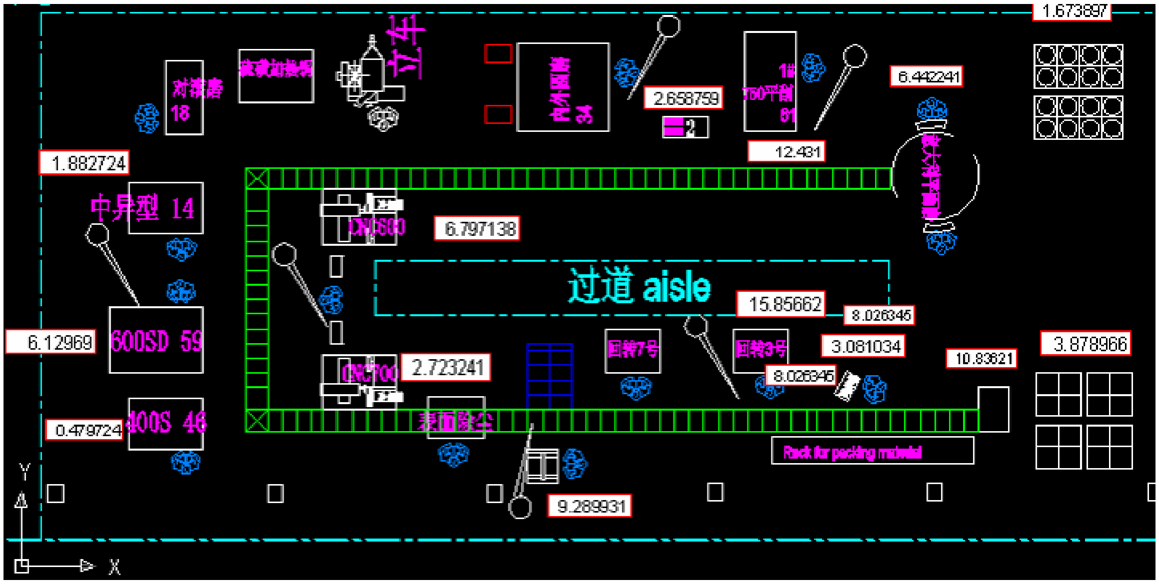

Figure 26: Saint-Gobain's modified design for middle room

Figures 27 and 28 are showing the CAD drawings for the designs of the large room. The following are points to describe the differences between the WPI-HUST design and Saint-Gobain’s proposed design:

- One SBP machine was added. The reason for this is because there is a long distance from pre-inspection to the SBP machine.
- Pre-inspection area has been moved. This was done to try to reduce the distance from the pre-inspection area to the SBP machine.
- The positions of the balance machine and the JS machines have been changed. Doing this allows for the machines to be in the order of the manufacturing flow.
- The packing area has been moved because it was in the way of the shipping are. The packing area has been moved next to the JS machine.
- One worker has been added to the SBP machine, each of the diamond side machines, both hole face machines, the balance machine, the JS machine, and two workers has been added to the packing area. Adding workers to

the machines with high machine utilization times allows for the flow to become balanced.

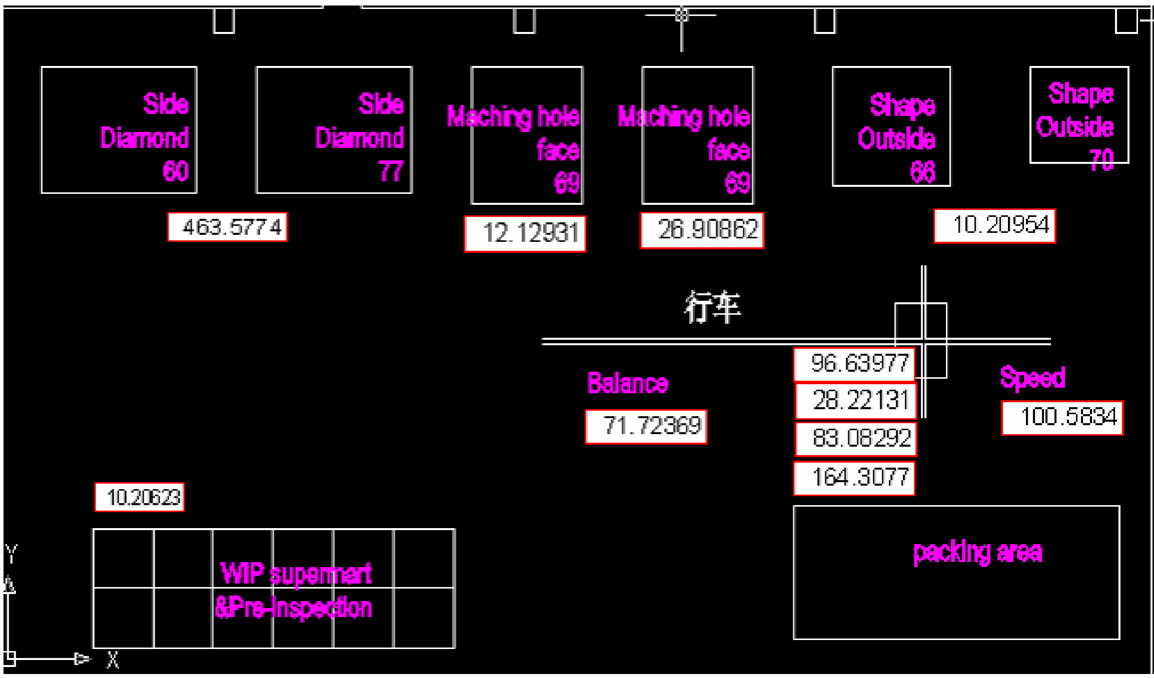

Figure 27: Saint-Gobain's proposed design for large room

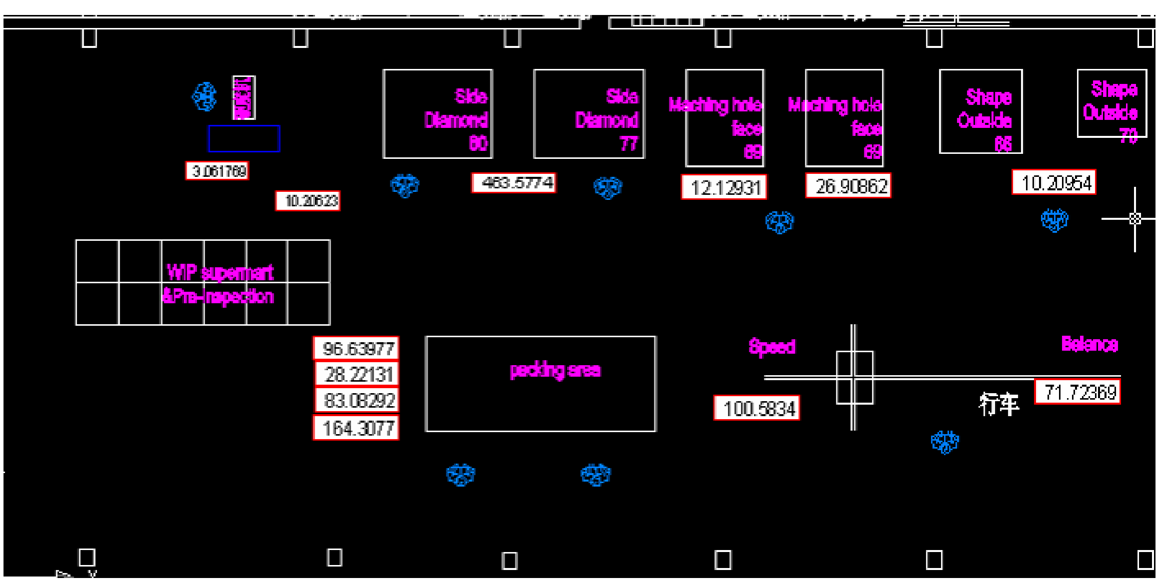

Figure 28: WPI-HUST proposed design for large room

Figure 29 is the modified proposed design for the large room. The following points will show the differences between Figures 27 and 29:

- The pre-inspection area has been removed.

- Each machine has a worker added to it. This will cause flow to be unbalanced.
- A new JS machine has been added. This does not make sense because there is no need to add a JS machine. The side diamond machine is where bottleneck occurs and would be more helpful if there was a machine added there.
- The positions of the balance machine and the JS machine have been changed. This was not necessary unless there had been a change in the manufacturing process flow.

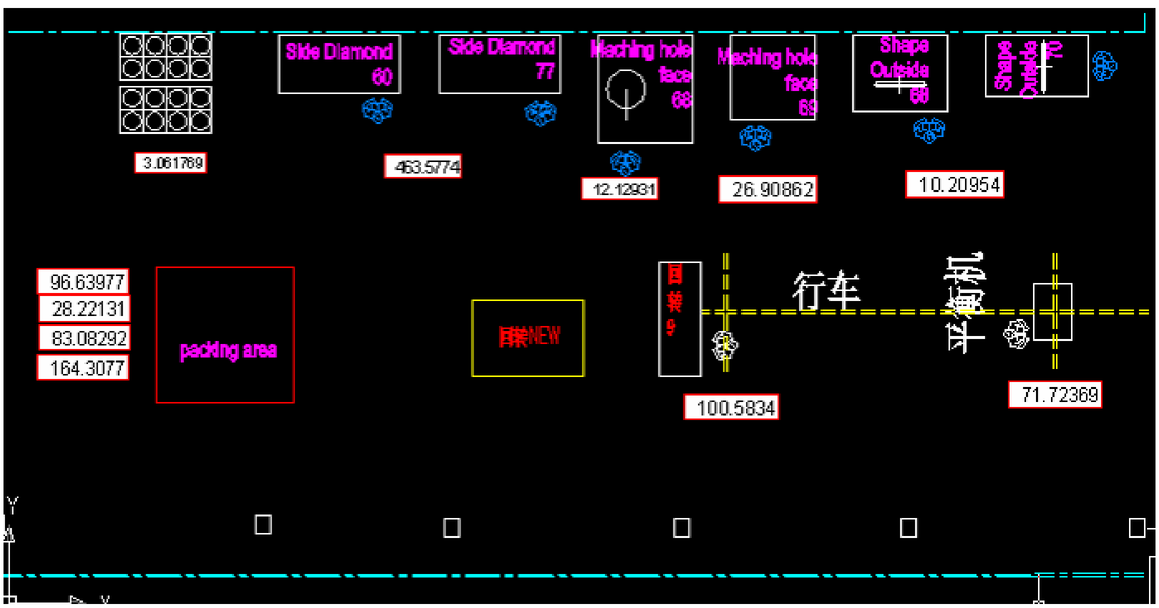

Figure 29: Saint-Gobain's modified design for large room

According to the analysis performed for the cell designs, the project team has developed a decision table to help decide which design is best suited for Saint-Gobain. Please note that the maximum score is 100. The weighting for each category is given in the table.

Table 7 shows that the WPI-HUST proposed design scored the highest among the designs given. The WPI-HUST design has the highest scores for every category. At this point, it is possible to recommend to Saint-Gobain that the WPI-HUST design would be the best for the company in trying to apply lean manufacturing.

	S-G proposed design	WPI-HUST proposed design	S-G modified design
Flow (less travel back) 0.10	60	90	70
Transportation (less travel from kiln to pre-inspection) 0.15	60	85	70
Transportation (less travel from packing area to shipping area) 0.15	60	90	80
Manpower utilization 0.15	60	85	70
Machine utilization 0.15	60	85	80
Product flow speed balance 0.20	60	85	80
Worker safety 0.10	70	90	85
Total score	61	87	76.5

Table 7: Decision table for the three proposed cell designs

4.3 Scheduling

Figure 30 shows a sample of an FCFS rule schedule. The chart makes it possible to see that the rule has a lot of empty space in between orders. A process that takes a long time will hold up other orders from being processed.

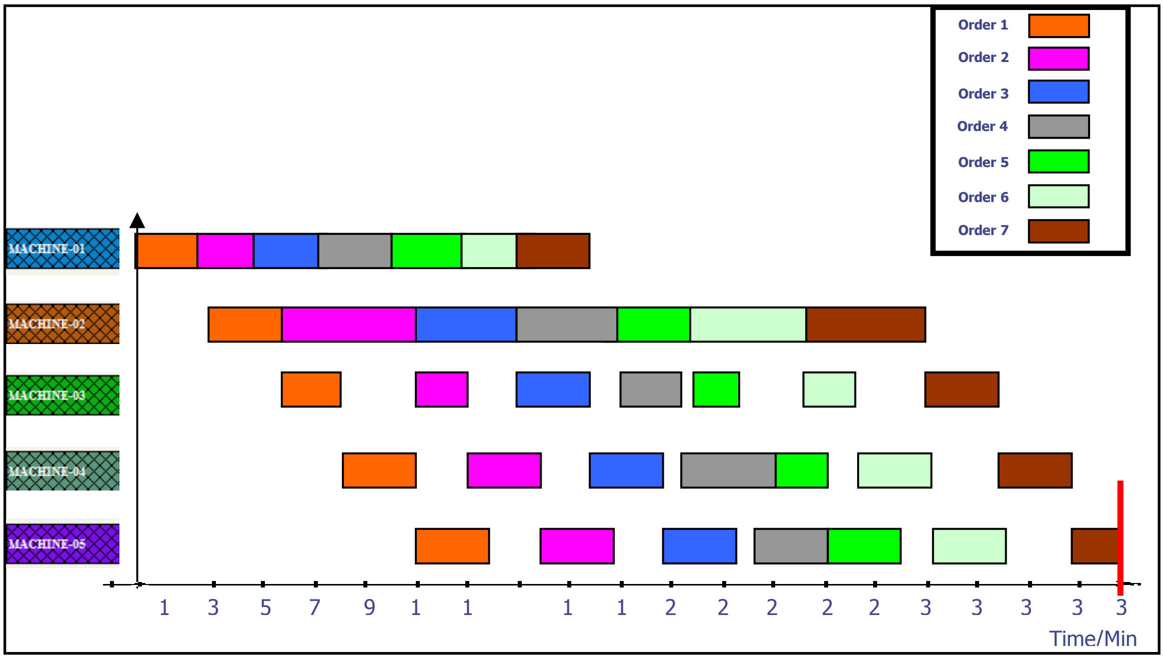

Figure 30: FCFS rule sample

Using the modified data (Table 8) Saint-Gobain gave the team, they applied the LPT rule of scheduling. They then compared the results against the FCFS rule to see how much of an improvement the LPT rule gave.

Order number	101221893	101258245	101274077	101274738	101279239	101294273	101294274			
Pieces produced	300	400	300	300	300	300	300	Sum	Average	STDEV
	Order 1	Order 2	Order 3	Order 4	Order 5	Order 6	Order 7			
Process steps										
VSIDER	49.04	92.30	49.04	49.04	49.04	49.04	49.04	386.54	55.22	16.35
SIDES_S	129.81	0.00	79.33	79.33	79.33	79.33	79.33	526.46	75.21	38.13
PLA_BUSH	60.57	105.77	60.57	60.57	0.00	60.57	60.57	408.62	58.37	30.76
CEM_BUSH	0.00	0.00	0.00	0.00	53.37	0.00	0.00	53.37	7.62	20.17
FACE	34.62	34.62	34.62	34.62	34.62	34.62	28.84	236.53	33.79	2.18
300SD	0.00	0.00	0.00	0.00	0.00	432.70	396.63	829.33	118.48	202.60
BAL610	64.18	85.58	64.18	64.18	64.18	64.18	64.18	470.67	67.24	8.09
JS	29.81	81.88	29.81	29.81	26.83	29.81	29.81	257.76	36.82	19.90
CONFINAL	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PAKBLOTT	30.29	40.38	30.29	30.29	30.29	30.29	30.29	222.12	31.73	3.81
PAKCARTN	43.27	55.29	43.27	43.27	43.27	43.27	43.27	314.91	44.99	4.54
Total	441.59	495.82	391.11	391.11	380.92	823.81	781.96	3706.31	529.47	191.31

Table 8: Tool room modified data

Figure 31 shows the FCFS scheduling rule applied to Saint-Gobain's modified layout. From the figure, it is possible to make some key points:

- The four ARTERS are not needed for the production. Two of the machines are not even used in this order set.
- The plastic bush machine acts as a bottleneck.
- The CNC 300 shows that it is a variation from the typical orders.
- The lead time of all orders is 1561 minutes.
- The lead time of the typical orders (variations disregarded) is 750 minutes.

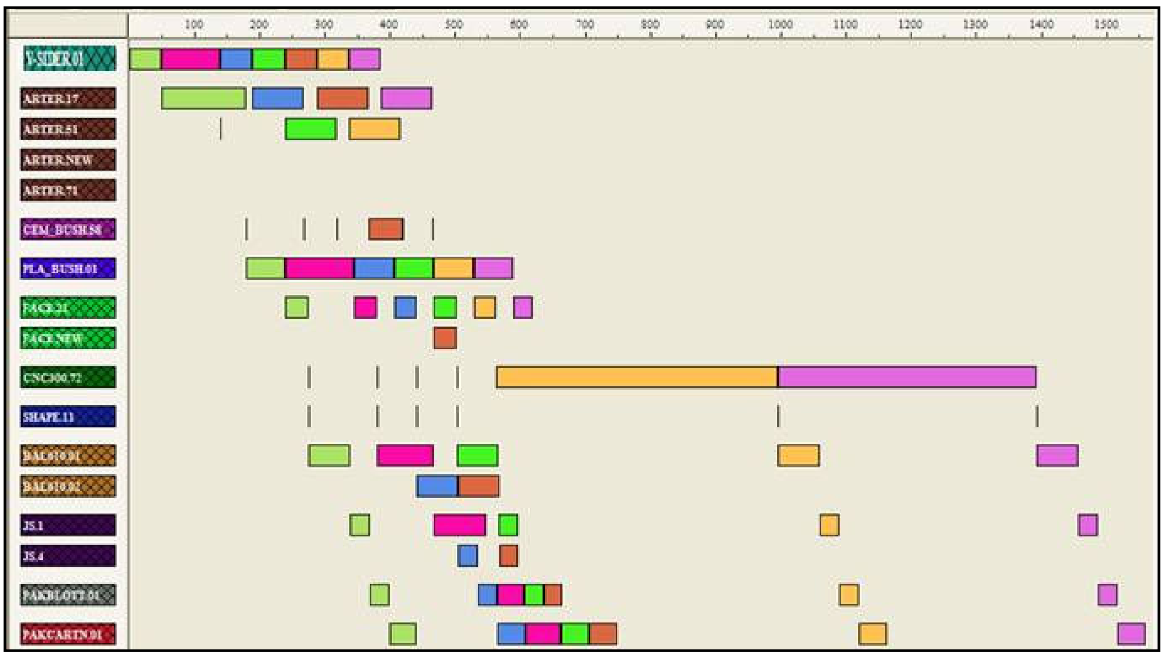

Figure 31: FCFS rule for tool room

		Scheduling of SG's latest layout		
Order number	Operation time	Begin Time	End Time	Lead Time
10221893	441.59	0	441.59	441.59
10258245	495.82	49.04	663.22	614.18
10274077	391.11	141.34	607.93	466.59
10274738	391.11	190.38	706.49	516.11
10279239	380.92	239.42	749.76	510.34
10294273	823.81	288.46	1161.77	873.31
10294274	781.96	337.5	1558.4	1220.9
Average	529.47			663.29

Table 9: Lead time for scheduling of Saint-Gobain's latest layout

After rescheduling, Figure 32, the team found that:

- The lead time of all of the orders is 1570 minutes. This is an increase of 9 minutes for lead time when compared to Figure 31.
- The lead time for the schedule that disregards the variations is 773 minutes, an increase of 23 minutes from Figure 31.

From the points made for Figures 31 and 32, the team was able to come up with the following conclusions:

- Remove the two ARTERS that are not used.
- Add a driller.
- Remove one face machine.
- Remove one BAL_610 machine.
- Remove one JS machine.
- Reduce the number of workers.
- Separate the variations to allow for the shortest possible lead time.

Figure 32: Rescheduling

The following improvements had been made in the modified scheduling 1 versus the scheduling on Saint-Gobain's modified layout:

- The lead time of all orders is 1513 minutes. This is 48 minutes less than the original schedule
- The lead time of orders while disregarding the variants is 712 minutes, an improvement of 38 minutes.

While the improvements made above are very good, the team felt that it should try the LPT rule for scheduling. In the LPT rule, the products with the most variation would get processed first. The main purpose of this rule would be to make use of available waiting time to reduce waste. LPT rule makes it so that processes is completed using the minimum amount of resources possible. Using fewer resources should save the company cost.

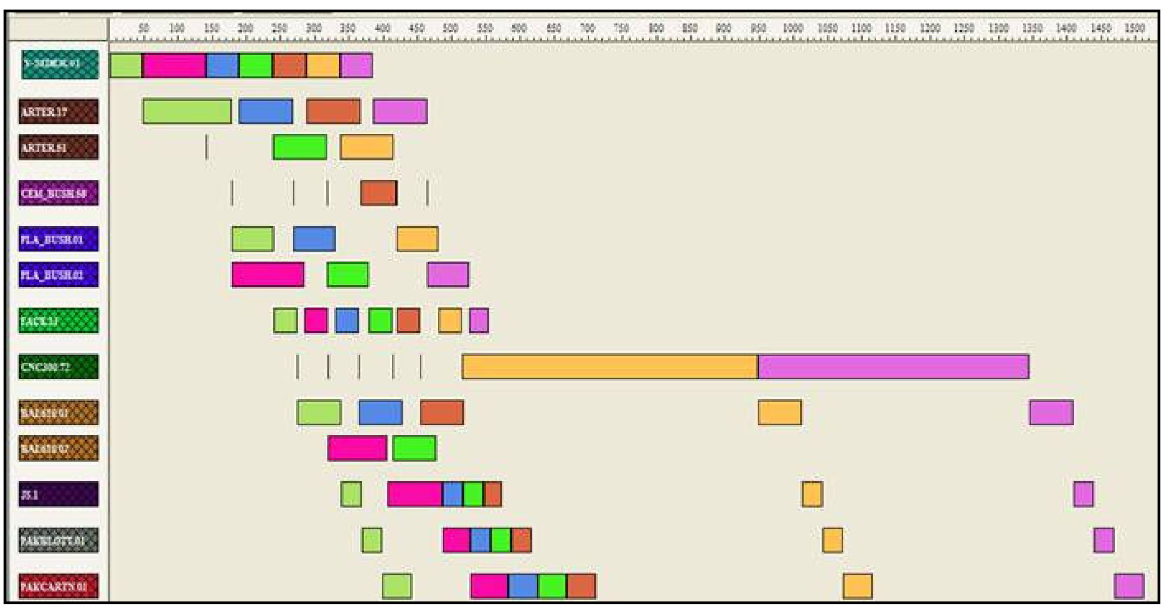

Figure 33: Modified scheduling 1

		Scheduling of SG's latest layout			Modified Scheduling 1				
Order number	Operation time	Begin Time	End Time	Lead Time	Begin Time	End Time	Lead Time	Improved	By 100%
10221893	441.59	0	441.59	441.59	0	441.59	441.59	0	0.00%
10258245	495.82	49.04	663.22	614.18	49.04	544.86	495.82	118.36	19.27%
10274077	391.11	141.34	607.93	466.59	141.34	588.13	446.79	19.8	4.24%
10274738	391.11	190.38	706.49	516.11	190.38	631.4	441.02	75.09	14.55%
10279239	380.92	239.42	749.76	510.34	239.42	674.67	435.25	75.09	14.71%
10294273	823.81	288.46	1161.77	873.31	288.46	1112.2	823.31	50	5.73%
10294274	781.96	337.5	1558.4	1220.9	337.5	1508.9	1171.4	49.5	4.05%
Average	529.47			663.29			607.88	55.41	8.94%

Table 10: Modified scheduling 1 versus scheduling on S-G's modified layout

Figure 34 shows scheduling by longest process time with all of the machines intact. Since it is important to reduce resources in the LPT rule, the following figure is a much better representation of this.

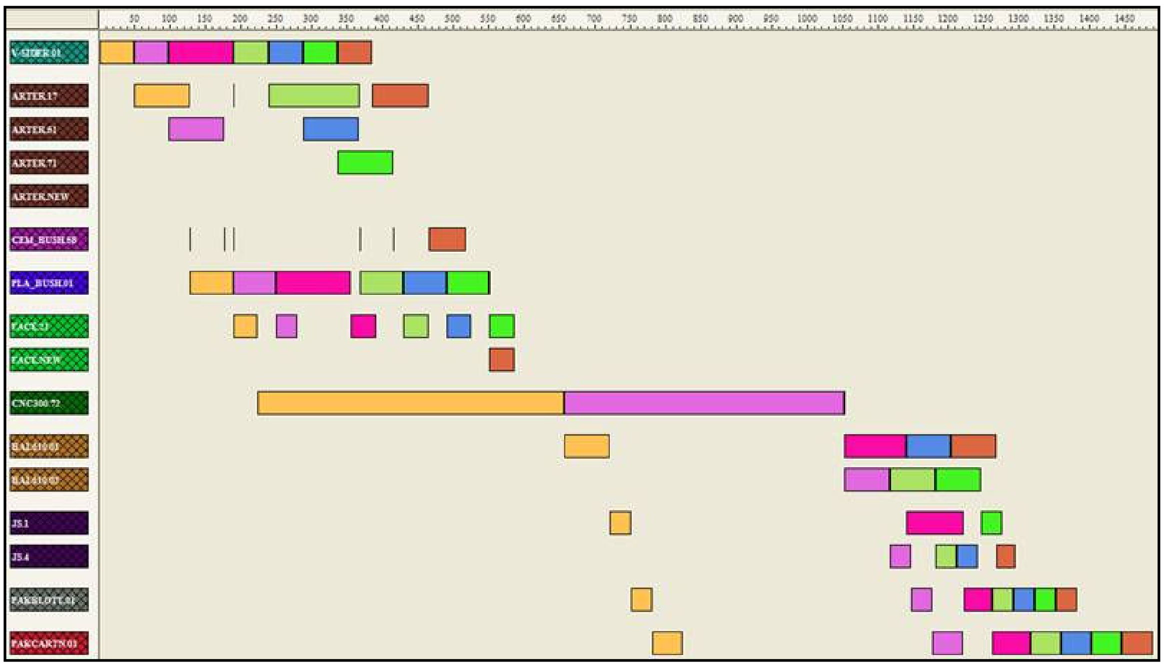

Figure 34: Scheduling by LPT rule

The differences between Figures 34 and 35 are:

- Three of the ARTER machines were removed.
- The FACE NEW machine was removed.
- BAL_610 was removed.
- A JS machine was removed.

In Figure 35, the process was rescheduled by moving the processes left or right to make sure that the processes in each ellipse do not overlap. This allows only one worker to operate all of the steps in an ellipse. This figure shows that lead time was also reduced to 1221 minutes, which is an improvement of 340 minutes when compared to the FCFS scheduling based on Saint-Gobain's modified design.

The LPT rule for scheduling makes the most sense as it allows the company to reduce cost by reducing resources. It also allows the company to produce grinding wheels by taking into consideration the variations. LPT rule makes it so that the workers can work on grinding wheels continuously.

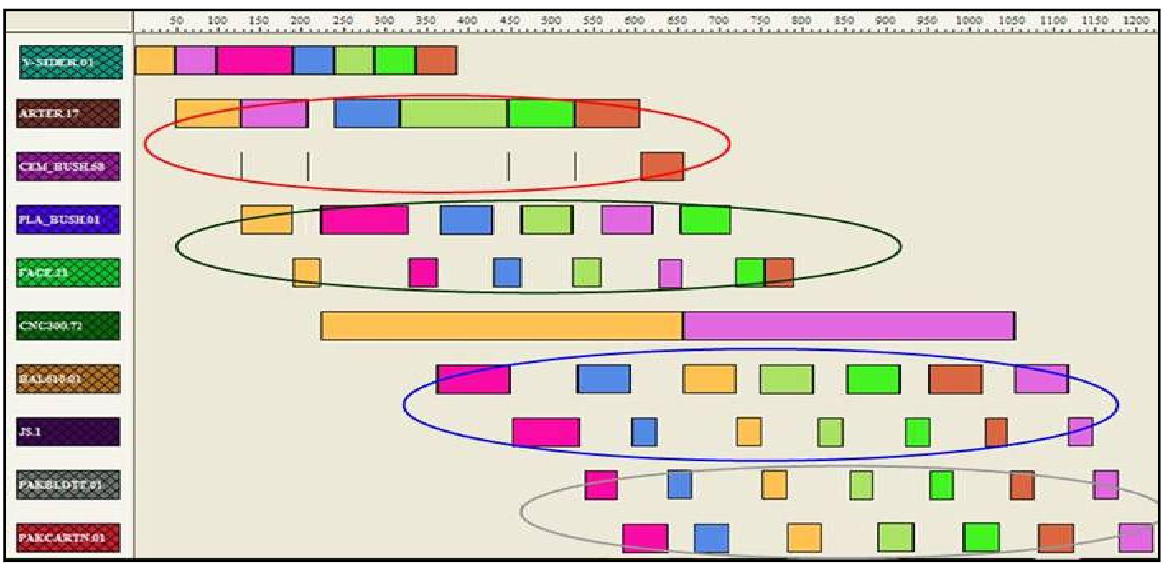

Figure 35: Scheduling by LPT rule with resources removed

4.4 Final Designs

The team has developed two final designs for the tool room based on data analysis and scheduling.

The following are the differences between the WPI-HUST proposed final design 1 and Saint-Gobain's proposed design 1:

- One driller was added. According to the schedule, if a driller is added, the total cycle time will be reduced by 38 minutes when disregarding the variants.
- There is one less ARTER. Only one ARTER is necessary. If there are more, this process step will be completed too quickly and the following process step will become a bottle neck.
- The driller and the face were moved in to the main production line. This was essential because it will reduce transportation time and distance traveled.
- The cement bush machine was moved closer to the worker operating the driller. Also, it has been placed in its proper location according to the flow of manufacturing. This will allow the worker to operate both the driller and the cement bush machines.
- One JS machine is moved.

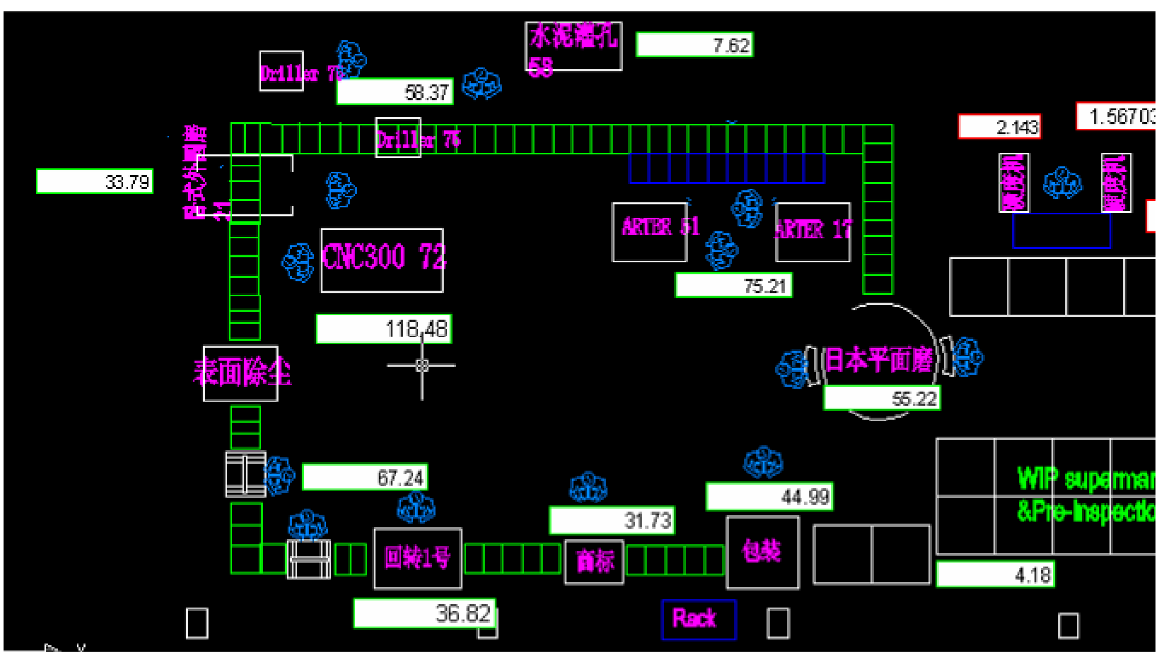

Figure 36: WPI-HUST proposed final design 1 for tool room

Figure 37 is the second proposed final design of the tool room. The following are the differences between the teams second design and the company's proposed design:

- One ARTER, one balance machine, and one JS machine were removed from the cell. It is not necessary to have an excess of these machines.
- The ARTER and the cement bush machines, the driller and the face machines, the balance and the JS machines, and the blotter and packaging areas will share one worker each.

From the four floor plans the team has, they did floor space calculations. To do this, they placed boxes around the entire work area of the tool room in each one of the four designs. The team also calculated the moving distance in the tool rooms of the four proposed designs. They did this by using straight lines from one point to the next. It is a very raw measurement but will suffice.

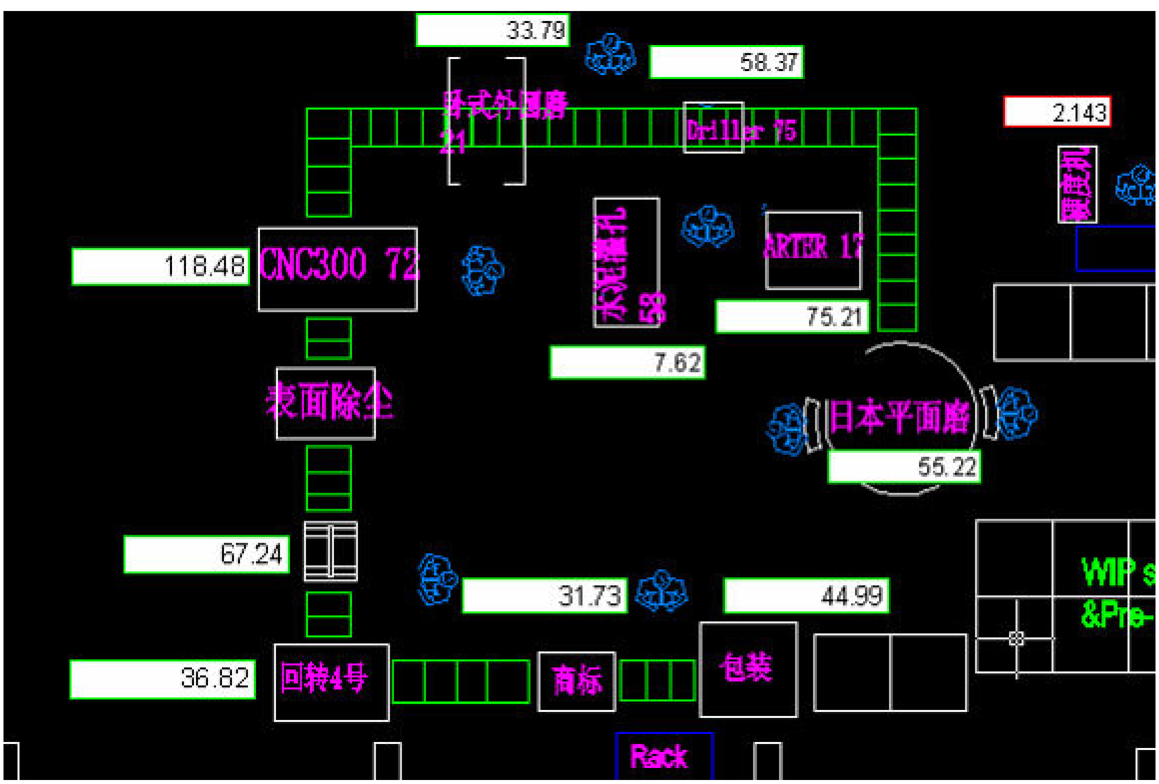

Figure 37: WPI-HUST proposed final design 2 for tool room

Table 11 shows that the WPI-HUST proposed designs save the company a lot of floor space and a lot of moving for the workers. The overall designs of WPI-HUST are very economical.

	Saint-Gobain's proposed design	Saint-Gobain's modified design	WPI-HUST proposed design 1	WPI-HUST proposed design 2
Floor Space (m^2)	300	235	200	146
Manpower	13	16	14	8
Workers moving distance (m)	98	66	52	38

Table 11: Floor space, manpower and distance of the four proposed designs

Table 12 is a decision matrix with the four proposed designs for the tool room. The table helps to determine which designs are the best. According to Table 12, the two best designs are the WPI-HUST proposed designs. Design 1 and design 2 both have very high scores relative to the scores of Saint-Gobain's proposed designs. If one of the designs had to be chosen to implement as the cell for the tool room, WPI-HUST's proposed design 1 would best fit the bill as it has the highest overall score.

	S-G proposed design	S-G modified design	WPI-HUST proposed design 1	WPI-HUST proposed design 2
Flow (less travel back) 0.10	60	80	90	90
Transportation (travel less from kiln to pre-inspection and from packing to shipping) 0.15	60	80	90	90
Lead time 0.15	60	80	90	70
Manpower utilization 0.15	65	70	80	95
Machine utilization 0.15	70	75	90	80
Product flow speed balance 0.20	60	80	90	90
Worker safety 0.10	70	90	95	95
Total score	63	79	89	87

Table 12: Decision table with Saint-Gobain's proposed designs and WPI-HUST final designs

5 Conclusion

From the results above, the WPI-HUST project team can strongly recommend to Saint-Gobain Abrasives Shanghai to reconsider their proposed plans for multiple cell layouts. The designs that WPI-HUST has proposed, according to the data that they team received from the company, would better suit the company. From the final designs section, both WPI-HUST proposed designs scored much higher than the designs by Saint-Gobain. Those designs were developed after complete data analysis and scheduling analysis. Either one of the project teams design would save the company money by reducing the use of resources. The two designs would also do a great job of removing the wastes, as defined by the lean manufacturing principles, from the manufacturing process.

For the scheduling methods, the FCFS rule that the company is currently using is an archaic method of scheduling. There is no logic to this method at all. The LPT rule for scheduling would work best for the company as it allows for all products, including those orders with variations, to be processed in a timely manner. Scheduling using the LPT rule means most of the time where waiting happens will be utilized because orders will constantly be produced.

Saint-Gobain has the right idea in that it is a company that wants to implement lean manufacturing. Lean manufacturing will allow the company to remove wastes from its manufacturing process and will save the company money. It will also allow the company to be more productive when it is manufacturing products. The company's initial proposed cell design did not have much in analysis to back up if whether their design would be feasible. The WPI-HUST team has provided the company with complete analysis with their proposed cell designs. Implementing lean manufacturing at this company is very much feasible.

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