AC 2008-767: DEVELOPING A MANUFACTURING PLANT LAYOUT UTILIZING BEST-IN-CLASS CONCEPTS OF LEAN MANUFACTURING AND THEORY OF CONSTRAINTS OF OPTIMAL MACRO-FLOW

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Developing a Manufacturing Plant Layout Utilizing Best-in-class Concepts of Lean Manufacturing and Theory of Constraints of Optimal Macro-Flow

Abstract

Developing a plant layout for a manufacturing facility is a project that utilizes a combination of art and science. Although creating plant layouts has been an activity that has been performed by manufacturing and industrial engineers for decades, there is no one set formula or method that will ensure achieving the best possible optimum outcome.

Many manufacturing companies are striving to adopt lean production techniques that eliminate waste to enhance flow of products through their production facilities. Tools utilized to implement lean production techniques include: kanban, supermarkets, first-in first-out (FIFO) lanes, pacemaker processes, management time frames, etc. Numerous companies are also implementing theory of constraints (TOC), which is a management philosophy to meet customer demand through synchronized production, to enhance flow of products to generate money for the corporation at an expedited rate. TOC utilizes tools like drum-buffer-rope (DBR), throughput accounting, and constraint management to achieve this.

Although, companies are striving to implement lean manufacturing and TOC trough the implementation of the above mentioned tools, they miss out on implementing an optimized macro-flow in their facilities. Macro-flow is the optimization of the entire flow within the facilities of a company, which allows them to avoid sub-optimization within narrow departments or functional areas. Lean manufacturing and TOC stress the importance of maintaining a consistent macro-flow within the entire manufacturing facility for products, to achieve the highest impact in improving the productivity and profitability of a manufacturing plant.

For creating the most optimum macro-flow within a facility, dimensionless block diagrams have been used by plant layout engineers. However, the way these dimensionless block diagrams are created and implemented have a lot of subjectivity built into them. This paper suggests an objective means using weightages to create the dimensionless block diagram to reduce the substantial subjectivity that creeps into the creation of the dimensionless block diagrams. With the proposed method, facility planners will be better able to optimize the macro-flow in a manufacturing facility as necessitated by lean manufacturing and TOC principles.

Plant Layout as Practiced Today

Industries have attempted to create efficient plant layouts since the dawn of industrialization, and many methods have been utilized by industrial, production, and manufacturing engineers to come up with the most efficient plant layout. However, there is not a set methodology that can be repetitively applied to all plant layout exercises so that they turn out as the most efficient plant layout. In this sense, creating of plant layouts is more of an art than a science[1,2,3].

To aid in coming up with the best layout, one needs to search for alternative solutions which should push one to become creative in coming up with a solution that is most efficient. Kirck[3, 4] has summed up these efforts in a worthy to repeat manner, which have been elaborated below:

1) Exert the necessary effort to come up with an optimized solution. This needs to be done by allocating ample time to address the problem, and forcing oneself to concentrate fully on the problem during that time.

2) Do not get bogged down in details too soon, but also do not suggest solutions with no back up technology. An example[3] of this is one operation research analyst who supposedly during World War II suggested that the German submarine force could be destroyed by boiling the ocean. When asked how that could be done his response was, "I come up with solutions that others need to figure out how to implement."

3) Ask ample questions on the forefront to highlight the problem from multiple angles. The simple questions of what, who, when, where, which, how, and why go a long way in achieving this.

4) Seek several alternatives and avoid premature satisfaction. Falling in love with a design early on hampers incorporation of better ideas later on, and makes the plant layout engineers defensive when challenged on their assumptions. Having various options allows the management team to mix and match several aspects from differing layouts based on constraints that they would like to keep in creating a new layout.

5) Avoid conservatism. Not thinking outside the box for things that have not been attempted by anyone restricts the firm from making quantum leaps in improving their productivity and profitability. Attempting to tweak what is presently available pushes a firm into simple variations of the present layout resulting in little or no payoff for the effort expended in improving the layout.

6) Avoid premature rejection. Rejecting an idea without letting others contemplate and build on it, can make a firm lose good ideas. An idea which is presented as part of a brainstorming session never has all aspects tackled when it is initially presented. Only on subsequent thought can the shortcomings and weaknesses of an idea be appropriately addressed if the benefits of the idea are substantial.

7) Benchmark—learn how others have done it. A good source for how people have solved analogous problems is to consult trade magazines, websites, libraries, and by talking with trade peers as to how they have solved problems of similar layout.

8) Try the group approach, but at the same time remaining conscious of its limitations. Brainstorming, involves a small group of people who have diverse knowledge to allow ideas to flow from to come up with the most efficient layout. Initially, no criticism of the ideas is allowed to be able to generate and capture all ideas that the participants have, and then begin the evaluation process to cull the ones that are totally infeasible. Building on each others ideas is encouraged to allow better ideas to flow. Limitations of the idea

generation method can be using the wrong experts who do not have adequate exposure to other industries to allow them to cross pollinate ideas from other fields.

With all these rules of thumb too, “many of today’s layouts are the product of evolution rather than careful design[3]”. This stems from the size and the nature of the problem itself. Unless a person like Charles Sorensen[5], Vice-President of Production for the Ford Motor Company, is involved in creating a plant layout using experience and rules of thumb, you have to repeat the exercise several times before getting it correct.

Sorensen’s story of how he created the production facility to assemble the B-24 Liberator bomber during World War II is worth revisiting to learn what can be described closest to a method for creating a plant layout. The established B-24 bomber facility was assembling an airplane a day, and there was felt a need to increase production to 25 bombers a day. Sorensen, using his 35 years of experience in designing and building manufacturing plants was able to envision how the plant should be structured after an overnight thinking spree on the day he and Edsel Ford visited the old bomber manufacturing facility. The proposed macro-flow of the plant was created by Sorensen on a piece of paper, and was accepted and signed by Edsel Ford. Eventually, the US Government funded the two-hundred million dollar manufacturing plant from which 8,800 B-24’s rolled off the assembly line in six years with over 34 thousand employees working at its peak employment level of what came to be known as the Willow Run Bomber Plant that was located near Detroit.

The one principle that Sorensen kept in mind in designing the plant was smooth flow of the product throughout the manufacturing facility, which is most often mentioned today as the core lean manufacturing and TOC principle. The entire plane's design was broken down into essential units and a separate production layout was created for each unit[5] to create overall optimum flow. The production of the entire plane was next arranged so that only the required number of units are built and delivered in the proper sequence to the assembly line to make the finished plane.

Optimizing Macro-Flow in the Plant

Macro-flow can be defined as the flow of raw materials and information from the point they enter a manufacturing facility and gradually become a product, to the point where the finished product leaves the factory. Many times, only the flow within the actual production shop has been optimized with little attention paid to the multiple times that the raw material, information, in-process parts and the finished product are moved beyond the flow in the production shop.

To enhance macro flow with in the entire factory, departments and functional cells need to be positioned such that the flow in the entire factory is as efficient as can be. For optimizing the macro-flow, a method that has been used to ensure that the functional departments that carry the majority of the flow are positioned closed to each other is called the dimensionless block diagram[1].

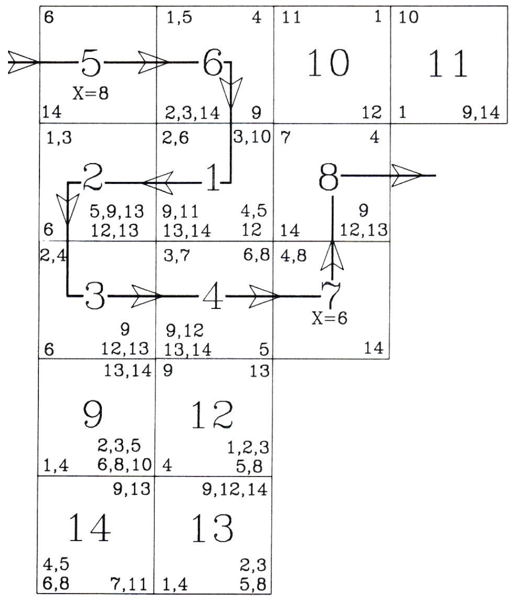

Figure 1. Traditional Dimensionless Block Diagram[1]

In the traditional method of creating the dimensionless block diagram, the functional departments, production work-cells, and cost centers are identified, and how information needed for the manufacture of the products, people, and products should flow through them is captured in a matrix. Next, based on the experience of the employees, a matrix showing the importance of locating two departments or work-cells close to one another is created as shown in Figure 2. The "AEIOU-X" scale is used to assign importance in locating two departments or work-cells close to each other: A is assigned where it is absolutely essential to locate two departments close to each other, E is essential, I is important, O is ordinary importance, U is unimportant, and X is to not locate close to each other.

		Weightage	Fabrication	Welding	Paint	Assembly & PO	Receiving	Stores	Warehouse	Shipping	Restrooms	Maintenance	Tool Room	Locker Room	Cafeteria	Office
1	Fabrication	11		4	3	1	1	4	0	0	2	3	2	1	2	2
2	Welding	12			4	0	1	2	0	0	1	1	0	1	1	0
3	Paint	13				4	0	2	0	0	1	0	0	1	1	0
4	Assembly & PO	14					1	3	4	3	2	0	0	2	2	2
5	Receiving	6						4	0	-4	1	0	0	1	1	2
6	Stores	5							-4	0	1	0	0	0	0	2
7	Warehouse	3								4	0	0	0	0	0	1
8	Shipping	8									1	0	0	1	1	2
9	Restrooms	2										1	1	4	3	3
10	Maintenance	10											4	0	0	0
11	Tool Room	9												0	0	1
12	Locker Room	4													3	0
13	Cafeteria	1														3
14	Office	7														

Figure 2. Activity Relationship Diagram With Importance Categories

Next, paper rectangles like the one shown on the left in Figure 3 are created for each department or work-cell. The number of the department or the work-cell for which the relationship for the specific department has been categorized as “A” or absolutely essential is then written in the left top corner, the one for category “E” in the top right corner, the one for category “I” in the left bottom corner, the one for category “O” in the right bottom corner, and the one for category “X” in the center. The relationships for the Tool Room for data in Figure 2 are shown on the right in Figure 3.

Figure 3. Blocks of Departments Created for the Dimensionless Block Diagram

Next, using the rectangles for each department, the dimensionless block diagram is created as shown in Figure 1, using the experience of the plant layout engineer in deciding how to place the departments close to each other. In this paper, a better method to create the macro-flow using the dimensionless block diagram using weightages has been proposed.

The first step in the proposed method is to assign weightages to the various categories as shown in Figure 4. There is a tendency to consider everything equally important, and hence it is recommended that the categories of A, E, I, O, U and X do not exceed 5%, 10%, 15%, 25%, 40% and 5% respectively.

		Weightages
A	5%	4
E	10%	3
I	15%	2
O	25%	1
U	40%	0
X	5%	-4
Total	100%	

Figure 4. Assigning Weightages to Categories of Relative Importance

The category of “U” or unimportant is assigned a weightage of zero, and moving from that on, the category of “O” is assigned 1, “I” is assigned 2, “E” is assigned 3, “A” is assigned 4, and “X” is assigned negative 4. Using these weightages, the relationship chart shown in Figure 2 is now converted into a relationship chart with weightages as shown in Figure 5 below.

		Weightage	Fabrication	Welding	Paint	Assembly & PO	Receiving	Stores	Warehouse	Shipping	Restrooms	Maintenance	Tool Room	Locker Room	Cafeteria	Office
1	Fabrication	11		4	3	1	1	4	0	0	2	3	2	1	2	2
2	Welding	12			4	0	1	2	0	0	1	1	0	1	1	0
3	Paint	13				4	0	2	0	0	1	0	0	1	1	0
4	Assemply & PO	14					1	3	4	3	2	0	0	2	2	2
5	Receiving	6						4	0	-4	1	0	0	1	1	2
6	Stores	5							-4	0	1	0	0	0	0	2
7	Warehouse	3								4	0	0	0	0	0	1
8	Shipping	8									1	0	0	1	1	2
9	Restrooms	2										1	1	4	3	3
10	Maintenance	10											4	0	0	0
11	Tool Room	9												0	0	1
12	Locker Room	4													3	0
13	Cafeteria	1														3
14	Office	7														

Figure 5. Activity Relationship Diagram With Relationship Importance Weightages

Next, to be able to differentiate the relative importance between the departments or the work-cells, each department or work-cell is assigned a weightage as shown in Figure 6. As can be seen, the most important department of the 14 departments or functional areas is the assembly and the pack-out department, which is assigned a weightage of 14. Similarly, the least important department is the cafeteria, which is assigned the weightage of 1. The graphical presentation shown in Figure 6 allows easy comparison between the relative weightages of the departments.

		Weightage	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Fabrication	11														
2	Welding	12														
3	Paint	13														
4	Assemply & PO	14														
5	Receiving	6														
6	Stores	5														
7	Warehouse	3														
8	Shipping	8														
9	Restrooms	2														
10	Maintenance	10														
11	Tool Room	9														
12	Locker Room	4														
13	Cafeteria	1														
14	Office	7														

Figure 6. Assigning Weightages to the Departments or Functional Areas

Now, as we have assigned the weightages to the relationship matrix (Figure 5), and have assigned the weightages for the departments or the functional areas (Figure 6), we can create a combined weightages chart, or an overall weightages chart showing the importance of the departments and the relationships as shown in Figure 7 that can be said to be a summary of which departments and their relationships are the most important for the entire holistic macro-flow in the facility.

		Weightage	1 Fabrication	2 Welding	3 Paint	4 Assembly & PO	5 Receiving	6 Stores	7 Warehouse	8 Shipping	9 Restrooms	10 Maintenance	11 Tool Room	12 Locker Room	13 Cafeteria	14 Office
1	Fabrication	11		44	33	11	11	44	0	0	22	33	22	11	22	22
2	Welding	12			48	0	12	24	0	0	12	12	0	12	12	0
3	Paint	13				52	0	26	0	0	13	0	0	13	13	0
4	Assemply & PO	14					14	42	56	42	28	0	0	28	28	28
5	Receiving	6						24	0	-24	6	0	0	6	6	12
6	Stores	5							-20	0	5	0	0	0	0	10
7	Warehouse	3								12	0	0	0	0	0	3
8	Shipping	8									8	0	0	8	8	16
9	Restrooms	2										2	2	8	6	6
10	Maintenance	10											40	0	0	0
11	Tool Room	9												0	0	9
12	Locker Room	4													12	0
13	Cafeteria	1														3
14	Office	7														

Figure 7. Matrix of Combined Importance of Departments and Mutual Relationships

Creating the Weighted Dimensionless Block Diagram for Optimal Macro-Flow

Once the matrix for the combined importance of the weightages for the departments and their mutual relationships has been developed, it is now a matter of following a systemic process to create the dimensionless block diagram. For creating the dimensionless block diagram, we start by placing the cutout blocks of departments with the highest overall weightages in the center of the sheet. As the highest overall rating in the matrix of combined importance of departments and mutual relationships shown in Figure 7 is 56, which is related to departments #4 (Assembly and PO) and #7 (Warehouse), we place these two departments in the center of the sheet as shown in Figure 8.

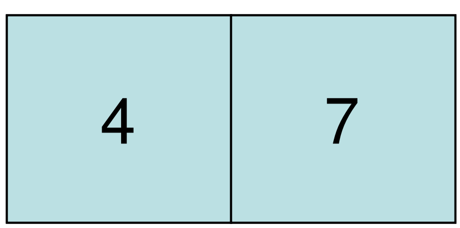

Figure 8. Creating the Dimensionless Block Diagram Using the First Two Departments

Now, we look for the next highest overall weightage number which in our case is 52 for department #3 (Paint) and department #4 (Assembly and PO). Next, we check whether #3 (Paint) needs to be near #7 (Warehouse) or not, based on their overall weightage numbers. Since the overall weightage between #3 (Paint) and #7 (Warehouse) is 0, they need not be close to each other. Hence, we place #3 (Paint) to the left of #4 (Assembly and PO). The resulting three departments will look as shown in Figure 9.

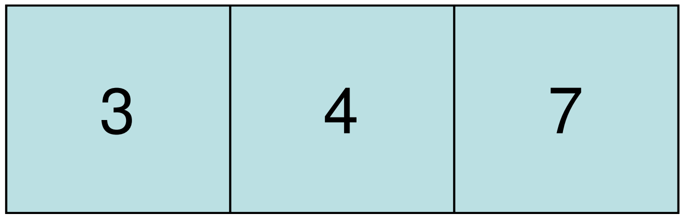

Figure 9. Adding One Department at a Time to Create the Dimensionless Block Diagram

We follow this procedure, and identify the next highest overall weightage number from the overall weightage matrix, which in our case is 48 for department #2 (Welding) & department #3 (Paint). We also know that department #2 (Welding) needs to be located close to department #3 (Paint), but we do not know whether department #2 (Welding) also needs to be near department #4 (Assembly and PO), or not. For making this decision, we look at the overall weightage for departments #4 (Assembly and PO) and #2 (Welding). Since, the overall weightage between them is 0, we need not place it over or above #3 (Paint) to make it also closer to #4 (Assembly and PO). The other option then is to place it on the left of department #3 (Paint) as shown in Figure 10 below.

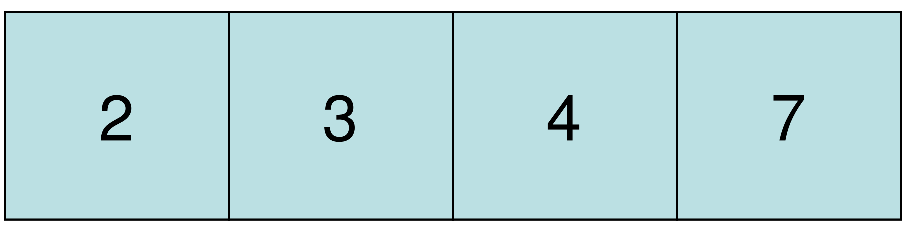

Figure 10. Adding Department #2 to Build the Dimensionless Block Diagram

We continue to build the dimensionless block diagram based on the same logic. The next highest overall weightage number is 44. This occurs in two instances: for department #2 (Welding) and department #3 (Paint), and for department #1 (Fabrication) and department #6 (Stores). Since department #2 (Welding) and department #3 (Paint) have already been included in the dimensionless diagram, we now look to adding departments #1 (Fabrication) and #6 (Stores) to the dimensionless block diagram.

Looking to first place department #1 (Fabrication), we need to first answer the question: which department should be placed closest to department #1 of the four departments #2, #3, #4, and #7 that are already placed into the dimensionless block diagram. The overall weightages for department #1 with respect to the four departments on the dimensionless block diagram are 44, 33, 11, and 0. Hence, department #1 is best placed close to departments #2, and #3, which we do by placing it above department #3 as shown in Figure 11.

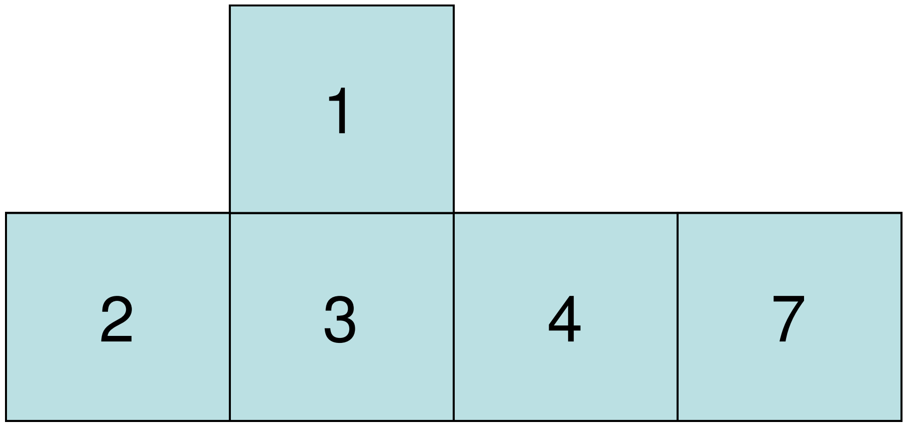

Figure 11. Add Department #1 to Continue Building the Dimensionless Block Diagram

Next, we look at placing department #6 in the dimensionless block diagram. The overall weightages for department #6 with respect to departments #2, #3, #4, and #7 that have been placed in line on the dimensionless block diagram are 24, 26, 42, and, negative 20, respectively. This suggests to us that department #6 should located close to department #4, but away from department #7. To make this happen, we move department #7 below department #4, and place department #6 above department #4 and to the right of department #1 as shown in Figure 12.

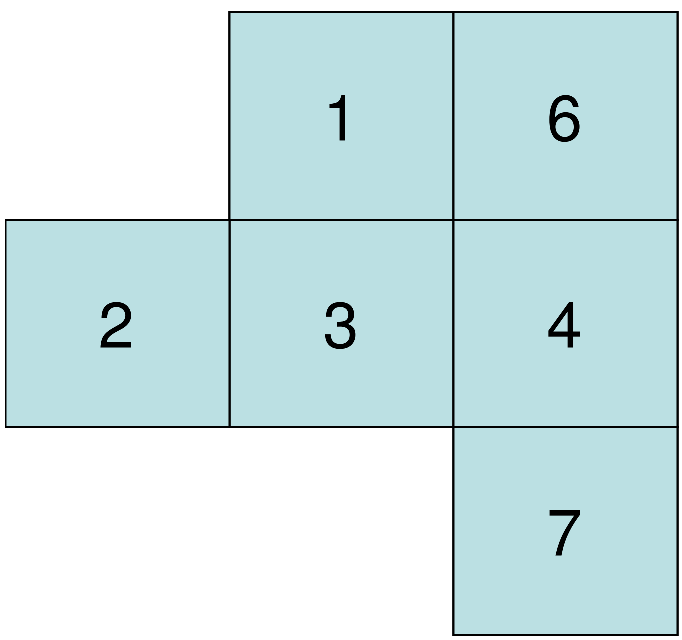

Figure 12. Add Department #6 to the Dimensionless Block Diagram

Following this logic, we complete placing all of the departments to create a dimensionless block diagram for the macro-flow of the entire facility as shown in Figure 13.

Figure 13. Completed Dimensionless Block Diagram

Conclusions

The dimensionless block diagram suggests how best to arrange departments or functional areas and work-cells so as to achieve the best possible macro-flow for the entire facility. However, the dimensionless block diagram needs to be further translated into the actual layout for the facility by first determining the definite sizes needed for the departments or functional areas based on considerations of space requirements determined on the basis of how much production will actually flow from the respective departments or functional areas.

To create the final plant layout, the layout of the departments or functional areas will need to be created and then the area needed will have to be determined. Once the areas of the departments or the functional areas have been determined, the areas can be organized relative to each other keeping the dimensionless block diagram relationships in mind.

A good dimensionless block diagram in itself is not the final plant layout since further decisions based on the experience of the plant layout engineer still needs to be incorporated into the layout to make it flow optimally, but it can go a long way in ensuring that the holistic flow is optimized from the point raw materials enters a company till the point it leaves the company as a finished product. This should give the right start in implementing lean manufacturing and theory of constraint principles for any company.

Bibliography

1. Meyers and Stephens, *Manufacturing Facilities Design and Material Handling*, Third Edition, Pearson Prentice Hall, 2005.

2. Tompkins, Et Al, *Facilities Planning*, Third Edition, John Wiley & Sons, Inc., New York, 2003.

3. Francis, McGinnis and White, *Facility Layout and Location: An Analytical Approach*, Second Edition, Prentice Hall International Series in Industrial and Systems Engineering, 1992.

4. Krick, *Methods Engineering*, John Wiley & Sons, Inc., New York, 1962.

5. *Production Miracle At Willow Run*, downloaded from http://www.strategosinc.com/willow_run.htm on December, 15th 2007.