

Chapter 18 Lean Manufacturing

Objective:

In this chapter, we introduce the fundamentals of Lean Manufacturing. Concepts of waste elimination are discussed. Components for Lean including: Waste identification and elimination, set-up reduction, part families, cell formation, cell design, batches of one and pull systems are also discussed.

“Perfection is not attainable. But if we chase perfection, we can catch excellence.” Vince Lombardi

18.1 Introduction to Lean Manufacturing

Lean manufacturing or **lean production** are reasonably new terms that can be traced to Jim Womack, Daniel Jones and Daniel Roos' book, ***The Machine that changed the world*** [1991]. In the book, the authors examined the manufacturing activities exemplified by the Toyota Production System. **Lean manufacturing is the systematic elimination of waste.** As the name implies, lean is focused at cutting “fat” from production activities. It has also been successfully applied to administrative and engineering activities as well. Although lean manufacturing is a relatively new term, many of the tools used in lean can be traced back to Fredrick Taylor and the Gilbreaths at the turn of the 20th century. What Lean has done is to package some well-respected industrial/manufacturing engineering practices into a system that can work in virtually any environment.

Figure 18.1 provides a definition of lean as a function of the outcomes that one realizes. The definition comes from Womack and it identifies the results rather than the method of lean. In the following sections, the procedures and specifics of lean will be introduced.

18.1.1 The 3 M's of Lean

Lean manufacturing is a Japanese method focused on 3M's. These Ms are: **muda**, *the Japanese word for waste*, **mura**, *the Japanese word for inconsistency*, and **muri**, *the Japanese word for unreasonableness*. Muda specifically focuses on activities to be eliminated. Within manufacturing, there are categories of waste. **Waste is broadly defined as anything that adds cost to the product without adding value to it.** Generally, **muda** (or waste) can be grouped into the following categories:

- 1.Excess production and early production
- 2.Delays
- 3.Movement and transport

Definition of “Lean”

- Half the hours of human effort in the factory
- Half the defects in the finished product
- One-third the hours of engineering effort
- Half the factory space for the same output
- A tenth or less of in-process inventories

*Source: The Machine that Changed the World
Womack, Jones, Roos 1990*

Figure 18.1 An early definition of Lean.

4. Poor process design
5. Inventory
6. Inefficient performance of a process
7. Making defective items

These wastes are illustrated in Figure 18.2

Excess production results in waste because it captures resources too early and retains the value that is added until the product can be used (sold). In today's highly changing society, many items produced before they can be sold to a specific customer often go obsolete before demand is realized. This means that a perfectly good product is often scrapped because it is obsolete. Producing a product simply to keep a production resource busy (either machine, operator or both) is a practice that should be avoided.

Delays, such as waiting for raw material, also result in the poor use of capacity and increased delivery time. Raw materials and component parts should be completed at approximately the time that they will be required by downstream resources. Too early is not good, but late is even worse.

Movement and transportation should always be kept to a minimum. Material handling is a non-value added process that can result in three outcomes: 1) the product ends up at the right place at the right time and in good condition, 2) the

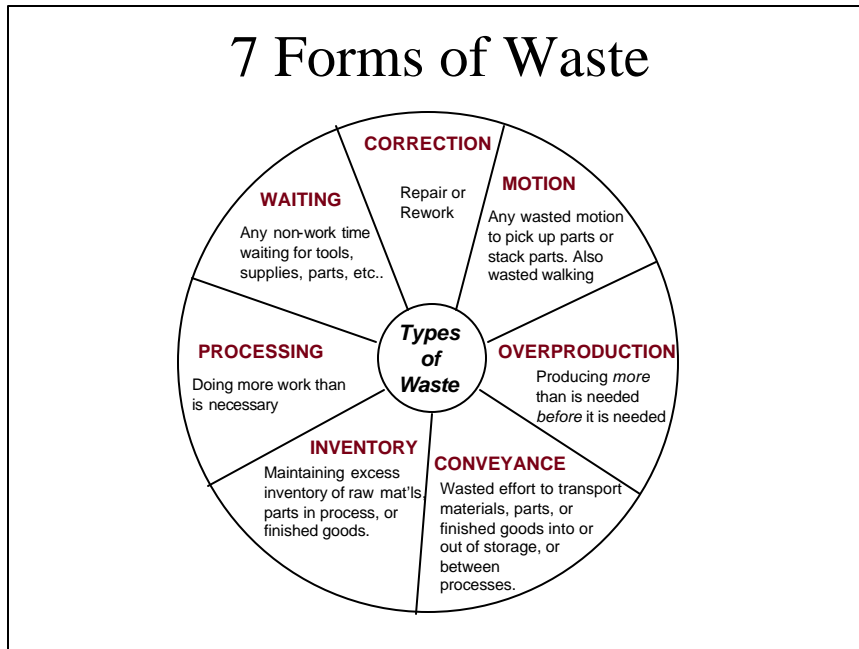


Figure 18.2 The seven Forms of waste.

part ends up in the wrong place, and 3) the part is damaged in transit and requires rework or scrap. Two of the three outcomes are no desirable, which further leads to minimizing handling. Because material handling occurs between all operations, when possible, the handling should be integrated into the process, and the transport distances minimized.

A poorly designed process results in overuse of manufacturing resources (men and machines). There are no perfect processes in manufacturing. Generally, process improvements are made regularly with new efficiencies embedded within the process. Continuous process improvement is a critical part of Lean Manufacturing.

Excess inventory reduces profitability. Today, it is not uncommon for a manufacturer to store a supplier's product at the production site. The supplier, right up until the time that they are drawn from inventory, owns the materials. In many ways this is advantageous to both the user and supplier. The supplier warehouses his material offsite, and the user does not need to commit capital to a large "safety stock" of material.

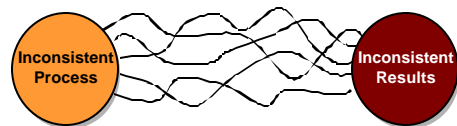
Insufficient (or poor) process performance always results in the over utilization of manufacturing resources and a more costly product. There is no optimal process in that improvements can always be made; however, many processes operate far below the desired efficiency. Continuous process improvement is necessary for a manufacturing firm to remain competitive. Excess movement or unnecessary part handling should be the first targets of waste elimination.

Poor quality (making defects) is never desirable. Labor and material waste results from producing any defect. Furthermore, the cost of mitigating poor quality (rework) can often exceed the price of the product. A critical balance between processing speed and quality exists. A process should be run as fast as possible without sacrificing acceptable quality.

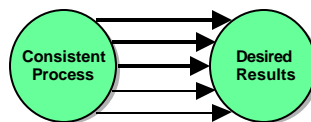
From the above discussion, it should be obvious that waste is a constant enemy of manufacturing. Waste elimination should be an on-going process that focuses on improving a process regularly. Regular reviews and worker input should be conducted as often as allowable.

The second “M” is for **mura**, or inconsistency. Inconsistency is a problem that increases the variability of manufacturing. **Mura** is evidenced in all manufacturing activities ranging from processing to material handling to engineering to management. Figures 18.3 and 18.4 illustrate a characterization of **mura** as Henry Ford wrote in 1926.

Quality Processes Yield Quality Results



Traditional = People doing whatever they can to get results



Lean = People using standard process to get results

Figure 18.3 Inconsistency is a problem in manufacturing.

(See Figure 18.4), the best target method should be initially identified. This method should become the “standard practice”, and the target for future process improvements.

Henry Ford - Standards

“To standardize a method is to choose out of the many methods the best one, and use it. Standardization means nothing unless it means standardizing upward.

Today’s standardization, instead of being a barricade against improvement, is the necessary foundation on which tomorrow’s improvement will be based.

If you think of “standardization” as the best that you know today, but which is to be improved tomorrow - you get somewhere. But if you think of standards as confining, then progress stops.”

*Henry Ford, 1926
Today & Tomorrow*

Figure 18.4 Henry Ford on standards (or against inconsistency).

The final “M” is for muri or unreasonableness. Muri applies to a variety of manufacturing and management activities. For instance, Figure 18.5 shows an example of being unreasonable by blaming someone for problems rather than looking at resolution of problems. It is unreasonable to blame rather than mitigate issues. This is true for all manufacturing activities -- do what is reasonable. Don’t be emotional!

New Paradigm: Non-Blaming Culture

Management creates a culture where:

- Problems are recognized as opportunities
- It’s okay to make legitimate mistakes
- Problems are exposed because of increased trust
- People are not problems - they are problem solvers
- Emphasis is placed on finding solutions instead of “who did it”




Figure 18.5 Be reasonable -- muri.

18.1.1 Active Exercises

Waste elimination and process improvement can be applied to virtually any process. For example, the local Department of Motor Vehicles (DMV) provides a variety of services. Examples of those include: 1) Administering a driving test, 2) Testing vision, 3) Testing applicant's knowledge of driving practice, 4) Registering vehicles and much more. The past ten years has seen many improvements for many of these activities. For instance, an interactive computer system is used to test a person's understanding of driving practice. A computer system is also used to issue the license. These are typical process improvements. Changes at the DMV were result of waste identification and process improvement.

For this exercise, you should identify a process at work or school that you feel lends itself to waste elimination. You should first characterize the process, noting the value added and non-value added activities. The non-value added activities should be eliminated (if possible). The value added activities should be examined and analyzed for potential improvements. Describe the system as it exists and as you think it should be. Describe how you went about identifying and eliminating waste.

18.2 Laying out a Lean Production Facility

Another critical aspect of Lean is the organization of the production facility. Since one of the keys to lean is waste elimination, the layout of any system should be arranged in such manners that waste of motion (material handling and material transport) and elimination of inventory is part of the object for the layout. You may recall that there are two traditional forms of layout in manufacturing: process and product. In a **process layout (or job shop as it is informally called)**, *machines are organized and clustered by type*, where typically all mills are in one department, all lathes in another, etc. In a **product layout (or flow shop)**, *machines are located so that sequential operations are performed at adjacent machines*. These types of layout are illustrated in Figures 18.6 and 18.7 respectively.

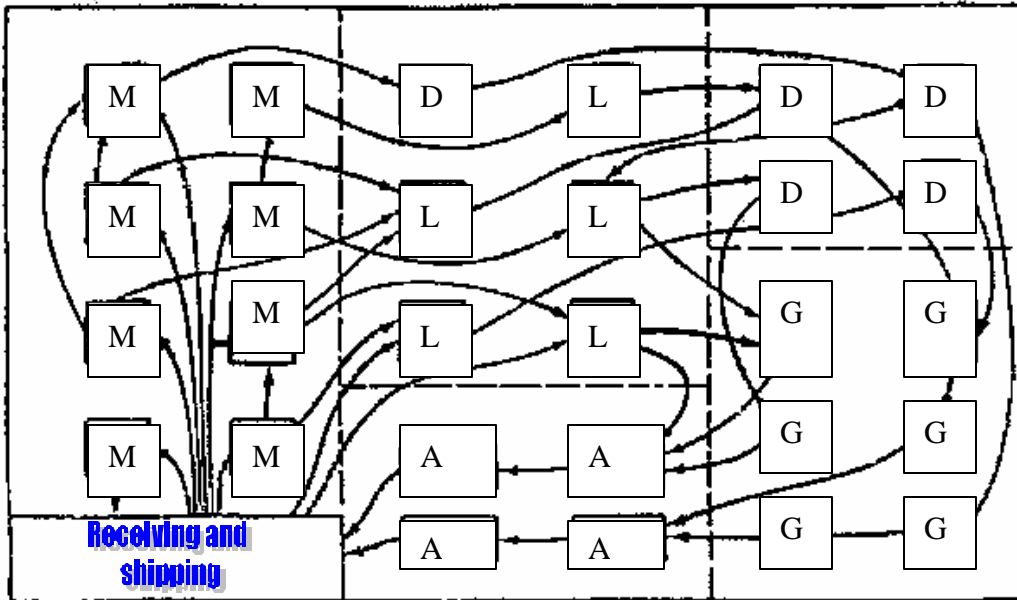


Figure 18.6 A typical process or job shop layout.

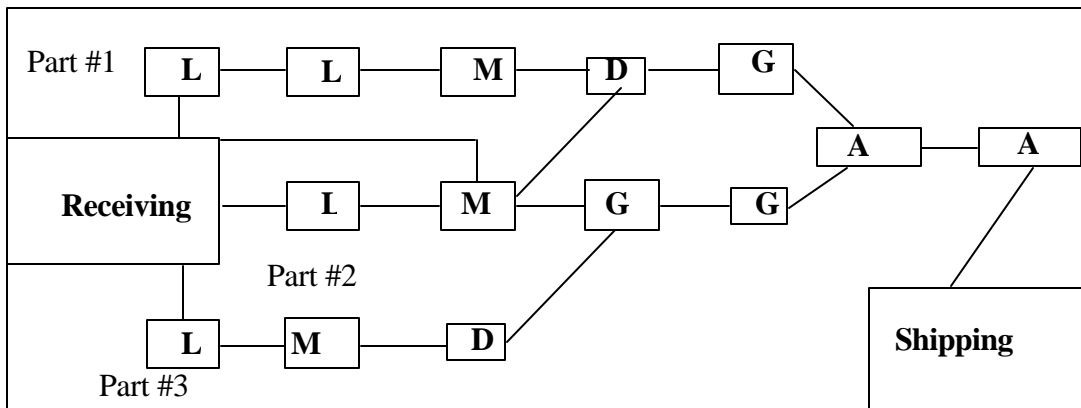


Figure 18.7 A typical product or flow shop layout.

Process layout is typically employed for a large variety of products that are made in very small batches (ones or twos). The advantages of Process Layout are: 1) the flexibility of the system to produce almost any part that fits within the volumetric boundaries of the machines, 2) an in depth understanding of a specific process can be obtained, and 3) some tooling and fixtures can be shared. The disadvantages of process layout are: 1) the spaghetti flow is difficult to manage and control, 2) there is usually a lot of inventory in front of each machine, 3) set up is usually expensive, 4) material handling times are large, and 5) it is difficult to automate these types of systems.

Product layout systems are used effectively for the economic production of high volume goods. The advantages of these systems are: 1) large batches can be produced inexpensively, 2) material handling is minimal, 3) in-process materials are minimized, 4) it is easy to control these systems, and 5) automation is more achievable and justifiable. The disadvantages of these systems are: 1) they are inflexible, in that only one or very few products can be produced on them, 2) set up time for these systems is very large, and 3) duplicate tooling is required to replace worn tooling so that maintenance can be minimized.

Process systems work effectively on “one of a kind” type of production. As batches get larger, these systems fail to produce the required “economies of scale”, and that production time and cost remains relatively constant. Product systems work very effectively on single item production. For instance, high volume products like soda, beer, canned foods, cigarettes, and many automotive components are effectively produced on these flow systems. The reason that these items are so inexpensive is in part because of the way they are produced. Unfortunately, the high capital cost and long set-up for these systems mandates

large volumes to offset these initial costs and then the changeover costs associated with these systems.

In general, very low volume items should be produced on process type systems, and very high volume items should be produced on product type systems. A problem facing most manufacturers is that the general trend today is for medium volume batches that change regularly. This means that process and product layout fails to meet the requirements for much of what is demanded today. The result is that a hybrid of the two systems has been developed. It is called a manufacturing cell. See Figure 18.8 and 18.9. Cells are used to make families of parts, rather than just one-of-a-kinds or high volume items. Cells are logical clusters of machines organized to produce a variety of parts requiring the same equipment type, tooling and fixtures. Cells are intended to provide as many of the benefits of process and product layouts as possible.

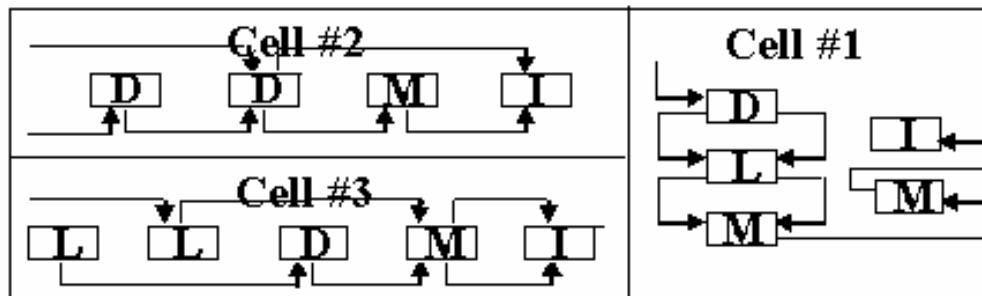


Figure 18.8 A manufacturing cellular layout.

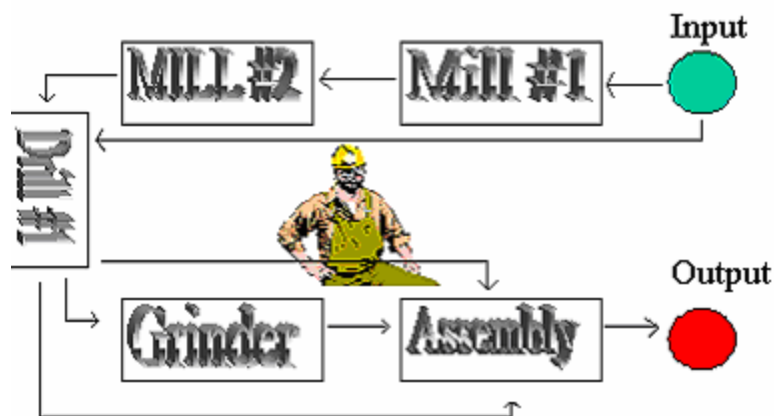


Figure 18.9 A U - shaped manufacturing cell.

In many ways, cellular layout separates and groups products within a manufacturing system into smaller units. The strategy here is to identify parts that belong to the same “product families”. A **product family** is a group of products that normally look similar and require the same (or similar) processing

steps to produce. Traditionally, designers have formed product families by grouping products that provide similar functions into a common product family. Examples might be: springs, clips, brackets, etc. The problem however becomes one where functional names may create very large families (for instance, brackets typically form a large portion of products the automotive industries make) or function may require different processes as the size scales. **Group technology (GT)** was introduced as a method to characterize products into code-able families. A descriptive code was used to characterize the product geometry, function and/or method used to make the part. As database systems have become more powerful, the code has been replaced with descriptive fields in a database. Today, more formal techniques are used to identify cells. In the following section, a methodology to organize factories, machines, tooling will be presented.

18.3 Production Flow Analysis

Production flow analysis (PFA) is a technique that is used to organize machines into a logical grouping. PFA was first introduced by J. L. Burbidge [Burbidge, 1971] to solve product family formation problems. When applied to a single factory, the classic framework for manual implementation of PFA consists of four stages, each stage achieving material flow reduction for a progressively reducing portion of the factory: Factory Flow Analysis (*FFA*), Group Analysis (*GA*), Line Analysis (*LA*) and Tooling Analysis (*TA*).

In *FFA* (Figure 18.10), dominant material flows between shops (or buildings) are identified. In addition, if parts are observed to backtrack between any of the shops, these flows are eliminated by a minor redeployment of equipment. *FFA* may often be redundant for a factory that essentially consists of a single machine or fabrication shop.

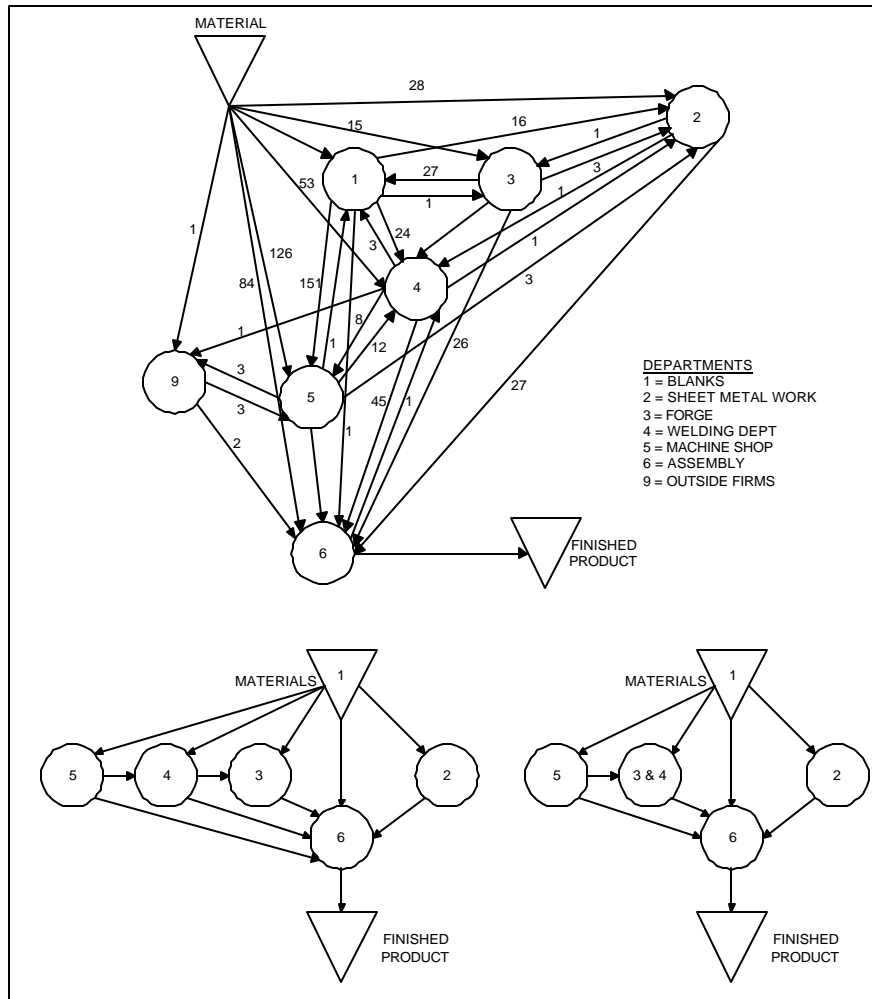


Figure 18.10 A typical Factory Flow Analysis. (Source: Burbidge, J. L.1971, April/May. *Production Flow Analysis. The Production Engineer*, 139-152.)

In GA (Figure 18.11), the flows in each of the shops identified by FFA are analyzed. GA analyzes operation sequences of the parts being produced in a particular shop to identify manufacturing cells. Loads are calculated for each part family to obtain the equipment requirements for each cell. Each cell usually contains all the equipment necessary to satisfy the complete manufacturing requirements of its part family. Due to sharing and non-availability of equipment, some inter-cell material flows and flows to/from vendors may arise.

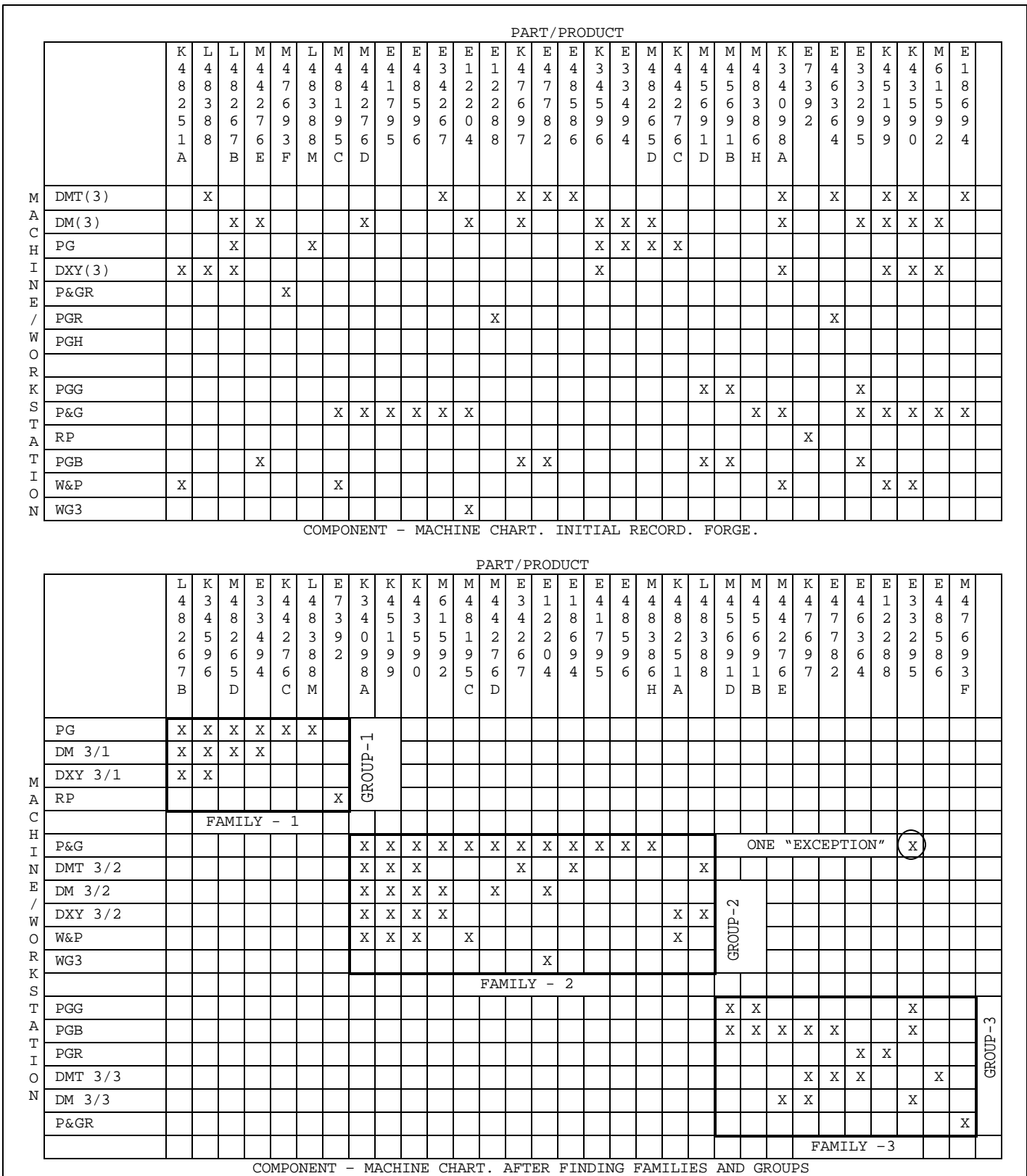


Figure 18.12 Group Analysis (Source: Burbidge, J. L.1971, April/May. Production Flow Analysis. *The Production Engineer*, 139-152.)

In *Line Analysis (LA)* (Figure 18.12), a linear or U-layout is designed for the machines assigned to each cell. The routings of each part assigned to the cell and the frequency of use of each routing are used to develop a cell for efficient transport as well as minimum material handling and travel by operators.

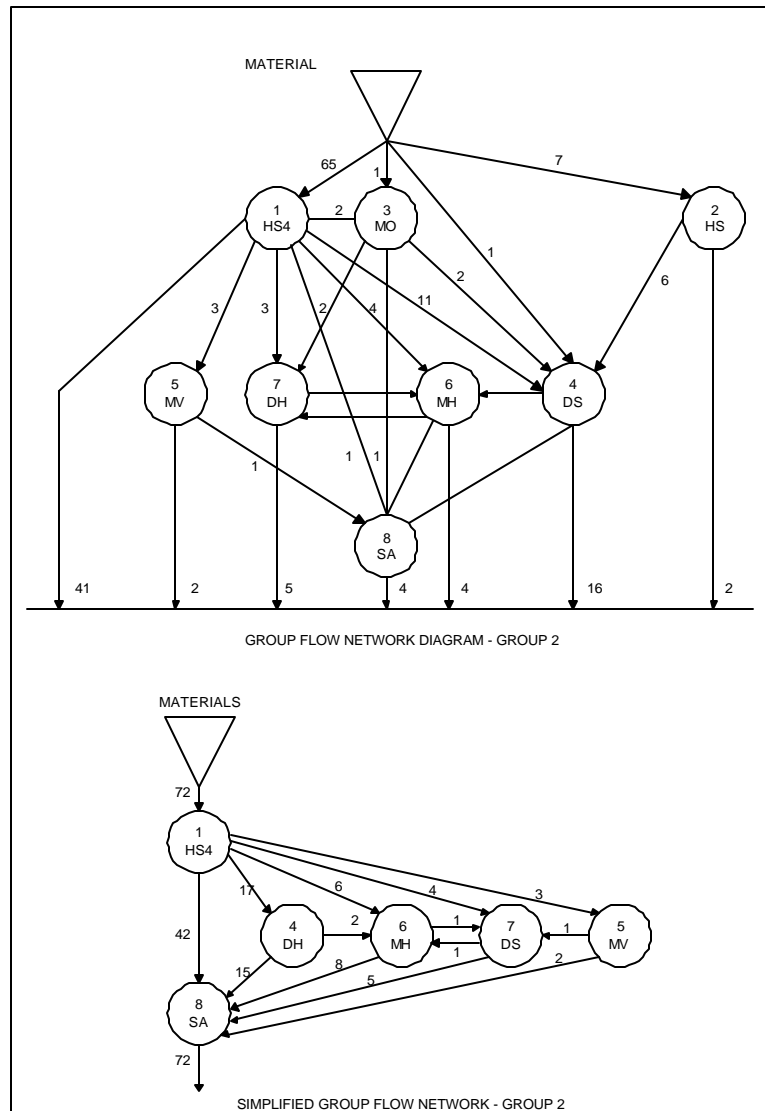


Figure 18.12 An example of Line Analysis. (Source: Burbidge, J. L.1971, April/May. Production Flow Analysis. *The Production Engineer*, 139-152.)

In *Tooling Analysis (TA)* (Table 18.1), the principles of GA and LA are integrated with data on the shape, size, material, tooling, fixturing, etc. (attributes of the parts). TA helps to schedule the cell by identifying families of parts with similar operation sequences, tooling and setups. It seeks to sequence parts on each machine and to schedule all the machines in the cell to reduce setup times and batch sizes. This increases available machine capacity on bottleneck work centers in the cell.

Table 18.1 An example of Tooling Analysis. (Source: Gallagher, C. C. & Knight, W. A. (1973), *Group Technology*, London, UK: Butterworths.)

Digit 1	Digit 2		Digit 3	Digit 4	Digit 5	Digit 6	Digit 7	Digit 8			
Method of holding	Dimension			Matching with			Material	Surface accuracy			
	3 Jaw chuck		D _w	L	Special attachments	Boring tool carrier				Quadruple single point tool holder	
Bore dia. φ	Over all										
0	3 Jaw chuck outer			< 40	L/D _w <0.1	w/o	w/o	w/o	GG-formed	rough turned ∇	0
1	3 Jaw chuck inner	42 φ	160	41.....100	L/D _w <0.5	Axial copying	Boring, counter-sinking, reaming, tapping.	Uniform cutting, w/o accuracy.	ST-formed	fine turned ∇∇	1
2	4 Jaw chuck	60 φ	250	101...200	L/D _w up to limit of chuck	Face copying	Only outer turning.	Uniform cut, or staggered cut, with accuracy, simple boring up to 48 φ.	NE-formed	outer fit	2
3	Spring collet	80 φ	315	301...400	Shafts<500	2 Axis copying	1 with 2	Outer shaping, chamfering, inserting with form tool, not copying.	GG-cut off	inner fit (+ outer)	3
4	Mandrel or arbor	80 φ	400	401...500	Shafts 500...1000	Conical Surface tapering±12°	Shaping, etc. with form tool; with 3; rot copying.	3 with 4	ST-cut off	positional accuracy	4
5	Jig or fixture	125 φ	500	501...1000	Shafts 1m...2m	Steep cone	Inner shaping inserting chamfering; with 3; copying.	Shaping, inserting chamfering with form tool; copying.	NE-cut off	polishing	5
6	Between centers			> 1000	Shafts 2m...5m	Short thread milling	Inner & outer at the same time	5 with 2 & 1 or 3	GG-bar	knurling, etc.	6
7	Chuck-center				Shafts > 5m	Threading with lead screw		6 with back tool holder	ST-bar		7
8	Steadies					Thread with copying			NE-bar		8
9	Eccentric (face plate)					Unround copying		Automatic cycle with 4 ^h & 5 th digits	non-metal		9

Several techniques are available to form clusters for FFA, GA, LA and TA. These techniques use routing or process planning information in order to identify families. In the following sections, some of these techniques will be described and illustrated.

18.3.1 Rank –Order Cluster Algorithm

King (1979) presented a rank-order cluster algorithm that is quite simple. We use his method to show how component families can be determined in our shop. The data from Table 18.2 will be used to illustrate this procedure. King's algorithm can be stated as follows:

Step 1. For $\forall j$, calculate the total weight of column w_j :

$$w_j = \sum_{\forall j} 2^i M_{ij}$$

	A-112	A-115	A-120	A-123	A-131	A-212	A-230	A-432	A-451	A-510
SAW01	/		/	/	/			/	/	
LATHE01				/						
LATHE02	/		/		/			/	/	
DRL01		/								/
MILL02		/								
MILL05						/	/			/
GRIND05	/									
GRIND06										/

Figure 18.2 The initial PFA matrix for our example.

Step 2. If w_j is in ascending order, go to step 3. Otherwise, rearrange the columns to make w_j fall in ascending order.

Step 3. For \forall_j calculate the total weight of row w_j :

$$w_j = \sum_{\forall_j} 2^j M_{ij}$$

Step 4. If w_j is in ascending order, stop. Otherwise, rearrange the rows to make w_j fall in ascending order. Go to step 1.

The rank-order clustering algorithm sorts the matrix into a diagonal block structure. The diagonal blocks are not always mutually exclusive. Final judgment has to be made by the user.

One of the major drawbacks of applying this algorithm is the need of storing the binary word. In order to implement this procedure on a computer, the word length is $\max(n, m)$, where n is the number of machines, and m is the number of components. For a moderate problem with 50 machines and 2000 components, it is impossible to calculate the weights before sorting. For the

machine weights, 50 words of 2000 bits are needed! A word of 2000 bits requires 250 bytes. To overcome this problem, direct comparison of elements, either row or column, can be used. A digit-by-digit comparison is performed, beginning from the most significant digit. Each row or column of the matrix is treated as a binary number; no weight is ever calculated. Unfortunately, this procedure has a computational complexity of a cubic order, namely, $O[ij(i + j)]$ (King and Nakornchai, 1982), where i and j are the number of rows, and columns, respectively.

Table 18.3 shows the procedure of rearranging the PFA matrix in from Table 18.2.

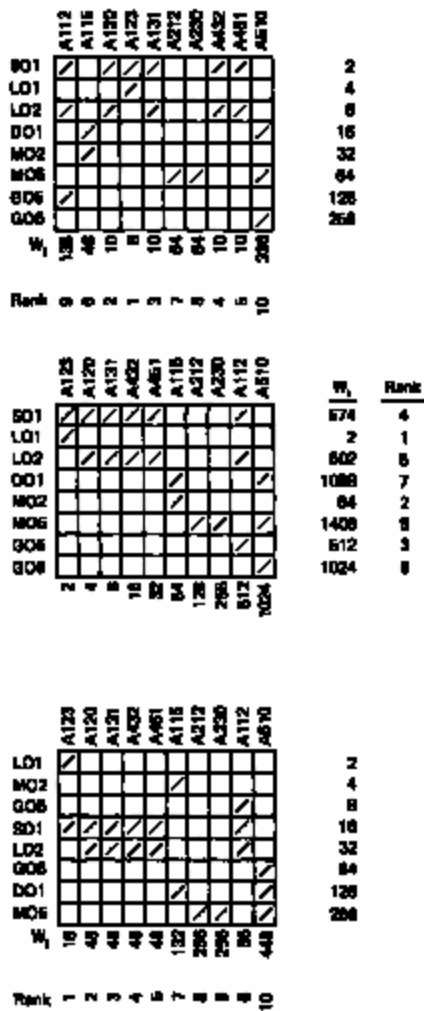


Figure 18.3 Rank-order cluster algorithm tables.

	A123	A120	A131	A432	A451	A112	A115	A212	A230	A510	W_i	Rank
LO1	/										2	1
MO2							/				128	5
GOF											64	2
SO1	/	/	/	/	/						126	4
LO2		/	/	/	/						124	3
GO6									/		1024	6
DO1							/				1152	7
MO5								/	/	/	1792	8
	2	4	8	16	32	64	128	256	512	1024		

	A123	A120	A131	A432	A451	A112	A115	A212	A230	A510	W_i
LO1	/										2
GO5											4
LO2	/	/	/	/	/						8
SO1	/	/	/	/	/						16
MO2							/				32
GO6									/		64
DO1							/				128
MO5								/	/	/	256
	18	24	24	24	24	26	160	256	256	510	

Stop

Table 18.3 (Continued)

After we obtain the final matrix, we can determine (although somewhat arbitrarily) that components A123, A120, A131, A432, A451, and A112 form a family that needs SAW01, LATHE01, LATHE02, and GRIND05, A115, A212, A230, and A510 form the second family.

18.3.2 The Direct Clustering Technique

An improvement over the rank-order clustering algorithm was proposed independently by Chan and Milner (1982) and King and Nakornchai (1982). The algorithms proposed in both papers are almost identical. The technique is called direct clustering.

The technique is based on the idea of using blocks and rods, and by changing the sequence in which components and machines are listed in the matrix. For convenience, we denote those cells requiring a particular operation (/) as positive cells, and those with blank entries as negative cells. The direct cluster algorithm consists of going through the matrix sequentially, and moving the columns with the topmost negative cells to the left and the rows with the leftmost positive cells to the top of the matrix sequentially, and moving the columns with the topmost negative cells to the left and the rows with the leftmost

positive cells to the top of the matrix. In repeated trips, the positive cells move toward the diagonal of the matrix in a clustered pattern.

The basic rule is that each component or machine must be moved together with its respective row or column entries during matrix transformation, as if the cells or the blocks were linked together by imaginary rods. The algorithmic procedure is as follows.

Step 1. For $\forall i$, calculate the total number of positive cells in row w_i :

$$w_i = \sum_{\forall j} M_{ij}$$

Sort columns in descending order.

Step 2. For $\forall j$, calculate the total number of positive cells in column w_j :

$$w_j = \sum_{\forall i} M_{ij}$$

Sort columns in ascending order.

Step 3. For $i = 1$ to n , move all columns j , where $M_{ij} = 1$, to the right, maintaining the order of the previous rows.

Step 4. For $j = m$ to 1 , move all rows i , where $M_{ij} = 1$, to the top maintaining the order of the previous columns.

Step 5. If the current matrix is the same as the previous matrix, stop, or else go to step 3.

The same PFA matrix in Table 18.2 is rearranged using the direct clustering algorithm. The procedure and result are shown in Table 18.4. As can be seen the result in this figure is the same as that obtained by the rank-order clustering algorithm. However, the direct clustering algorithm does not always work. When one or several of the machines are bottleneck machines, the iteration stops very quickly. A bottleneck machine is a machine that is used by a large number of components and prevents the further rearrangement of columns. The rest of the matrix is not rearranged because bottleneck machines block them. It happens especially in large matrices. To solve the bottleneck problem, human intervention is needed. When the iteration stops prematurely, identify the bottleneck machines and continue the iteration, disregarding the order of those rows.

We also may have a final matrix with blocks not mutually exclusive. When closely investigating the matrix, we may find that only a few cells caused this problem. Those cells can be considered as exception cells. Mark the exception cells with an asterisk (*), treat them as negative cells and then reapply the algorithm. Another technique increases the number of machines of a specific type and merges machines of the same type. This can be done by adding new rows and merging two rows respectively. More elaborate examples of the direct clustering algorithm can be found in Chan and Milner (1982) and King and Nakornchai (1982).

So far, we have illustrated two algorithms for part-family formation. Many other methods have been developed, such as the similarity coefficient method, the set-theoretic method, and the evaluative methods. None of these methods is as simple as the ones introduced here.

Step 1		A-112 1	A-115 2	A-120 3	A-123 4	A-131 5	A-212 6	A-230 7	A-432 8	A-451 9	A-510 10	Σr
A	SAW01	/	/	/	/	/	/	/	/	/	/	6
B	LATHE01			/								1
C	LATHE02	/	/		/			/	/			5
D	DRL01	/	/								/	2
E	MILL02		/									1
F	MILL05					/	/			/		3
G	GRIND05	/										1
H	GRIND06										/	1
Σc		3	2	2	2	2	1	1	2	2	3	

Step 2		6	7	2	3	4	5	8	9	1	10	Σr
A				/	/	/	/	/	/	/		6
C			/	/	/	/	/	/	/	/		5
F	/	/									/	3
D		/									/	2
B				/								1
E		/										1
G								/				1
H											/	1
Σc		1	1	2	2	2	2	2	2	3	3	

Step 3		(Row A)									
		6	7	2	10	3	4	5	8	9	1
A				/	/	/	/	/	/	/	/
C				/	/	/	/	/	/	/	/
F	/	/	/								/
D		/	/								/
B				/							/
E		/									/
G								/			/
H			/								/

Table 18.4 An example using direct clustering.

The results also vary. Family formation is not always objective; many other factors such as the cost of implementing the machine cell and material-handling costs have to be considered. The problem should not be considered as just clustering cells in an incidence matrix. The methods discussed here provide a starting point for further improvement.

18.3.3 Mathematical Programming in Group Technology

In solving the group-technology problem, there are two approaches that have been used extensively: heuristic algorithms and mathematical programming models. Mathematical programming deals with the optimization of a function

consisting of several variables. In addition, the variables must satisfy a set of constraints that are inequalities and/or equalities (Zoutendijk, 1976).

Step 3 (Row C to H)

	2	6	7	10	4	3	5	8	9	1
A				/	/	/	/	/	/	/
C					/	/	/	/	/	/
F	/	/	/							
D	/		/							
B				/						
E	/									/
G										
H				/						

Step 4 (Last column)

	2	6	7	10	4	3	5	8	9	1
A				/	/	/	/	/	/	/
C					/	/	/	/	/	/
G										/
F	/	/	/							
D	/		/							
B				/						
E	/									/
H				/						

Step 4 (Rest of the column)

	2	6	7	10	4	3	5	8	9	1
A				/	/	/	/	/	/	/
C					/	/	/	/	/	/
G										/
B				/						
F	/	/	/							
D	/		/							
H				/						
E	/									/

Family 1

Family 2

Table 18.4 (Continued)

When applying mathematical programming models to group-technology problems, most models consider a measure of the distance, d_{ij} , between part i and part j . Some of the measures used most often are the Minkowski distance measure, the weighted Minkowski distance measure, and the hamming distance (Kusiak, 1990).

Given the distance between parts, the objective function can be defined as consisting of a set of variables satisfying the constraints that minimizes the total sum of distances between any two parts i and j . Two models that have been applied to the group-technology problem are the p -median model and quadratic programming (Kusiak, Boe, and Cheng, 1993). Both models are utilized to group n parts into p families. Unlike the p -median model, however, the quadratic programming model requires that both the number of part families and the number of parts in a family be specified beforehand.

There are two general categories of mathematical programming models: ones that are prescriptive and ones that are descriptive. Linear programming models are prescriptive because the objective function is predefined and once the model is "turned on," the decision variables that optimize the objective function are determined. On the other and, descriptive models start with the

definition of the decision variables, and during simulation, for example an estimate of the overall system performance is provided (Askin and Standridge, 1991).

Askin and Standridge (1991) developed a mathematical statement for assigning part operations and machines to group utilizing binary ordering of the machine-part matrix to determine independent groups. Boctor (1991) proposed a mixed-integer linear program to minimize the number of exceptional elements in the machine-part group formulation problem. Another mathematical approach in solving the problem of exceptional elements in cellular manufacturing was presented (Shafer, Kern, and Wei, 1992). A The model dealt with the minimization of three costs: (1) intercellular transfer, (2) machine duplication, and (3) subcontracting. Srinivansan, Narendran, and Mahadevan (1990) developed an improvement over the p -median model in the problem of creating part families in group technology. The assignment method was found to be superior in the quality of the solution, as well as computational time. The problem of grouping parts and tools was solved using 0-1 linear integer problem and the Lagrangian dual problem (Ventura, Chen, and Wu, 1990).

18.3.4 Production Flow Analysis And Simplification Toolkit

Production flow analysis and simplification toolkit (PFAST) is a technique introduced in Irani, et al [2001] is presented. Much of the material comes directly from their paper.

The evaluation and simplification of the material flow network in a facility prior to undertaking the design of the layout can now be achieved using the Production Flow Analysis and Simplification Toolkit (PFAST). PFAST is an experimental library of programs for machine grouping, part family formation, cell layout and shop layout design developed at The Ohio State University (Daita, Irani & Kotamraju; Irani & Zhou). It extends the classical framework of Production Flow Analysis to the analysis of flows at any level of resolution in a facility. Examples of levels of resolution are: Between buildings, between departments or shops in the same building, between cells in a shop, between machines in a manufacturing cell, between locations around a single machining center, etc.

In a typical facility layout study, it is assumed that the layout design will eliminate inefficient material flow in the facility. Therefore, no effort is made to simplify the material flow network that is input to the block layout algorithm that generates the optimal layout. The symptoms shown in Table 18.5 usually indicate the inefficiency of material flows in a facility that is due to one or more of the causes listed in Table 18.6.

Table 18.5 Symptoms of Inefficient Material Flows in a Facility

-
- Large travel distances in the material flow diagram
 - Perceived shortage of floorspace for facility expansion
 - High WIP inventory levels and inter-machine transfer batch sizes
 - High levels of finished product inventories
 - Bottleneck resources with large queues
 - Large cycle times for order fulfillment
 - Significant queuing and material handling delays
 - Significant forklift truck activity
 - Poor order tracking capability
 - Highly unpatterned material flow network
 - Absence of a network of material handling aisles
 - Inefficient communications between workcenters
 - Low machine and labor utilization
 - Absence of scheduling based on resource constraints
 - Inflexibility to handle demand and/or part mix changes
-

Table 18.6 Causes of Inefficient Material Flows in a Facility

-
- Building architecture
 - Locations of manufacturing departments
 - Locations of support services and utilities
 - Design of the network of material handling aisles
 - Locations of input/output points of access between departments
 - Shortage of space for facility expansion
 - Process plans for making parts and products
 - Variety of routings in the part mix
 - Current manufacturing technology
 - Current material handling equipment
 - Current parts and WIP storage systems
 - Current material handling scheduling policies
 - Choice of subcontracted operations and/or parts
-

In addition to layout design, PFAST outputs could help to evaluate other strategies for material flow simplification, as shown in Table 18.7.

Table 18.7 Utility of Algorithms in PFAST

-
- Consolidation of buildings and departments
 - Strategic duplication of equipment among departments
 - Formation of manufacturing cells and focused factories
 - Design of a network of material handling aisles
 - Modification of process plans and product designs
 - Systematic investment in Flexible Manufacturing Cells
 - Choice of subcontracted operations and /or parts
 - Reduction of variety of routings in the part mix
 - Elimination of parts that complicate the flow network
 - Enhancement of flexibility in routing products
-

Since PFAST algorithms use three types of input data – operation sequences, machine-part matrices and From-To charts – they could be used for a variety of applications, as listed in Tables 18.8 (a)-(c).

Table 18.8(a) Using PFAST for Material Flow Analysis

-
- Descriptive statistics for routing data
 - Descriptive statistics for material flow network in facility
 - Grouping of similar routings
 - Detection of redundant variety in routings
 - Identification of “misfit” (or outlier) routings
 - Analysis of in-house vs. subcontracted material flows
 - Elimination or reduction of poorly utilized material flow paths
 - Detection of flow backtracking in routings
 - Detection of flow backtracking in material flow network
 - Detection of cross flows among aisles in the facility
 - Detection of recurrent combinations (or sequences) of operations in routings
 - Evaluation of current vs. desired flexibility of existing manufacturing equipment
 - Creation of alternative routings for key products
-

Table 18.8 (b) Using PFAST to plan for Cellular Manufacturing

-
- Rapid assessment of feasibility of conversion to manufacturing cells
 - Range for the number of cells that could be introduced
 - Composition (machine group and part family) and size of each cell
 - Equipment variety in each cell
 - Part mix variety in each cell
 - Analysis of homogeneity of part mix and routings
 - Parts that do not belong to any cell
 - Parts whose routings span more than one cell
 - Parts with “exception” operations in their routings
 - Parts that could be produced in more than one cell
 - Duplication of equipment required in two or more cells
 - Alternative solutions for the cell composition problem
 - For a fixed number of cells
 - For a variable number of cells
 - Analysis of the stability of cell compositions
 - Giving focus to Integrated Product and Process Design (IPPD) activities in order to eliminate intercell flows
-

Table 18.8 (c) Using PFAST to support Facility Layout

-
- Pareto Analysis of parts using multi-criterion sampling
 - Sorting of parts to identify those with identical routings
 - Design of a block layout for a factory site, building, department or shop
 - Design of a flowline or U-layout for a cell
 - Design of non-traditional layouts
 - Hybrid Cellular Layouts
 - Cascading Cells
 - Modular Layouts
 - Virtual Cellular Layouts
 - Strategic duplication of equipment in several shops or departments
 - Strategic consolidation of shops or departments
 - Design of a flexible layout using multiple samples of routings
 - Design of a network of material handling aisles
-

18.3.4.1 Input Data for PFAST

In order to illustrate the capabilities of the current algorithms in PFAST, a 12-machine, 19-part example from the literature was used, as shown in Table 18.9. Table 18.10 shows the area of each machine. Based on this data, we can obtain

its machine-part matrix (Table 18.11), asymmetric From-To Chart (Table 18.12) and symmetric From-To Chart (Table 18.13) for the machines.

Table 18.9 Essential Data for PFAST

PART #	OPERATION SEQUENCE	BATCH QUANTITY
1	1,4,8,9	2
2	1,4,7,4,8,7	3
3	1,2,4,7,8,9	1
4	1,4,7,9	3
5	1,6,10,7,9	2
6	6,10,7,8,9	1
7	6,4,8,9	2
8	3,5,2,6,4,8,9	1
9	3,5,6,4,8,9	1
10	4,7,4,8	2
11	6	3
12	11,7,12	1
13	11,12	1
14	11,7,10	3
15	1,7,11,10,11,12	1
16	1,7,11,10,11,12	2
17	11,7,12	1
18	6,7,10	3
19	12	2

Table 18.10 Area of each Machine in the Facility

Machine	Area of the Machine (expressed in # of grid squares)
1	1
2	1
3	1
4	2
5	1
6	2
7	3
8	1
9	1
10	3
11	3
12	1

Table 18.13 Symmetric From-To Chart for the Routings in Table 18.9

		TO											
		1	2	3	4	5	6	7	8	9	10	11	12
F R O M	1		1		8		2	3					
	2				1	1	1						
	3					2							
	4						4	14	11				
	5						1						
	6							3			3		
	7								5	5	9	8	2
	8									8			
	9												
	10											6	
	11												4
	12												

18.3.3.2 Using PFAST for Material Flow Simplification and Facility Layout

The algorithms in PFAST use three types of input data— operation sequences, machine-part matrix and From-To Chart — instead of only From-To charts. This makes it possible to use the outputs from two or more programs in a synergistic fashion. In this section, some examples of these synergistic uses are presented to illustrate the possibility of simplifying the material flow network in a facility prior to designing a physical layout for it.

Prevention of redundant machine duplication in a cellular layout: Tables 18.14 and 18.15 suggest that, to implement a cellular layout with two cells, machine 1 would have to be duplicated in each of them. However, the design skeleton in Figure 14(a), in conjunction with the routings in Table 18.9 and Table 18.11, indicate that machine 1 is *always* the first machine in all the operation sequences. Therefore, it may be possible to design a hybrid layout for the facility where all machines of type 1 are retained in a functional group.

Table 18.14 Final Machine-Part Matrix obtained using Algorithm PG-TSP

MACHINE		5	2	3	6	9	8	4	1	7	10	11	12
P A R T	11				1								
	8	1	1	1	1	1	1	1					
	9	1		1	1	1	1	1					
	7				1	1	1	1					
	1					1	1	1	1				
	3		1			1	1	1	1	1			
	10						1	1		1			
	2						1	1	1	1			
	4					1		1	1	1			
	5				1	1			1	1	1		
	6				1	1	1			1	1		
	18				1					1	1		
	14									1	1	1	
	16								1	1	1	1	1
	15								1	1	1	1	1
	12									1		1	1
	17									1		1	1
	13											1	1
	19												1

Table 18.15 Final Machine-Part Matrix obtained using Algorithm PG-QAP

MACHINE		5	3	2	4	8	9	6	1	7	10	11	12
P A R T	11							1					
	8	1	1	1	1	1	1	1					
	9	1	1		1	1	1	1					
	7				1	1	1	1					
	1				1	1	1		1				
	3			1	1	1	1		1	1			
	10				1	1				1			
	2				1	1			1	1			
	4				1		1		1	1			
	6					1	1	1		1	1		
	5						1	1	1	1	1		
	18							1		1	1		
	14									1	1	1	
	16								1	1	1	1	1
	15								1	1	1	1	1
	12									1		1	1
	17									1		1	1
	13											1	1
	19												1

Purchase of multi-function flexible equipment to combine steps in the operation sequences of a family of parts: Table 18.16 shows that each of the substrings of operations — 4→8, 8→9 and 4→8→9 — has a high frequency of occurrence in the original routings (Table 18.9). Subject to equipment design constraints, this string matching result could be used to replace the three single-function machines — 4, 8 and 9 — by a multi-function machining center. This

planned introduction of flexible automation would eliminate inter-operation material handling, loading/unloading and setups for the following parts: 1, 2, 3, 6, 7, 8, 9 and 10.

Table 18.16 Distinct Common_Substrings in the Routings in Table 18.9

No.	Common_Substring	Frequency of Occurrence	% Occurrence
S1	1 → 4	3	15.79
S2	1 → 4 → 7	2	10.53
S3	1 → 7 → 11 → 10 → 11 → 12	2	10.53
S4	3 → 5	2	10.53
S5	4 → 7	4	21.05
S6	4 → 7 → 4 → 8	2	10.53
S7	4 → 8	6	31.58
S8	4 → 8 → 9	4	21.05
S9	6 → 4 → 8 → 9	3	15.79
S10	6 → 10 → 7	2	10.53
S11	7 → 8 → 9	2	10.53
S12	7 → 9	2	10.53
S13	7 → 10	2	10.53
S14	8 → 9	6	31.58
S15	11 → 7	3	15.79
S16	11 → 7 → 12	2	10.53
S17	11 → 12	3	15.79

Design of a Next Generation Layout (NGL): Traditionally, the Cluster Analyses of Figures 18.10-18.13, in conjunction with Tables 18.10 and 18.11, would be used to implement a 2-cell or 3-cell layout. Instead, using the results in Tables 18.12 and 18.13, the Next Generation Layout (NGL) in Figure 18.14 could be implemented. This layout is a combination of a cell (M2), three layout modules (or multi-process departments) — (M1, M3, M4) — and a single machine (#2) arranged in a network layout.

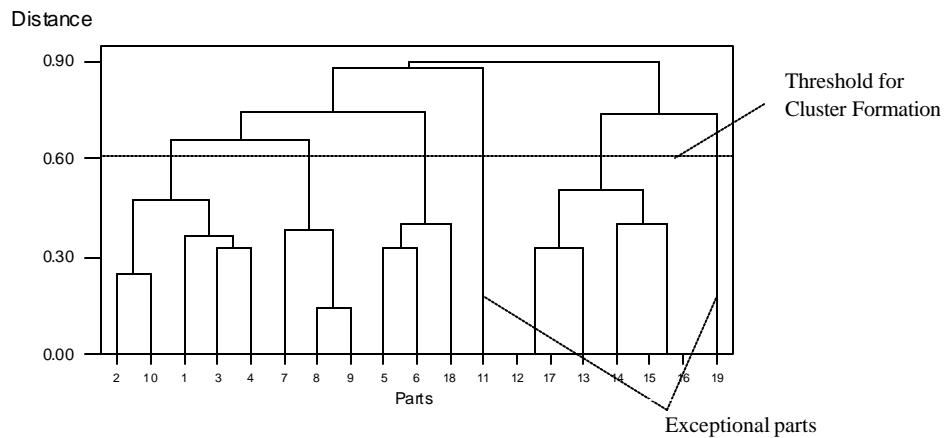


Figure 18.13 Formation of Part Families using Algorithm HC-SC

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K-means Cluster Analysis
The final cluster-membership for each part is shown in C14. The distances between the parts and the four cluster centroids are shown in C15, C16, C17 and C18 respectively.

Worksheet 1

	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15	C16	C17	C18
	1	2	3	4	5	6	7	8	9	10	11	12	Initial	Result	C1	C2	C3	C4
1	1	0	0	1	0	0	0	1	1	0	0	0	3	3	2.06	2.10	0.87	2.65
2	1	0	0	1	0	0	1	1	0	0	0	0	0	3	2.50	1.88	0.87	2.24
3	1	1	0	1	0	0	1	1	1	0	0	0	0	3	2.29	2.26	1.04	2.65
4	1	0	0	1	0	0	1	0	1	0	0	0	0	3	2.50	1.82	1.04	2.24
5	1	0	0	0	0	1	1	0	1	1	0	0	0	2	2.69	1.59	1.94	2.00
6	0	0	0	0	0	1	1	1	1	1	0	0	0	2	2.29	1.59	1.85	2.45
7	0	0	0	1	0	1	0	1	1	0	0	0	0	3	1.50	1.94	1.32	3.00
8	0	1	1	1	1	1	0	1	1	0	0	0	1	1	0.50	2.60	2.10	3.46
9	0	0	1	1	1	1	0	1	1	0	0	0	0	1	0.50	2.40	1.94	3.32
10	0	0	0	1	0	0	1	1	0	0	0	0	0	3	2.29	1.66	1.04	2.45
11	0	0	0	0	0	1	0	0	0	0	0	0	0	2	2.29	1.19	1.94	2.45
12	0	0	0	0	0	0	1	0	0	0	1	1	0	2	3.04	1.09	2.18	1.41
13	0	0	0	0	0	0	0	0	0	0	1	1	0	2	2.87	1.24	2.25	1.73
14	0	0	0	0	0	0	1	0	0	1	1	0	2	2	3.04	1.09	2.18	1.41
15	1	0	0	0	0	0	1	0	0	1	1	1	4	4	3.35	1.44	2.33	0.00
16	1	0	0	0	0	0	1	0	0	1	1	1	0	4	3.35	1.44	2.33	0.00
17	0	0	0	0	0	0	1	0	0	0	1	1	0	2	3.04	1.09	2.18	1.41
18	0	0	0	0	0	1	1	0	0	1	0	0	0	2	2.69	1.09	2.10	2.00
19	0	0	0	0	0	0	0	0	0	0	0	1	2	2	2.69	1.19	2.02	2.00

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Figure 18.14 Formation of Part Families using Algorithm NHC-KM

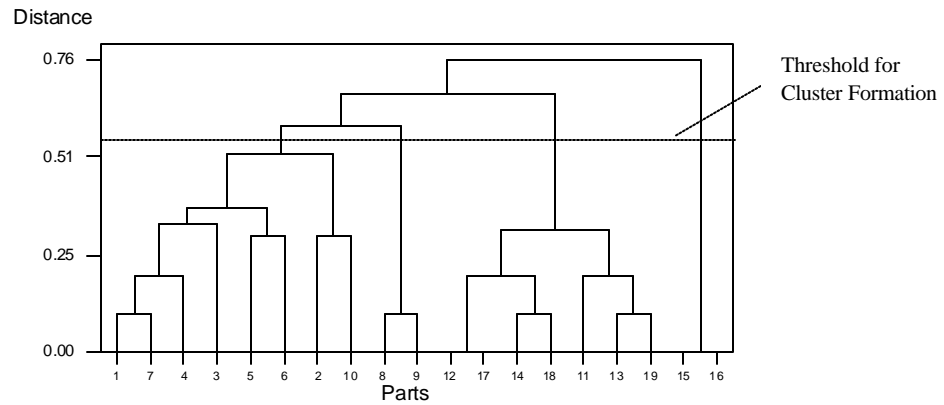


Figure 18.15 Formation of Part Families using Algorithm HC-LD

Table 18.17 Layout Modules obtained by Cluster Analysis of the Common_Substrings in Table 18.16

Module #	Cluster of Common_Substrings	Layout Module created from the Cluster
M1	S1, S2, S5, S6, S7, S8, S9, S11, S14	<pre> 1 ↘ 6 → 4 → 8 → 9 ↕ ↗ 7 </pre>
M2	S3, S15, S16, S17	<pre> 1 → 7 ↔ 11 ↔ 10 ↘ ↓ 12 </pre>
M3	S4	3 → 5
M4	S10, S12, S13	6 → 10 ↔ 7 → 9

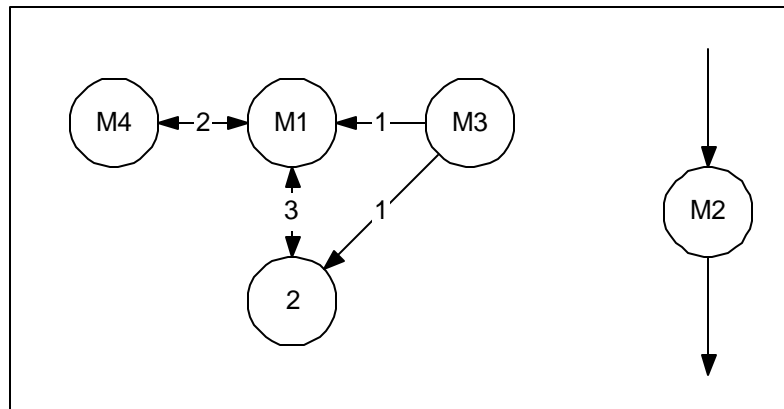


Figure 18.16 Next Generation Layout (NGL) for the Facility described in Table 18.9

Synthesis of multiple design skeletons and flow directions during the design of a block layout for a facility: The design skeletons in Figures 18.17(a) and 18.18(a) would suggest to the facility planner to locate machines 10 and 11 *across* from each other in the spine layouts of Figures 18.18(b) and 18.18(b). However, Figure 18.17 suggests that machines 7, 10 and 11 are best located in a cell on one side of the aisle. Or, those machines could be replaced by a single multi-function machining center to eliminate the delays that occur when consecutive operations are done on separate machines, or in separate departments.

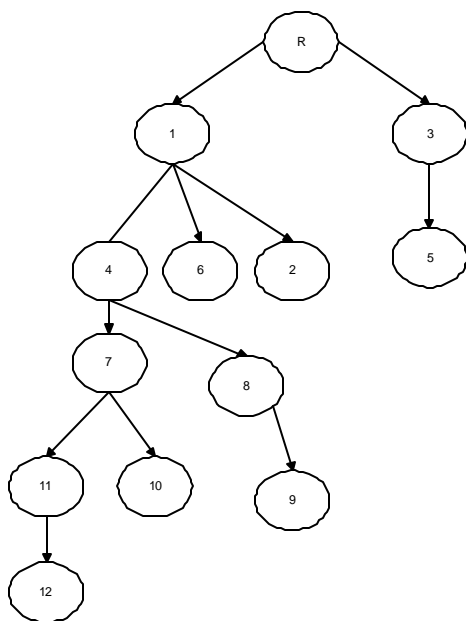


Figure 18.17(a) Design Skeleton obtained by Algorithm MSA

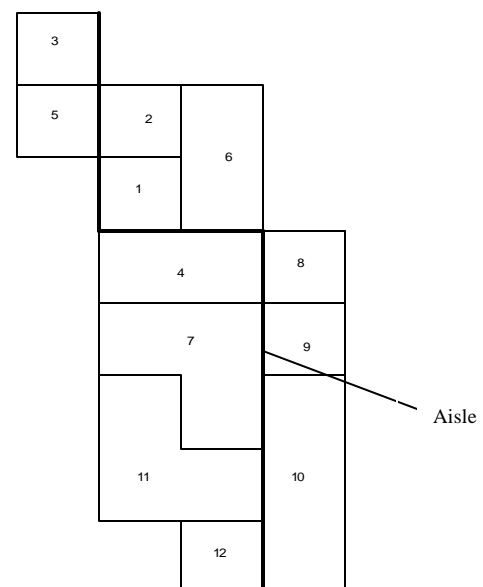


Figure 18.17(b) Final Layout based on Design Skeleton in Figure 18.17(a)

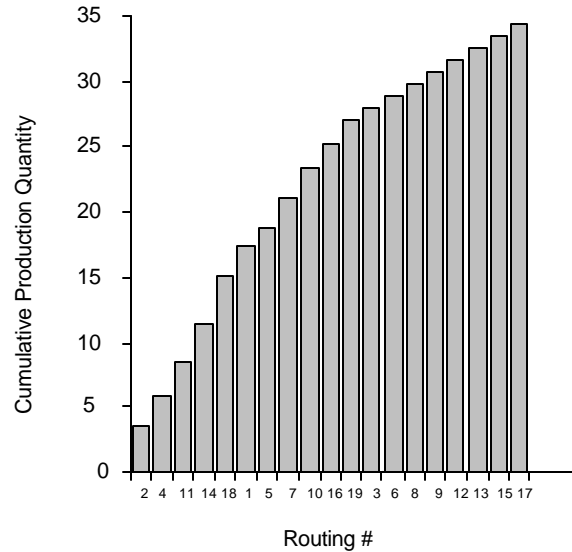


Figure 18.20 Sorting of Routings using Algorithm SORT-PQ

Table 18.18 Product Routings in Table 18.12 sorted by Production Quantity

Routing #	Production Quantity	Cumulative Production Quantity
2	3	3
4	3	6
11	3	9
14	3	12
18	3	15
1	2	17
5	2	19
7	2	21
10	2	23
16	2	25
19	2	27
3	1	28 ✕
6	1	29
8	1	30
9	1	31
12	1	32
13	1	33
15	1	34
17	1	35

Controlling the complexity of the product mix in custom manufacturing facilities: In custom manufacturing and Make-To-Order (MTO) facilities, it is important to base the design of the facility layout on a sample of parts (or products) that excludes “outlier” routings i.e. routings that are highly dissimilar from the other routings. If the cluster agglomeration levels in Figure 18.15 are studied, then the pairs of parts — (8,9) and (15,16) — are seen to merge with the two dominant clusters at low values of similarity. The dissimilarities between these routings and those of the parts already in the clusters is confirmed by Table 18.9. The routings of parts 8 and 9 are the *only* routings to use machines 3

and 5. And, in the cluster of parts 12~17, parts 15 and 16 are the *only* ones that require machine 1 for their first operations, whereas, machine 1 is used by **all** the parts (1~5) in the other cluster.

From the above example, the reader should see that PFA is a highly interactive process even using analytical and computer tools. PFA can be effectively used to form part families and manufacturing calls; however, the process is not automatic.

18. 4 Controlling a Lean Production Facility

The foundation of Lean manufacturing is to create efficient methods for producing goods. Eliminating waste, minimizing inconsistencies and taking a reasonable approach to producing products and managing facilities is the key to lean manufacturing. The largest portion of time a part spends in a manufacturing facility is spent waiting rather than having value added. The result is that Lean Manufacturing has become more than just eliminating waste. A new key has become reducing lot sizes and applying better production control methods. In this section, we will introduce several production control techniques that have been used as part of lean developments.

18.4.1 An analogy: Marching soldiers

In Eliyahu Goldratt's book ``The Goal'' [Goldratt, 1996], the importance of a bottleneck in a factory is described through an analogy to a troop of boy scouts out for a march. One of the scouts, who is carrying an extra-heavy backpack, walks more slowly than the rest, so a gap keeps opening between him and the scouts in front. This is then connected to how inventory masses up in front of a slow machine in the factory.

But this is less than half the story. In a column of marching soldiers, the problem is not a slow marcher falling behind. Each soldier carries the same weight, so the line is balanced, and there is no pronounced bottleneck. The problem is variability amplification: If the first soldier for some reason speeds up a little bit, the second soldier will see a gap open in front of him, and take this as a signal to speed up, as well. But he will have to speed up more than the first soldier did, in order to catch up with him. When he has caught up, he then needs to slow down again to avoid bumping into the one in front.

Now the third soldier sees a gap opening up even faster than the second one did, so he has to speed up by even more, and has to slow down more abruptly when he has closed the gap. This way, the small change in speed amplifies down the line like a whiplash, and the poor guy at the end of the line will alternate between running flat out and marching in place.

This is what occurs in a kanban line. The last machine in the line tries to track the demand process, but adds some noise to it due to process variability. The second last machine tries to track the input process of the last machine, but adds some more noise. This amplifies the noise upstream, so the first machine in the line will alternate between working at capacity and waiting for something to be taken out of its output buffer. To get rid of the problem, one has to eliminate all process variability, such as machine failures and operation time variability. This can be time-consuming and expensive.

How do soldiers counteract this age-old problem? If the soldiers are recruits, they get the attention of a very loud drill sergeant that yells out the cadence. More seasoned soldiers will be singing a marching song as they go along, and any infantry outfit has a large supply of these songs. Both of these techniques have the effect of distributing the proper cadence to every soldier in the line, simultaneously.

This is what the CONWIP control does. It passes the demand information, without any noise, to the first machine in the line. All downstream machines know that any part arriving in their input buffer can be worked on, so they hear the signal, too.

But marching soldiers do not close their eyes and march blindly. Even if they receive the proper cadence, they will still be watching the distance to the marcher in front. If the gap widens, they will take longer strides, and if it narrows, they will shorten their steps. This way, the marchers act on two types of information at once: The global information flow that determines the overall speed, and the local information that is used for minor adjustments.

This is also the way our hybrid policy works: The CONWIP control gives a global information flow (like the drill sergeant), and the kanban control gives a local flow of information (like watching the distance to the guy in front). In our hybrid policy, the global information flow from the demand process is supplemented by the local information from the buffer levels. This attains the advantages of CONWIP control, while using the strengths of kanban control to cancel its disadvantages.

18.5 The Five Steps of Lean Implementation

The process used to implement lean manufacturing is a straightforward one. However it is critical that lean is implemented in a logical manner. The steps associated in implementing lean follow:

Step 1: Specify Value

Define value from the perspective of the final customer. Express value in terms of a specific product, which meets the customer's needs at a specific price and at a specific time.

Step 2: Map

Identify the value stream, the set of all specific actions required to bring a specific product through the three critical management tasks of any business: the problem-solving task, the information management task, and the physical transformation task. Create a map of the Current State and the Future State of the value stream. Identify and categorize waste in the Current State, and eliminate it!

Step 3: Flow

Make the remaining steps in the value stream flow. Eliminate functional barriers and develop a product-focused organization that dramatically improves lead-time.

Step 4: Pull

Let the customer pull products as needed, eliminating the need for a sales forecast.

Step 5: Perfection

There is no end to the process of reducing effort, time, space, cost, and mistakes. Return to the first step and begin the next lean transformation, offering a product that is ever more nearly what the customer wants.

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Glossary of terms

Andon lights/boards - a system of flashing lights used to indicate production status in one or more work centers; the number of lights and their possible colors can vary, even by work center within a plant; however, the traditional colors and their meanings are:

green - no problems

yellow - situation requires attention

red - production stopped; attention urgently needed

autonomation - in Toyota parlance, automation with a human touch. Autonomation normally refers to semi-automatic processes where a machine and human work as a well planned system. Literally, the English translation of jidoka.

baka-yoke - a manufacturing technique of preventing mistakes (error-proofing) by designing the manufacturing process, equipment, and tools so that an operation literally cannot be performed incorrectly; an attempt to perform incorrectly, as well as being prevented, is usually met with a warning signal of some sort; the term poka-yoke is sometimes referred to as a system where only a warning is provided.

Balanced production – a system where the operations for various machines are approximately the same. A well-balanced system has a takt time only slightly larger than the operation time.

cellular manufacturing - an approach in which manufacturing work centers [cells] have the total capabilities needed to produce an item or group of similar items; contrasts to setting up work centers on the basis of similar equipment or capabilities, in which case items must move among multiple work centers before they are completed; the term group technology is sometimes used to distinguish cells that produce a relatively large family [group] of similar items.

cycle time - the normal time to complete an operation on a product. This is NOT the same as takt time, which is the allowable time to produce one product at the rate customers are demanding it.

error-proofing - a manufacturing technique of preventing mistakes (baka-yoke) by designing the manufacturing process, equipment, and tools so that an operation literally cannot be performed incorrectly; an attempt to perform incorrectly, as well as being prevented, is usually met with a warning signal of some sort; the term poka-yoke is sometimes referred to as a system where only a warning is provided.

flexible manufacturing system - an integrated manufacturing capability to produce small numbers of a great variety of items at low unit cost; an FMS is also characterized by low changeover time and rapid response time.

flow manufacturing – a manufacturing methodology that pulls items from suppliers through a synchronized manufacturing process to the end product. The principle goal is a faster response to customer demand.

heijunka - A production scheduling/leveling tool, essentially to distribute kanban cards in an efficient manner.

Hoshin Kanri – a strategic planning approach that integrates the practices of leadership with those of management.

jidoka - a Japanese word which translates as autonomation; a form of automation in which machinery automatically inspects each item after producing it, ceasing production and notifying humans if a defect is detected; Toyota expands the meaning of jidoka to include the responsibility of all workers to function similarly, i.e. to check every item produced and to make no more if a defect is detected, until the cause of the defect has been identified and corrected.

jishu kanri - self-management, or voluntary participation.

just-in-time - a production scheduling concept that calls for any item needed at a production operation - whether raw material, finished item, or anything in between, to be produced and available precisely when needed, neither a moment earlier nor a moment later.

jutsu - to talk, or 'the art of' (i.e., 'leanjutsu: the art of lean production').

kaikaku - A rapid and radical change process, sometimes used as a precursor to kaizen activities.

kaizen - the philosophy of continual improvement, that every process can and should be continually evaluated and improved in terms of time required, resources used, resultant quality, and other aspects relevant to the process.

kanban - a card or sheet used to authorize production or movement of an item; when fully implemented, kanban (the plural is the same as the singular) operates according to the following rules:

1. All production and movement of parts and material take place only as required by a downstream operation, i.e. all manufacturing and procurement are ultimately driven by the requirements of final assembly or the equivalent.

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2. The specific tool which authorizes production or movement is called kanban. The word literally means card or sign, but it can legitimately refer to a container or other authorizing device. Kanban have various formats and content as appropriate for their usage; for example, a kanban for a vendor is different than a kanban for an internal machining operation.
 3. The quantity authorized per individual kanban is minimal, ideally one. The number of circulating or available kanban for an item is determined by the demand rate for the item and the time required to produce or acquire more. This number generally is established and remains unchanged unless demand or other circumstances are altered dramatically; in this way inventory is kept under control while production is forced to keep pace with shipment volume. A routine exception to this rule is that managers and workers are continually exhorted to improve their processes and thereby reduce the number of kanban required.

karoshi - death from overwork.

lean manufacturing or **lean production** - the philosophy of continually reducing waste in all areas and in all forms; an English phrase coined to summarize Japanese manufacturing techniques (specifically, the Toyota Production System).

line balancing - equalizing cycle times [productive capacity, assuming 100% capacity utilization] for relatively small units of the manufacturing process, through proper assignment of workers and machines; ensures smooth production flow.

mixed-model production - capability to produce a variety of models, that in fact differ in labor and material content, on the same production line; allows for efficient utilization of resources while providing rapid response to marketplace demands.

mizusumashi - the classic 'water spider', who performs a wide range of tasks which allow workers to perform 'value-added' tasks.

mokeru - the Japanese term for the industrial engineering, more properly translated as 'profit-making I.E.'.

muda (waste) - activities and results to be eliminated; within manufacturing, categories of waste, according to Shigeo Shingo, include:

- 1.Excess production and early production
- 2.Delays
- 3.Movement and transport
- 4.Poor process design
- 5.Inventory
- 6.Inefficient performance of a process
- 7.Making defective items

mura - inconsistency

muri - unreasonableness

nagara - smooth production flow, ideally one piece at a time, characterized by synchronization [balancing] of production processes and maximum utilization of available time, including overlapping of operations where practical.

ninjutsu - the art of invisibility (applies to management)

one piece flow – producing one unit at a time, as opposed to producing large batches.

poka-yoke - a means of providing a visual or other signal as to the location or condition of a part characteristic. Often referred to as 'error-proofing', poka-yoke is actually the first step in truly error-proofing a system (see baka-yoke).

pull system - a manufacturing planning system based on communication of actual real-time needs from downstream operations ultimately final assembly or the equivalent - as opposed to a push system which schedules upstream operations according to theoretical downstream results based on a plan which may not be current.

5S's - refers to the five Japanese words seiri, seiton, seison, seiketsu, shitsuke. These words are shorthand expressions for principles of maintaining an effective, efficient workplace.

seiri - eliminating everything not required for the work being performed

seiton - efficient placement and arrangement of equipment and material

seison - tidiness and cleanliness

seiketsu - ongoing, standardized, continually improving seiri, seiton, seison

shitsuke - discipline with leadership

6 Sigma – a structured process improvement program for achieving virtually zero defects in manufacturing and business.

seiban - Seiban is the name of a Japanese management practice taken from the Japanese words "sei", which means manufacturing, and "ban", which means number. A Seiban number is assigned to all parts, materials, and purchase orders associated with a particular customer job, or with a project, or anything else. This enables a manufacturer to track everything related with a particular product, project, or customer. It also facilitates setting aside inventory for specific projects or priorities. That makes it great for project and build-to-order manufacturing.

sensei - one who provides information; a teacher, instructor, or rabbi.

setup time - work required to change over a machine or process from one item or operation to the next item or operation; can be divided into two types:

- 1.internal: setup work that can be done only when the machine or process is not actively engaged in production; OR
- 2.external: setup work that can be done concurrently with the machine or process performing production duties.

shojinka - continually optimizing the number of workers in a work center to meet the type and volume of demand imposed on the work center; shojinka requires workers trained in multiple disciplines; work center layout, such as U-shaped or circular, that supports a variable number of workers performing the tasks in the layout; the capability to vary the manufacturing process as appropriate to fit the demand profile.

SMED - abbreviation for Single Minute Exchange of Die; literally, changing a die on a forming or stamping machine in a minute or less; broadly, the ability to perform any setup activity in a minute or less of machine or process downtime; the key to doing this is frequently the capability to convert internal setup time to external setup time; variations on SMED include:

- 1.Single-digit setup: performing a setup activity in a single-digit number of minutes, i.e. fewer than ten.
- 2.OTED: One touch exchange of die; literally, changing a die with one physical motion such as pushing a button; broadly, an extremely simple procedure for performing a setup activity.

standard operations – clearly defined operations and standardized steps for both workers and machines.

takt time - takt, is a German term for rhythm or pace. Takt time is the allowable time to produce one product at the rate a customer demands it. This is

NOT the same as cycle time, which is the normal time to complete an operation on a product (which should be less than or equal to takt time).

teian - a proposal, proposition, or suggestion. A teian system can be likened to a system that allows and encourages workers to actively propose process and product improvements.

Toyota - changed from the true form, Toyoda, meaning abundant rice field, by the Toyota marketing department. Toyoda is the family name of the founders of the Toyota Motor Company.

Value Stream Mapping (VSM) – a process to determine the value added to a product as it goes through a manufacturing system.

water spider - one who performs a wide range of tasks which allow workers to perform 'value-added' tasks.

WCM - world class manufacturing is the philosophy of being the best, the fastest, and the lowest cost producer of a product or service. It implies the constant improvement of products, processes, and services to remain an industry leader and provide the best choice for customers, regardless of where they are in the process.

Outline:

- Introduction to Lean Manufacturing
- Set-up reduction
- Group technology
- Control of lean systems
- Product examples and illustrations
- Chapter summary

Review Questions

Review Problems

References/Bibliography