LEAN Manufacturing Implementation

A Complete Execution Manual for Any Size Manufacturer

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LINE LAYOUT AND WORKSTATION IDENTIFICATION WITH PROCESS LINKING AND BALANCING

Up to this point, information collected has identified the processes, their associated demand, and the effective minutes available to do work. With this information, Takt time can be calculated. Takt time defines the rate at which the line must run to achieve the desired daily output. The sequence of events (SOEs) have been developed. These SOEs document the individual tasks in sequential order, the time required to complete the identified tasks, and the quality criteria at the individual task level. The next consideration is how many resources will be required to achieve the capacity of the line.

What is a resource? Resources can be any of the following:

- People
- Workstations
- Machines
- Inventory

The Lean manufacturing methodology proceeds with the assignment of resources differently than does the MRP order launch methodology. MRP assumes infinite capacity is available in the manufacturing processes or in the

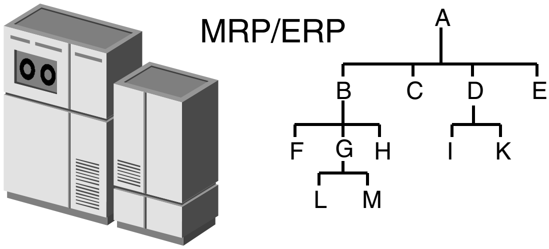

Figure 4.1 MRP Requires an Indented Bill of Material

"departments." Orders are periodically issued to meet demand based on the explosion of demand by the master schedule. Once MRP performs the time-phasing routines, the "load" in each of these departments is determined. Priority of the released orders is assigned according to the due dates and the available capacity in the department. As long as the order load does not exceed the stated capacity during the assigned time period, the plan is good.

To establish the correct start and due date for these orders, which in turn establishes the load in each department based on the net requirements, an indented bill of material (BOM) is required. The indented BOM is a key component for MRP system operation. The BOM lists the parts and quantities required to build a product. It also captures the lead time offset information for each level in the BOM necessary for time-phasing calculations that establish start and due dates for MRP-generated orders (Figure 4.1). Total manufacturing lead time of the finished product is also determined by summing the lead times for each process sequentially through all levels in the BOM.

This BOM offset function electronically communicates to the MRP system how a product is manufactured and is the basis for production schedule development. The different levels of the BOM represent the sequential build of the product through the manufacturing facility, much as a "goes into" chart. On a department-by-department basis, the sum of all orders released by due date establishes the load on that department for that period.

The indented BOM can also impact the organization of manufacturing departments. The manufacturing department shop floor layout in many factories often resembles the levels of the BOM. Similar functions or manufacturing processes are intentionally grouped together in departments to mirror the levels in the BOM. Early MRP implementations frequently promoted organizational structures that reflected the structure of the indented BOM.

The demands for maintaining and operating an MRP system require the involvement of a diverse and knowledgeable skill base. Coupled with the Sloan model of individual manager responsibility for the return-on-investment in each respective department, the installation of MRP systems contributed greatly to modern-day organization charts. In addition to facilitating execution of the production schedules, it also seemed quite logical to create and consolidate MRP maintenance responsibilities in functional organizations within the company.

Most MRP companies today assign responsibilities for BOM creation and maintenance to design engineering, forecasting to sales and marketing, planning and inventory management to materials management, and routing file management to manufacturing engineering. Fragmentation of this knowledge into functional departments for its creation and maintenance dovetails comfortably with the justification for departmental growth.

THE CONSEQUENCES OF IMBALANCE

Even with the advent of modern planning systems and the impact they have had on departmentalization of the shop floor and organization of the administrative areas, very little attention was paid to ensuring that the manufacturing departments were created equally with equal capacities. Resources are assigned to departments simply based on their similarity. The resulting unequal capacity creates many of the problems seen on shop floors today. Many of the activities on the shop floor today can be traced to attempts to balance order loads with department capacities.

Think about the activity on the shop floor today. If a released order load falls below the stated capacity of the department, additional orders are often requested from the production control group. When this occurs, production control may have to release firm planned orders in advance of their release date. Pulling orders forward in the schedule can cause future shortages. Shortages cause excessive expediting activities and the related costs.

As released order load approaches stated capacity, orders can begin to miss their due dates. Falling behind schedule generates either late orders or overtime. To complicate schedule adherence issues, manufacturing supervisors are usually measured by the efficiency and utilization (absorption) of their assigned labor and machine "resources." A common way to optimize these performance measures is to keep as many resources as possible as busy as possible. This translates into fewer changeovers, with longer runs of products used to amortize changeover inefficiency. Pulling orders ahead of scheduled due dates to group like work together in order to maximize utilization or reduce efficiency loss due to changeover is a typical solution for maximizing absorption performance goals. This grouping of work is commonly referred to as *batch manufacturing*.

Using batch manufacturing methodologies, run quantities are based solely on machine productivity considerations. Batch manufacturing allows machines to become productive when large quantities of a product are built. Through repetition, even labor resources become more efficient with longer runs of the same products. In some cases, the absorption goal takes precedence over customer satisfaction goals. Where absorption goals are most important, actual market demand often receives second priority after efficiency and utilization.

This focus on productivity has pitted manufacturing departments against sales and marketing departments for years, regardless of industry. This conflict exists today in many manufacturing companies. Batch processing becomes especially problematic when trying to build a dissimilar mix of products. What is the optimum amount? How much is too much? Which order has the highest priority? Resolution of these issues is a major contributor to costly day-to-day expediting activities.

Natural balancing does evolve to level off the absorption demands of each department. This balance takes the form of buffer inventory. Department managers soon get very smart about maintaining enough inventories or released orders in advance of demand to smooth demand fluctuations and still achieve their absorption goals. While manipulating orders by grouping them together helps to optimize department performance measures, this methodology always results in excess inventories, parts shortages, missed due dates and late orders, and high working capital inventory investment.

The costs of batch manufacturing are significant. Aside from the large shop floor square footage that must be dedicated to store buffer inventories, machine and labor capacity is prematurely consumed to produce orders incorrectly prioritized just to satisfy absorption goals. The resulting inventory produced in advance of forecasted demand solely to achieve departmental efficiency and utilization metrics often becomes excess or obsolete when actual demand does not materialize.

Because of imbalanced capacities and the need for maximum efficiency and utilization, manufacturing departments with excess capacity will always seek work from the upstream departments. If the department is the gateway work center, work is in the form of released shop orders from the planning system. If the request for additional work is in excess of what is recommended by the planning system, orders will be "pulled ahead." The practice of pulling orders ahead assures a vicious cycle of material shortages, expediting, and a series of changing due dates.

For departments with excess capacity to have the same opportunity to maximize productivity with the amortized changeovers of long runs enjoyed by other departments, they must usually find additional work to do. On the surface, overcapacity seems like a good problem to have, but department managers with excess capacity spend much of their time seeking additional work to keep their department running at full utilization. Unless they can keep their resources consumed, they will always look "nonproductive" or underabsorbed when compared to other departments. In addition to the squandered capacity, the resulting inventory allowed to accumulate downstream is always at high risk of becoming excess or obsolete.

Undercapacity departments on the downstream side of feeding departments with excess capacity experience just the opposite problem: work piles up. As work continues to backlog, the usual solution is to increase capacity. Short of capital expenditure, the only way additional short-term capacity can be created is by adding extra hours or shifts. If real capacity remains unchanged long term, overtime costs are a certainty as the department is constantly bombarded by expediting requests and the reprioritization of production orders.

If the department downstream from the undercapacity department has higher capacity and the same need to maximize productivity, pressure to change priorities in the undercapacity department to satisfy the downstream department's need for productivity will be relentless. These activities go on daily in many manufacturing facilities today. Unfortunately, they have become a way of life in those facilities. Entire organizations dedicated to expediting exist solely to deal with this daily rebalancing act on the factory floor.

THE LEAN APPROACH TO ACHIEVING BALANCE

Lean manufacturing considers all of this expediting and scheduling activity to be a waste of time, human effort, and money. Large, undisciplined, slow-moving buffer inventories are also considered waste by Lean manufacturing. Because extra activity and excess inventory add time and cost to the product, they should be eliminated. Lean manufacturing methodologies overcome these imbalance problems. The Lean manufacturing methodology is an alternative operating system that defines balance by utilizing only the resources necessary to meet customer demand. The ideal level of resource utilization to meet customer demand can mean the suboptimization of existing resources. For this reason, the Lean methodologies often conflict with the current measurement system of resource absorption.

Lean lines are progressive production lines established with a facility layout that allows standard work tasks to be accomplished in a sequential and progressive manner. Where possible, all the processes necessary to produce a product are *physically* linked together. This physical linkage of the resources permits work tasks to be distributed, accumulated, and balanced evenly throughout the entire manufacturing cycle. When a unit is sold, the entire line "ratchets" the next unit downstream. The Lean line is designed so that all processes work at the same speed. Because products are produced one piece at a time at the same rate, this type of line is often referred to as a "flow" line" (i.e., like liquid flowing through a pipe).

The Lean methodologies approach the utilization of available capacities much differently than the MRP model. The Lean manufacturing methodologies project required future capacity, calculate the resources for each process, and arrange the facility so these resources are located adjacent to one another. Because all resources work at the same rate and are physically linked together at their point of consumption, the batching or grouping of work to achieve efficiency and utilization by individual department is unnecessary. A daily sequenced listing of customer demand is necessary, but MRP-generated shop orders are not required to schedule the processes of the Lean line. The Lean manufacturing methodologies concentrate first on achieving balance among the manufacturing processes, with the need to achieve departmental efficiency, utilization, and absorption as secondary goals.

The Lean manufacturing methodologies are line-balancing techniques where the identified SOE labor and machine times are simply divided into parts equal to a Takt time. Balancing to Takt and physically linking manufacturing processes enables the completed output of one process to be directly consumed by another. This dramatically reduces inventories and cycle times. Because manufacturing processes are simply divided into equivalent elements of work, the grouping of similar labor and machines into "departments" is no longer necessary. Only the resources required to produce the demand are located on the line.

When no longer constrained by the rules of imbalanced departments, pools of work-in-process buffer inventories are not permitted to accumulate. Once manufacturing processes are balanced and linked together and manufactured in sequence, products can be produced nearer their actual work content time. Only one unit is ratcheted at a time through all processes and off the end of the line for every Takt time (Figure 4.2). The wait and queue times necessary for the normal routing of products through the different manufacturing departments in batches is greatly reduced or eliminated.

Takt time is a time–volume relationship. It is calculated by dividing the amount of time available to perform work by the desired throughput volume for each process. Takt establishes the rate at which a process must operate to achieve the designed output.

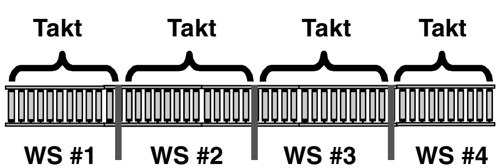

Figure 4.2 Takt Production of Work Content Time

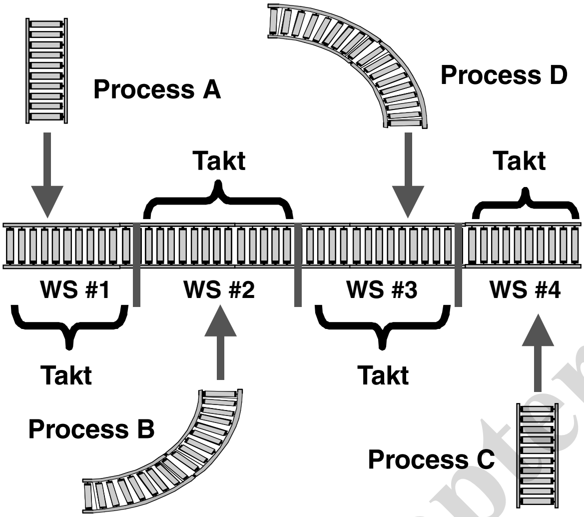

Figure 4.3 Processes Balanced and Linked Together

The goal of Lean manufacturing is to establish and design a manufacturing line capable of sequentially producing multiple products, one at a time through the processes necessary to produce the product. The Lean line can achieve this goal using only the amount of time required to actually build the product. The actual work time required to produce a product through its various manufacturing processes is almost always shorter than the time required to route batches of products through a factory. The techniques of Lean manufacturing eliminate the nonvalue-adding wait time and reduce scheduling and queue times (Figure 4.3).

The Lean manufacturing methodologies cause products to be produced one unit at a time, at a formulated rate, without wait time, queue time, or other delays. Product is *pulled* through the line using a signal from a downstream process, as opposed to being *pushed* by the planning system with a launch of orders. Time spent making products with no customer demand is considered "nonvalue-added" time. Application of the Lean manufacturing methodologies eliminates nonvalue-added time (Figure 4.4).

CALCULATING RESOURCE REQUIREMENTS

To determine the amount of resources (people, workstations, machines, or inventory) required to achieve the throughput volume for each process identified

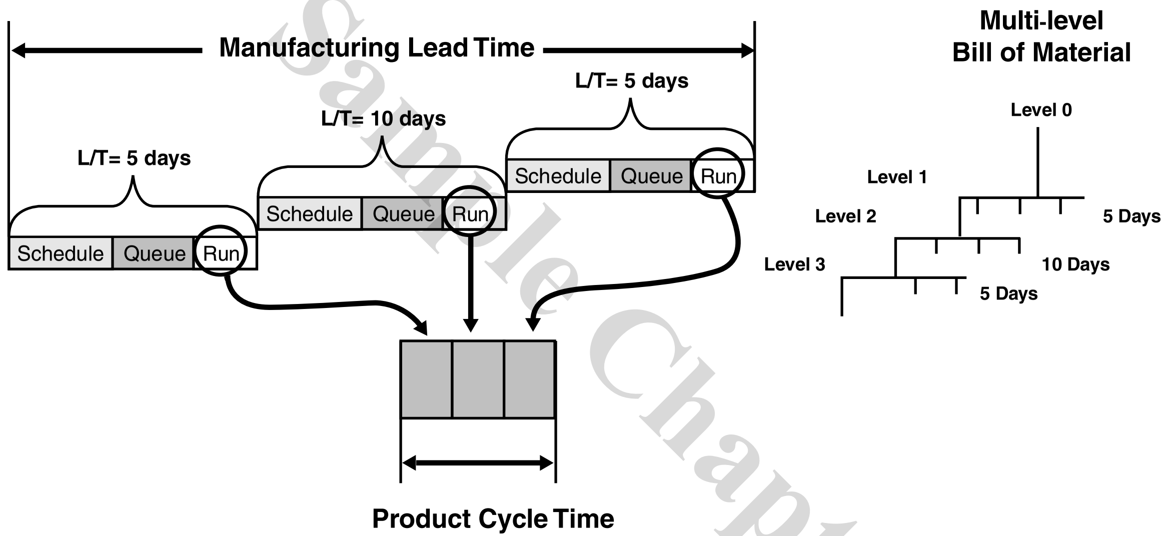

Figure 4.4 Production in the Work Content Time

Product ID **Widget**			**Sequence of Events**						Process ID **Final Assembly**
Seq. #	Sequence Description	V.A.	Set-Up M	Set-Up L	Required Machine	Required Labor	Move M	Move L	Quality Information
10	Retrieve dolly and unit frame	*		2.75					Match frame with sales order
20	Set frame on stand	*		1.3					
20	Seal all weld joints on back of frame with sealant					2.1			Seal must cover all areas
30	Place bolts through frame and dolly					0.6			
40	Attach torque gun and tighten bolts					1.3			Torque 40 PSI

Σ All Times = 9.05

Figure 4.5 Sum of All Times: Value- and Nonvalue-Added

on the process flow diagram, two mathematical values are necessary. The first figure (the numerator) is the standard time identified on the SOE. The SOE time is the sum of all labor and machine categories of work. This includes the nonvalue-adding times of dynamic setup, rework, and move and the quality criteria inspection times. Summing these times with the value-added time elements for each process defines the total work content time for that specific product/process combination (Figure 4.5). Labor and machine times are summed separately.

The denominator of the resource calculation is the Takt time for that process. Takt time may be different for every process based on the throughput volume of the process. Factors that affect throughput volume per process are scrap, rework, and options.

$$\text{Takt} = \frac{\text{Work Minutes per Shift} \times \text{\# Shifts per Day}}{\text{Throughput Volume per Day}}$$

The basic resource calculation formula is:

$$\frac{\text{Standard Time}_{\text{SOE}}}{\text{Takt}} = \text{\# Resources}$$

		Processes							
Products	V_c	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Product 1	25	2.6	6.6	4.0	10.5	1.5	30.0	10.0	12.0
Product 2	31	2.7			11.0	1.5	27.5	10.0	14.0
Product 3	50	2.5	4.5	4.0			25.0	10.0	11.0
Product 4	6		7.0	4.0	15.0	2.0	32.0	10.0	16.0
Product 5	12	2.9	5.5		13.0		29.5	10.0	13.0
Product 6	6	3.5		4.0	14.0	1.8	31.0	10.0	15.0
Σ of Total Volume = 130									

Figure 4.6 Different Products Have Different SOE Times

where resources are people, workstations, machines, or inventory. Takt time is a measurement of *rate*. SOE time is a measurement of *time*.

While the resource calculation is straightforward, it is seldom calculated using only one standard time. In a mixed product family environment, the standard times for each of the products chosen to run on the Lean line can vary. The resource calculation with only one standard time is appropriate only for one product using one process. Very few manufacturers produce only one product. Most manufacturers produce a wide variety of products with many options, with many different products using different processes. With many different products, it is not uncommon for each product to have a different SOE time through a process. Reviewing the standard time process map reveals this dynamic characteristic.

With so many products, each with a different SOE time, selecting a single time to populate the numerator of the resource calculation is not so straightforward. For process F in Figure 4.6, which time should be selected for the resource calculation? The times range from 25.0 minutes to 32.0 minutes. The best solution is not to pick the fastest or the slowest time. The average SOE time must be calculated to determine the standard time to be used for determining resources for manufacturers producing multiple products.

The volume at capacity (V_c) of product 4 is six units per day. If the line were designed for the highest number, 32.0 minutes on average, but only six units per day are produced, it is possible that resource requirements would be overstated, as the bulk of the remaining products require less than 32.0 minutes to be completed in that process. If 32.0 minutes were used to design the line, when making product 3 the line would run faster than required to produce the throughput volume.

Considering the Takt time formula, producing product on the line faster than the SOE time would result in the daily output being completed sooner than the effective work minute per shift of the Takt formula. Instead of completing work in the 435 minutes with the greater SOE time of 32.0 minutes, the daily rate could be completed in 340 minutes. In reality, operators will not maintain the speed for the entire work day just to finish early, but would more likely use the 95 minutes to pace their output to match the daily rate.

Neither choice is acceptable, as the Lean line prefers to produce at a steady rate throughout the day for the entire time of the planned effective minutes. Conversely, if the Lean line were designed using 25.0, the line would run too slowly not only when producing product 6 but for all products with an SOE time greater than 25 minutes. The better solution is to develop a production sequence of products with a mix of both high and low SOE times run throughout the day as a way to balance the line.

When products were chosen for inclusion in the line design, a grouping of products representative of all potential products and all volumes was selected. It would be an incredible coincidence if this exact product mix and volume chosen for designing the line actually occurred as the daily requirement. Knowing that to be the case, the Lean manufacturing line is designed for a product and volume mix most likely to occur on any given day.

The same logic can be used when choosing a representative time to be used for the resource calculation. An average time must be determined to perform resource calculations for each process. However, additional information is needed to make this time estimate even more accurate. A better estimate would be to weight the times to match the products that are produced most often in the process. Therefore, additional calculations are necessary for each process to establish a standard time weighted (ST_w). Using the times and volume at capacity (V_c) from the standard times process map, the standard time weighted calculation is

$$\frac{\Sigma\, V_c \times \text{SOE Std Time}}{\Sigma\, V_c} = ST_w$$

where the numerator is calculated as

Process F

$$\begin{aligned}
&\text{Product 1 } V_c\ 25 \times \text{SOE } 30.0 = 750\\
&\text{Product 2 } V_c\ 31 \times \text{SOE } 27.5 = 852.5\\
&\text{Product 3 } V_c\ 50 \times \text{SOE } 25.0 = 1250\\
&\text{Product 4 } V_c\ 6 \times \text{SOE } 32.0 = 192\\
&\text{Product 5 } V_c\ 12 \times \text{SOE } 29.5 = 354\\
&\text{Product 6 } V_c\ 6 \times \text{SOE } 31.0 = 186\\
\hline
&\qquad\qquad \Sigma\, V_c \times \text{SOE} = 3585
\end{aligned}$$

and the denominator is

$$\frac{\Sigma \text{ of } V_c}{\text{Volume for Process F}} = 130$$

The ST_w is

$$3585 \div 130 = 27.6 \text{ minutes}$$

Takt time is

$$\frac{7 \text{ hours} \times 60 \text{ minutes} \times 1 \text{ shift} = 420 \text{ minutes}}{\Sigma \text{ of Total Process F Volume} = 130 \text{ units}} = 3.23 \text{ minutes}$$

Substituting the newly calculated standard SOE time of the basic resource calculation with the new standard time weighted, the number of resources for process F is calculated as

$$\frac{ST_w}{\text{Takt}} = \# \text{ Resources}$$

Therefore, the number of resources for process F is

$$\frac{27.6}{3.23} = 8.54 \text{ or } 9 \text{ resources}$$

The number of resources is rounded up to the next whole number. This makes sense, because it is not possible to have a portion of a person, workstation, machine, or amount of inventory. If the fractional value is 0.1 or greater, the number should always be rounded up. If less than 0.1, the number may be rounded down, which would translate to one less resource. Consider the rounding down carefully, as it is better to have too many resources than not enough. Resources can always be adjusted after the line is operating smoothly.

Always remember that the standard time is a weighted average and Takt time is based on an estimated product mix and volume. These numbers represent *averages*. Attempting to achieve precision when making rounding decisions on an average number often reaps diminishing returns. The decision to round up or down is subjective, based on knowledge of the particular process. To be conservative, the Lean methodologies suggest erring on the high side by rounding up.

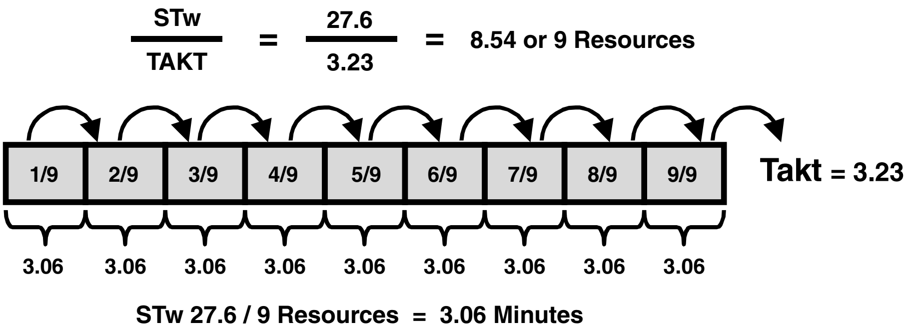

Figure 4.7 Balanced Workstations at Takt

With most products, the lowest component of product cost is labor. A resource can always be removed, but adding a resource later can be more difficult. In the end, the goal is to make the Lean manufacturing line as successful as possible to produce product in the Takt time. The rounding up of resources can provide extra latitude when it comes to achieving the Takt time targets. This is particularly true when defining human resources. Humans are not machines, and their productivity can vary from day to day. Rounding up resources should be considered when designing the Lean manufacturing line. If an error is made by including the cost of one additional labor resource, it will still have little effect on the total product cost.

If the ST_w is divided by the rounded-up number of resources (9 in this case), the resulting work content time at each resource will be 3.06 minutes (27.6 ÷ 9 = 3.06 minutes). This time is less than the Takt time of 3.23 minutes. The difference in time gives some leeway to the operators and helps to assure the Takt time target can be met (Figure 4.7).

The number of required resources must be determined for every process identified on the process flow diagram. The resource calculation is an expression of the amount of resources per process required to produce the throughput volume identified in the identified process Takt time.

The resource calculation is the line-balancing component of the Lean manufacturing methodologies. This technique is profoundly simple both in concept and practice. Consider the value of being able to balance all manufacturing processes required to produce a product or subassembly so they are completed at the same time! This ability to balance manufacturing processes is the major difference between Lean manufacturing and the MRP launch of orders into manufacturing.

The balancing of work is the key to producing product in its work content time. When the nonvalue-added elements of wait and queue time have been eliminated from the manufacturing lead time, significant lead time reduction results. Working in balance is also the key for significantly reducing or eliminating work-in-process inventories that will ultimately lead to the reduction of finished goods inventory. The less time products spend in the manufacturing process being manufactured, the easier it is to manage customer orders. Overhead costs are reduced due to the elimination of expediting and planning system transactions.

Because work in every process is balanced using a Takt time derived from required throughput volume, the varying standard times of different processes are of little consequence. The number of resources required to meet the Takt time target goal is the important factor. The Lean methodologies seek to achieve Takt at each process. The resource calculation identifies the amount of resources needed to achieve that Takt time goal.

DEFINING RESOURCES

Now that the *amount* of resources needed has been calculated, defining the physical attributes of the individual resource is required. If the standard time used to determine the amount of resources is the labor time from the SOE, then the resource calculated first will be the number of required people. The resulting resource figure is the number of persons required to produce the throughput volume for the time identified on the SOE.

While other factors will impact the final number of people needed to staff the Lean line, initial resource calculation should provide a "sanity" test for accuracy and an indication of productivity opportunities. The calculated labor resource head count for the Lean line future volume should be in proportion to the current head count and current volume. Comparing the two validates the results of the resource calculations. Wide fluctuation in the head count/volume comparisons may require an investigation of the SOE times used for resource calculation or the causes of productivity loss.

If the SOE times are valid, then by summing the number of people identified as resources for the future throughput volume and comparing it to the existing head count, the scope of productivity improvement can be estimated. SOE times assume 100% productivity, and the final resource calculation may need to be increased by the current productivity factor. Compare this number to the current head count. If current head count is greater than the calculated resource, the difference is the amount of productivity improvement available to the Lean line. Compare only processes that are similar before and after the implementation.

After the number of persons required to staff the Lean line has been determined, each person will require a physical location from which to perform the work defined for that process. Therefore, the resource calculation simultaneously defines both required people and the number of physical workstations. Individual workstations can take various forms. If the process is *assembly,* and the product is a kitchen appliance, the workstation is likely to be a workbench. It could also be a flat surface, a roller conveyor, or a ball transfer table. For a larger product, the workstation could be a painted location on the shop floor sized to the dimensions of the product. Depending on the product, the manufacturing process could be a combination of several different types of workstations. However, the total number of workstations must match the number of resources calculated for each process.

As part of the final line design layout, each workstation must be defined by its physical attributes and the dimensions of its footprint on the shop floor. Every effort should be made to keep the footprint as small as possible to optimize the amount of valuable shop floor used. If the physical dimension of the product is 12 inches wide and 6 inches deep, a 6-foot-wide workbench is not really necessary to complete the work. An alternative to one large bench might be to paint a line down the middle to separate the table into two 36-inch workstations that will still accommodate the work just as well. If possible, two workstations (resources) can occupy the same space as one workbench. If the product is only 6 inches deep, a 48-inch-deep workbench is not really necessary. Lean methodologies consider excess workstation space as wasteful. Often, creativity is required to size the workstation to the work to be performed.

If the SOE time for the process is a machine, the resource calculation will be the number of machines required to meet the Takt time target. As with the workstations identified for the labor resources, a footprint of the machine resource is necessary. This would include the footprint of any support equipment or ancillary tables, benches, die carts, etc. needed to operate the machine.

If the amount of machine resources required exceeds the number of machines available, additional resources must be added. These resources can take the form of additional machines, multiple cavity dies or stations, additional inventory, or additional shifts. The Lean methodology only determines the amount of resources required to achieve the Takt time target. The Lean methodologies cannot create capacity where none exists. As part of the line design layout, the physical placement of all required resources must be established.

A common method for achieving balance to Takt time on a machine is to build additional inventory to accommodate the differences between Takt time and the cycle time of the machine. Rather than just estimating the amount of inventory to build, the Lean methodology requires that the appropriate quantity be calculated. The correct amount of inventory is calculated using the resource calculation. For a machine process, the formula would be:

$$\frac{\text{Cycle Time of Machine}}{\text{Process Takt Time}} = \text{\# Units of Inventory}$$

If a machine process similar to *paint* requires 60 minutes to continuously travel the conveyor length through a drying tunnel, and the Takt time is 3.23 minutes, the units of inventory would be 19 units. In this case, the 19 units of additional inventory would be the number of paint hooks attached to the conveyor on which 19 units are hung, each spaced to exit the tunnel every 3.23 minutes. Even though it takes a single unit 60 minutes to travel the distance through the paint process, the 19 units in the tunnel will support a 3.23-minute Takt time for the Lean line.

Another common machine time is a “burn-in” process similar to the ones used in quality procedures. If the burn-in is 120 minutes with a Takt time of 3.23 minutes, the units of inventory would be 120 ÷ 3.23 = 38 units. The machine time indicates that 38 burn-in stations or connections are required, where one unit starts the burn-in process every 3.23 minutes and another completes it every 3.23 minutes. For line design layout purposes, the footprint for the physical location of these 38 units must also be considered.

THE PHYSICAL LAYOUT OF RESOURCES

After resources have been quantified and their physical attributes defined, configuring the resources into a factory layout that facilitates visibility and movement of products must be completed. During SOE development, two items were identified as always being nonvalue-added — setups and moves.

The new factory layout should reduce or eliminate significant amounts of move time for product and materials. In addition, the physical placement of feeder (subassembly) processes at points in the line where that material is consumed into the downstream product assembly will reduce both move and wait time.

A paper simulation of the new facility should be created to relayout the factory into the Lean configuration. A paper simulation is preferred over a CAD drawing for two important reasons:

1. **Team participation:** A relayout of the factory to take advantage of the benefits of the Lean implementation should be a team activity. Many members of the company may have excellent ideas about how to improve the flow of product through the factory. The factory relayout is a good time to test the theories of team members. Participation should include shop floor personnel who work in manufacturing every day. Relayout of

the factory on a conference room table using a large sheet of paper invites contribution by all members. It is easier to work around a table for this activity than to lean over an engineer's computer monitor while creating a CAD drawing of the layout.

2. **Low cost:** The most effective line layouts are the result of numerous layout iterations. These iterations should be encouraged to achieve "buy-in" from all the team members. These iterations occur as individual team members around the table offer their own ideas or suggest changes to previous ideas. Good debate over optimum solutions for layout issues usually results in consensus. Iterations and debate often take the form of the relayout and movement of resource facsimiles. Using properly scaled paper cutouts of the resources facilitates the debate. Moving paper representations of resources around on a paper model is faster and cheaper than representing every idea in a computer system.

Begin the process by creating a large paper layout showing the perimeter of the new Lean area. The larger the paper, the better it will be for allowing team participation. Indicate all unmovable objects ("monuments"), such as power tunnels, roof supports, drains, large expensive-to-move equipment, and other permanent building structures. For each of the resources identified, prepare a paper cutout of its footprint, scaled to match the perimeter drawing.

Beginning at the point closest to the customer (usually shipping) and working upstream, lay out the calculated resource paper cutouts following the mixed-product process flow diagram. Test all ideas that minimize movement and optimize the flow of product from one workstation to another. Create footprint cutouts for all supporting fixtures, racks, and carts used to manufacture product even though they are not manufacturing resources themselves. Be sure to set aside space to accommodate required material movements, such as lift truck aisles and large material containers. Design workstations to be compact, but as ergonomic as possible for the operator.

The optimum line design should not be constrained by current legacy work flows. With monuments in mind, the layout should assume a clean slate with no barriers in preparation of the ideal line layout. The best line layout may suggest traversing an existing aisle. An aisle is not a monument! Keeping OSHA regulations and environmental and safety considerations in mind, the shop floor layout of the optimum Lean solution should take precedence over any previous arbitrary obstruction placements.

If money were no object, it would be possible to move anything and everything. As a practical matter, there are some items that may be too cost prohibitive to move. For some moves, the return on investment to do so does not justify relocation. Examples include heavy machine tools mounted on engineered concrete pads, dirty and dangerous processes, EPA processes that require special venting or maintenance requirements, or loud processes. It does not make sense to relocate such processes next to an assembly process. The final line design should recommend practical and cost-justified solutions to maximize the Lean methodologies and reflect common sense.

All of these examples should be considered when finishing the layout. When completed, all team members must agree to the final line design. The steering committee must also approve and sign off on the new Lean line layout. The paper layout with the resource cutouts should then be converted into a formal facility layout drawing, usually with a CAD system, by the manufacturing or facilities engineer. From the final layout, a facility plan for installing the line must be created. This usually involves dropping air and electrical lines, relocation of workbenches, and contracting with riggers and other contractors. If the new layout requires that production be shut down for a period of time, a schedule for the shutdown and relayout must also be developed.

ASSIGNING TASKS FOR EACH WORKSTATION

Once the number of resources has been determined, and each process has been balanced to a Takt time target, the exact work and quality inspection to be performed at each workstation must be defined. The SOE documents the sequential tasks for completing the work of each process. The individual work tasks to be completed at each workstation are defined by summing the time elements of the work tasks listed on the SOE until an amount equal to a Takt time is reached (Figure 4.8).

THE IN-PROCESS KANBAN SIGNALING METHODOLOGY

Very seldom is it possible to make a perfect cut-off on the SOE at the exact Takt time target. Because summing the tasks rarely equals a perfect Takt time, there will automatically be minor imbalances in the workstation definition. To overcome these minor differences in time and the natural imbalance between persons staffing the line, *in-process kanbans* (IPKs) are placed on the downstream side of the workstation. The IPK provides a temporary "parking space" for units that are completed faster than the downstream workstation can consume them.

An IPK is also used to signal when it is time to start production of the next unit in sequence. For the IPK signal to work, operator discipline is required. Only one partially completed unit of production is allowed in an IPK at a time. Units are not allowed to stack up. Work cannot commence at a workstation until

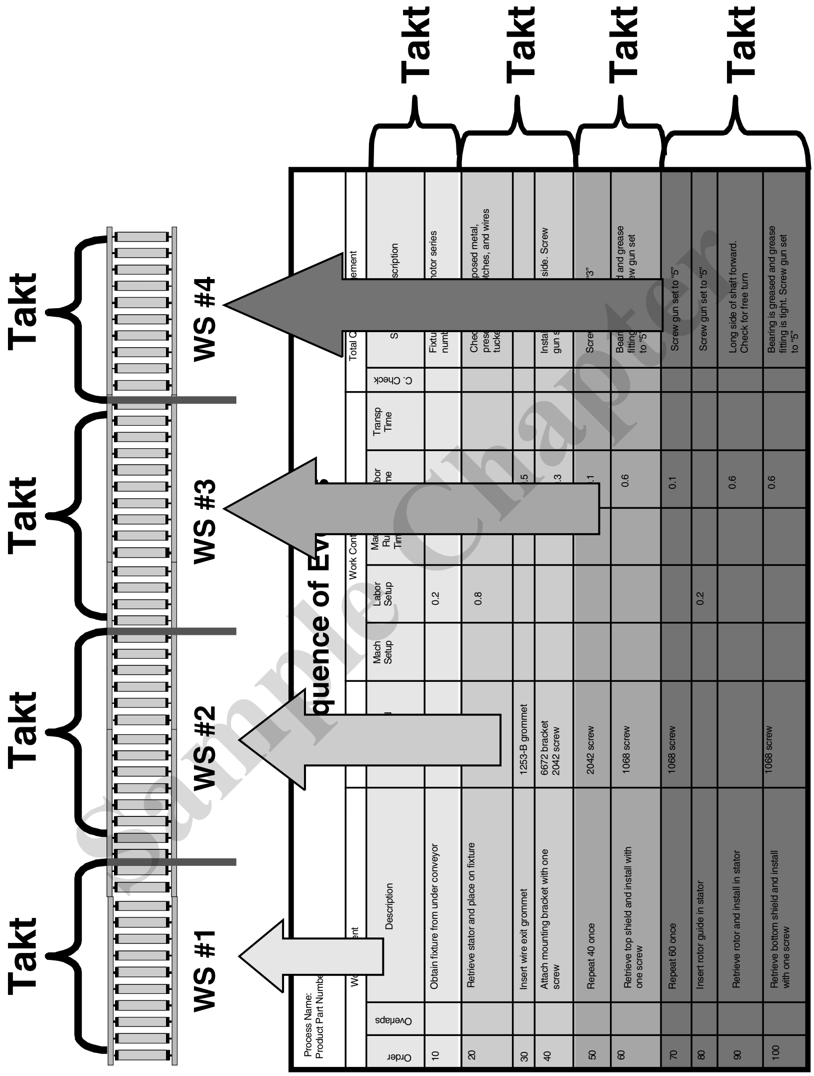

Figure 4.8 Grouping Work Content to Workstation Takt

its IPK becomes empty. The only way an IPK can become empty is for the unit to be consumed by the downstream process. The empty IPK is the signal and is the communication to the operator in the upstream workstation to begin work on the next product.

Once the IPK signal is received in the workstation to begin work on the next unit, the operator "pulls" the next partially completed unit from the upstream workstation, thereby creating an empty IPK signal for that operator. Response to the IPK signals located at each workstation throughout the Lean line and upstream into the feeders is what gives the Lean line the appearance of flowing downstream. When all workstations are balanced, the entire line ratchets every Takt time an IPK signal is received (i.e., a drumbeat or cadence).

The IPK is critical to the operation of the Lean line. IPKs control the speed of the line and help to smooth factors that cause imbalance. Different operators work at different speeds, some units take a little more time to complete at the workstation, or the component parts do not fit together well. If there were no way to control these causes of minor imbalance on a Lean line, faster workstations would just accumulate large piles of work in process as a solution for overcoming imbalance. Enforcing IPK discipline is the secret to making the Lean line flow and causing the operators on the line to work as a team to produce product at the same rate.

Scheduling production in the Lean factory is considerably simplified once factory layout and IPK signaling discipline drives the flow of work through the factory. Production scheduling on the Lean line begins at operation #1 of the Lean line, at the finished goods level. Because products are manufactured one unit at a time, they can be sequenced to move down the Lean line in the same order the customer requirement was received. The planner has only to determine the order of manufacture.

Products are introduced into the Lean line one unit at a time following predetermined sequencing rules designed to assure a balanced rate on the mixed-product line. Upon receiving an empty IPK signal, the operator in the first workstation of the Lean line simply pulls the next customer order into production by following the preset sequence the planner has chosen. This assures a first-in–first-out priority sequencing of customer orders.

Subassemblies are produced in feeder processes following the same IPK signaling methodology. With a balanced line and using IPKs to signal production, there is no need to order launch and schedule batch subassembly production. The output from these feeder processes is consumed directly into the downstream processes, and subsequent production in the feeder is initiated using the IPK kanban as a signal for replenishment.

In special cases, such as configure-to-order custom products, a sales order configuration document may be required to be sequenced along with the product.

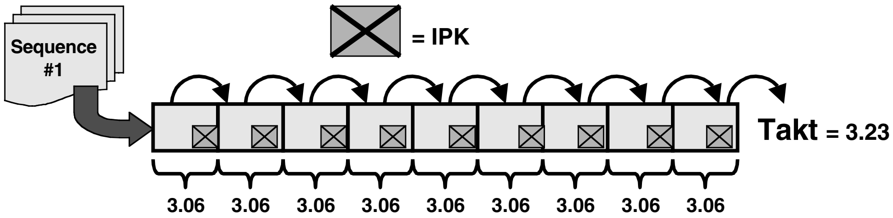

Figure 4.9 Sequence Customer Demand versus Schedule Production

This "configuration traveler" moves along with the product as it advances through manufacturing. The traveler indicates to the operator which parts are to be used to build the special configuration. The feeder process must also be sequenced in the same order as the consuming downstream processes (Figure 4.9).

DISCIPLINE FOR MAINTAINING WORKSTATION BALANCE

Because balanced processes are so critical to the success of a Lean line, periodic rebalancing is necessary to fine-tune the line. The Lean manufacturing line constantly seeks to achieve perfect balance to the established Takt time target. However, many problems can cause a line to become unbalanced. Over time, line operators can pick up bad habits. When imbalances are not corrected immediately, the Lean line will eventually fail. Management should look for the following signs of imbalance and correct them immediately:

- **Nest building:** An individual operator has decided to take ownership of a workstation. Some of the signs are personal items such as calendars, pictures, radios, and other creature comforts. This is a common habit that indicates an unwillingness to respond to the IPK. Because this person is unwilling to move in response to an IPK, he or she unilaterally decides when and where to do work. The rule on the Lean line is that people move to work; work does not move to the person. Don't wait until personal items accumulate at the workstation. Correct nest building as soon as the first item appears.
- **Stash cache:** Always ready for a rainy day, this person maintains his or her own private cache of parts. The justification for hoarding parts is usually a story about a parts shortage that occurred years ago. On a Lean line, operators build and material handlers provide parts! The same can be said for tools. Justification also includes a tale about needing a certain

tool to build a special model many years ago. Tools necessary to produce the products at every workstation should be provided by the company. Tools and equipment are company property and belong at the workstation. Look for tool boxes, drawers, shelves, file cabinets, and any other place where tools and parts can be stashed for future use. Continually enforce the 5S philosophy of "a place for everything and everything in its place."

- **I'm special:** Because of company tenure, longevity, or special skills, this operator feels he or she has earned the right to choose the work he or she will do. If uncorrected, such operators will cherry-pick only the units they prefer to work on. Sometimes they also establish nests and initiate a stash cache where they can be left alone to work only on the products of their own choosing. When observing the Lean line, pay attention to the product mixes in the IPKs. Confirm that the daily sequence selected by the planner is being followed on a first-in–first-out basis.
- **The better idea:** Operators usually have great ideas and suggestions for improvement, but they cannot be allowed to incorporate those individual ideas unilaterally. If one operator acting alone decides to stop using a piece of equipment or to reshuffle work, it can throw the entire line out of balance. Operators must be encouraged to channel those ideas appropriately. Demand the use of continuous process improvement and kaizen meetings as the forum to channel these suggestions. New ideas and process improvements impact the entire line and must be managed.
- **Speed trumps Takt:** Prior to the implementation of the Lean manufacturing line, operators were always instructed to build as much product as possible as fast as they could. In companies where absorption has always been the primary performance measurement, the ability to do this was a sign of an individual's value to the company. With the Lean line, these same operators are now instructed to produce only one unit at a time in response to an IPK signal. When work is completed, it moves to the IPK. The new Lean environment will feel unnatural to them, and their old habits will not disappear simply because management wishes it so. Assure compliance to IPK signals. The IPK is the secret to maintaining one-piece flow, and management must maintain the discipline of one-piece flow. Do not allow operators to place more than one unit in an IPK. If there is a line balance problem, it will manifest itself as a breakdown at the IPK. Do not ignore this important warning sign. Employ the balancing techniques to resolve the problem.

One of the primary reasons Lean lines become imbalanced after their start-up is management indifference to these warning signs. Lines do not fail in one day. They fail over a long period of time as a result of a series of small actions that never get corrected. After spending so much time designing the Lean manufacturing line, it is easy for team members to think of reasons to shift responsibility for operation and maintenance of the line to someone else. Allowing indifference to flourish is the first step in returning to the old practices that caused transition to Lean manufacturing methodologies in the first place.

Silence is acceptance. Monitoring the Lean line is the responsibility of all managers. When a member of the management team observes a violation of Lean methodologies and chooses to do nothing, the message received by operators that their current behavior is acceptable is reinforced. Managers must correct operator violations immediately by explaining the violation and providing training in the correct methodology. All the work required to convert the facility to Lean can be lost if the new line is not maintained and improved. Always practice "management by walking around" (MBWA).

Another common mistake is assuming that the company's conversion to Lean manufacturing is merely a project of the month with a beginning and an end date. In a successful Lean implementation, nothing could be further from the truth! Lean manufacturing must become a way of life and the chosen manufacturing methodology for operating the facility. Factory conversion to Lean must be championed as a "top-down" activity, with the expected benefits articulated and weaved into the fabric of the company culture. Sponsorship from the grass-roots level only will jeopardize long-term success.

As the workstations achieve balance, always move any remaining imbalance to the final workstation. Then, by applying a series of balancing techniques, work to eliminate the imbalance at the final workstation. Always seeking ideal balance on the Lean line requires continuous process improvement discipline throughout the organization (Figure 4.10).

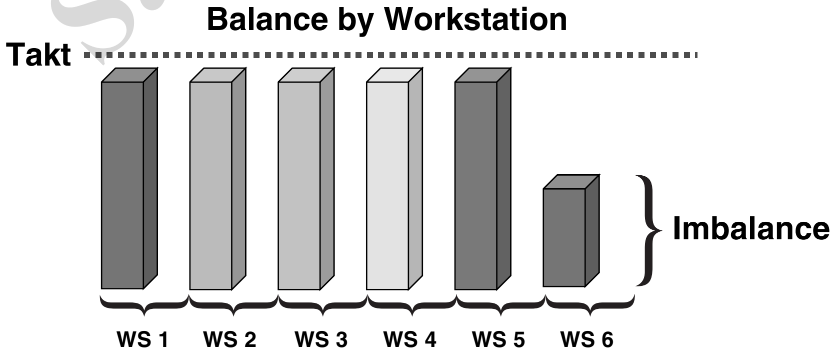

Figure 4.10 Seek Balance to Takt at Each Workstation

There are some simple techniques that can be used to overcome imbalances in the workstations. Use of these techniques should be implemented in the order presented. The first techniques are the simplest to apply and have the lowest cost. Each imbalance should begin with the first technique and progress through the additional techniques until the imbalance is resolved. Use the following techniques to continuously solve workstation imbalance:

1. **Look for work that can be eliminated:** Dynamic setups and moves are *always* candidates for elimination. Moves and setups have been identified on the SOE. Using continuous improvement techniques, exploit all opportunities for eliminating nonvalue-added work. Quality inspection work is also a candidate for elimination, along with process improvements that simplify work. Quality criteria and process improvement may require assistance from quality assurance and manufacturing engineering.
2. **Relocate work from workstation to workstation:** Relocation of work is one of the most common techniques for achieving workstation balance. Using the sequence of events, relocation is accomplished by reassigning work tasks from the SOE from one workstation to the next. Make sure the relocation of work is technically feasible and will not adversely affect quality.
3. **Add IPKs to the imbalanced workstation:** IPK = Inventory = $ Investment. If the addition of IPKs is necessary, make certain that all efforts to eliminate nonvalue-added work and all opportunities to relocate work have been completely exhausted first. Adding additional IPKs also means that additional production time will be required to manufacture the additional units. Avoid the temptation to guess the correct amount of IPK inventory to keep at the workstation. The correct amount of IPK inventory to be added is calculated as follows:

$$\frac{\text{Effective Minutes per Day}}{\text{Takt}} - \frac{\text{Effective Minutes per Day}}{\text{ST}_w \text{ of Process}} = \text{IPK Quantity}$$

$$\text{Extra Time Required} = \text{IPK} \times \text{ST}_w$$

4. **Add resources:** Adding machine or labor resources is often the most expensive solution to solving line imbalances and should be the last resort. However, the cost of adding resources should always be compared to the cost of adding IPK inventories. When justifying a capital expenditure request to purchase new equipment, the cost to carry the

calculated daily amount of IPK inventory along with the cost to carry and manage the inventory can be compared to the cost of purchasing new equipment. Make the best business decision for your company based on these costs.

5. **Sequence properly:** On a mixed-product line, the order of manufacture can have an impact on the balance of the line. Avoid sequentially running products with identical work content times. If possible, follow long work-content-time products with short work-content-time products. Mixing the sequence of products on the line throughout the day will help achieve the desired daily rate.

Seeking perfect balance at each workstation is a never-ending activity as mix and volume change. Balance is also affected as processes are improved. Lean manufacturers never achieve perfect balance. However, this does not mean that it should not be pursued. As optimum balance is achieved, the capability to produce product in its work content time is also achieved. This reduces the total manufacturing cycle time, which leads to the reduction of response time to customers and reduction of inventories. A manufacturer's capabilities to reduce response time and the total cost of production are powerful weapons for increasing market share.

Lean manufacturing is a completely different way of operating a manufacturing company. It is no magic bullet that will miraculously correct a long legacy of problems, but it does provide a set of operating techniques that yield immediate benefits. Continuing successful operation of your Lean manufacturing lines requires a commitment to seek continuous improvement using all the methodologies learned during the transformation process. For many companies, this dedication will require changing the company culture. All the hard work will be rewarded with all the benefits of Lean manufacturing.

DESIGNING 5S INTO THE LINE DESIGN

Order and neatness are critical elements of the working environment. All material locations must be clearly marked. Only the necessary tools, fixtures, gauges, and other resources should be present at the workstations. No clutter or mess should be tolerated on the Lean line. There is no need to rely on the output of a shop floor control system to determine the location or progress of an order.

Implementation of the Lean manufacturing methodologies supports the concepts of 5S. The elements of 5S and applied Lean methodologies are complementary.

Sifting (Seiri)

Remove items not used to manufacture products on a regular basis.

1. A major component of the Lean manufacturing line implementation is the removal of items identified as unnecessary for the production of product. Such items include tool boxes, file cabinets, lockers, tables, stools, personal items such as microwave ovens, desks, tables, shelves, and drawers. These items offer temptations to accumulate unwanted materials such as parts, tools, books, and other items not required to manufacture product.
2. The temptation to accumulate these types of items is part of the human condition. There is a comfort level that comes with surrounding oneself with familiar objects. This comfort level may be based on past experiences like parts shortages, the unavailability of tools and fixtures, or a need to know how to produce infrequently demanded products. Operators like to create comfort with a "home away from home," made up of a collection of personal items. Often, these personal items are accumulated in a personal workstation. The establishment of personal workstations conflicts with the Lean manufacturing concepts of balance and flexibility.

Sorting (Seiton)

Identify and arrange items that belong in the area — a place for everything and everything in its place.

1. In addition to the physical location of workstations where work is actually performed, there are always tools, fixtures, and parts that must be located so the operator can easily access them. Each of these required items should have an assigned location either at the workstation where the item is used for daily production or adjacent to the point of usage. Suggestions include silhouette boards for tools and fixtures located within operator reach, painted squares on the floor, suspended air and electrical lines, and kanban racks and containers.
2. For all materials not used directly at the workstation, assigned locations are also important. Such materials include pallet jacks, forklifts, cleaning materials, trash receptacles, and any other portable material-handling fixtures. A "parking space" should be placed adjacent to the workstation where the item is used most frequently. The space should be painted, and material handlers must be disciplined to return the item to its parking space when not in use.

Sweeping (Seiso)

Maintain order, sweep, and clean.

1. The reasons for maintaining a clean workplace are obvious. Operators should take pride in their workplace, and that pride is reflected in the product they build. Just as important, a clean workplace also provides an early warning system of problems. A cluttered workplace can hide problems such as rejected materials that indicate a defective quality process, spare parts that may indicate a faulty kanban system, or incomplete units that indicate an imbalance on the Lean line. A clean Lean line environment helps to make these potential problems conspicuous.
2. Time to perform these cleaning activities can be built into the Takt time calculation. A statement of minutes per shift makes up the numerator of the Takt time calculation. Time needed to perform cleanups at the beginning and end of each shift can be built into this calculation. Since resources for Lean manufacturing lines are based on the Takt time calculation, incorporating this activity into this calculation will provide the time necessary to do this work every day.

Standardize (Seiketsu)

Practice management discipline.

1. Making the most of Lean manufacturing methodologies requires the minimization of individual interpretations when decisions must be made. Much effort has been invested in the design of the Lean line so that operators can maximize the time spent building product, with less time spent making decisions. Operators have been trained to respond to decisions using the Lean manufacturing methodologies. All operators should follow the same rules.
2. A key benefit for the Lean manufacturer is the ability to perform MBWA, management by walking around. Walking through a Lean facility, it is very easy to see what is happening in manufacturing. The IPK product flow indicates what to do and when to do it. The supervision required can often be decreased, because of the simplicity of the Lean line design.

Sustain (Shitsuke)

It is management's responsibility to reinforce and demonstrate leadership.

1. Monitoring work conditions is the responsibility of the managers as they perform MBWA. When a member of the management team observes a violation of rules and chooses to say nothing about it, operators assume their behavior is acceptable. Operators are limited to individual interpretations at their workstations. Management must take ownership of solving problems on the Lean manufacturing lines. Managers have the advantage of seeing the bigger picture of the whole line. This is MBWA.
   - Monitor work conditions. Use newly established housekeeping policies as a management tool to focus on details. Small details are the first to deteriorate on the line. Look for items that do not belong. Solve problems immediately.
   - Monitor operator flexibility. The ability of a Lean line to vary mix and adjust its volume on a daily basis, based on actual daily demand, is a key differentiator of your Lean line and batch manufacturing. This ability provides a competitive advantage to your company. Flexible employees are key elements of Lean manufacturing.
   - Monitor overtime. The need for overtime should always be a temporary condition. It should be used for unanticipated spikes in demand, for only a short period of time. If overtime is permanently required, it may be time to rebalance the Lean line with a new volume capacity.
   - Monitor teamwork. Encourage team performance. Request ideas for continuous improvement. Allow people to have control over their own destiny. Be certain the teams focus on the performance of the line. Make certain teams have a simple and accessible kaizen or continuous improvement mechanism for improving the product or its processes.
   - Monitor the line's performance. The proof of success is performance. Establish performance measurements for the line. Track them and publish them. Post performance measurements on the line to display the daily production target, along with progress of actual production.
   - Monitor in-process quality. Establish and continue emphasizing the value and importance of inspecting for quality criteria. The final objective is for all defects to be caught and fixed before they ever reach the quality assurance final inspection process, the last point of rejection, or the customer. Perform spot checks on the lines. Have a team leader or manager pick a unit at random from a conveyor or IPK and verify that the work at that point is no more or less than it should be and that it is done correctly. Do this frequently and in plain sight!
   - Monitor training. Employee training is critical to ensuring a consistent and repeatable flow of product every day. The better trained employ-

ees are, the more flexible they are. The more flexible employees are, the better the line will flow.

2. Operation of the Lean manufacturing methodologies requires a shift from the way work was done in the past. Lean manufacturing methodologies are powerful, but they require support and maintenance. The benefits received from the implementation of the Lean manufacturing methodologies will be in direct proportion to management's commitment to making them work on the shop floor. When members of the management team do MBWA, they must be observant for any violation of the Lean rules (quality checks, teamwork, flexibility, and IPK compliance). Make corrections immediately. Doing nothing condones the behavior.