Applied Lean Business Transformation

A Complete Project Management Approach

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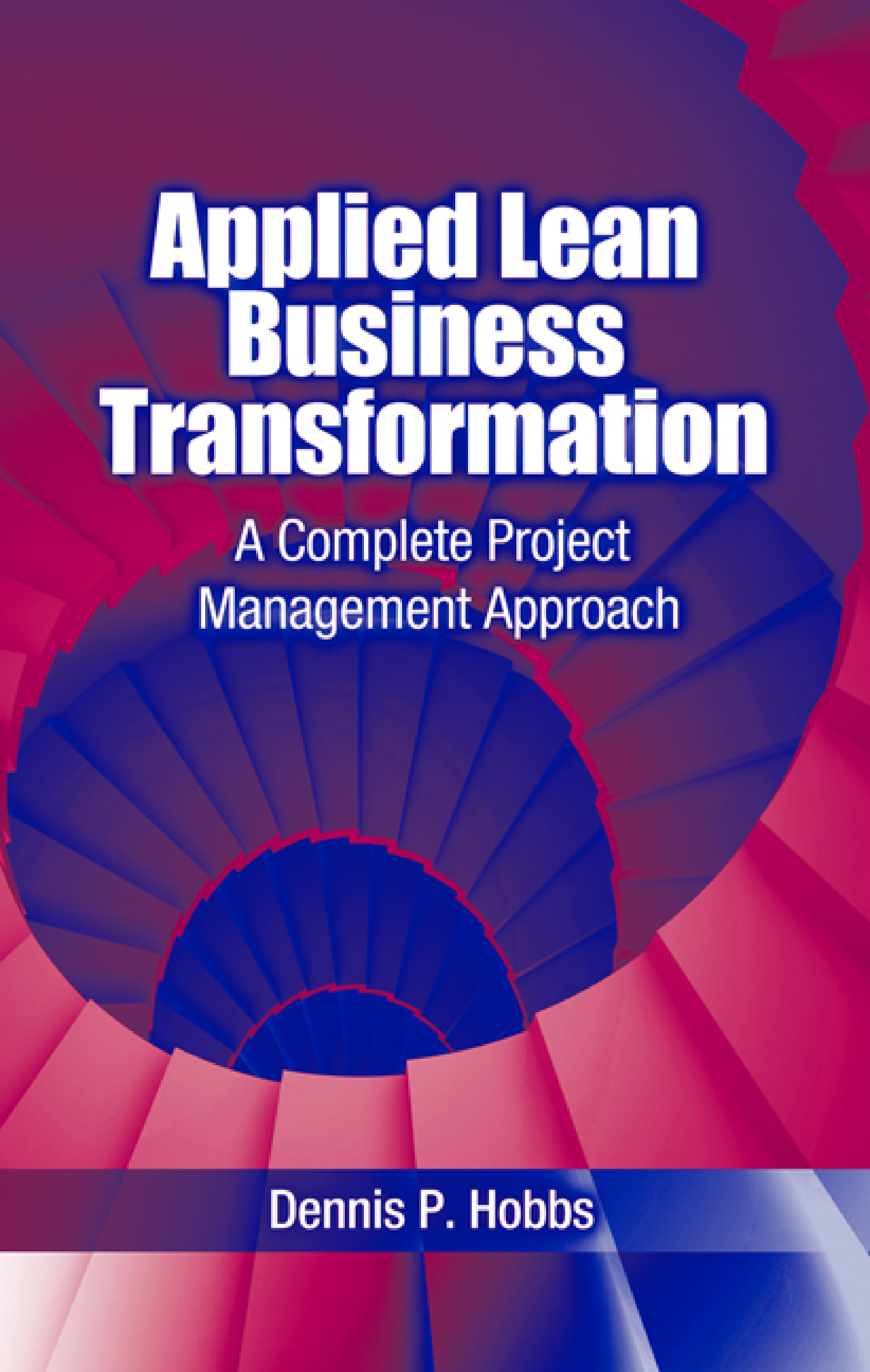

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THE LEAN LINE: RESOURCES, LINE DESIGN, AND MANAGEMENT

Information collected so far has identified the processes, the demand for those processes, and the effective minutes available to do work. With this information, the Takt time for each process is calculated (Table 7.1). (Remember from Chapter 6 that Takt time defines the *rate* the line must run to achieve a desired daily output and specifies the *frequency* for the completion of one unit of finished goods.) Standard work definitions (SWDs) have also been developed documenting the individual tasks of standard work in sequential order, the time required to complete the identified tasks, and the quality criteria at the individual task level. With this knowledge, the number of individual resources necessary to produce the customer demand in the various processes can be determined. A resource is defined as:

> *The investment of a person, machine, workstation, or inventory utilized during a manufacturing process to add value to raw materials for the construction of a product or for completing an administrative activity. Resources can be people, workstations, machines, and inventory.*

UTILIZING RESOURCES: THE LEAN APPROACH

All manufacturing operating systems use resources to manufacture products, but Lean manufacturing methodology utilizes resources differently than the order-

Table 7.1. Process Map with Takt Times in Minutes (Takt = Planned Work Minutes × Shifts ÷ Throughput Volume)

Family Description	Part Number	V_c	Weld		Volume Modifier	Volume Modifier × V_c	Weld Rework		Volume Modifier	Volume Modifier × V_c	Assembly		Volume Modifier	Volume Modifier × V_c	Custom Lights & Sound		Volume Modifier	Volume Modifier × V_c
			Machine	Labor			Machine	Labor			Machine	Labor			Machine	Labor		
V5A	75903101	2.00			1.100	2.20			0.100	0.20			1.000	2.00			0.400	0.80
V6A	76000202	0.40			1.100	0.44			0.100	0.04			1.000	0.40			0.400	0.16
A4H	76102402	3.00			1.100	3.30			0.100	0.30			1.000	3.00			0.400	1.20
U5	76100002	2.00			1.100	2.20			0.100	0.20			1.000	2.00			0.400	0.80
805	72200002	4.00			1.100	4.40			0.100	0.40			1.000	4.00			0.400	1.60
806	72210002	6.00			1.100	6.60			0.100	0.60			1.000	6.00			0.400	2.40
T5AH	72208902	2.00			1.100	2.20			0.100	0.20			1.000	2.00			0.400	0.80
T5LOAH	70524102	0.375			1.100	0.83			0.100	0.08			1.000	0.75			0.400	0.30
S5	72208602	1.00			1.100	1.10			0.100	0.10			1.000	1.00			0.400	0.40
TM270	71801802	2.00			1.100	2.20			0.100	0.20			1.000	2.00			0.400	0.80
G3	70542002	5.00			1.100	5.50			0.100	0.50			1.000	5.00			0.400	2.00
G4A	70550402	2.50			1.100	2.75			0.100	0.25			1.000	2.50			0.400	1.00
		30.65				**33.72**				**3.07**				**31**			0.400	**12**

	Weld	Weld Rework	Assembly	Custom Lights & Sound
Takt Time	**13**	**143**	**14**	**36**
Planned Work Minutes	438	438	438	438
Shifts	1	1	1	1
Throughput Volume	**33.72**	**3.07**	**31**	**12**

launch methodology of traditional planning systems. For designing a new Lean operating system, the process flow of a product, the processes used to complete manufacturing of the product, the standard work at each process for each product, the production Takt rate, and customer demand are required information elements. The remaining information element needed to design and operate a Lean manufacturing line is the amount of resources needed to achieve the daily customer demand: the number of *people, workstations, machines*, and *inventory* resources that must be assigned to each process to achieve the Takt time target.

The primary reason for the existence of a manufacturing facility is to satisfy customer demand by producing and delivering high-quality products in the shortest amount of time possible. Once a company has made the decision to meet customer demand by being a manufacturer, managing people, workstations, machines, and inventory resources as effectively as possible becomes "job number one." The single largest expense for most manufacturing companies is the resources required to operate the manufacturing facility. Managing resources is serious business — if poorly managed, the costs of resources can ruin or seriously handicap even the best of companies.

Over time, if not controlled, wasteful non-value-adding activities silently creep into the manufacturing processes, requiring more and more resources to compensate for them. Slowly, the waste becomes invisible and is simply taken for granted as a cost of doing business. The seven wastes of manufacturing (overproduction, inventory, extra processing steps, motion, defects, waiting, and transportation) are the result of these creeping, insidious non-value-adding activities. Manufacturers know waste is there, but in their day-to-day concentration on meeting customer demand, they cannot see it. Instead, they choose to ignore it because they do not know how to eliminate it. Unfortunately, the costs of waste must be recovered somehow. The fastest, easiest way is to absorb these costs into the selling prices of products. It's a great solution until customers choose not to pay the price of your products and takes their business to a competitor offering a better price. As waste becomes systemic over time, its associated hidden costs become institutionalized and seemingly impossible to eliminate.

Lean and waste. Lean manufacturing methodologies include formal processes that systematically deconstruct traditional manufacturing practices to identify waste so it can be eliminated. When waste has been squeezed out of processes, selling price is no longer the sole competitive differentiator for a Lean manufacturer. Other important differentiators provide additional leverage when deploying strategies for capturing market share: shorter lead time, improved quality, and working capital reduction. A Lean transformation *systematically* seeks to identify and eliminate wastes that have been accumulated in manufacturing costs over time. A Lean operating system eliminates the overproduction of products in a factory caused by a policy of maximum utilization of resources by using *only* the resources necessary to meet customer demand. Because customers rarely order the same amount or variety of products on a given day, instead of using WIP and FGI inventories as balancing mechanisms to offset fluctuations in utilization, a Lean operating system modifies the amount of resources to match changing customer demand each day using flexible resources. Because workstations, machines, and inventory are stationary, inanimate, and inflexible objects, people are the only flexible resource. A Lean system requires the human resources to adjust to changes in customer demand so that the necessary resources required on any given day match the customer demand. When unsold units are not produced, the waste of overproduction is avoided.

Lean = marketplace advantage. Producing products with minimum waste using measured utilization of resources makes sense. Having the ability to avoid the wasteful production of unsold products gives a Lean manufacturer a big cost differential over a non-Lean competitor. Traditional production methods *enable* the production of hidden waste in manufacturing processes. Because waste increases cost, to remain profitable, a non-Lean manufacturer has no choice but to pass on the cost of waste to customers in the price of their product. If selling price is a major differentiator for a customer, a non-Lean manufacturer has little latitude to modify the product's price to meet or beat a Lean competitor. In the marketplace, a traditional manufacturer loses out to Lean competitor who can adjust the cost gap between the profit margin and selling price as a sales differential.

How Lean does it. Lean manufacturing is the production of a product minus all non-value-added work. In Lean, manufacturing a product requires only the sum of its standard work content time and the cost of its materials. Manufacturing response time should not exceed the sum of the work content time of the product: any time in excess of standard work content time is waste. *The goal of a Lean manufacturing line is to produce a product in the sum of its work content time only.* Any non-value-added activity that causes response time to exceed work content time is a candidate for reduction or elimination by a kaizen process.

Lean versus traditional operating system management of resources. Traditional operating systems evolved from the need to maximize the utilization of resources, particularly machines. The approach of traditional planning systems to managing the manufacturing process is very different from the Lean approach. Not until Lean operating systems became popular, causing rethinking of the true costs of utilization and inventory, did manufacturers try to understand the differences between the two systems. A Lean operating system is not difficult to comprehend, but for most manufacturers who have spent their entire careers in traditional operating systems, the different approach required to make a Lean operating system to work in their factories and offices is not intuitive. No consultant, sales person, book, industry article, or seminar can convince a manufacturer of the superiority of a Lean operating system. Management must make the intellectual investment to understand the differences and reconcile how Lean would be an improvement over the current operating method. To better understand the differences between traditional and Lean operating systems, a review of the traditional system will be helpful.

UTILIZING RESOURCES: THE TRADITIONAL APPROACH

Traditional planning systems assume that an infinite capacity of resources is available to manufacturing. Production orders are issued by a planning system to meet customer requirements based on the demand established by a *master schedule*. The frequency of the replanning process is set by the planning group based on the volatility of customer demand. Once the planning system performs time-phasing routines based on the due dates of customer demand, a schedule of work for each individual department is established. The priority of released production orders is determined by its due date and the available capacity in each department. As long as the planned order load does not exceed the stated capacity of a department during the assigned time period, the production plan is considered valid. An individual department manager usually has the final say and as to whether the recommended plan is valid.

The indented BOM establishes start and due dates. To establish correct start and due dates for production orders, which in turn establish the load in each department based on the net requirements, an indented BOM is required. The indented BOM is a key data source for the planning system operation. The indented BOM not only lists the component parts required to manufacture the product, but it also includes department lead times and quantities per each component part required to schedule production of a product. Using the due date of the SKU at the master schedule level as a starting point and using the lead-time offset information for each level in the BOM, start and due dates are established for released orders for each department down through all the levels of the BOM until the start date at the gateway department is established. In traditional manufacturing, the lead time of a finished product is established by summing all of the offset lead times of each department sequentially through all levels of the indented BOM beginning at the gateway department up to the master schedule.

The indented BOM establishes build sequence. The BOM offset function also describes to the planning system how a product is manufactured and electronically communicates the build sequence of subassemblies. Using the offset

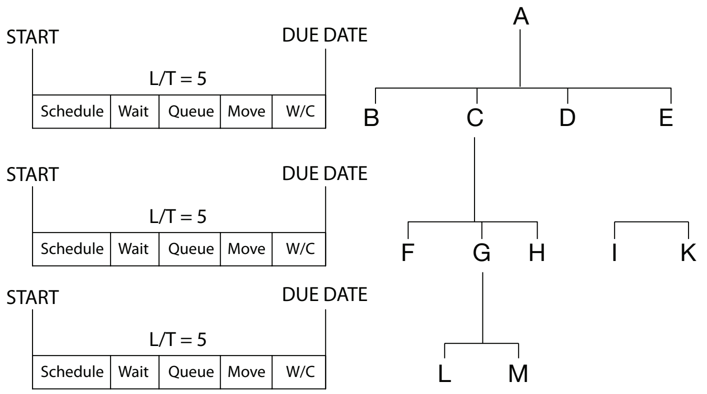


Figure 7.1. An indented bill of materials establishes due and start dates for production orders released in a standard planning system.

lead time recorded for each level of the BOM, and the due and start dates recommended by the replanning process, individual production schedules for every department are developed. The different levels of the BOM represent the sequential build of the product through the manufacturing facility much like 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. Figure 7.1 illustrates how an indented BOM establishes start and due dates for production orders released from the planning system.

The indented BOM impacts the company's organization. The indented BOM is a crucial component for the operation of a traditional operating system that impacts the organization of the manufacturing departments and the management structure of the entire company. Manufacturing departments are often established to mimic the levels of an indented BOM. Similar functions or manufacturing processes are intentionally grouped together in departments to mirror the levels in the BOM. Shop floor layouts use the indented BOM to determine the physical location of the departments in the factory. The structure of data collection and data maintenance responsibilities frequently reflect the structure of the indented BOM. Accommodating database maintenance of the planning system often dictates the organizational structure in a company.

Traditional planning systems require significant information maintenance. The demands of maintaining and operating a planning system require a diverse skills base. Planning systems and individual managers' responsibilities for ROI and utilization of resources in their respective departments contribute greatly to the organization charts in many companies: the organization is designed around responsibilities required for the operation and maintenance of the planning system. Not only is the planning system used for the facilitation of production schedules, but it also requires the development of departmental policies and procedures from engineering, quality control, purchasing, forecasting, shop floor, routings, and capacity planning to cost accounting. Most companies use planning system maintenance requirements to define the responsibilities of individual departments, e.g., BOM creation and maintenance is the responsibility of design engineering, forecasting is the responsibility of sales and marketing, planning and inventory management is the responsibility of materials management, and routing file management is the responsibility of manufacturing engineering. A planning system has a voracious appetite for accurate, up-to-date information. A planning system needs the most current, accurate information to perform the planning function. If the information used to complete the planning routine is incorrect, the planning system's output will be equally incorrect! Successful planning systems require the database maintenance responsibilities to be assigned to a specific department.

Lean challenges traditional organizational structures and planning system information. Implementing a Lean operating system often challenges the indented BOM logic used to establish the departments and the company's organizational structure. Challenging existing departmental roles and responsibilities causes resistance to the potential organizational and structural changes that may be needed by the Lean operating system. Over time, many departments have become dependent on the planning system as a depository for information and to provide feedback from production operations. Their jobs may have been designed around the operation and maintenance of the planning system — they need to input information into the planning system and they need to receive output from it to perform their jobs. Their jobs may have even been justified by the need for data maintenance of the planning system. A Lean operating system does not depend on the output of a planning system to utilize resources to meet customer demand. Reliance on planning system information to operate a Lean manufacturing facility is greatly diminished or completely unnecessary. Once the Lean system is in operation, the departments formerly dependent on planning system information will soon notice the lack of information flowing from the planning system. The reduced dependency on information coming from and going into the planning system may cause great concern about the changing status of the company and the need for some jobs, which, of course, causes great concern for a department manager whose function has been the maintenance of data for the planning system. Some may fear their jobs are going to disappear. Fear created by the change to the Lean system may cause people to go into a job preservation mode. Until an alternative Lean method is developed to replace the data provided by the planning system, the current flow of information must be maintained.

Lean challenges traditional staffing requirements. In many organizations, meeting the increasing needs of traditional planning system information maintenance is a primary justification for expanding departmental staffing requirements. Needing to operate or maintain required planning system information is a good way for department managers to *empire build* the size of their organizational footprint: increased dependence on system output and needing a correspondingly larger staff increases their importance and power. Some may be motivated to grow planning system data requirements to create an even greater need for an increased administrative headcount. Their importance and power have become tied to the existence and size of the planning system. Any incentive to challenge the inputs and outputs of the planning system is nonexistent. Because a Lean operating system requires less traditional information, these department managers often become resistors during a Lean transformation project. They see the reduced reliance on information currently generated by and for their departments as a threat to their status and power.

Traditional modern planning systems significantly impact the departmentalization of the shop floor and the organization of administrative areas, but they give very little attention to ensuring that all manufacturing departments are designed with equal resource capacities. Instead, resources are assigned to a department based simply on its function or the type of work done — similarity of function is the sole reason for assigning resources to a department in a traditional operating system. Using this simple criterion for assigning resources ignores the need for having a balanced capacity among all departments on the manufacturing shop floor. The unbalanced resource capacity leads to some departments having more capacity than others. When the excess capacity in an unbalanced department is fully utilized, production output will be in excess of customer demand. The reverse is true for the departments with less capacity than customer demand. Utilization in those departments is not a problem, but meeting on-time customer demand is! With traditional planning systems, smoothing out these imbalances can only be accomplished by creating buffer inventories or through constant expediting activities to reprioritize customer demand. Neither of these smoothing alternatives changes the *form, fit, or function* of the product. It's non-value-added activity caused by the need of the planning system to achieve 100% utilization in all departments. These overproduction and expediting activities are considered *waste* in a Lean operating system.

ACHIEVING UTILIZATION BALANCE: THE TRADITIONAL APPROACH

Utilization imbalance creates many problems currently seen on the shop floor. Even with a traditional planning system, manufacturing departments seek to achieve balance. Significant efforts are given to rearranging production order loads among the departments with different capacities. Some departments may expedite production orders after they are released to the shop floor. Others may attempt to achieve balance on a default basis by using WIP inventories as their only available balancing mechanism. The shop floor square footage footprint must be increased to accommodate storing the buffer inventories. All departments try to achieve maximum utilization of the resources assigned to them even if it means building unsold inventories, working overtime, or missing customer due dates to make it happen. None of these efforts to achieve resource balance among the manufacturing departments change the *form, fit, or function* of the product. They're considered waste in a Lean operating system.

Utilization and department managers. Maximum utilization of resources allocated to the department is an important component of a manager's annual performance review (and any subsequent pay raise). Managers are therefore highly motivated to achieve maximization of their department's resources. The goal is to achieve a utilization factor as close to 100% as possible: if the department has excess capacity, more work must be added to keep resources 100% utilized. For example, resources underutilized by a planned production order load can be maximized by pulling orders forward from the planning horizon and producing them ahead of their original planned due dates. Running production orders ahead of schedule satisfies the manager's need for departmental utilization, but doing so creates unsold inventory. This 100% utilization strategy is costly if customer demand cannot absorb the output. Because the cost of inventory is more expensive than the cost of labor, a strategy to build excess unsold inventory to achieve utilization goals can cost more than underutilized labor. Even so, the quest for 100% utilization will always trump meeting customer demand in any department with capacity in excess of customer demand. Managers who are measured on the efficiency and utilization (absorption) of their assigned labor and machine resources will do everything in their power to keep their resources as busy as possible. For example, grouping production orders with similar work content together so they can be run sequentially to create longer production runs to reduce inefficiencies caused by changeovers is a common technique. This type of work grouping, known as *batch manufacturing*, is encouraged by the need to achieve maximum utilization. Consider the result of all this production order management activity in departments on a typical shop floor. To maintain database accuracy for the next MRP reschedule, the reprioritizing of production orders requires timely production order status reporting to the planning system. “Gaming” the operating system at the expense of meeting on-time customer demand does nothing to change the *form, fit, or function* of the product being produced. It’s all non-valued added activity and considered *waste* in a Lean operating system.

Utilization and the production control group: if manufacturing departments have excess capacity. If the released order load is below the stated capacity of a department, then the manufacturing group will request additional orders from the production control group until full utilization of the department is ensured. The only way the production control group can meet this request is to release firm planned orders in advance of the planning system’s recommended release dates (known as *pulling orders forward from the planning horizon*). If no customer demand exists for these orders issued in advance of their recommended release dates, then the result will be overproduction and unsold inventory. Pulling orders forward also results in material shortages or the cannibalization of materials already allocated to other released production orders, leading to excessive expediting activities and premium transportation costs, the need to maintain larger inventories of parts, unsold finished goods that can lead to slow-moving, obsolete inventory, and strained supplier relationships. All of the consequences of pulling orders forward are components of the seven wastes of production. They do nothing to change the *form, fit, or function* of the products being produced.

Utilization and the production control group: if manufacturing departments have limited capacity. In capacity-constrained departments, as the released order load approaches or exceeds the stated capacity in these departments, compromised or even missed due dates are a frequent experience. A capacity-constrained department cannot process the volume of production orders received from the upstream department. Production orders are rarely completed in the sequence necessary to satisfy production priorities downstream. Production orders must constantly be reprioritized to satisfy the downstream processes. If order priorities are uncertain, there is even greater risk for producing customer demand out of sequence, further putting customer due dates at risk. If unsold inventory is produced in a capacity-constrained department, delaying an actual customer production order, then customer satisfaction will the further compromised. Reprioritization of production orders can also cause an increased need for machine setups. When a machine setup is required, even more capacity is lost, resulting a never-ending cycle — constantly attempting to meet on-time delivery of production orders, but always being behind. Capacity-constrained departments always have past-due orders that require the added expense of overtime to meet customer due dates. Working extra shifts and weekends is a way of life in capacity-constrained departments. If a department downstream from a capacity-constrained department needs to maximize utilization, then the pressure on the capacity-constrained department to rearrange its priorities will be relentless. Figure 7.2 illustrates the factory floor expediting of released production orders in an attempt to satisfy the changing priorities and utilization requirements of unbalanced departments. In an imbalanced facility, demand is constantly reshuffled. It's a no-win situation for capacity-constrained departments. In some companies, entire organizations are dedicated to performing the expediting activities required for dealing with the daily rescheduling/rebalancing act occurring on their unbalanced factory floors. None of these activities change the *form, fit, or function* of the product being produced. They're all non-value-added and considered *waste* in a Lean operating system.

ACHIEVING PRODUCTION GOALS: THE TRADITIONAL APPROACH

The struggle to achieve inventory management (or turn rate) and customer service goals versus productivity, absorption, utilization, and efficiency goals has been the source of major conflicting objectives between manufacturing departments and sales and marketing departments for years and continues in most manufacturing companies today. Just observe production planning personnel, expediters, and planners and production managers. Notice the amount of time devoted to winning their respective productivity battles. These victories often come at the expense of meeting customer on-time due dates. Reconciliation of conflicting objectives is a major cause of daily expediting activities. Shuffling production orders to achieve production goals can result in achieving a default resource balance between departments with unequal capacity, but achieving this balance not only creates turmoil on the shop floor, but it also comes at great cost. Shuffling orders and reconciling conflicting objectives do not change the *form, fit, or function* of the product being produced. They're non-valued-added and considered *waste* in a Lean operating system.

Productivity and department managers. Machine setups can be time consuming. Operators and department managers rarely want to perform them. Just as needing to achieve 100% utilization is facilitated by grouping work together, a batch manufacturing strategy enables machines to be more productive. Run quantities are established based primarily on machine productivity considerations and are usually larger and longer than required to meet customer demand. Labor resources are also more efficient when performing repetitious, long runs of the same product. Most companies using a batch manufacturing strategy have

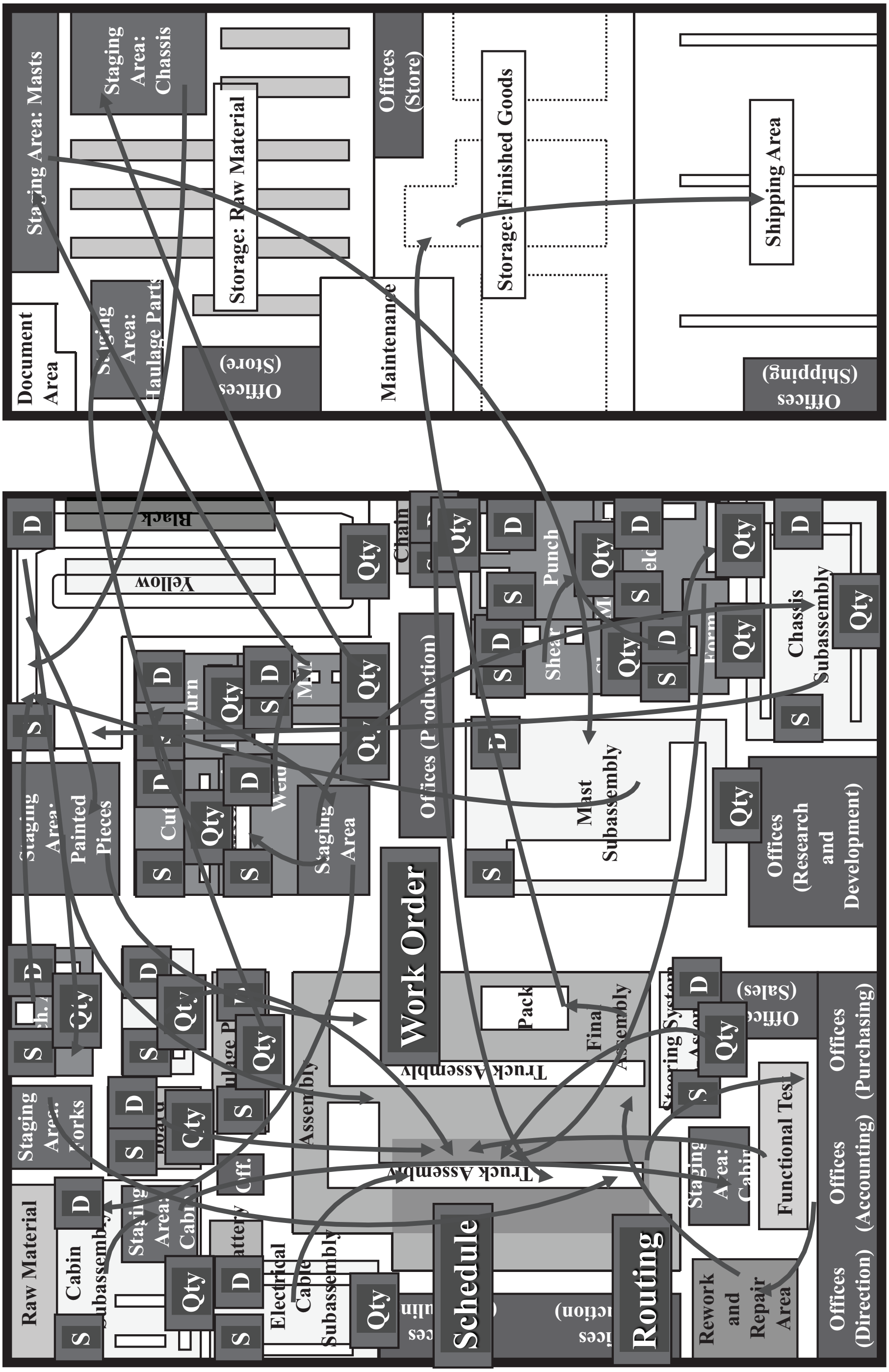


Figure 7.2. Factory floor expedition of released production orders to satisfy utilization requirements of unbalanced departments.

a simple calculation method for setting their batch sizes: "to produce as much as we can as fast as we can." Running large batch quantities therefore usually takes precedence over inventory considerations and customer-demand priorities. After all, inventory management performance measures and meeting customer demand are the responsibility of production planning managers, not manufacturing department managers. Department managers quickly learn to develop individualized inventory strategies to allow smoothing demand fluctuations to achieve their personal absorption goals. For example, they group production orders together to help optimize their departmental performance measures, even if the strategy results in part shortages, missed due dates and late orders, and a resulting high investment of working capital in unsold inventory. They accumulate as many production orders as possible, including orders in advance of their release dates, to facilitate having the ability to *cherry pick* orders and batch them together. They increase the lead time recorded on the indented BOM to cause earlier release of production orders from the planning system. Increasing lead time works great for batching production orders to maximize productivity, but it also results in a longer customer-quoted lead time, which can lead to lost business and sales revenue from customers who demand shorter lead times. Because department managers are not measured on inventory investment or on-time shipments, maximum productivity and utilization always trump all other company performance goals. None of this activity changes the *form, fit, or function* of the product being produced. It's non-value-added and considered *waste* in a Lean operating system.

Productivity and manufacturing costs. Achieving productivity using a batch manufacturing strategy is costly. Machine and labor capacities are prematurely consumed to produce orders that have been incorrectly prioritized in favor of satisfying productivity goals. Parts shortages occur, due dates are missed, and customer orders are late. Unsold inventory causes a higher investment of working capital. The resulting inventory is at risk of becoming slow moving or obsolete if customer demand does not materialize. Expediting and reprioritization activities require management time and effort. None of these costs or activities change the *form, fit, or function* of products produced. They're non-value-added and considered *waste* in a Lean operating system.

Productivity and department managers: if manufacturing departments have excess capacity. Managers of departments with excess capacity devote a significant amount of time looking for additional work to keep their resources productive and utilized. Excess capacity might seem like a good problem to have, but for department managers who must meet their productivity performance goals by running at full utilization, excess capacity can be a managerial headache. Unless resources are kept fully consumed, these department managers will

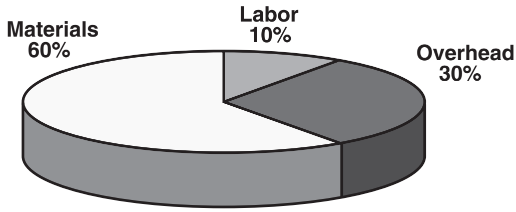


Figure 7.3. Materials: the most expensive element of product cost.

receive a negative variance from the controller's office declaring their unutilized capacity to be nonproductive. Meeting productivity and full utilization goals motivates department managers to waste resources by using their excess capacity on the production of unsold inventory. Materials are expensive. They're the most expensive component of product cost (Figure 7.3). Undisciplined, slow-moving buffer inventories that accumulate in traditional operating systems are costly to maintain and at risk for obsolescence. The activities associated with maintaining excess inventory add lead time and cost to a product, but do not change the *form, fit, or function* of the product being produced. Overproduction of products is non-value-added and considered *waste* in a Lean operating system.

Productivity and department managers: if manufacturing departments have limited capacity. Departments with less capacity than a feeding department have a much different utilization problem than departments with excess capacity. Instead of needing work to keep their resources productive, these managers have a reverse utilization situation. WIP inventory is always in queue waiting to be worked on. The solution for these department managers is to somehow increase the capacity of their departments so the queued inventory can be produced on schedule. Short term (unless a capital investment is received to increase the number of human or machine resources), the capacity of these departments can only be increased by adding extra hours and/or extra shifts. If the real capacity remains unchanged for the long term, these managers will constantly be requested to expedite and reprioritize production orders. Perpetual overtime costs are almost guaranteed because operating for extra hours is the only solution for addressing the capacity constraints. Overtime does not change the *form, fit, or function* of the product being produced. It's non-value-added and considered *waste* in a Lean operating system.

ACHIEVING BALANCE WITH LEAN MANUFACTURING

Lean manufacturing offers an alternative to the traditional operating system solutions. Instead of launching production orders from the planning system into manufacturing and then reprioritizing, rearranging, and regrouping these orders while building unsold inventory as the strategy for achieving the balance of capacities on the shop floor, the Lean operating system balances resource capacities *before* introducing customer demand into the factory. In a Lean environment, expediting and scheduling activities are a waste of time, human effort, and money. They do nothing to change the *form, fit, or function* of the product being produced. They should be eliminated.

Utilization. Lean manufacturing eliminates most of the non-value-added activities caused by the rescheduling and reprioritizing of production orders after they have been issued to the shop floor. Resources are balanced before a production order is issued. Balance is achieved by utilizing only the resources necessary to meet customer demand based on a statement of the daily rate of sales. Rather than operating at 100% capacity at all times regardless of the daily customer demand and shuffling production orders around to maximize utilization of resources, Lean does just the opposite. Lean matches the amount of resources assigned to a manufacturing area based on customer demand: demand = resources. Matching resources to demand often results in *intentional underutilization* of the available resources allocated to a department, which conflicts with traditional operating system performance measurements for resource absorption.

Factory layout. Instead of being organized into departments of like resources, Lean manufacturing processes are physically arranged in a layout based on the sequential flow of the standard work for a product. Often the layout mirrors the mixed-product PFD that details the sequential order of production for the products being manufactured (see Chapter 6). The processes necessary to produce a product are physically located adjacent to one another so that the output of one process is consumed directly into the next downstream process with little to no wait or move time. The manufacturing processes are divided into groups of work equal to a Takt time so that all processes complete their output at the same rate. The number of groups of equal amounts of work is dependent on the standard work content time of each process. This causes the rate of completion to be balanced. Units completed at each process spend little to no time waiting to be worked on at the next process. Grouping similar labor and machines into departments is no longer necessary. Only the resources required to produce the demand are located on a Lean line. Figure 7.4 illustrates a typical Lean line factory model. Excess resources not required for relocation to the Lean manufacturing line are available for the production of any other products not being produced on the lean line.

Labor resources. On most days, the mix and volume of products required by customer demand will likely be different from the quantities used for the initial

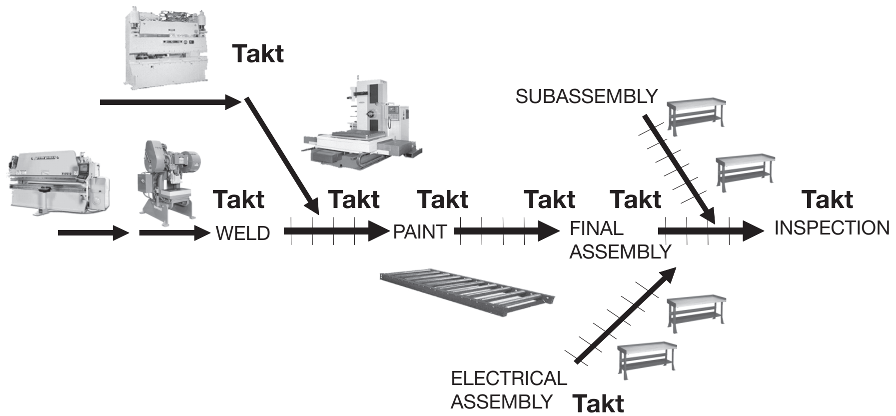


Figure 7.4. A typical Lean factory model.

design of the line. The standard work of each product in each process may also be different. If the mix, volume, or standard work changes, redesigning a Lean line is unnecessary. Although the machine resources on a Lean line are inflexible, when daily requirements change, the human resources on a Lean line can be changed. Only the human resources are flexible enough to meet changing daily demand requirements. The human resources required to produce the products at the Takt rate can be changed. Depending on customer demand on any given day, the daily headcount on a Lean line is variable. Only the number of human resources necessary to meet demand is assigned to the Lean line on a given day (which may result in using fewer resources than the number currently assigned to the department). Figure 7.5 illustrates a balanced Lean manufacturing line.

The ability of the Lean system to assign only the labor resources needed each day to match customer demand challenges current utilization measurements. Current utilization performance measurements are static based on the number of labor and machine resources already assigned to a department. Planned output is based on the full utilization of available capacity. If the available capacity is in excess of customer demand, but the capacity remains fully utilized, then the result can only be unsold inventory. Lean manufacturing discounts the traditional utilization measurement. Lean performance measures do not include utilization as a key performance indicator. Instead, Lean manufacturing performance measurements emphasize quality, response time, and process linearity. As a performance measurement, the underutilization of resources not required to meet daily customer demand is of no consequence.

Production. Products on a Lean line are manufactured one unit at a time at a Takt rate based on an order sequence established by a planner. This physical

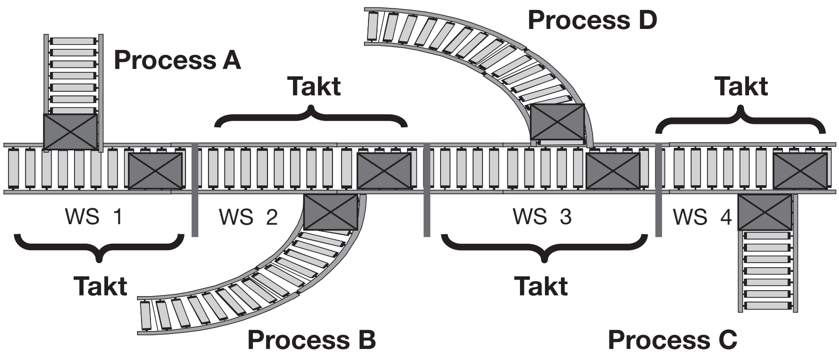


Figure 7.5. A balanced Lean manufacturing line: resources are linked and balanced to produce one unit at a time.

linkage of orders to resources permits work tasks to be distributed, accumulated, and balanced evenly throughout the entire series of manufacturing processes. Each process completes its standard work at the same output rate. As a completed unit of product is consumed by a customer, the entire line ratchets another unit downstream through each process in response to the demand to replenish the consumed unit. This sequential building of one unit of product every Takt time for the duration of available minutes each day results in the daily customer demand being packed off one unit at a time from the last process every Takt time. Even though the Takt time for each process might be different based on process volume, a Lean line is designed so all processes complete standard work at the same speed. Lean lines are often referred to as *flow lines* because products are produced one unit at a time and at the same rate, resembling liquid flowing through a pipe.

Capacity utilization. Lean methodologies approach the utilization of available capacity differently than traditional planning system models. The layout design for a Lean manufacturing factory is done only once. The amount of resources is determined by dividing SWD labor and machine times into groups of work equal to a Takt time. A series of mathematical modeling calculations determines the number of resources needed to meet the designed V_c. These calculations ensure that the optimum number of resources and staff are assigned to each process to meet current demand expectations of the V_c. The calculated resources must also ensure that a capacity sufficient to meet customer demand 1 to 3 years into the future will be available to the line. Once the number of resources is known, the facility is physically rearranged so that the output of each resource is physically located next to the downstream consuming process. Once the Lean line is designed with sufficient resources to meet the designed capacity, using only the number of resources required to satisfy a single day of demand is necessary. All resources work at the same rate based on the process Takt time. Batching or grouping work to achieve efficiency and utilization by an individual department is unnecessary. Individual departments no longer exist on a Lean line. There is only one department in a Lean factory — manufacturing. Planning system-generated shop orders are no longer required to schedule a Lean line. Only the sequencing of demand according to preestablished customer priorities is necessary. No production order is required to authorize work. Lean manufacturing concentrates on meeting daily customer demand with the required resources to complete the standard work using an in-process kanban signal to authorize an additional Takt time amount of work. The standard work content to be completed for any product is designed into the Lean line. When a customer's product enters the Lean line, the standard work will be applied cumulatively through each Takt time until completion. Achieving departmental efficiency, utilization, and absorption goals is secondary to achieving customer satisfaction.

Inventory management. If a manufacturing line is not constrained by imbalanced departments, WIP buffer inventories cannot accumulate. Only a single unit of production at a time ratchets through all the processes and is packed off the end of the line. Wait and queue times required for the normal routing of products in batch-size quantities through the various manufacturing departments is greatly reduced or eliminated. Once manufacturing resources are balanced and physically linked together and manufacturing is in a preset sequence, products are produced on a FIFO priority sequence. Shuffling, expediting, and utilization enhancement activities for production orders are no longer necessary.

Determining the Amount of Resources Needed Using Takt Time

Resources are defined as people, workstations, machines, and inventory. A *people* resource is an operator who manually touches the product and performs a Takt time amount of work. A *workstation* resource is a physical location on the shop floor (the footprint) where an operator completes a Takt time amount of work. A *machine* resource is a device in which the work content cycle time is equal to or less than the Takt time. Machines are considered to be a homogeneous process if they perform the same function at the same cycle time, e.g., stamping. Machines that perform different functions are considered to be a stand-alone process, e.g., drill, grind, form, or weld. An *inventory* resource is the amount of inventory needed to offset imbalances in processes in which the standard or cycle time is greater than the Takt time. Inventory can be used to maintain the targeted Takt time when a process is incapable of achieving the Takt time rate.

Takt time establishes the production rate of a process. The goal of a Lean manufacturing line is to complete one unit of production from every process in its predetermined Takt time. As a unit of production is consumed by customer demand, another unit moves downstream through each process until a product is completed. Standard work times can vary greatly from one process to another. For example, more standard time is required for a person to build a motor assembly in a feeder process than to mount that motor with four bolts onto a frame in the final assembly process. No two processes are exactly the same. No two processes require an identical amount of standard work time for completion. If a process requires standard work content greater than its Takt time, the required work can only be accomplished within its Takt time target by adding more resources. The number of resources required to complete the standard work in its Takt time target can be determined by dividing the standard work of the process by the desired output rate of the process (Takt time). Each resource within a process is the amount of standard work tasks equal to or less than the Takt time: one resource = one Takt time. Standard work assigned to a specific workstation is the basis of the concept of *standardized work*.

Resources and Lean. Obviously, a product cannot be produced if the correct number of operators is not available to staff the workstations to complete the standard work required for the product. If too many operators are assigned, productivity will be sacrificed. If too few operators are assigned, the customer demand for that day cannot be competed in the required Takt time target. In a Lean environment, only the exact number of operators needed to meet customer demand that day is assigned to the line: workstation staffing is determined daily based on customer demand. During the initial line design of the Lean line, the number of workstations required for future V_c was established, but the workstations set in place to meet future volume may not be necessary to produce a smaller volume required today. Because a workstation is an inanimate object, it must be physically located. In the Lean operating system, no rule states that a workstation must be staffed with a human resource every day. If daily customer demand is less than the designed volume of the line, rearranging or removing physical workstations daily makes little sense. Instead, adjusting the number of flexible labor resources assigned to the available workstations is a more logical solution, even though reducing the number of operators means that all workstations will not be staffed on that day. Matching labor resources to actual customer demand instead of the number of physical workstations will cause underutilization of those workstations, potentially generating issuance of a negative variance from the cost accounting group.

Two mathematical values are necessary to determine the amount of resources (people, workstations, machines, or inventory) required to complete the standard work content within the Takt time target for each process identified on a PFD: SWD time and Takt time:

SWD time ÷ Takt time = the number of resources

Remember: SWD time is a measurement of *standard time* and Takt time is a measurement of *rate*.

The numerator. Standard time identified on the SWD for the process required is the numerator (Figure 7.6). SWD time is the sum of *all* labor work, including the non-value-adding time of dynamic setup, rework, move, and any quality criteria inspections. Regardless of the type of work being done, until non-value-added work is eliminated through process improvements or kaizen activities, human and machine resources are still required to do the work. Summing the non-value-added times with the value-added time elements for each process defines the total work content time for a specific product and process combination. Additional factors affecting throughput volume per process are scrap, rework, and options.

The denominator. Takt time for a process is the denominator of the resource calculation. Each process has its own Takt time based on throughput volume. Takt time is a time/volume relationship. Takt time is calculated by dividing the amount of time available to perform work each day by the desired throughput volume of each process. Takt time will be different for every process where the throughput volume of the process is affected by scrap, rework, or optionality. Takt establishes the rate at which a process must complete one unit of production to achieve the designed V_c output. Although the calculation is the same, machine times are calculated separately from labor processes. Labor work content time cannot be co-mingled with machine time because each one can have a separate cycle or standard time for the same process.

This basic formula uses the standard times from the SWD and solves for the number of resources required by defining the number of groupings of work that are equal to the Takt time. Grouping work into equal amounts of Takt time allows a Lean manufacturing line to be balanced to respond to the downstream consumption of one unit of production. Workstations balanced to a Takt time allow the placement of one unit of production into the adjacent downstream workstation at the same rate regardless of how much standard time is required to produce the product in an upstream process (e.g., a feeder process). This balance allows the entire Lean line to flow a product off the end of the line according to the Takt time for the line and permits all upstream processes to produce another unit of production in unison at a rate equal to the Takt time.

Process Name: Final Assembly
Product Part Number: Range Top Model 12

Standard Work Definition

Work Element			Work Content					Total Quality Management	
Order	**Description**	**Parts Consumed**	**Machine Setup**	**Labor Setup**	**Machine Run Time**	**Labor Time**	**Move Time**	**Check**	**Self-Check Description**
10	Obtain fixture from under conveyor			0.2					Fixture matches motor series number
20	Retrieve stator and place on fixture			0.8					Check shell for exposed metal, presence of all notches, and wires tucked in
30	Insert wire exit grommet	1253-B grommet				0.5			
40	Attach mounting bracket with one screw	6672 bracket 2042 screw				0.3			Install on wire exit side; screw gun set to **3**
50	Repeat 40 once	2042 screw				0.1			Screw gun set to **3**
60	Retrieve top shield and install with one screw	1068 screw				0.6			Bearing is greased and grease fitting is tight. Screw gun set to **5**
70	Repeat 60 once	1068 screw				0.1			Screw gun set to **5**
80	Insert rotor guide in stator			0.2					Screw gun set to **5**
90	Retrieve rotor and install in stator					0.6			Long side of shaft forward; check for free turn
100	Retrieve bottom shield and install with one screw	1068 screw				0.6			Bearing is greased and grease fitting is tight; Screw gun set to **5**

$\sum$ **STANDARD TIME PER UNIT**

Figure 7.6. Standard work time must include value-adding and non-value-adding times.

Table 7.2. Process Map with Standard Times for Six Different Products with the Same Process

Production Information		Standard Time per Product/Process							
Product	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	30	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	5		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	8	3.5		4.0	14.0	1.8	32.0	10.0	15.0

Factories with multiple products. Most manufacturers rarely make a single product only. They produce a wide variety of products having many options that may use different manufacturing processes. As each product moves through the same processes, having different standard times is not uncommon. Most companies therefore operate in a mixed-family environment by selecting a group of representative products with a variety of standard times to run on their Lean lines. Table 7.2 illustrates different products with different standard times for the same process. The resource calculation equation is straightforward, but resource calculations using only the discrete standard time for one product will likely not be accurate enough when producing a family of products. For a *mixed-model* Lean line, using the same group of products as selected to design the line and determining an *average* standard time per process for that product family is more accurate for determining resources. An average standard time per process based on the discrete observed standard times for a representative group of products yields a standard time that is more representative of the actual time of each product in each process. By definition, this average SWD time is unlikely to ever exactly match the actual discrete observed standard time. Using the same logic as when selecting the V_c for a family of products, the resulting average standard time will be representative of all products of a family that are produced in each process *most of the time* on the line. (Unlike V_c, which is estimated, standard work content time is a discrete observed time, but as with V_c, the goal of an average standard time is reasonable accuracy versus precision.)

Determining standard time for mixed-model production lines. Naturally, some products require more standard time to complete while others require less. The products chosen for the design of a Lean line were *representative* of all products to be manufactured on the line and an *estimated volume* was used as a statement of capacity, but unlike the decision process used to select representative products and volume, standard times are *discrete observed values.* For standard times, product and volume estimates are based on what happens in the factory most often. Actual standard times per product in each process are not subject to the same level of subjectivity allowed for choosing representative products and estimated volumes. Standard times are times observed as actual work is performed.

If, however, many products have different standard times, selecting a single time to use in the numerator of the resource calculation is impossible. Using the process map in Table 7.2, look at Process F. Which time should be selected for determining the number of resources for this process? The times range from 25.0 to 32.0 minutes. The best answer is not the fastest time or the slowest, but an average.

Now look at the volume of Product 6. The expected V_c is 8 units per day with a standard time of 32.0 minutes. If the line were designed using the highest standard time of the 32.0 minutes for Process F, along with predicted sales of only 8 units per day for Product 6, resource calculations for all 130 products would be determined based on a standard time of 32.0 minutes. The highest-volume product is Product 3. Product 3 has a V_c of 50 units and a standard time for Process F of 25.0 minutes. Using the higher standard time of 32.0 minutes in a resource calculation would overstate the number of resources required to produce the average mix of products listed in Process F. For example, if the average mix of products on a given day is Products 1, 2, 3, and 5, with standard times of 30.0, 27.5, 25.0, and 29.5 minutes, respectively, and these products are produced in a process designed for 32.0 minutes, each time a product having a standard time less than 32.0 minutes is produced, resources will be idle for 32.0 minutes minus the standard time of Process F for each of the other 117 products. The daily volume for Process F is 117 (Product 1 + 2 + 3 + 5 = 117 units). Each time a unit is produced, idle time is created 117 times during a work shift: 32.0 – 30.0 minutes (Product 1), 32.0 – 27.5 minutes (Product 2), 32.0 – 25.0 minutes (Product 3), and 32.0 – 29.5 minutes (Product 5). Idle time, of course, is *waste*. To make the average standard time as accurate and realistic as possible, the standard time to be used must be *weighted* to reflect the products produced most frequently based on the daily V_c of the products most commonly manufactured: average time is *weighted* toward the products produced most often. The revised average time is known the *standard time weighted* (STW).

Using a 435-minute day to produce a designed line capacity of 130 units, the Takt time would be 3.35 minutes. If the line has been designed using the highest standard time for Process F of 32.0 minutes, the number of resources would be based on the standard time calculation of 32.0 minutes ÷ 3.35 Takt, resulting in 9.55 resources or 9.55 people working at 9.55 workstations (resources/workstations = standard time ÷Takt time). The time required to build 130 units at 32.0

minutes = 4160 minutes. Using the shortest time for Process F of 25.0 minutes, the time to build 130 units at 25.0 minutes each = 3250 minutes. The difference is 910 minutes or the potential nonproductive time possible each day. Spread evenly over the 9.55 workstations on the line, these 910 extra minutes can result in 95 total minutes of idle time per 435-minute day at each workstation or 44 seconds for each of the 130 units produced each day. Instead of needing all 435 minutes at a Takt rate of 3.35 each day, the daily rate for 130 units at 25.0 minutes would require only a 340-minute day (3250 ÷ 9.55). With this scenario, 95 minutes each day would be lost productivity.

Operators have two options for utilizing this daily idle time of 95 minutes: use the 44 seconds to complete the production of 130 units of work in 340 minutes and be reassigned to another workstation (or go home) or slow their working pace by 44 seconds per unit so their output matches the required daily rate. For most operators, the most popular option is to slow the pace of work. Slowing the working pace is more difficult to detect by management. Each of these options reduces productivity, so neither option is acceptable.

Producing products at a steady rate throughout the day for the entire time of planned effective minutes is preferred. If the Lean line is designed using the shortest time of 25.0 minutes, the line will run too slowly, not only when producing Product 6, but also when producing all products with a standard time greater than 25.0 minutes. Based on the daily mix, Takt time targets will be missed and the output of daily customer demand will be jeopardized. On the other hand, forcing operators to work too fast will compromise quality. A line running too slowly or operators working too quickly will sacrifice optimum productivity and quality.

Humans are not machines and a standard time weighted will never be precise. When selecting a standard time representative of the majority of products produced, develop an *average time* for products using a combination of the high and low standard times with an average mix of V_c expected to be run daily. Perfect numerical productivity cannot be guaranteed, but the time spent selecting the best possible STW is worth the effort. Carefully establish a STW that minimizes idle time and lost productivity.

Representative products and times. When products were chosen for inclusion in the design of the line, the logic used was to select products and volumes representative of all potential products to be produced for the product/volume mix most likely to occur on any given day. The estimated product mix and volume were somewhere between precision and a high level of accuracy, even though estimates are insufficient when predicting customer demand on resources. What customers will buy on any given day cannot be predicted with 100% precision. A similar logic could have been used to choose a representative standard time for resource calculations, but for the mixed-model Lean line, a *weighted* standard time was used to complete the resource calculations for each process. A STW matching the projected mix and volume of products sold and produced most frequently in processes results in the best estimate of standard time for an average population of products, but will still never be 100% precise.

To weight the times, additional calculations are required for each process to establish the standard time weighted. Using the standard times and V_c from the process map in Table 7.2, STW is calculated as:

$$\frac{\Sigma V_c \times \text{SWD standard time}}{\Sigma V_c} = \text{STW}$$

where the numerator is calculated as:

Process F

Product 1	V_c 25	×	SWD 30.0	= 750
Product 2	V_c 30	×	SWD 27.5	= 825
Product 3	V_c 50	×	SWD 25.0	= 1250
Product 4	V_c 5	×	SWD 32.0	= 160
Product 5	V_c 12	×	SWD 29.5	= 354
Product 6	V_c 8	×	SWD 32.0	= 256
Σ	V_c130	×	SWD	= 3595

and the denominator is calculated as:

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

The STW is calculated as:

$$3595 \div 130 = 27.6 \text{ minutes}$$

and Takt time is calculated as:

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

Substituting the standard time used for the non-weighted resource calculation with the new STW, the number of resources for Process F is now calculated as:

$$\frac{\text{STW}}{\text{TAKT}} = \text{number of resources}$$

Rounded up, the number of resources for Process F is 9:

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

Determining Additional Information Using a Process Map

So far, a process map has been used to accumulate all of the necessary product, process, and volume information collected by the process and materials transformation teams to design the Lean facility. The same process map can now be used to capture additional information necessary for the design of the Lean line.

To document standard work times. The existing process map can now be expanded to document the standard work times from the SWD required for each product at each process. (Remember that the standard work times are *observed* machine cycle or labor times for one unit of production.) The process map can be used to multiply the individual standard work content time by the V_c factored by any volume modifier (rework, scrap, or optionality) previously documented for each product at a process. The sum of required work content times the volume of each product is used to calculate the STW (see STW calculations above). The STW is then divided by the Takt time to determine the number of resources necessary to produce the V_c for that process in the Takt time target. Table 7.3 illustrates a completed process map with the calculations used to determine the number of machine and labor resources required for each process to produce the stated V_c at the Takt rate.

To track the completion of tasks. A process map can also be used as a project management tool by a Lean champion to keep track of tasks assigned to individual process and materials team members. When a Lean transformation project begins and the teams have been identified, required project information is often deconstructed and assigned to individual team members for collection. As individual team members collect information about products, demand, processes, volume modifiers, and SWD times, the data can be posted in an appropriate cell on the process map. As the transformation project advances, incomplete information becomes more and more obvious simply by its omission from its corresponding cell. As team members complete their individual assignments, they can be reassigned to assist in the collection of information missing from the process map. The process map allows the focus of team member efforts to zero in on any remaining missing pieces of information. By concentrating on only the required and missing data, the valuable time of team members is optimized.

To document/validate information. A process map can also document and experiment with multiple iterations of information. Often, project discussions or new information will result in suggestions or alternatives to an original value on the process map. Using the process map as a spreadsheet, multiple iterations of information can be input and tested until the optimum solution is achieved. Returning to the original data, if necessary, is easy. Used as a planning device, a completed process map can test the impact of changes in mix or volume of products on manufacturing resources. Having future visibility of *what if* volumes can help with *make or buy* decisions and the timing for capital equipment expenditures. *What if* scenarios can also be tested by comparing projected sales increases to resource availabilities to project how many and when labor and machine resources should be increased. The resource calculator can be a communication linkage between the sales and marketing and manufacturing departments. These two diverse organizations can use the resource calculator independently to reconcile the production plan with a sales plan so both departments will be synchronized. The sales and marketing and manufacturing groups can validate that the available manufacturing resources can support the sales plan. By including a conditional response signal to volumes increases, the process map can also flag when new resources will be required to meet any future demand volumes and provide sufficient advance timing for negotiating the best contract for the company.

Remember: Standard time weighted is an *average of times* and Takt time is based on an *estimated product mix and volume*. These numbers are *averages* based on absolute values. Attempting to achieve precision when making rounding decisions based on an average quantity often yields diminishing returns for the effort expended. The averages are based on what happens on your shop floor most of the time and the decision to round up or down is subjective, based on personal knowledge and experience with a particular process. Because forecasting with 100% accuracy is impossible, erring on the high side when determining resources is always the best practice. Rounding up quantities of resources addresses several things.

How to handle fractional values. Having a portion of a person, a workstation, a machine, or complete inventory is, of course, impossible. Even if a resource calculation yields a fractional value of 0.1, *round it up* to the next whole number. If a fractional value is less than 0.1, the number of resources may be rounded down. Rounding down, however, translates into having *one less* resource with the remainder of resources calculated to exactly a Takt time. If a value is rounded down, the number of remaining resources will have little latitude for achieving the standard time in a Takt time target. Consider rounding down carefully. It's better to have too many resources than not enough. Resources can always be adjusted after a line is operating smoothly.

Table 7.3. Completed Process Map with Standard Work Times and Calculated Machine and Labor Resources for Each Process

Family Description	Part Number	V_c	Weld		Volume Modifier	Volume Modifier × V_c	Weld Rework		Volume Modifier	Volume Modifier × V_c
			Machine	Labor			Machine	Labor		
V5A	75903101	2.00	40	45	1.100	2.20	30	30	0.100	0.20
V6A	76000202	0.40	55	60	1.100	0.44	30	30	0.100	0.04
A4H	76102402	3.00	45	50	1.100	3.30	30	30	0.100	0.30
U5	76100002	2.00	55	60	1.100	2.20	30	30	0.100	0.20
805	72200002	4.00	40	45	1.100	4.40	30	30	0.100	0.40
806	72210002	6.00	35	40	1.100	6.60	30	30	0.100	0.60
T5AH	72208902	2.00	50	55	1.100	2.20	30	30	0.100	0.20
T5LOAH	70524102	0.375	50	55	1.100	0.83	30	30	0.100	0.08
S5	72208602	1.00	55	60	1.100	1.10	30	30	0.100	0.10
TM270	71801802	2.00	60	65	1.100	2.20	30	30	0.100	0.20
G3	70542002	5.00	45	50	1.100	5.50	30	30	0.100	0.50
G4A	70550402	2.50	50	55	1.100	2.75	30	30	0.100	0.25
		30.65				**33.72**				**3.07**

	Weld Machine	Weld Labor	Weld Rework Machine	Weld Rework Labor
Takt Time	**13**	**13**	**143**	**143**
Planned Work Minutes	438	438	438	438
Shifts	1	1	1	1
Throughput Volume	**33.72**	**33.72**	**3.07**	**3.07**
Weighted Time (STW)	**45.00**	**50.00**	**30.00**	**30.00**
Resources Required	3.46	3.46	0.21	0.21
Resources Available	5	5		1
Utilization	**69%**	**69%**		**21%**
	OK	**OK**		**OK**

Manual Input

Resources Required ÷ Resources Available

$$\frac{\Sigma V_c \times \textbf{SWD Std Time}}{\Sigma V_c}$$

Final Assembly		Volume Modifier	Volume Modifier × V_c	Custom Lights & Sound		Volume Modifier	Volume Modifier × V_c
Machine	Labor			Machine	Labor		
	330	1.000	2.00		215	0.400	0.80
	400	1.000	0.40		215	0.400	0.16
	360	1.000	3.00		220	0.400	1.20
	340	1.000	2.00		220	0.400	0.80
	360	1.000	4.00		260	0.400	1.60
	320	1.000	6.00		260	0.400	2.40
	300	1.000	2.00		260	0.400	0.80
	300	1.000	0.75		260	0.400	0.30
	400	1.000	1.0		260	0.400	0.40
	425	1.000	2.00		220	0.400	0.80
	360	1.000	5.00		220	0.400	2.00
	300	1.000	2.50		220	0.400	1.00
			31				**12**

14	**14**
438	438
1	1
31	**31**
0.00	**344.70**
0.0	24.1
	25
	96%
	OK

36	**36**
438	438
1	1
12	**12**
0.00	**237.55**
0.0	6.6
	7
	95%
	OK

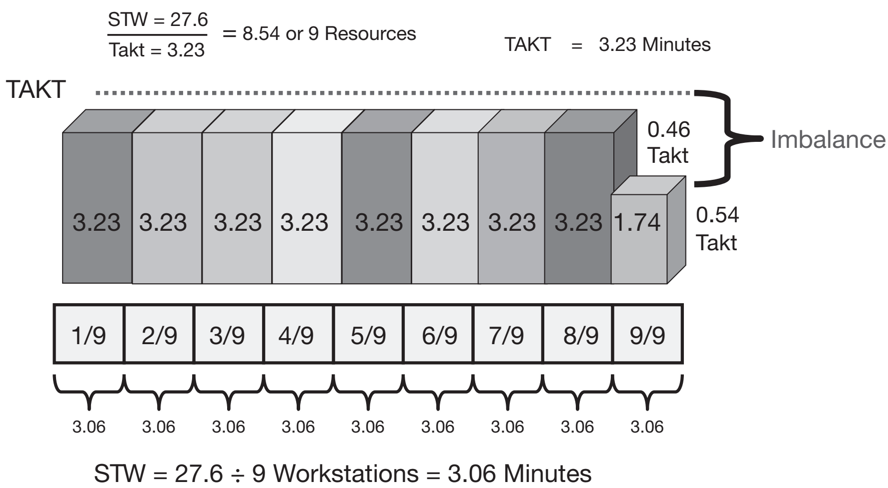


Figure 7.7. Imbalance spread over all workstations.

How to handle productivity concerns. A resource can always be removed, but adding a resource into the design of a factory line later can be difficult. The lowest component of product cost for most products is labor. There is no need to obsess over a few extra labor resources that are a result of rounding. The goal in the end is to make a Lean manufacturing line as successful as possible to produce a product in the Takt time target. Rounding up the number of resources can provide enough extra latitude to achieve Takt time targets, but still minimize excess idle time. Providing this latitude is particularly important when defining human resources. Humans are not machines. Their productivity can vary from day to day. The cost of one additional labor resource will have little effect on total product cost, but having one additional labor resource can make a huge difference when trying to achieve the Takt time target of a line. If the added resource proves to be excessive in the future, the resource can be reassigned with little or no effect on the daily operation of the line.

Figure 7.7 illustrates the balancing effect of a lean manufacturing line. If the STW of 27.6 is divided by the rounded up number of calculated resources, 9 in this example, the resulting standard work assigned to each of the 9 work stations becomes 3.06 minutes (27.6 ÷ 9 = 3.06 minutes). This time is less than the Takt time target which remains at 3.23. By spreading the STW over the rounded up number of resources, the imbalance of 1.74 minutes (0.54) is evenly distributed across all workstations. The difference in time provides extra seconds to the operators, helping to ensure that the Takt time target will be met. In this example, 9 workstations – 8.54 calculated resources = 0.46 of one Takt time or 1.48 minutes.

The 1.48 minutes ÷ 9 workstations = 9.8 additional seconds at each workstation. These 9.8 seconds still represent lost productive time each day at each workstation, but until the 0.54 of Takt time at workstation 9 can be eliminated through kaizen or an improvement project, the Lean line will still be successful. In the long term, the best alternative is to eliminate the 0.54 of Takt time (1.74 minutes of standard time) using kaizen to reduce the number of workstations to exactly 8.

Remember: Assigning *only* the resources needed to produce customer demand within the Takt rate is a key strength of the Lean operating system. The number of resources required to produce customer demand must therefore be determined for *every process* identified on the process flow diagram. When complete, the results of these resource calculations will be expressions of the amount of resources needed per process to produce the V_c in the established Takt time rate. Offsetting unequal standard work times using resource modification is a simple technique that achieves the balance in a Lean operating system. Consider the value of being able to complete all manufacturing processes required to produce a product or subassembly at the same time! Using only minimum resources avoids the production of WIP and FGI inventories. Also do not forget that using only the minimum resources required to meet a volume requirement will challenge the traditional performance measurements of utilization. Until the 1- to 3-year V_c is reached, lower customer demand will always require fewer resources than initially designed into the line to meet the higher future sales volumes.

The Lean approach versus the traditional approach. When comparing a Lean operating system to the three manufacturing paradigms used in traditional planning systems, the ability of a Lean system to adjust manufacturing resources to match customer demand is a major difference between the two systems. Because standard work content is assigned to the individual workstations, flexible labor resources can be trained to move to different workstations as needed to complete the standard work. In traditional planning systems, the standard department structure provides the platform for performance tracking and cost accounting purposes. In a Lean operating system, however, individual departments are not needed to track performance. Performance tracking is done for the entire Lean line as a single unit. Only the *resources required to produce the daily customer demand* are assigned to a Lean line. Excess resources not needed for the production of customer demand are assigned to other production requirements. There is no need to size batches to maximize the utilization of a department, route batches from department to department, or to create buffers of unsold inventories to offset fluctuations in capacity or customer demand. All of the resources required to produce the V_c are in place on a single Lean manufacturing line. A variety of mixed-model products can be produced on this single line sharing these same resources. Each day, a schedule for the number of units to be produced that day, up to the V_c, is developed based on the quantity of products that customers have ordered. The schedule can be different each day based on varying customer demand. There is no need, however, to change the physical factory layout. The line remains the same as designed: the number of workstations remains static; only the number of human resources staffing the line is changed to match a change in customer demand.

Balance. Balancing the standard work assigned to a workstation is critical for producing a product in its work content time. A traditional planning system assumes wait and queue times are automatic. Therefore, they are built into manufacturing response time when production orders are routed through departments in batches. As standard work is balanced and assigned to a workstation on a Lean line, the non-value-added elements of wait and queue time are eliminated from manufacturing lead time. Balanced workstations complete work at the same rate, advancing products through each workstation without the need to stop and wait in a queue. Products accumulate the standard work assigned at each workstation until all of the standard work has been completed and the finished product exits the last workstation. By not stopping to wait or build up in a queue, products are completed in only the sum of their *touch* work content time. Completing products in the sum of their work content time results in significant lead-time reductions compared to routing batches of products through the factory. As greater balance is achieved allowing products to flow at the same rate through all processes in manufacturing, WIP inventories serving as a buffer for capacity variations between departments shrink. If the sum of work content time is less than the customer-quoted lead time, the need for buffer FGI inventories can also be reduced or eliminated altogether. As products flow from one process to the next, units of production are consumed immediately in the next production workstation. There is no wait or queue time: the accumulation of inventories is prevented. Overhead costs are reduced by eliminating expediting activities, material shortages, and numerous planning system transactions. As products spend less time in the manufacturing processes, customer-quoted lead times become shorter and shorter. Because work in every process is balanced using a Takt time derived from required throughput volume, small variations in the standard times of different products in different processes have little impact on the ability of a Lean line to manufacture a diverse mix of different products.

Assigning the correct number of resources to all processes so that the Takt time target for each is met is critical. A Lean operating system seeks to achieve the Takt time target for each process. Mathematic calculation of the resources for each process identifies the ideal amount of resources needed to achieve each Takt time target. Too many resources results in waste; too few resources causes Takt time targets to be jeopardized. The ideal ratio of resources to demand is demand = resources.

Defining the Types of Required Resources

After the amount of resources needed to produce customer demand has been calculated and assigned to the process, the types of required resources must be defined. Remember the four types of resources: people (operators), machines, workstations, and inventory (used to offset resource imbalances). A workstation is a physical location on the shop floor where standard work is performed. A workstation is required for each defined labor resource. Each operator must have a designated location where the Takt time amount of standard work can be completed.

People. If the standard time used to determine the amount of resources is the labor time from the SWD, then the human resource calculation establishes the number of people required to complete a volume of standard work in the Takt time target. The initial resource calculation provides a *sanity test* of the accuracy of the labor resource observations and is an early indicator of productivity opportunities. The calculated labor resource headcount (number of people) for the projected future volume of a Lean line should be in proportion to the current headcount at the current volume. For example, if the current production is 100 units per day and the current headcount is 60, then an increase in V_c to 150 units for the Lean line should require an approximate increase in headcount to 90 persons. Comparing the current actual headcount to a future projection of labor resources helps to validate the results of the resource calculations. Because the resource calculations use pure work content from the observed SWD time, a *reduced* proportional head count number is often reported when compared to today's actual headcount. Other factors that affect headcount, such as efficiency and personal fatigue and delay, are not present in the raw resource calculation. While these factors can modify the final resource count (workstations and people), it is best to begin the design of the Lean line with a pure unadulterated resource number to serve as a goal for identifying only the value-added work required for operation of the Lean line. Do not dismiss wide fluctuations in headcount/volume comparisons. A large variation may suggest that a review of the SWD times or the V_c projections may be needed. Human resources in excess of the required resources for a process are a preliminary indicator of a productivity opportunity for that process. Once the SWD times and V_c have been validated for accuracy, summing the number of required human resources for all processes and comparing the results to the existing headcount for those same processes can indicate which processes have the largest proportion of non-value-added time. Inefficiencies for those processes requiring excess resources can then be prioritized for future kaizen activities. When the standard times for an SWD are documented, factors causing inefficiency are not included. An SWD assumes 100% productivity with no time allowed for personal fatigue and delay. Although humans are not machines and experiencing some amount of inefficiency is a realistic expectation, *no inefficiency factors* should be factored into the standard time resource calculation at this time because this calculation will become the *baseline* for future productivity measurements. The initial calculation should be *unaffected* by the subjectivity of personal fatigue and delay factors. Later, if needed, 100% standard times and the final resource calculation result can be increased by a realistic, carefully considered productivity factor to compensate for human inefficiency. Remember, increased resources always add costs to a product. Always consider adding resources very carefully.

Workstations. A workstation must be a designated physical location where human resources are assigned to complete a Takt time amount of standard work. The resource calculation simultaneously defines the required number of human resources and the number of physical workstations. Each human resource requires a physical work location at which they can perform the standard work defined for that particular process. Although individual workstations are a one-to-one match to the number of human resources, workstations may take various forms. For example, if the process is *Assembly* and the product is a kitchen appliance, one workstation could mean one workbench, while another might be a length of roller conveyor sized to the product being produced. Other workstation examples include a ball transfer table or a series of burn-in stations. For larger products, a workstation could be a painted space on the shop floor that is sized to the dimensions of the product. Depending on the product, the manufacturing process could also be a combination of several different types of workstations. The total number of workstations must still match the total number of human labor resources calculated for each process. A workstation must also be placed as close as possible to the next downstream consuming workstation so non-value-added move time between both workstations is minimal or nonexistent. As part of final line design layout, each workstation must be defined by its physical attributes and the dimensions of its footprint on the shop floor. Allowing for ergonomics, optimize the amount of valuable shop floor used and minimize the need for an operator to take extra steps when flexing between workstations. Make every effort to keep the footprint of a workstation as small as is practical based on the size of the product being produced. For example, if the physical dimension of a product is 12 inches wide and 6 inches deep, a 6-foot-wide workbench and the shop floor square footage it requires is unnecessary. Not even considering the wear and tear on the operator by the end of the day, the extra 5 feet is simply excess space that requires movement of 2.5 to 4 feet in each direction, left and right, every other

Takt time, throughout the day, to reach the upstream or downstream workstation. If the V_c is 100 units, this unnecessary activity must be repeated 100 times per day, resulting in wasted movement 100 times a day. In Lean manufacturing, the extra shop floor space used and the repetitive non-value-adding movement of the operator is nothing but *waste*. Even though the company may have numerous workbenches available to the Lean reconfiguration, sizing a workstation to a product may reveal that one workstation ≠ one workbench. For the 12-inch product, two workstations could be created by painting a line down the middle of a 6-foot-wide workbench. The line separates the workbench into two 36-inch-wide workstations that will still comfortably accommodate the 12-inch physical size of the product. Two workstations can now occupy the same shop floor square footage space as the single workbench/single workstation did before. Similarly, if the product is 6 inches in depth, then the space required for a 36-inch-deep workbench would be unnecessary. Workstations must be sized so they are comfortable for the operators using them, but the shop floor space can be greatly minimized by designing the size of workstations to match the size of the work to be performed. Excess workstation space is wasteful. It consumes the valuable square-footage footprint on a shop floor. Consider the financial value of a square foot of shop floor when designing workstations. If the company had to buy or lease the space, what would be the cost for a square foot of factory shop floor space? How much cost (square footage) can be avoided by appropriately reducing the size of workstations to match the size of the work? How much setup and move time could be eliminated by designing minimum-sized workstations and placing them next to one another?

Machines. If the SWD time for a process is for a machine, the resource calculation will determine the number of machines required to produce the designed volume and meet the Takt time target. The number of required machines can be calculated in the same way as human resources and workstations are calculated, without the need for a weighting factor. The cycle time of a machine is always the same. Just as labor resources have a footprint on the shop floor, a footprint must be determined for each machine. The footprint of a machine must also include the footprint of any support equipment, including any ancillary tables, benches, die carts, etc. needed to operate the machine. If the amount of required machine resources exceeds the number of available machines, then additional machines must be added. Machine resources are expensive resources. Purchase of an additional machine includes not only the machine itself, but also multiple cavity dies, workstations, and additional inventory. Additional shifts may be necessary. Unlike the relatively simple act of hiring a human resource, procuring additional machines requires an investment of real capital. As part of final line design layout, the physical footprint of all required machine resources must be located, even if an actual machine has not been received from a supplier or if a machine is projected to enter service at some time in the future. Lean methods can only determine the amount of machine resources required to achieve a Takt time target. Lean methods can make a machine as efficient as possible, but capacity cannot be created where none exists. If acquiring additional machine resources is not an option, then another method to achieve the balance needed to achieve Takt time with an existing machine is to maintain additional inventory to accommodate the difference between Takt time and the cycle time of the machine throughout the day. This solution not only requires additional inventory, but it also requires time to produce the additional units and management time to maintain the inventory.

Inventory. Inventory is an expensive resource. Maintain only the minimum amount of inventory necessary to overcome an imbalance. Selecting the minimum amount of inventory necessary to maintain Lean line production is determined by using a resource calculation. This resource calculation uses the cycle time of the machine process as the numerator and the Takt time of the process as the denominator. The quotient is the number of units of inventory required to ensure that the Lean line continues to flow at the Takt rate. To determine the amount of inventory required to offset imbalances:

$$\frac{\text{Cycle time of machine}}{\text{Process Takt time}} = \text{number of units of inventory}$$

Figure 7.8 compares a dynamic machine to a static machine. It illustrates the impact on inventory by each type of machine.

Inventory for a dynamic process. The machine process of *Paint* is totally automated. A cycle time of 60 minutes is required for one unit to continuously travel the conveyor length through the robotic paint and drying tunnel. This type of process is defined as *dynamic* and describes units continuously moving through a process (Figure 7.8). As an upstream operator hangs one unit on a hook on the conveyor at a rate of one unit per every Takt time, another downstream operator removes a completed unit from the conveyor every Takt time. With a cycle time of 60 minutes and a Takt time of 3 minutes, 20 units of inventory (resources) are required to offset the imbalance of Takt time to machine time for the *Paint* process. For the *Paint* process to achieve the 3-minute Takt time, 20 units of additional inventory must be hung on the hooks attached to the moving conveyor. The speed of the conveyor is adjusted so each paint hook is spaced to exit the *Paint* process every 3 minutes. Even though each individual unit requires 60 minutes to travel the distance through the *Paint* process, 20 units of inventory must remain in the paint tunnel to support the 3-minute Takt time.

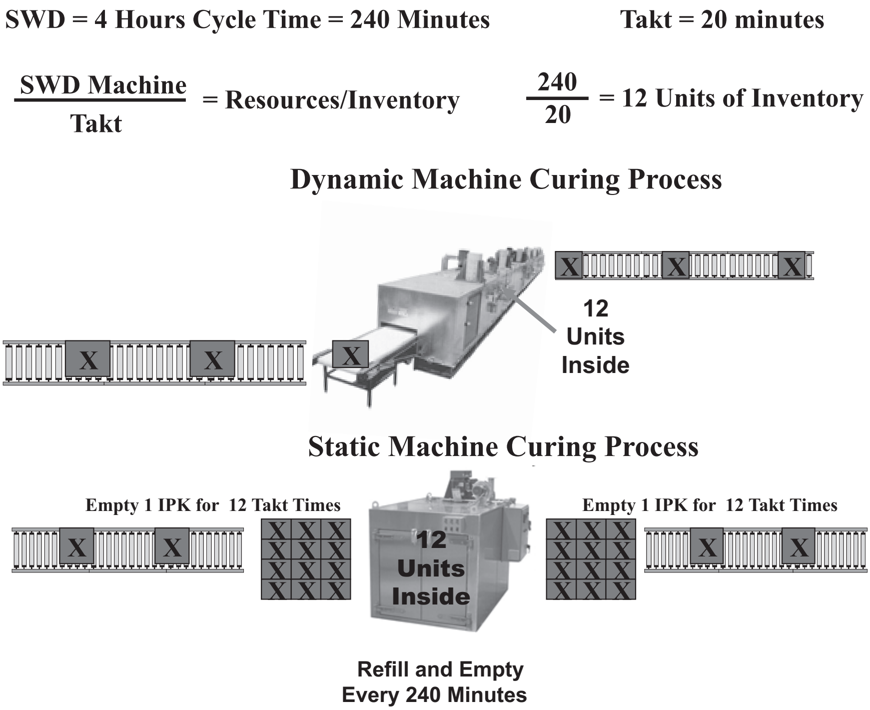


Figure 7.8. A dynamic machine versus static machine: impact on inventory resources used to offset machine cycle time.

Inventory for a static process. Another common machine process is *Burn-in*, which is similar to processes used for quality procedures. The type of machine used for *Burn-in* is considered to be a *static* machine. Unlike a dynamic process, units in a static machine do not move during processing (Figure 7.8). If the *Burn-in* process is 60 minutes with a Takt time of 3 minutes, the units of inventory would be 60 ÷ 3 = 20 units. The inventory amount is the same as for the dynamic *Paint* process, but the static machine will require *twice as much* inventory to keep the Lean line flowing at Takt rate. The machine time indicates that 20 *Burn-in* stations or connections are required and the process has been validated that all 20 units must be started at the same time. The 20 units necessary for the *Burn-in* process will therefore require an additional 60 minutes of queue time to accumulate at a Takt rate of every 3 minutes before sufficient units will be available to be placed into the *Burn-in* stations. Once these 20 units have been accumulated, they can be moved into the *Burn-in* station and the 60-minute cycle time can begin processing. Before the 20 new units can be placed in the static machine to begin the 60-minute processing time, the now completed machine load of the previous 20 units must be removed from the machine to be available for consumption downstream at the 3-minute Takt rate interval. During the 60-minute processing time of the static machine, one unit of inventory is consumed every 3 minutes reducing the queue at the downstream workstation while, at the same time, one unit of inventory is being added to the queue every 3 minutes at the upstream queue. At the Takt rate of one per 3 minutes, 60 minutes is required to exhaust the downstream queue of 20 units while replenishment of the upstream queue of 20 units requires the same 60 minutes at a Takt rate of every 3 minutes. Throughout the day, while 20 units are being processed in the static machine every 60 minutes, 20 units of additional inventory on either side of the static process are being accumulated upstream every 3 minutes while a unit is consumed every 3 minutes downstream. Because an upstream and downstream queue inventory is required to balance the 60-minute cycle time to the Takt rate, the inventory quantity for the static machine is therefore double what is required for a dynamic process. The static machine process requiring the loading and unloading of inventory queues repeats itself every 60 minutes throughout the day. Never is the *form, fit, or function* of queue inventory ever changed. The value of these 20 units of inventory in the upstream and downstream queue is considered *waste* by Lean. Not only is this inventory resource expensive, but space is also needed on the shop floor to park this inventory. Movement and handling of inventories by planners and material handlers is also required: inventory = cost.

Assigning the Standard Work to Workstations

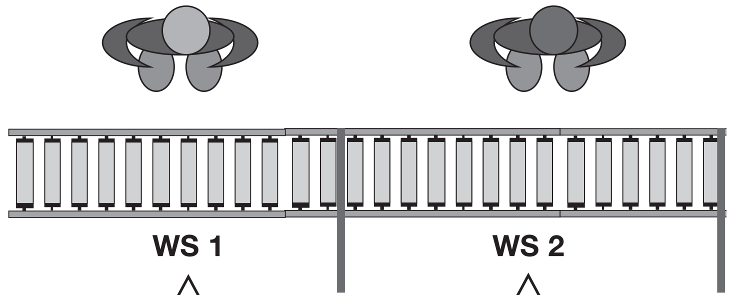
The SWDs document the sequential tasks for completing the work of each process. Once the number of workstation resources has been determined, specific work tasks from the SWD to be completed at each workstation, along with the quality inspections identified for each workstation, can be defined. We already know that in a Lean operating system, each workstation performs an assigned series of standard work tasks equal to the Takt time for the work. We also know that assigning standard work tasks to a designated workstation is the only way to achieve the balance that a Lean operating system requires to run at a measured rate. When a Lean system begins operation, each workstation must complete only the work tasks assigned to that particular workstation: nothing more, nothing less. The individual work tasks assigned to each workstation are defined by summing both the value-added and the non-value-added work content time elements of the sequential tasks listed on the SWD until an amount of work equal to (or close to) the Takt time is identified. Once balanced to its Takt time, all workstations complete work at the same speed, with each workstation sequentially adding a Takt time amount of work to a unit of production until a completed unit exits the last workstation. A Lean line therefore indexes one unit through each process one unit at a time at the Takt rate. Balanced workstations allow a Lean line to *flow* from one workstation to the next, throughout the day, and to meet daily customer demand in the *effective* minutes per day. Figure 7.9 illustrates a Takt time of standard work assigned to each workstation using the SWD.

Balancing the Standard Work at Workstations

Perfect balance is the ultimate Lean nirvana. Perfect balance is the goal of a Lean operating system. Unfortunately, the real world is never perfect. Workstation balancing is rarely an exact science. When standard work is assigned to a workstation, breaking standard work precisely at a Takt time is often difficult. Sometimes work cannot be stopped mid-completion (a minimum element of work is a tenth of a minute) and sent to the next workstation. If perfect balance were achieved, all non-value-added work would be eliminated, work standards would be so absolute that operators could be totally repetitive, and all work tasks on the SWD would be *fail safe* with no need for quality inspections. This, of course, would be a perfect world! Even though perfect balance may never be achieved, every effort to achieve the goal of perfect balance should be the focus of all continuous improvement and kaizen activities in the future. Figure 7.10 illustrates unbalanced standard work within a process requiring a series of workstations.

Although it may be impossible to attain perfect balance in all processes, five simple techniques can be used to overcome *minor* imbalances in workstations. These techniques should be the foundation for all future continuous improvement and kaizen projects. The techniques should be completed in a sequential order based on their *cost of implementation*. The least-cost solution is identified as technique 1. All efforts to resolve an imbalance should be exhausted using technique 1 before proceeding to the second or the third technique, and so on. Starting the balancing exercise with technique 1 is not only the lowest-cost solution, but it should also be the simplest solution to implement. Begin each imbalance resolution activity with technique 1 and progress through each additional technique in sequence until an imbalance is resolved.

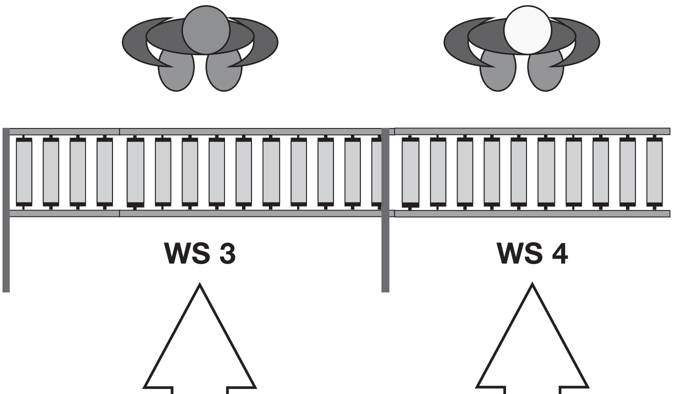
Technique 1: Look for work content that can be reduced or eliminated. Many work tasks listed on a SWD have been identified and documented separately as non-value-added tasks. Even so, operators are still required to perform these tasks as a part of the Takt time amount of work assigned to the workstation. Setups and moves are *always* candidates for elimination. Quality inspection work is also a candidate for elimination. These tasks have been documented on the SWD. By using kaizen techniques, along with improvements that reduce the work content itself, the elimination of non-value-added work tasks reduces the *elapsed time* required to complete a process. Elimination of non-value-added work also reduces the total *work content time* of a process, its cost, and ultimately,



Process Name: Final Assembly		Standard Wor nitions		
Product Part Number: Range Top M 12				
Work Element			ork Content	
Order	Description	Parts Consumed	ine up	Labor Setup
10	Obtain fixture from under cor			0.2
20	Retrieve stator and place on e			0.8
30	Insert wire exit grommet	1253-B grommet		
40	Attach mounting bracket with one screw	6672 bracket 2042 screw		
50	Repeat 40 once	2042 screw		
60	Retrieve top shield and install with one screw	1068 screw		
70	Repeat 60 once	1068 screw		
80	Insert rotor guide in stator			0.2
90	Retrieve rotor and install in stator			
100	Retrieve bottom sheild and install with one screw	1068 screw		

Standard Time (W) ÷ Takt = Number of People and Workstations

Figure 7.9. Takt time of standard work assigned to each workstation using the standard work definition.



Standard Work Definitio				
Wo ntent			T Quality Control	
Machine Run TIme	bor me	Move Time	TQM	-Check Description
				F e matches motor series n er
				C shell for exposed n presence of all n s, and wires tucked in
	.5			
	.3			I on wire exit side; S gun set to **3**
	.1			S gun set to **3**
	.6			E g is greased and g fitting is tight; screw g t to **5**
	.1			S gun set to **5**
				S gun set to **5**
	0.6			L ide of shaft forward; c for free turn
				E g is greased and g fitting is tight; screw gun set to **5**

= Takt

= Takt

= Takt

= Takt

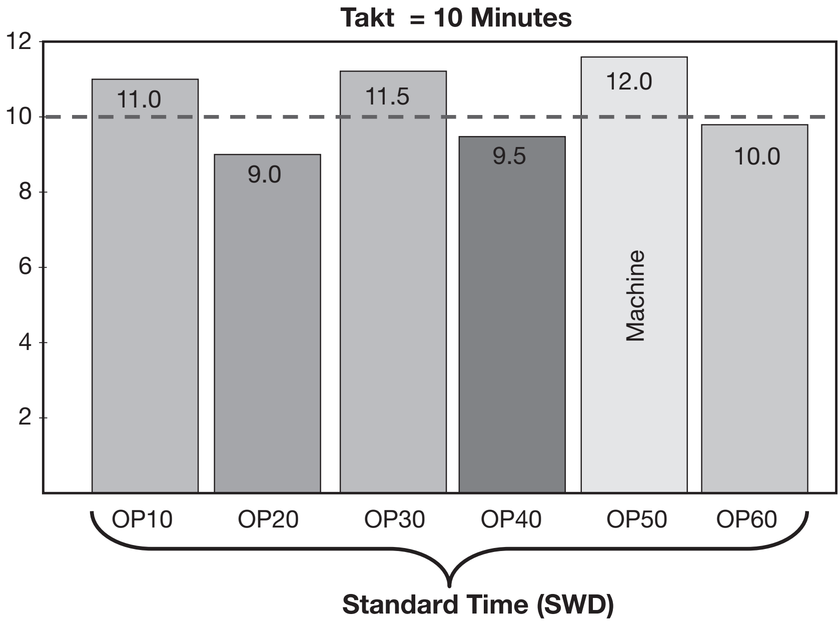


Figure 7.10. Unbalanced assigned standard work and Takt times in a process having a series of workstations.

manufacturing response time. The cost of implementation required to reduce or eliminate work at a workstation is small or nonexistent. Only the creative energy of an operator or kaizen team members is required. Because the cost-to-benefit ratio of reducing or eliminating work can be significant, always use the technique of identifying work that can be reduced or eliminated as the first effort in balancing the standard work content of a workstation.

Technique 2: Relocate work from one workstation to another workstation. Relocating work is a very common technique for achieving workstation balance. It is a common practice in traditional manufacturing systems. Using the SWD as a guide, relocate work by reassigning individual work tasks from one workstation to another, ensuring that relocation of the work is technically feasible and does not adversely affect quality. Most of the time, little or no cost is incurred. Relocation is simply a matter of moving a task from one workstation to another. In some cases, costs such as adding a fixture, a jig, or some other type of equipment may be necessary. Relocation of component inventories to the new workstation may also be required.

Technique 3: Add inventory to an imbalanced workstation. If the first two techniques for eliminating a process imbalance have been exhausted, escalation to the third balancing technique of adding resources as a buffer to maintain the Takt time of the process is required. Imbalance at a workstation can occur in both labor and machine work tasks. Imbalance is caused when the standard time of a process is greater than the Takt time. If the resource constraint is labor, adding an extra labor resource (operator) is a simple solution. When the imbalance is caused by a machine resource, units of additional WIP inventory may need to be placed on either side of a workstation to overcome the imbalance. Adding resources of any kind always increases cost (resources = cost). Exercise caution when making a decision to add resources, especially inventory. If the addition of inventory to buffer an imbalance is necessary, be certain that all efforts to eliminate the non-value-added work or to relocate the work have already been completely exhausted before choosing to add resources as a solution to the imbalance. Adding additional inventory at the workstation often means that additional production time will also be required to manufacture additional units for inventory. These added units must be maintained as extra IPKs, upstream and downstream of the imbalance, to create signals for replenishment and signals for when to stop making units (see Figure 7.8). If adding resources is the next-best solution for overcoming imbalance, avoid the temptation of guessing at the correct amount of inventory to be kept at a workstation. A formula can be used to determine the correct amount of IPK inventory to be added to an imbalanced workstation:

$$\text{Inventory} = \frac{\text{workstation minutes}}{\text{Takt}} - \frac{\text{workstation minutes}}{\text{STW}}$$

$$\frac{438}{10} - \frac{438}{12} = 43.8 - 36.5 = 7.3 \text{ or } 8 \text{ units}$$

$$\text{Time} = \text{STW} \times \text{inventory} = 12 \text{ minutes} \times 8 \text{ units} = 96 \text{ minutes}$$

The calculated number of IPKs must be placed at the upstream side *and* downstream side of an imbalanced workstation to ensure that the Takt time is maintained.

Technique 4: Add resources. Additional human resources, workstations, machines, or inventory resources all add cost to a process and ultimately to a product. Adding a labor or workstation resources is usually less expensive, but adding machine and material resources is always the most expensive solution for solving a line imbalance. If adding machine resources is necessary, always compare the cost of this solution with the cost of just adding inventory. To justify a capital expenditure request to purchase new equipment, the costs of carrying a calculated amount (see equation above) of buffer inventory, along with the costs of managing and storing the inventory, must be compared against the cost of purchasing new equipment. Because imbalanced workstations require more elapsed time each day to process the daily rate of sales during the effective minutes of Takt time, extended work time will be required to produce the buffer inventory. This extra work time must be added either before or after the normal shift time, which causes overtime that results in increased product cost. Depending on the comparison of the cost of inventory to the cost of a machine resource, adding another machine to overcome an imbalance might be less expensive than adding and maintaining the buffer inventory. When choosing to add resources as the solution to process imbalance, comparison of the cost of a new machine resource versus the costs of maintaining inventory will justify the best business solution for the company. Remember that no matter which solution is selected, any additional resource will remain in place every day, consuming costs. Only by eliminating the imbalance itself can the cost of added resources be eliminated. Eliminating the causes of imbalance is the number one reason for sponsoring continuous improvement projects and kaizen teams.

Technique 5: Use mixed-model sequencing. Lean manufacturing lines are almost always mixed-model manufacturing lines. With a mixed model line, no single product standard time was used when balancing the line. Mixed-model Lean lines are designed using some products with greater standard work times than others. A Lean line is balanced using a *standard time weighted* (STW) across a broad population of products weighted toward the *most frequently produced* products. Even with an STW across a broad population of products, the *order* of the models produced can impact the balance on a mixed-product line. Avoid sequential running of products having identical work content times for the process on a mixed-product line. Also, do not group all *low* or all *high* work content time products together and run them back-to-back on a Lean line. A Lean line is better balanced by running *longer* work-content-time products with a standard work time that *exceeds* the Takt time followed by products with a standard work content time that is *less than* Takt time. Over the course of a day, balance is achieved by missing the Takt times for large work content time products and beating the Takt times for shorter work content time products (Figure 7.11). This is accomplished by performing a daily routine in which the order for running product models on the Lean line is established by sequencing large work content time products interspersed between products having a shorter work content time in a process. This sequencing routine also establishes the priority of the products to be produced on the Lean line that day. Responsibility for creating this sequencing document must be assigned to a specific person who has knowledge of the products, processes, and product volumes. The resulting sequencing document

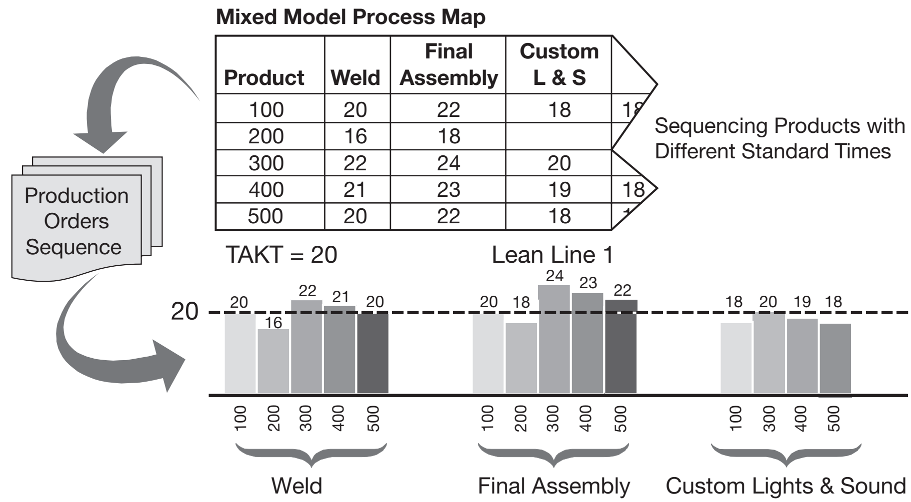


Figure 7.11. Sequenced production mix based on standard times: balance achieved by missed Takt times for longer work content time products and beaten Takt times for shorter work content time products.

must also be tested against the resources to be certain line capacity has not been exceeded. Usually, this work is performed by a planner.

Although Lean manufacturers rarely achieve perfect balance on Lean manufacturing lines in their facilities, the pursuit of perfect balance at each workstation must be a never-ending activity. Daily product mix and volume constantly changes from the mixes and volumes used to design the Lean line. Even if a line is designed to meet a preset mix and volume of sales, a customer will rarely remain committed to their promised mix or volume. Processes are improved. New products are introduced and old ones are dropped. Operators have good days and bad days. Changes occur daily that impact the balance of workstations. Lean lines are designed to produce a mix and volume that happens most of the time, but there is no guarantee that this mix and volume will be what customers want when it comes time to spend their money. Lean lines are based on history, yet they must operate in the here and now. Anomalies in product mix and demand that challenge the design of Lean lines will always exist. Lean manufacturers must always remain as flexible as possible to meet ever-changing customer demand. The key is to design a Lean line reflecting the customer demand that occurs most of the time. Occasionally, on a single day, the daily mix of products may cause the Lean line to miss a target Takt time in several or even all of the processes. It happens on all lines, even a carefully calculated Lean line, but having an average of 95% accuracy in mix and volume prediction is much better than being surprised each day by the changing whims of fickle customers. The Lean line is designed to respond to daily customer changes with a measured systematic response. Tomorrow the customer mix will likely revert to the predicted normal. Most manufacturers can live with a few days of unusual demand out of the ±250 working days per year.

As optimum balance is achieved, the capability to produce product in its work content time will also be achieved. Each small improvement incrementally reduces total manufacturing cycle time and leads to a reduction in response time to customer demand with a corresponding reduction in inventories. A manufacturer's capability to reduce response time and the total cost of production is a powerful weapon in the fight for increased market share. Today, 60 years later, Toyota continues to work on both large and small incremental process improvements. No improvement is too small.

DEVELOPING THE INITIAL SHOP FLOOR LAYOUT

Once a mixed-model PFD has been created, the processes have been identified, and the resource quantities have been calculated, an initial shop floor layout that locates the placement of all the resources is required. The workstation physical attributes (e.g., a 6-foot table versus a 3-foot workstation) have also been defined. The non-value-added setups and moves were identified when the SWDs were created. Setups and move times can be greatly reduced or eliminated just by placing resources and materials in proximity to the point where they will be consumed. Locate feeder (subassembly) processes at points on the line so that partially completed materials can be consumed directly into a downstream process (possible because the processes have been balanced to a Takt time). The final configuration of the resources in the factory layout should facilitate visibility and minimize non-value-added movement and wait time of products, thereby reducing or eliminating any significant amount of setup and move time for products and materials.

The initial Lean line layout is performed by process team members. The initial layout is a paper facsimile of the new facility that illustrates the placement of all resources (workstations and machines) according to the mixed-model PFD. At this point, a paper facsimile is preferable to a CAD drawing. Using a simple paper, perimeter-scaled drawing and scaled footprint cutouts of the resources to record multiple resource location iterations by team members is low in cost and encourages experimentation for determining the ideal placement of workstation and machine resources. To encourage testing and retesting of all ideas for the minimization of shop floor space, setups, and moves from process team members and to facilitate the forward flow of work sequentially through all processes recorded on the mixed model PFD, keep the rules for the new layout out of the factory to only a few.

Although process team members are responsible for the completed line design layout, members of the materials team as well as facility personnel, production management, and anyone else who has a stake in the final design or is interested in the process should be invited to participate. When complete, consensus is required for final acceptance of the new shop floor layout. Team participation and low-cost modeling facilitate achieving a successful Lean line factory floor layout design.

Encourage team participation. To take advantage of the benefits of a Lean transformation, designing the layout of a new factory (or the relayout of an existing factory) requires teamwork. Include shop floor operators who work in the manufacturing area every day. Other employees may also have excellent ideas about how the flow of product through the factory can be improved. Some might have been thinking about improvement ideas for years, but have never had the opportunity to express them. Although the process team is ultimately responsible for the final line design, a layout session is a particularly good time to test all ideas. Allow all interested persons to have their say. The good ideas can then be considered by the process team. Use a conference room table large enough to accommodate seating for all participants in the exercise. A large conference table allows all participants to contribute their ideas. Working around a table is also much easier than leaning over an engineer's computer monitor while a CAD system produces a layout. Locate the perimeter drawing in the center of the table. To encourage contributions, use a large sheet of paper for the perimeter drawing.

Create the model. Begin this process with a large paper layout that shows the perimeter of the new Lean area. Indicate all unmovable objects, such as power tunnels, roof supports, drains, large expensive-to-move equipment, and any other permanent building structures (known as *monuments*) on the perimeter drawing. For each resource (workstation and machine) identified on the process map, prepare a paper cutout of its footprint scaled to match the dimensions of the perimeter drawing. Using the perimeter drawing, begin at the point closest to the customer (usually shipping) and work upstream from the end of the line. Place the scaled shop floor paper footprints following the mixed-product PFD. Continue placing resources on the perimeter drawing until all of the resources that have been calculated on the process map have been placed on the perimeter drawing. Add or subtract any resources not identified on the process map. Test all resource placement ideas that minimize movement and optimize the flow of product from one workstation to another. Also create shop floor paper footprint cutouts for all supporting fixtures, racks, and carts used to manufacture product — even though these items are not manufacturing resources themselves. Fixtures, racks, and carts still require square footage space on the shop floor. Their inclusion can be challenged later to determine if their presence is really necessary or could be eliminated. This is also true for items such as personal toolboxes, chairs, stools, filing cabinets, parts storage, and any other item not necessary for performing the work content assigned to each workstation. Additionally, allocate suitable space to accommodate required material movement, such as space for lift truck aisles and the movement in and out of workstation material containers. Remember that workstations should be designed for minimum movement, yet remain as ergonomic as possible for operators who work there every day.

Make numerous iterations. The most successful line layouts are the result of numerous iterations of the possible arrangements. These iterations occur as participants move around the conference room table and suggest new ideas or changes to previous ideas. Use appropriately scaled paper cutouts to represent the shop floor footprint of the resources to facilitate debate. By moving the simple paper footprint representations of the resources around on the perimeter drawing, participants can get "instant" shop floor modeling. Test alternative ideas instantaneously by simply moving the paper cutouts around until the *ideal* placement of each is identified. Then exhaust all design suggestions from all participants and encourage numerous iterations to reach agreement on the *optimum* factory design more quickly and achieve final acceptance from all participants. Vigorous debate about the *optimum* solution for a layout issue usually results in agreement on the *best* solution. When this process is completed, you will have the new Lean line design for your factory.

Achieve an optimum line flow. In preparation for a new Lean line layout, assume a clean slate and no barriers. Keeping ergonomics, OSHA regulations, environmental and safety considerations, local ordinances, and monuments in mind, do not constrain the design of an optimum line by current legacy workflows or departmental boundaries. For example, the optimum line layout might suggest traversing an existing aisle. An aisle is not a monument, so redirect the aisle if it interferes with the flow of products on the Lean line. In the layout of a Lean shop floor, unencumbered product flow should take precedence over any existing or arbitrary placement of obstructions. Achieving optimum flow of the Lean line is paramount.

Develop the final layout. All resource layout options and factory monuments must be considered when designing the final layout for a Lean factory. Address all disagreements before the design is complete. Once the final layout is completed, obtain agreement on the final design from all process team members. At this point, convert the paper layout and resource cutouts into a formal facility layout drawing (usually done by the manufacturing or facilities engineer using a CAD system). The steering committee must then approve and sign off on the new line layout. For deployment of the final layout, a facility plan must now be created. A deployment plan usually includes the 5S workstation design, scheduling the installation of air and electrical drop lines, relocating workbenches, and contracting with riggers and other contractors. If the new layout requires production to be shut down for a period of time, develop a shut-down schedule to minimize factory down time and to synchronize any final relayout of the new Lean line.

If money were no object, then anything and everything could be moved in a new Lean factory layout (or a relayout), but from a practical standpoint, some items are just too costly to move. The return on investment does not justify relocation of items such as heavy machine tools mounted on engineered concrete pads, processes that are dirty or dangerous, processes that require special venting or maintenance requirements (EPA), and processes that produce loud noise. Relocating processes such as these makes no financial sense. The *ideal* line design might recommend a pure flow through dedicated resources, but an *optimum* final line design will include practical, cost-justified alternative solutions that maximize Lean principals while reflecting good common sense.

IMPLEMENTING THE SHOP FLOOR LAYOUT

During floor layout or when redesigning or relocating workstations, relocate *only* the necessary materials needed for the new Lean line. Move all unnecessary materials away from the line. Make instantaneous decisions. Final disposition of unnecessary materials can be made after the floor layout is completed and the Lean line is operating. When redesigning workstations, use scheduled production shut-down time for locating mechanical services such as air and electrical drop lines, the installation of lighting, and general maintenance of the shop floor not already completed during the original deployment plan.

When a factory is being transformed to a Lean operating system, most resources (workstations and people) will likely require relocation so the new Lean line will resemble the mixed-product PFD. Because resources are already undergoing redesign and relocation, this is the perfect time to implement the 5S initiatives: apply 5S as part of the factory redesign rather than implementing 5S initiatives as a stand-alone project later.

Workstations. Determine workstation size based on the size of the product. Do not provide more space at a workstation than is necessary to perform the standard work for the product. Excess space invites the accumulation of unnecessary materials. Place only the tools required by the assigned standard work at each workstation. Do not allow any unnecessary floor-standing or tabletop tool boxes. Required tools have already been identified by the standard work of the SWD and assigned to the workstation. Use a silhouette board showing all tools required at the workstation. Anything other than the tools needed to do standard work are superfluous and must be removed. Unnecessary tools and equipment take up valuable space and are a waste of resources. Remove unnecessary drawers and shelves from workbenches to eliminate the temptation to squirrel away extra parts, rejected units, and personal items by operators. As part of management by walking around, look for calendars, radios, pictures, and other personal items that are signs of ownership of a work station. On a Lean line, operator flexibility demands that on *any* given day *any* operator will be able to work at *any* workstation. When an operator assumes ownership of a workstation, they are unwilling to move to other workstations in response to the IPK signal. When this occurs, the Lean line is no longer flexible.

Materials. Ensure that all kanban material storage locations are clearly marked and access to material handling equipment is available. Assign a location where operators can access fixtures, gauges, jigs, and tools required to do standard work. Paint the footprint of specialized production materials such as trash receptacles, pallet jacks, fork trucks, and cleaning materials on the shop floor. These specialized items must be returned to their footprint when not in use. None of these materials are allowed to be at a workstation if they are not being used to complete standard work.

Housekeeping. Operators spend half of their waking hours in their workspaces. A clean workspace promotes quality in the products being built and is important for the comfort and safety of operators. A clean workspace also provides an early warning system for potential problems. Good housekeeping on the shop floor makes problems easier to spot. Any item not in its proper place is very conspicuous in a clean workspace. Exposed problems are more likely to be resolved, but hidden ones are not. Looking for problem-solving opportunities is an important part of management by walking around. When calculating Takt time, subtract the time required for cleaning up from the available minutes per day for each process. Making time available to the process removes any excuses for not maintaining good housekeeping at each process.

Meetings. Allow time for meetings at the beginning of each shift to provide operators from both shifts with an opportunity to communicate any information about the operation of process. This time is subtracted from the available minutes per day when determining Takt time for the process. Allowing time for meetings and clean-up activities eliminates excuses for not performing them. Less effective minutes each day will shorten the Takt time and might cause resources to be increased, but the investment is worth it.

MANAGING THE NEW LEAN LINE

So far, the standard work time has been recorded as accurately as possible by observing operators perform their work. These observations were used in the mathematic calculations that determined the number of resources required by each process to meet the Takt time target. From those mathematic calculations, the standard work documented on the SWD was assigned to each workstation in groups equal to a Takt time. Continuous improvement in the form of fine tuning the line by using the balancing tools has begun. Even though objective mathematical calculations were used to determine the resources, one variable common to all line designs still remained: the human resources.

Minor imbalances will *always* exist because a Lean line is staffed by human resources. Why? The reasons are as numerous as the number of human resources! Operators are not machines. They have different working habits. They have good days and bad days. They're preoccupied with problems at home or aren't feeling well. They don't work at the same speed. Some are just naturally faster and others are slower. Generally, the output of most operators varies as the day goes on. They're faster in the morning than in the afternoon. To overcome minor differences in workstation times and natural imbalances between individual operators staffing the line, a *regulator mechanism* is needed to keep the work flowing at the calculated Takt rate for the line. This regulator mechanism is a *production kanban* (also known an in-process kanban or IPK).

Use a Production Kanban

The IPK system is one of the major differences between a traditional planning system and the Lean operating system. Before a Lean manufacturing factory layout can be considered as complete, the physical placement of all IPKs must be completed. The Lean line cannot flow at the balanced Takt rate without the IPK signaling system being in place to regulate the desired speed of the line. Without IPK regulation of the Takt rate, all of the individual differences of the human resources operating the Lean line will accumulate to create significant imbalances. Operators working on the Lean line must be trained in the operation of IPKs. They must follow the established operating rules of the production kanban. Chapter 2 introduced the concept of using the IPK as the authorization for the expenditure of labor, machine, and material resources. The following sections review the IPK discussion in Chapter 2 and describe how the IPK system works to regulate the production rate of the Lean line.

The physical IPK. Once a workstation has been balanced and the standard work has been assigned, a physical IPK is placed on the downstream side of the

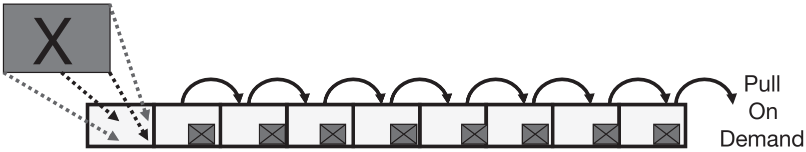


Figure 7.12. Using an in-process kanban as the authorization to do work.

workstation. When an operator completes the standard work assigned to the workstation, this partially completed unit is placed in the space designated as the IPK. Work on the next unit cannot begin until another signal authorizing work is received at the workstation. Until the partially completed unit of production is moved into the adjacent workstation downstream, therefore *exposing* the IPK, the rules of kanban require that the operator cannot begin work on the next unit. Once the unit is moved and the IPK is exposed, the authorization to produce the next Takt time amount of work on the unit waiting in the upstream IPK is given. When the unit is moved from the upstream IPK into the downstream workstation, the upstream IPK becomes *exposed*, thereby authorizing production of the next unit upstream. Only then is the operator authorized to begin work on the next unit. The next partially completed unit is then retrieved from the upstream workstation's IPK and the Takt cycle begins all over again (Figure 7.12). In Lean manufacturing, certain rules are associated with IPK signaling systems. Without the IPK system in place on the line and operator discipline to operate the system, all work content performance variations causing imbalance to occur today will persist, ultimately resulting in the failure of the line: the IPK signaling system is a key component for successful operation of a Lean line.

IPKs are visual. An IPK, empty or full, is a *visual signal* for an operator. As long as a partially completed unit resides in a workstation's IPK, beginning work on the next unit is not authorized. Only an empty IPK authorizes the next Takt time amount of work to begin. An IPK simply provides a temporary parking place for a unit that has been completed faster at the upstream workstation than the downstream workstation can consume it. This empty/full IPK mechanism and the simple work rules associated with an IPK overcome small imbalances at workstations and cause the completion of one finished unit to exit the last workstation every Takt time. IPK authorization of work helps regulate the speed of a Lean line. If left unregulated, imbalances will occur and the Lean line will eventually fail to meet customer demand for the day. At the end of the day, if balanced, a fully staffed Lean line producing one unit at a time, at the Takt rate throughout the day, will yield the required V_c or customer demand for that day. Figure 7.13 illustrates the placement of IPKs at all workstations on a Lean line.

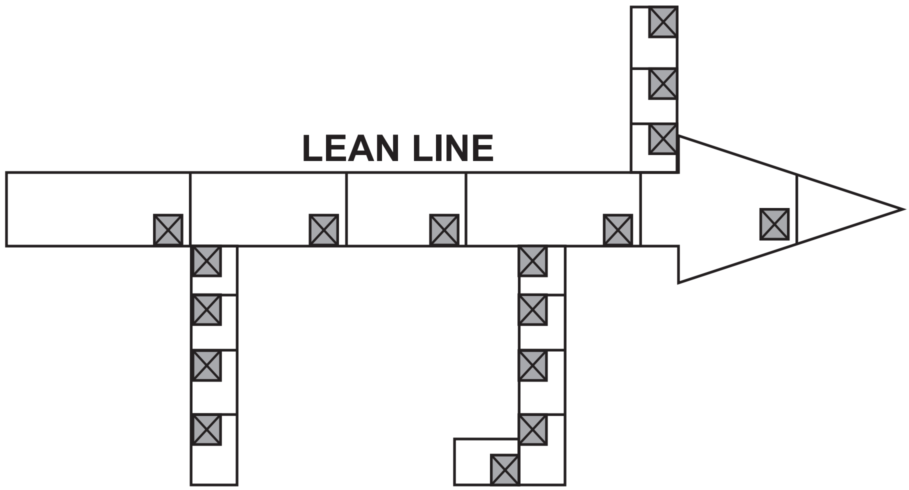


Figure 7.13. An in-process kanban placed at each workstation on a Lean manufacturing line.

IPKs act as a pull system. The IPK mechanism acts as a *pull system*, creating signals upstream from the last workstation (or in a backward direction) all the way back to the first workstation, that authorizes work to begin on the next unit of production at the same speed regardless of the standard work content time of the process. The first workstation therefore works at the same speed as the last! Compare this balanced-workstation pull system to a traditional *push* system of launching orders into production after the BOM explosion of the planning system. Completion of orders is *pushed* through manufacturing by plugging production orders into the available capacity in each department. Balance is of little concern between departments in a traditional system. Customer priorities are often lost in the expediting of production orders. Unsold units that were produced to fulfill capacity imbalances go to a FGI warehouse to wait for a future customer order. Some become slow-moving or obsolete items. WIP inventories accumulate while productivity measurements soar!

IPKs prioritize production. Scheduling production in a Lean factory is greatly simplified once factory layout and kanban signaling begin to pull work through the factory. Production plans are achieved by sequencing customer demand based on FIFO (first-in/first-out) methodology. The IPK signaling system mandates consumption of partially completed units on a FIFO basis from the upstream workstation. In a mixed-model Lean line, it makes no difference which product or SKU resides in the upstream workstation. The operator simply pulls the next unit and completes the assigned work content for that model. Adhering to FIFO discipline is critical for meeting customer order priorities established by the planner. Only by following FIFO methodology can the correct priority sequence be maintained from workstation to workstation. Customer demand is always produced on a Lean line in the same FIFO sequence required by the customer and defined by the planner.

IPKs can also be used for subassembly and feeder processes. A balanced Lean line with IPKs that signal production in feeder processes does not need separate production orders to be launched or batch subassembly production to be scheduled to drive manufacturing in feeder processes. The output of a feeder process is always consumed directly into a downstream process. Feeder processes are physically located adjacent to the consuming downstream process to facilitate minimum movement and little to no queue time in the IPK. Feeder processes are balanced to match the Takt rate on the consuming Lean line. Because a feeder line is balanced with the rate of the downstream consuming process, output from a feeder process arrives at the IPK at the same time as it is needed in the downstream process to be consumed directly into the unit being produced. Subsequent production of the next unit in the feeder process is then pulled by use of the completed subassembly from the IPK at the last workstation, causing a series of IPK signals to flow all the way back to the first workstation of the feeder to authorize the production of another subassembly unit.

IPKs can also handle custom configurations. Customers frequently request special product configurations. Custom orders for most configured products are not a problem for a Lean line. A sales order configuration document (a *configuration traveler*) is sequenced with the product as it advances through the manufacturing processes to notify the operators of the changes required during production of the custom product (any special parts to be used and any custom building required for the custom configuration). Feeder processes are also sequenced in the same order as the consuming downstream processes so that a specially configured subassembly matches the configuration-to-order unit on the main line (Figure 7.14).

IPKs eliminate expediting decisions by operators on the line. The FIFO methodology of the IPK system eliminates the need for operators to make expediting decisions on the shop floor. Operators have no responsibility for maintaining schedules or deliberating priorities. They don't determine the product to produce next or the production order with the greatest priority. Priority changes needed to satisfy changing customer demand are invisible to operators in a Lean facility. They simply pull the next partially completed unit waiting in the upstream IPK. Planners are responsible for making expediting decisions. Priority

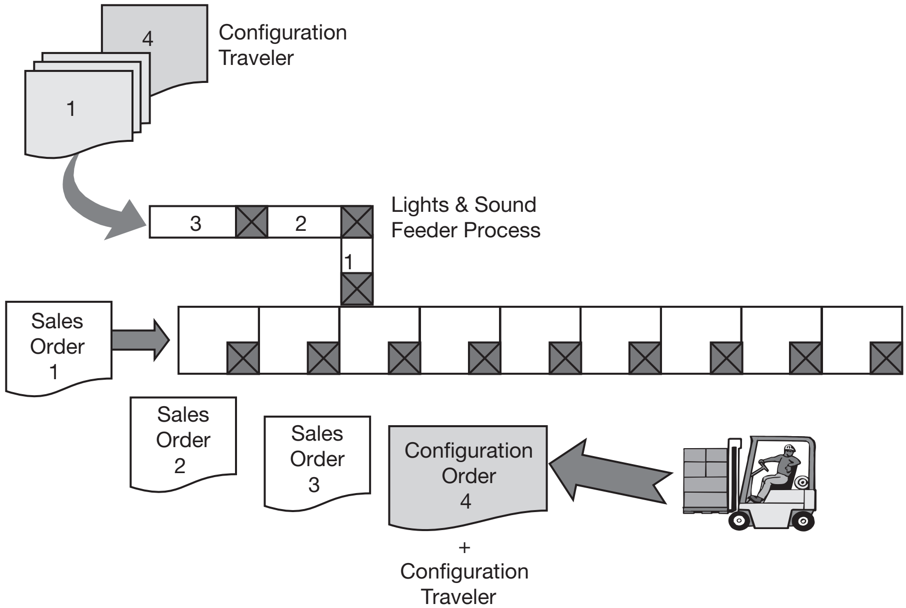


Figure 7.14. A sequenced feeder process with configuration traveler.

changes are accomplished by simply rearranging the sequence of customer orders before a unit enters the first workstation of the Lean line. Once a planner determines the correct sequence of orders to satisfy customer demand, the first operator at the first workstation simply begins production of a unit by pulling the first production order on the sequenced list of orders. Until a production order has been pulled by the operator and standard work has begun at the first workstation, the planner can change the sequence of the orders as many times as necessary to satisfy changing priorities in customer demand. Planners are also responsible for establishing the sequence of feeder lines. Once on the line, the products advance one workstation at a time using the ratchet effect of the IPK pull system.

IPKs require discipline. IPK signaling is critical to the operation of a Lean line. IPKs regulate the speed of the line. They help to smooth out minor factors such as operators working at different speeds, small standard time variations at workstations, and occasional component parts that do not fit together well that cause imbalances. Minor imbalances are common on any manufacturing line, but they still must be controlled. Having shorter standard times at workstations is not a solution. If uncontrolled by an IPK, operators completing standard work faster than the Takt time can accumulate large amounts of WIP. No IPK allows an operator to stay busy at the expense of building units in excess of demand at an individual workstation (known as *pyramid building*). Alternatively, operators slowing down their work pace to match the Takt time to maintain the appearance of balance is not a solution. Neither technique used as an alternative to proper balance is good: speeding up creates inventory and affects cost and slowing down affects productivity. For IPK signaling to be effective, operators must follow IPK discipline. Units cannot be allowed to stack up because one operator works faster than another or because a workstation is not properly balanced. Operators must allow only one partially completed unit of production at a time to be in the downstream IPK. Work cannot commence on the next unit at their workstations until the workstation's downstream IPK is empty. The unit in the IPK must be pulled by the downstream process. The empty IPK is the *only* authorization for an operator to begin working on the next unit.

Use the Managing-by-Walking-Around Technique

The concept of management by walking around (MBWA) isn't new. It wasn't invented by the Lean operating system. MBWA is a popular management technique used by managers in many businesses. It's also a common technique used by Lean operating system managers. How is MBWA different for a Lean manager? What does a Lean manager look for when walking around the shop floor? MBWA for a Lean manager is looking for signs that indicate management intervention is needed. What are these signs? What action should be taken if intervention is indicated?

Observe the IPKs. IPK signaling is crucial for a Lean line to be successful. If the Lean line is not operating as designed, improper use of the IPKs may be the first visual indicator of the viability of the Lean operating system. Any breakdown of the IPK system is an early warning sign of Lean line failure. MBWA is the best method for discovering these early warning signals. Operator discipline to following IPK signaling is the key to making a Lean line flow. Observe the IPKs when performing MBWA. Constant observation of the IPK system will alert a manager to problems affecting the flow and balance of the Lean line. Understanding how the IPK system operates allows many problems observed on the shop floor to be quickly identified.

Observe the processes. Balanced processes are also critical to the success of a Lean line. Going forward, periodic rebalancing will always be necessary to fine tune a Lean line. MBWA can reveal process imbalance opportunities. Constantly seek the perfect balance needed to consistently achieve an established Takt time target. If not monitored, the line may slowly be corrupted over time and become unbalanced. Operators might be picking up bad habits and incorporating them into their work practices. If bad work practices are allowed to continue, operators will interpret silence from management as acceptance of their work practices. Correct operator violations and bad work habits immediately. Explain any observed problems to the operator and provide training as needed to reinforce correct Lean methodology. If bad habits continue uncorrected and imbalances are left unresolved by management, the Lean line will eventually fail. The job of management is to look for signs of imbalance and take immediate responsibility to correct them. MBWA is an excellent way to observe imbalance on the Lean line. All of the work required to transform a facility into a Lean operating system can be compromised if the Lean line is not maintained and improved at all times.

Observe the operators. MBWA requires a manager to look for any key indicator or symptom that the line may be developing imbalances. Certain key indicators are often not easily identified by only casual observation. Identifying them requires paying closer attention. For example, certain operator behaviors can be indicators of imbalance. Behaviors such as nesting, hoarding, cherry picking, and operators acting independently are early warning signals that the line is becoming imbalanced. Learn to recognize these behaviors. They justify close inspection.

Nest builders. Nest building occurs when an operator decides to take ownership of a workstation by just staking a claim to it. Signs of ownership include the presence of personal items such as a calendar, a radio, cooking devices, and other “creature comfort” items. Nest building can be identified by the partitioning off of a workstation from other workstations, e.g., by using paper, cardboard, plastic, etc. In some cases, the partitioning may be done to prevent management from observing the operator, although the operator can still see the approach of management. Nest builders unilaterally decide when and how to do their work. They like batch-unit production. They like to accumulate production units that can be completed quickly, leaving them with free time to pursue activities other than standard work. Nest building is a symptom of an unwillingness to respond to IPK signals. Nest builders are unwilling to move from their nests to properly respond to an IPK signal because they don’t want to leave their personal items behind! A Lean line cannot operate effectively if a human resource refuses to be flexible. Remember the Lean rule: *an operator always moves to the work; work does not move to an operator*. Stop nest building as soon as the first personal item appears at a workstation or the first attempt is made to isolate a workstation from other workstations.

Pack rats. Pack rats are always ready for a rainy day. They maintain private caches of parts and materials. Their justification for hoarding these parts often includes a woeful tale about a shortage of parts a long time ago that caused the manufacturing line to stop. Even if the stash of parts has to stay at their workstations for years, pack rats are determined to never let a line stoppage for lack of parts ever happen again! Remember the Lean rule: *on a Lean line, operators build units and material handlers provide parts*. A similar story can justify hoarding tools. This time the tale will describe needing a certain tool to build a special configuration in the workstation a long time ago. Even though this situation happened years before, it could happen again. Pack rats will not be caught flatfooted the next time. Remember the Lean rule: o*n a Lean line, the tools and equipment necessary to produce the products are at every workstation and are provided by the company*. Tools and equipment are company property. Any tool necessary to produce the mix of products designed for the Lean line is already at the workstation, either placed there when the workstation was designed or added during 5S implementation. Stop any hoarding of tools. Look for toolboxes, drawers, shelves, file cabinets, and any other places where tools and parts can be stashed for future use. Continually enforce 5S philosophy: *a place for everything, everything in its place*.

The tenured operator. Because of tenure, longevity, or special skills, some operators think they have paid their dues and earned the right to choose the work they do. Producing many different items is beneath their dignity. These tenured professor operators like to *cherry pick* only units that they like to produce. Tenured professor operators will often stockpile work to complete later at their convenience. Tenured professor operators are also likely to be nest builders so they can maintain a pack rat inventory and be left alone to work on only products of their own choosing. When observing a line, pay close attention to the product mixes in the IPK of a tenured professor operator. Confirm that the daily sequence selected by a planner is being followed on a FIFO basis at the tenured professor's workstation.

The independent operator. Although operators usually have great improvement ideas, they cannot unilaterally incorporate these ideas. Ideas for process improvements can impact an entire line. They must be carefully managed. If an operator acting alone decides to add or delete standard work, stop using a piece of equipment, or reshuffle the work sequence, his workstation may be thrown out of balance and lead to imbalance all along the entire line. Operators should be encouraged to think about improvements, but it must be made clear that any ideas can only be implemented by using the proper procedures for change. An improvement idea must be appropriately addressed during process improvement meetings or a kaizen event. If the idea is adopted, the line can then be rebalanced so all processes will remain in balance.

Prior to the implementation of Lean manufacturing lines, productivity measures promoted utilization and efficiency. Operators were always instructed to build as many products as possible as fast as possible. In companies where absorption was always the primary performance measurement, an individual's ability to work fast was a valuable asset to the company, but with introduction of the Lean line, these same operators are now being trained to work by producing only one unit at a time in response to an IPK signal. As work is completed, it's moved to an IPK. The operators must then wait for more work to come from an upstream workstation or flex to other workstations in response to the IPK signal. When the new Lean line starts up, this new environment will feel unnatural to some operators. Old work habits do not go away just because management says so (speed trumps Takt!). Continue to enforce the discipline for operators to comply with IPK signals. Maintain the discipline of one-piece flow. Do not allow operators to place more than one unit in an IPK. The line should also flow at a Takt rate along all of the workstations. Line imbalance will manifest itself as a breakdown of IPK discipline or it will cause a line stoppage. If upstream operators must always wait every Takt time for work to be completed downstream before receiving an IPK signal, or if work at a workstation is always completed faster than the Takt time, causing the operator to wait, chances are good that the line has an imbalance in the standard work assigned to the workstation. Do not ignore these important warning signs of imbalance. When imbalance is suspected, apply the balancing techniques discussed earlier in this chapter to resolve it: reduce or eliminate non-value-adding work, relocate work, add resources, add inventory, and use mixed-model sequencing.

Going Forward: Avoid Management Indifference

A common mistake when making a transformation to Lean is to assume that the conversion to Lean manufacturing is a project with a beginning and ending date. Nothing is further from the truth in a successful Lean transformation. Lean manufacturing begins with a revolutionary transformation redesign that must become a way of life. Lean must be the chosen manufacturing operating system for running the facility from now on. Although noble, sponsorship from only the grass roots level of the organization will jeopardize the chances for the long-term success of a Lean operating system. The factory conversion to Lean must be championed as a *top-down* activity. The expected benefits must be articulated and woven into the fabric of company culture.

After spending so much time on designing the line, transferring the responsibility for the operation and maintenance of the line to the next generation is easy for transformation team members. They have spent so much time and energy on the transformation project. Allowing the skills and knowledge gained by the original team members to just "walk away" when the transformation project concludes, however, is a terrible waste of talent. Ensure that transformation team members mentor managers and new team members on subsequent Lean line design projects.

The primary reason a Lean line fails after startup is *management indifference* to the warning symptoms of line imbalances. Lean lines do not fail in single day — they fail over a period of time as a result of many small nonfatal actions that were never corrected — as expressed by the idiom *a death of a thousand cuts*. Over time, if management ignores the warning signals, the Lean line will atrophy to the old comfortable solutions and operating systems in place before the Lean transformation. Do not permit indifference to Lean methodology to spoil your success. Allowing indifference to flourish is the first step to returning to the old practices that caused the transition to Lean manufacturing methodologies to be needed in the first place. If this occurs, your company will become a statistic: just another company in the group claiming to be among the 22% who are dissatisfied with their Lean initiatives.[1]

Lean manufacturing is a completely different way of operating a manufacturing company. It requires hard work to implement. The transformation team must be willing to challenge existing manufacturing paradigms. Ongoing successful operation of Lean manufacturing lines requires the commitment to seek continuous improvement using and reusing all of the methodologies employed during the transformation process. Dedication to a Lean operating system will change existing company culture.

REFERENCE

1. George Koenigsaecker. Leadership and the lean transformation, in *Manufacturing Engineering*, November 2005: Vol. 135, No. 5; available at http://findarticles.com/p/articles/mi_qa3618/is_200511/ai_n15847432/.