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Capacity, Inventory, Variability and Manufacturing Strategy

- *The Barriers to High Factory Utilization and Why Utilization May Not Even Matter*
- *How Lean Manufacturing Reduces and Copes With Variability*
- *How Variability Affects Strategic Thinking*

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Capacity, Inventory and Manufacturing Strategy

The Barriers to High Factory Utilization and Why Utilization May Not Even Matter

Introduction

Capacity utilization, inventory and variability within a factory are often related in a vague and counter-intuitive way. When managers and schedulers fail to understand this relationship's nature, they make poor decisions about investments, manufacturing and market strategy. In addition, Schedulers may be caught in untenable positions where they are blamed for not meeting impossible expectations and cannot understand or explain why. Companies often purchase expensive and complex scheduling software when the root cause of their scheduling problem is in variability and system structure.

Capacity and Inventory

A Simple Example

To illustrate this phenomenon, we built a simulation model using the Simul8 software package, figure 1. The system consists of a simple production line with ten stations and inventory queues between all stations. Each station has a work time of 1.0 minute. On average, over many cycles, the line is perfectly balanced. However, the time on each cycle varies according to a standard distribution with a standard deviation of 0.2 minutes. Thus, a station that finishes work quickly on a given cycle can release its workpiece and immediately start on the next workpiece if it is available. However, the released workpiece may not be able to advance to the next station right away. These "interferences" cause inventory to accumulate between stations.

The model was operated over a range of production input rates. When the inventory levels stabilized, they were recorded. The average output rate during steady-state operation divided by the theoretical output rate of 1.0 units per minute gives equipment utilization percentage. Figure 2 shows the initial results.

While few factories resemble our model, most factories share its characteristic behavior in a qualitative way. An accurate depiction of a real factory through simulation is rarely practicable but numerical accuracy is unnecessary for understanding and using the principles.

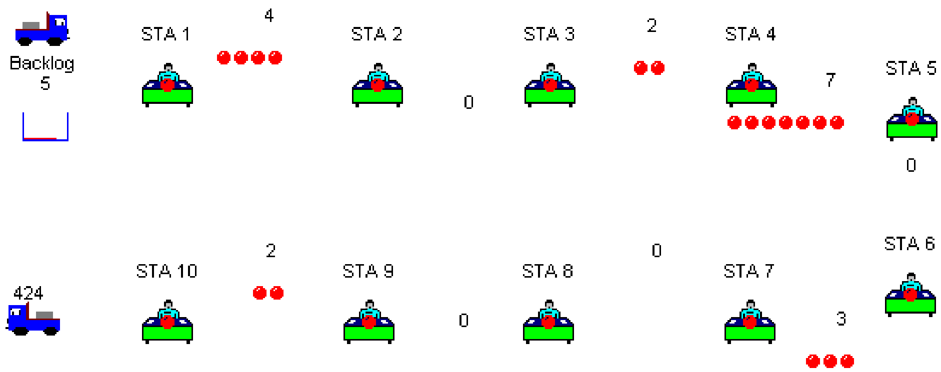


Figure 1-Simulation Model

The Utilization-Inventory Link

Figure 2 shows the results. At low utilization rates, each station has excess time available. Inventory between stations is rare and many stations are empty at a given moment. As the input rate increases, the stations still have adequate time to produce parts at the input rate but there is increasing probability of finding a workpiece in each station. Increasingly, workpieces are caught between stations. Up to about 80% utilization, the inventory increase is fairly linear and modest. At about 85% utilization, the rate of inventory increase accelerates and becomes very high as utilization approaches 100%. With an input rate above 100%, the system bottlenecks and inventory builds between stations and at the front of the line. The system cannot stabilize and inventory approaches infinity.

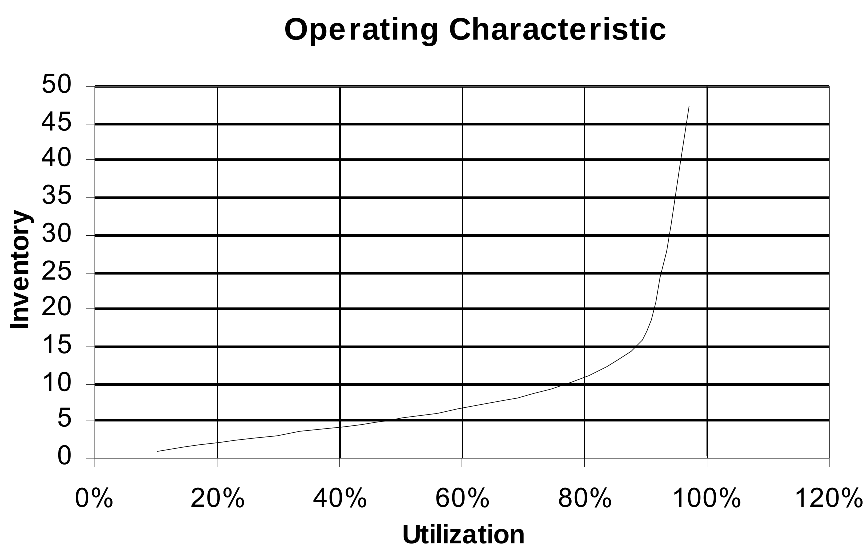


Figure 2-Typical Manufacturing System Operating Characteristic

The Effects of Variability

Variability is the cause of this behavior. In the model of figure 1, the only variability is the work time on each station and each cycle. In real life, variability takes many other forms but has the same qualitative effect. The cumulative amount of variability in the system affects the shape of the operating characteristic curve, as explained later.

Variability has many other deleterious effects. It often creates a flurry of unexpected activity for schedulers, quality specialists, supervisors and workers. This adds to cost but not to customer-perceived value. One former client estimated that 60% of their staff efforts related to unexpected variability. This sort of activity contributes to frustration and morale difficulties. These types of costs are difficult to capture and often attract little attention.

Forms of Variability

Demand-- Customer demand (internal or external) is an obvious and pervasive form of variability. It often creates inventory blocks that move through the system like a pig through a snake.

Batching-- When lots or batches move through a manufacturing system, they interrupt production for changeovers and these interruptions are a form of variability. The pig-snake analogy also applies here when a particular workcenter may have too much work at times while, at other times, it must wait for a subsequent batch.

Material handling methods may also create batches, for example, moving only a full pallet or full truckload.

Variable Routing-- When a single factory produces many different products or parts with different processing requirements, each may follow a unique route or sequence. Predicting the workload and queues at each workcenter under such conditions is problematic at best. When other forms of variability enter the picture, such prediction is impossible and queues build as compensation.

Breakdowns-- Machine outages interrupt production with unpredictable consequences. During breakdowns, inventory often builds upstream while downstream operations become starved for work. The maintenance deficiencies that cause breakdowns often contribute to quality defects as well.

Quality Defects-- When defects become known, the production sequence is interrupted while the defects are corrected. They may also cause unexpected workloads for repair or replacement.

Human Amplification-- People often exacerbate existing system variability. For example, supervisors overproduce the schedule to compensate for possible breakdowns and quality defects. Schedulers over schedule for many of the same reasons. This creates larger batches and greater delays.

Others-- many, many other sources of variability in a complex factory produce the same effects as the work time variability in our simple model.

Variability and The Utilization-Inventory Curve

The total amount of system variability changes the shape of the system’s characteristic operating curve. With perfect balance and no variability, the curve is essentially two straight lines (figure 3). From 0% utilization to 100% utilization, inventory increases linearly until each workstation is occupied full time. This is the limit of system output and attempts to feed more product into the system causes inventory to build and continue building to infinity.

With increasing variability above zero, the curve assumes a more hyperbolic shape. Inventory builds faster and earlier. In addition, the system “chokes” at lower utilization rates. In our model, a work time standard deviation of 1.0 minutes chokes the system at about 75% of ideal capacity. This becomes the maximum practical capacity of the system. This is why many factories can never seem to achieve their rated capacity.

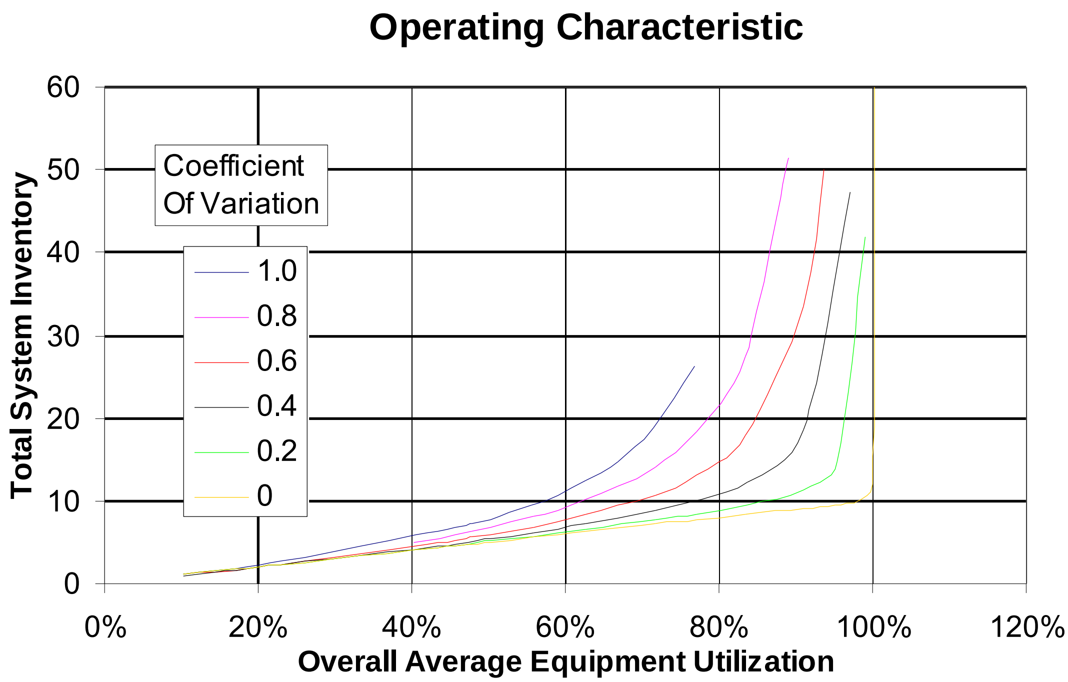


Figure 3- Effects of Variability on System Operating Characteristic Curve

Little's Law and Delivery Performance

Little's Law

Little's Law states that the average throughput time for a manufacturing operation is proportional to the inventory held within that operation. This has important implications for strategy and design of the manufacturing system, particularly when combined with the operating characteristic curves discussed above.

The Water Tank Analogy

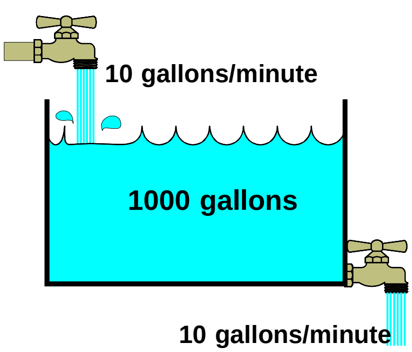


Figure 4- Little's Law

To illustrate Little's Law, think of a water tank and an input adjusted to 10 gallons per minute of flow. An output is also adjusted to 10 gallons per minute and the tank has 1000 gallons. Figure 4 illustrates.

The average throughput time (dwell time) for a drop of water in this tank is 100 minutes. Not every drop spends 100 minutes in the tank. Some drops move with the main flow and exit much sooner while others swirl in a backwater and take longer. Much like the orders in a factory.

Little's Law and The Utilization Curve

Throughput time affects delivery performance. When factories build to order, the throughput time limits delivery time. No order can be shipped in less than the throughput time. For factories that build to stock, throughput time affects stockouts. The longer the throughput time, the longer it takes to replenish a stockout. Moreover, the longer the throughput time, the more difficult it is to control inventory and maintain all items in stock. In addition, longer throughput times require more stock to maintain the same stockout rate.

In one way or another, throughput time affects delivery performance, inventory investment or both. As capacity utilization increases, the necessity for inventory increases and thus throughput time increases. This usually decreases delivery performance and often decreases inventory performance to a greater extent than just the utilization and internal queuing would predict. Figure 5 shows this effect.

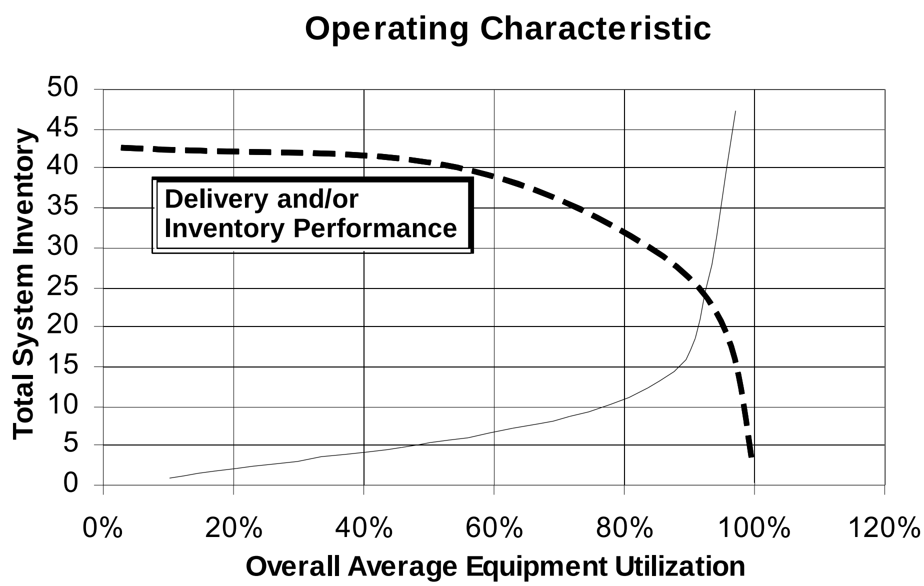


Figure 5- Operating Characteristic and Performance

Implications for Strategy

Finance

The sections below illustrate a few of the ways that variability, capacity and Little's Law affect the development of an effective Manufacturing Strategy.

The conventional wisdom of accounting considers excess capacity as waste. However, reserve capacity may reduce other forms of waste. These are strategic issues that require considerable reflection at the highest levels.

Investment and Capital

When considering capital investments in equipment, the effects on inventory should be a primary consideration. In many firms, additional equipment is rarely purchased until the existing equipment is at very high utilization. Attaining high utilization rates drives up inventory and this increased inventory may be greater than the cost of the new equipment.

As an example, a company that extruded plastic did not purchase a new extrusion line that required a one million dollar investment. Since their business was seasonal, they were forced to build a seasonal inventory of almost ten million dollars and warehouse space to store it. This was clearly shortsighted in the context of the capacity-inventory relationship. Since the management was unaware of this relationship and looked only at average annual capacity, they made decisions that required far more total capital than necessary.

Such policies may also work against marketing strategies that depend on delivery performance. Before implementing high utilization policies, management should consider not only the total investment (including inventory) but also the effect on marketing. In addition, utilization policies should distinguish between low cost equipment that needs only low utilization rates and high cost equipment.

Product Costing and Cost Structure

Conventional costing systems may not accurately distribute the cost of variability created by a wide product mix. The cost of this variability often appears in overhead accounts that are allocated in distorted ways. This also relates to marketing strategy as noted below.

Sales and Marketing

Customer Needs

Since high utilization is generally incompatible with high variability and low inventory, priorities for these variables should be established. The key is to clearly identify the customer's buying decision criteria.

When most customers buy only on price, this indicates that low-cost production has the highest priority. Low cost production indicates maximum utilization of capital. It might also indicate the use of backlog to achieve steady throughput. Both of these approaches increase throughput time and affect delivery adversely.

When delivery is the primary decision criteria for customers, excess capacity, low inventory and minimal backlog is the best approach. However, these strategies may increase cost.

"Build It and They Will Come"

Policies that prevent capacity investment until demand is proven often inhibit growth. New capacity requires time to commission and customers will rarely wait.

Companies that build capacity in anticipation of growth usually find that their new capacity attracts growth. Future pages will address these issues of capacity planning and strategy.

Product Variety

Increasing the product offering is a common marketing strategy. However, additional products rarely increase sales volume in proportion their number.

The result is a product mix with a few high-volume products and many low volume products. This brings further consequences, such as:

- The additional variety increases overall cost, primarily in overhead.
- The costing system may not accurately distribute the additional cost and under-price the low volume items.
- The additional variability may increase inventory and adversely affect delivery performance.

- When considering new products, executives should consider the effects of such product proliferation.

Variability As Competitive Strategy

A few, rare, manufacturers embrace variability as a competitive weapon. These are the firms that specialize in the unique, the unusual and the highly customized product. Their engineers and staff are competent in new designs, their production workers take responsibility for many decisions and their systems are optimized for uniqueness. Many such companies are small or they divide themselves into small units. This optimizes personal communication and encourages everyone to participate in decision making.

However, to be successful in this, firms must gear their order processing and manufacturing to coping with such variety (see below). This is difficult, but, when successful, highly profitable.

Variability In Manufacturing Strategy

Strategies for Variability

Manufacturers can either 1) reduce variability or 2) cope with it. Almost every element of Lean Manufacturing aims at reduction, coping or both.

Most variability is unnecessary, unproductive and indicative of an underlying problem. For these reasons, variability reduction is the first line of defense. TQM/Six Sigma is an example of variability reduction.

Occasionally, variability is irreducible for technical reasons or desirable for marketing reasons. In these cases, systems can be designed to cope with it. CNC processing equipment is an example of coping with variability. However, coping with variability (as opposed to reducing it) is often expensive and may produce have consequences.

Almost every aspect of Lean Manufacturing involves variability. Some elements of Lean reduce variability while others attempt to cope with irreducible variability. For more on this, see "Variability and Lean Manufacturing."

Embracing Variety and Variability

Coping effectively with variability can lead to an effective marketing strategy. Such strategies are quite difficult, but, when mastered, are also quite effective. Competitors simply cannot develop the ability to compete on this dimension. Variability as strategy usually takes one of two forms:

- Offering a wide range of products often with many new and different products.

- Offering to supply large orders, custom products or special projects on short notice.

The first approach requires high competence in product development and product introduction as well as high flexibility in manufacturing.

The second approach requires the maintenance of excess, idle capacity. When an order or project arrives, manufacturing can produce it quickly. Such idle capacity incurs cost and such strategies are only effective when pricing and margins compensate for this additional cost.

Reducing Variability

Reduced variability has many beneficial affects. Each element of Lean Manufacturing reduces variability in some way. These effects spread through the system in little-understood, often small and unnoticed ways. However, the cumulative effects are great. Here are some common sources of variability and typical reduction approaches.

Demand

Demand, especially customer demand, is often the most difficult variability to control. Customers want their product when they want it, not when it is convenient for the factory. The randomness of markets or inherent patterns of demand such as seasonality or daily peaks are often beyond the control of the manufacturer. Taiichi Ohno at Toyota went to great lengths to smooth production demand at Final Assembly. He recognized that this was where variability started. Swings in customer demand often amplify as they work upstream in the manufacturing system.

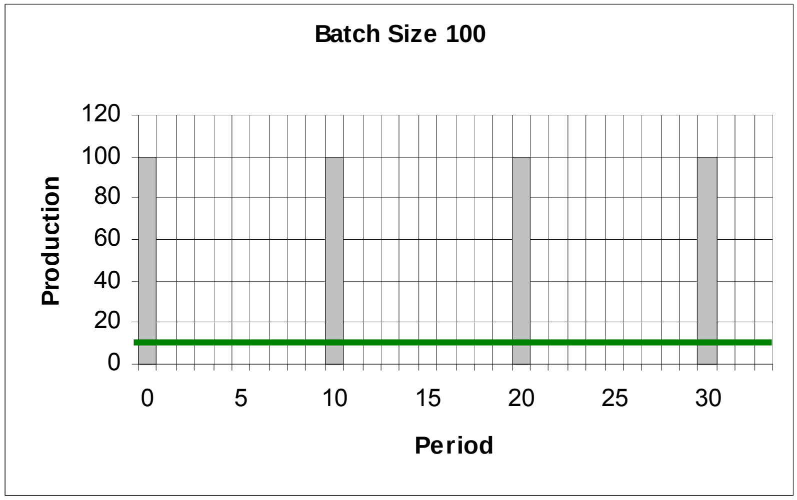
However, some aspects of customer demand are controllable. Sales and marketing often exacerbate inherent market variability. For example, special promotions may spike demand or commission structures may motivate sales people to close many deals near the end of each month. This type of variability can be controlled or at least mitigated.

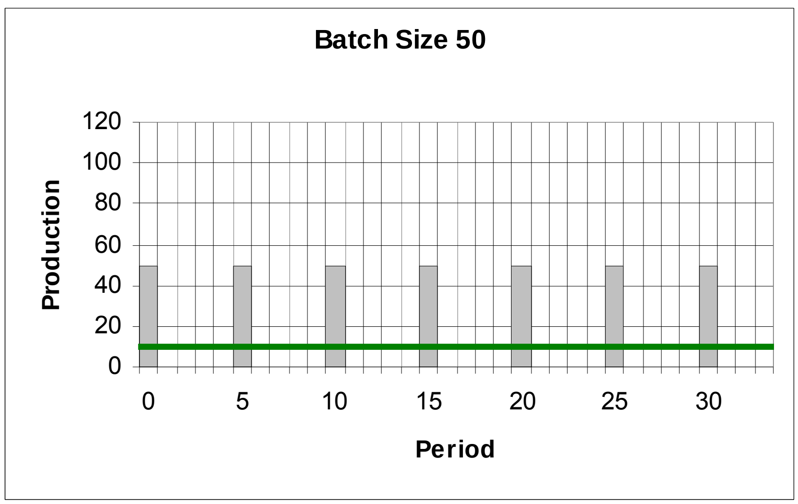
The demand variation that is beyond control must be dealt with through inventory or excess capacity. In any case, there is no point in adding additional variability as the demand changes move upstream.

Batching

Batching introduces a step function into the system. In figure 6, the demand is constant at 10 units per period. With batches of 100 units, production is intermittent and as many as 100 units are in inventory. Batches of 50 or 20 allow production to follow demand much more closely and reduces inventory. Figure 7 shows the standard deviation of the difference between production and demand for each lot size. Ideally, the batch size equals the smallest unit of demand, matching production exactly. Our pages starting at www.strategosinc.com/lean_lot_sizing.htm have much more on lot sizing.

The secret to reducing batch sizes is to reduce the setup cost for each batch. This is the Lean element known as Setup Reduction or SMED. You can find more information on setup reduction at www.strategosinc.com/setup_reduction.htm.





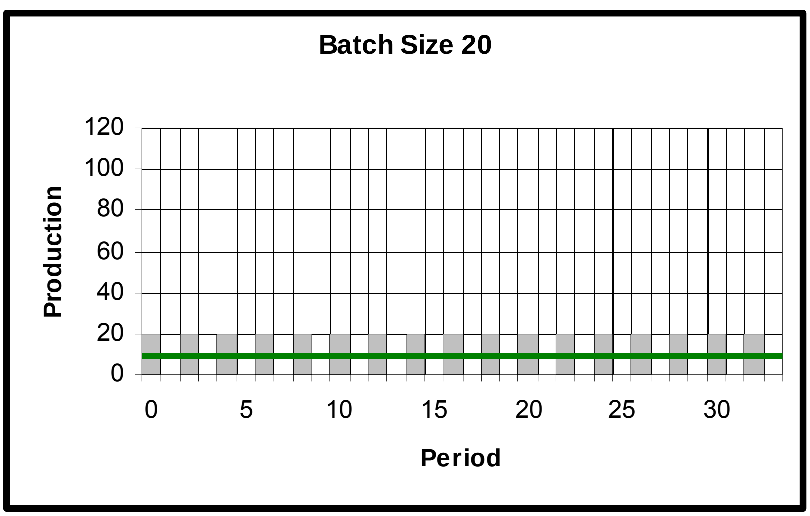


Figure 6 Production At Different Lot Sizes

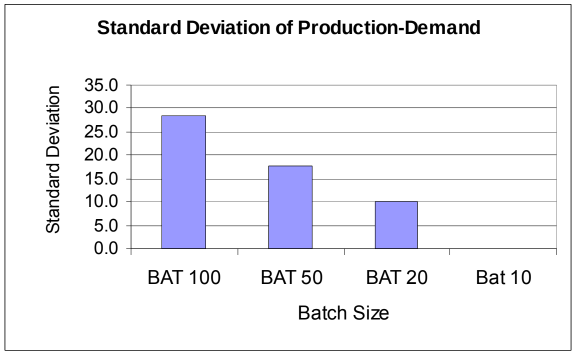


Figure 7- Standard Deviation of Production--Demand

Varied Routings

When products take multiple, different routes through a factory, this introduces variation into the material handling system. This situation is most often associated with functional layouts as shown in figure 8. The material handling required for such layouts may also introduce batching in the form of a "transport batch." The way to reduce routing variation is to utilize workcells and flow lines as shown in figure 8. at www.strategosinc.com/workcell.htm has more on cellular manufacturing.

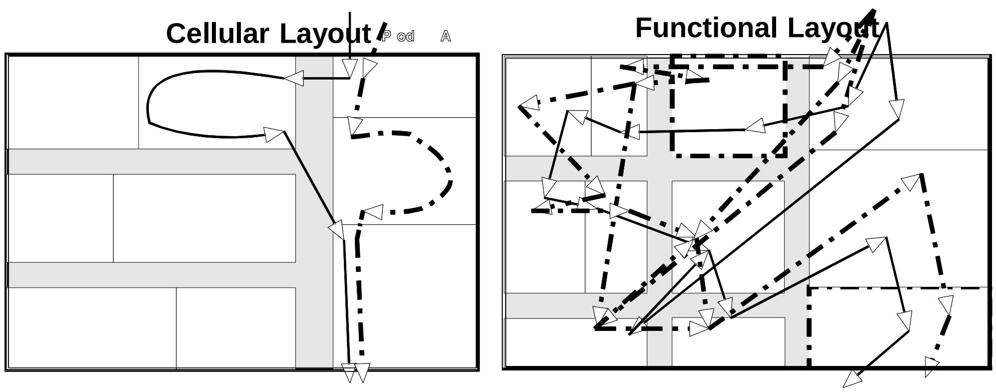


Figure 8- Routings in Functional and Cellular Layouts

Breakdowns

Breakdowns interrupt production . When breakdowns are frequent, inventory builds to prevent other operations from halting. Factories incur many hidden costs as well. The effects of breakdowns are similar to those of quality defects illustrated at www.strategosinc.com/quality_cost.htm. The solution, here, is total Productive Maintenance. TPM uses a combination of equipment selection, predictive maintenance, preventive maintenance and equipment reengineering to prevent unexpected breakdowns. For more on this, see out page on Reliability and Maintenance at www.strategosinc.com/mnt.htm.

Quality Defects

Quality defects interrupt production, usually in unpredictable ways. They generate unpredictable rework and general confusion. For an example of how a defect can create general chaos, see www.strategosinc.com/quality_cost.htm.

Human

People also generate considerable system variability. People have a naturally wide variation in their physical makeup, skills, knowledge and temperament. Improper training is often a cause because untrained people have unpredictable responses. Different experience levels can also produce differences in work times and responses to problems or unexpected situations.

Others

We have listed only a few of the more common causes of variation. There are many others ranging from weather conditions to raw materials. Whatever the source of variation, it is important to find the root causes and rectify them. The result is less inventory, faster throughput and lower cost.

Summary

This paper describes a simulation that applies, in principle, across a wide spectrum of manufacturing situations. The simulation demonstrated that high average utilization rates require large inventories. It shows how, through Little's Law, that high utilization often decreases delivery performance. Finally, our simulation shows the effects of variation on the nature of the relationship between inventory and capacity utilization. All of this has important consequences for Manufacturing and Marketing Strategy.

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