Columbia Business School

Revised December 11, 2000

XTM Bike Corporation: An Exercise in Process Analysis

XTM Corporation is a specialty manufacturer of high-performance mountain bikes. The firm is known among biking enthusiasts for its highly customized bikes, offering a wide range of frame sizes, equipment options, and colors. It builds each bike to exact customer specifications, as provided by a network of authorized dealers. The average wholesale price of a XTM bicycle is $750, which XTM receives after units are delivered. Currently, order volume is averaging 600 units per month, but this number varies significantly from month to month. Further, demand is growing due to the popularity of off-road biking as a sport, and next year the firm is projecting sales increases of 20%.

Bicycle production

The firm employs 21 production workers and 3 supervisory workers. The standard labor rate for most jobs in the plant is $18 per hour in wages and benefits; supervisors receive $50,000 per year in salary and benefits. This crew typically works one eight-hour shift a day, five days a week for 48 weeks a year. (For simplicity, assume each month has exactly 4 weeks.) Hourly workers are paid only for productive time.[1] Rent, insurance, utilities, and other fixed costs for the building and equipment average $20,000 per month.

The only part of the bicycle XTM actually fabricates is the frame; all other components such as handlebars, seats, the derailer mechanism, wheels and spokes, brakes, etc. are purchased from outside suppliers. Materials and parts cost $550 per unit on average.

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[1] Paying only for productive hours is accomplished in some cases by a *piece-rate system*, where workers are paid for each unit produced. Alternatively, workers in a given production area may be sent home early if they complete their work or reach their production quota before the end of a shift.

Frame fabrication is a relatively simple, two-step process. First, aluminum alloy tubing of various diameters is cut to the precise dimensions required for each frame style and size based on a computerized record of incoming orders. A tag giving the specifications for the order is attached to the frame at this point. Cutting and finishing the tube stock for a frame takes about 30 minutes, and the three workers in the cutting area are paid the standard labor rate.

In the second step, all the pieces required for a single frame are secured in a jig[2] where 6 skilled welders, earning $30 per hour in wages and benefits, weld the tubes together to form the basic frame. The alignment of the frame and the quality of the welds is considered critical to the performance of the final product.

It takes a welder about 45 minutes to reconfigure the jig and position the tubing for a new frame; another 45 minutes is required to complete the welds. Welding has always seemed to cause slow-downs in the plant, and on average, there are approximately 250 orders waiting to be welded between the cutting and welding areas.

The frames are then sent to the painting area, which is staffed by three workers earning the standard wage. It takes 30 minutes to paint a frame, after which it is placed on a rack to dry for 8 hours. On average, there are 30 frames in various stages of completion in the painting area.

The finished frames are then taken to the final assembly area, where a group of seven workers arranged in a line attaches the wheels, brakes, handlebars, and other equipment as ordered. Total assembly time averages about 1.5 hours per bicycle, and no time is required to switch from one bicycle to the next.

Completed bicycles are then boxed and sent to the loading dock for shipment to the final dealer locations. Shipping time averages 7 work days, and shipping costs run $25 per unit.

Process analysis

To analyze XTM's operation, let’s examine the process step-by-step and see what we can learn.

Diagramming the process

A first step in analyzing a production process such as XTM's is to diagram it. Such a diagram describes in visual terms the various operations of a process and the paths of material and information flow. While there are varieties of ways of constructing such a diagram, the following is a typical and useful notation. Figure 1 shows the standard symbols.

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[2] A *jig* is piece of equipment that is used to hold work in a fixed position. In this case, it would consist of a series of clamps mounted on a frame that could be adjusted to hold the pieces of a bicycle frame in proper alignment for welding.

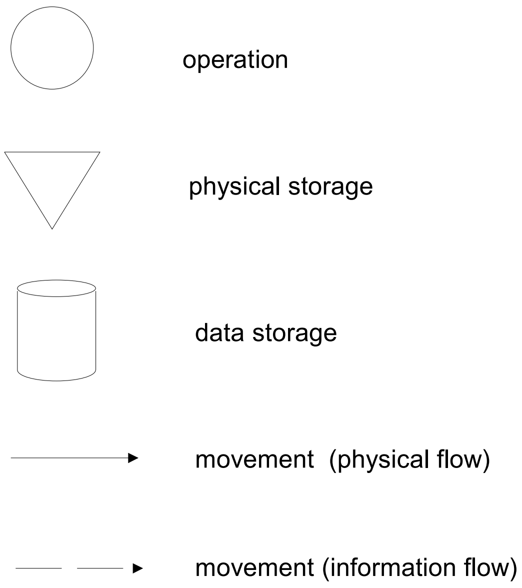

Figure 1: Standard Process Flow Symbols

Operations - These are individual process steps or tasks that are carried out in the production process, such as welding a joint, sewing a seam, filling a bottle of pills, grilling a hamburger, etc. Operations are represented by a circle and these circles are usually annotated with pertinent information about the operation.

Movements - These steps involve moving material, parts, or information from one point of the process to another. Examples include pumping liquid from a vat, trucking parts from a fabrication plant to an assembly plant, transmitting an order via modem, shuttling engine blocks from one work station to the next, etc. Transportation is represented by an arrow, with a dotted line arrow usually indicating a flow of information rather than a physical flow.

Storage - Material and information in the system that is not being operated on or transported is usually waiting in storage. Stored material is referred to as *inventory*, and is usually represented by an inverted triangle. Stored data can be represented by this symbol as well, though data stored in a database is commonly represented as a cylinder or drum as shown in Figure 1.

Constructing a process flow diagram

Using the symbols above, one can construct a process flow diagram of the XTM manufacturing process. Such a diagram is shown in Figure 2. Note that pertinent information about each element of the process is written next to the symbols. This allows one to visualize at a glance much of the process data.

Such a diagram essentially defines the process of interest; it shows inputs, outputs, resources, and activities at each stage of operation. (For service operations, similar diagrams can be constructed, though most often they will detail the sequence of activities a customer experiences in a service offering rather than physical product flows.)

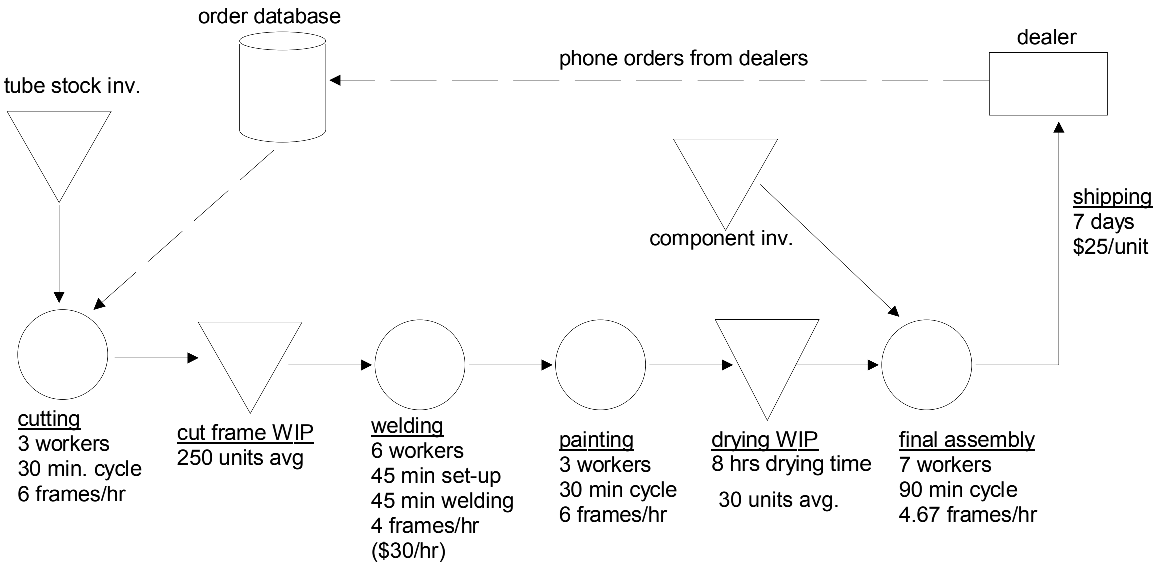

Figure 2: A process flow diagram of the XTM process

Basic cost analysis

An obvious first set of questions to ask about the XTM operations is: Is it a profitable operation? If so, how much profit is XTM making? If not, why not? And so on.

To answer these questions, we need to do some elementary analysis of XTM's cost structure. To get started, let's just consider the revenues and variable costs of production, i.e. materials, direct labor, energy, etc., in order to determine XTM's contribution margin. These calculations are performed as follows:

Revenue/unit	750.00	
Materials & Components	(550.00)	
Gross Margin	200.00	
Cutting Labor	(9.00)	[$18/hour times 0.5 hours]
Welding Labor	(45.00)	[$30/hour times 1.5 hours]
Painting Labor	(9.00)	[$18/hour times 0.5 hours]
Assembly Labor	(27.00)	[$18/hour times 1.5 hours]
Shipping	(25.00)	
Contribution Margin	85.00	

In percentage terms, the contribution margin is (85/750) * 100% = 11.33%. Every dollar in extra revenue contributes roughly 11 cents to earnings before depreciation and taxes. Since this figure only includes variable costs, it is most useful in performing *incremental* analyses of investment options and process changes.

For a more complete picture, we can add in the demand and fixed cost information. Assuming a demand rate of 600 units per month, we get the following numbers (in 1,000's of dollars) for one year of operation at XTM:

Annual Revenue	5,400	100.0%
Materials & Components	(3,960)	(73.3%)
Labor	(648)	(12.0%)
Shipping	(180)	(3.3%)
Net Contribution	612	11.3%
Supervisory Labor	(150)	(2.8%)
Rent & Equipment	(240)	(4.4%)
Operating Profit	222	4.1%

Thus, XTM is making an operating profit of $222,000 per year. At current operating levels, XTM incurs variable costs of 88.7% of sales and fixed costs of 7.2% of sales, leaving an operating profit of 4.1% of sales. Of course, other non-operating expenses (e.g., interest and taxes) are subtracted from operating profits to determine income to shareholders.

With these basic numbers in hand, we can now consider other quantities that will be of both financial and operational interest. For example, the *break-even* volume is defined as the lowest level of demand for which a firm's operating profit is positive. Since XTM makes a contribution of $85 per unit and total fixed costs are $390,000 per year it must sell 4,588 units annually (390,000/85) to break even, or 382 units per month, well below their current level of sales. Another quantity of interest is the sensitivity of XTM's profits to order volume. For example, if demand increases 20% to 720 units per month next year (as predicted), then the annual contribution rises to $734,400, resulting in an operating profit of $362,400, an increase of 63.24%.

Note, however, that these calculations do not tell a complete financial story in that they do not recognize the capital invested in XTM. The attractiveness of XTM as a business will also depend on the total capital it requires to operate. The profit of $222,000 per year might look attractive if the total capital deployed in the company is one million dollars, but distinctly unattractive if the company requires five million dollars of capital. Various measures of financial performance can be developed to evaluate profit as a function of some measure of invested capital, e.g. *return on equity* (ROE) or *return on assets* (ROA). We will not go into detail on these sorts of financial evaluations; this is something that is covered in detail in your finance courses. Since our focus is on operations, though, we will be considering how profits vary with the value of two important items: (1) inventories and (2) plant and equipment.

Capacity and bottlenecks

While a financial analysis is a useful starting point, it does not answer some important questions about XTM's operations. In particular, it suggests that the projected increase in sales volume next year will have a significant impact on profits. But is an increase in output possible? How much volume can XTM sustain? How heavily utilized is their process?

To answer these questions, we have to turn again to our process flow diagram. Note for each operation we have indicated the *cycle time* of the operation, i.e. the time required to perform the complete operation on a single unit. This term derives from the fact that, typically, each operation involves performing a sequence of tasks. As units are produced, workers and machines “cycle through” this sequence of tasks repeatedly, and the total time it takes to execute all the tasks in each cycle is called the “cycle time.” Thus, cycle time is essentially the total work (measured in units of time) required to perform an operation.

The *capacity* of each operation, in units per hour, is also given. This is determined by dividing the number of workers (or machines in the case of an automated process) by the cycle time of the operation. For example, there are 6 welders in the welding area and the welding operation has a cycle time of 1.5 hours (45 min. to position the jig and 45 min. to weld), yielding a capacity of 6/1.5 = 4 frames/hour. Similar calculations yield the production rates of each operation shown in Figure 2.

So how much can XTM produce? In this case, it is rather easy to see that since each bicycle has to go through each operation once, the output will be limited by the operation with the smallest capacity, which in this case is the welding operation. The operation that limits the output of a production process is called the *bottleneck* operation. For XTM, welding is the bottleneck. If a firm produces a range of different products, the bottleneck can be more difficult to identify. Since different products may have different cycle times at each operation, the bottleneck will usually depend on the mix of products being produced.

In general, one is likely to find bottlenecks in operations that are especially costly or consume scarce resources. For example, the capital equipment costs of the operation may be high or the labor force required may be highly skilled and thus difficult to expand and/or expensive to employ. This is likely the case for XTM, since the skilled welders are the most expensive workers in the process.

The bottleneck is important to identify for several reasons. By definition, it is the operation that limits the output of the entire process, and thus it defines the overall *process capacity*. This is an important quantity to know for obvious reasons. For example, we saw above that next year's projected 20% rise in sales will significantly boost profits. However, since the process capacity of XTM is 4 frames/hr or 640 frames per month, such a rise could not be supported without modifying the process, adding a second shift, or running the facility on overtime. The welding bottleneck is severely limiting XTM's ability to increase output. It would be nice to ‘break’ this bottleneck, that is, to increase the welding production rate. Then the output volume of the facility could be increased.

If a facility is operating at its maximum capacity, then the bottleneck is even more critical. In this case, if any production time is lost on the bottleneck operation (e.g. through lack of input parts or materials, quality problems, breakdowns, absenteeism, etc.), then that production time can never be recovered. Since the bottleneck operation is at maximum capacity, it cannot be ‘sped up’ to make up for the lost time. Thus, there could be significant opportunity costs due to lost sales from the lost production. For this reason, it is often critical to ensure that the bottleneck operation incurs minimal idle time and down time.

Utilization

Another quantity of interest is the *utilization* of each operation, defined roughly as the production rate divided by the capacity of the operation. Assuming that demand is currently being met, then the production rate is 3.75 units/hour (600 units/month divided by 160 hours of operation per month). The utilization of the assembly area, for example, is then the production rate divided by the area's capacity (4.67 units/hour), yielding a utilization of 3.75/4.67 = 80.3%. Note the bottleneck welding operation has the highest utilization at 3.75/4.0 = 93.7%. This, of course, is true in general.

If most of the costs of an operation are fixed costs, then utilization is especially important since it indicates how much output, and consequently revenue, is being generated by a fixed asset. It thus has a strong influence on any return on a measure of capital employed.

The utilization of the whole process is defined similarly to the utilization of an operation. It is just the ratio of the production rate to the process capacity. Since the process capacity is defined by the bottleneck capacity, it follows that the process utilization is defined by the utilization of the bottleneck operation. Note that even though the bottleneck operation may have few fixed costs, the process as a whole may have significant fixed costs (rent and supervisory pay in XTM's case). The overall process utilization is therefore quite important to the financial performance of most operations. We shall see later in the course that utilization also has a strong negative influence on certain operational performance measures, especially lead-time performance.

Balance

A sequential process, such as XTM's, is called *balanced* if all operations have the same capacity; otherwise, it is said to be *imbalanced*. XTM's process is somewhat imbalanced, with utilizations ranging from 62.5% in the cutting and painting area (3.75/6=0.625) to 93.7% in the welding area. The argument for a balanced system is that each operation is equally (and ideally highly) utilized, so that fixed costs are spread over the largest possible number of units, and investment in unused assets is minimized.

In practice, there are a variety of reasons one might tolerate - or even intentionally create - imbalances in a process. First, it may be that capacity investments have to be made in discrete amounts; that is, you can purchase one machine or two machines but not 1.317 machines; similar reasoning holds for workers. The discrete nature of capacity increases is likely to cause a moderate amount of imbalance in almost any process.

Imbalance may also be designed into a process if certain operations are highly unreliable in order to prevent *starvation* in a bottleneck operation. Starvation occurs when an operation runs out of material or parts to work on and is thus forced to become idle. It may be desirable in this case to make sure that operations feeding a bottleneck have some excess capacity. Then if the bottleneck operation is in danger of being starved due to a shortage of parts to work on, the production rate of the operations feeding it can be increased. Otherwise, irrecoverable production time would be lost.

Quality and yield

Understanding how quality is controlled and where potential failure points are in the process is another important step in process analysis. In XTM's case, there does not appear to be any formal quality control in the process. Rather, the process seems to rely on the skill and craftsmanship of the workers, especially the welders, to ensure quality output. We will discuss the relative merits of this approach and other more systematic approaches to quality management later in the course. For now, we shall simply try to observe generally where quality might need to be managed in a given process.

Note that in XTM's process there are several points where quality problems could arise other than welding. For example, it is not clear how quality in the painting and assembly area is managed. A more subtle area is the information quality in the XTM process, in particular errors in the customization requirements of each unit. It is likely that errors in equipment options, colors, or sizes would cause a great deal of frustration among customers and would be expensive to repair in the field.

Finally, one should be aware that quality problems can significantly impact the capacity of a process. This occurs because potentially productive time is wasted fabricating or assembling parts that may later be scrapped. In semiconductor manufacturing, for example, many complex integrated circuits (IC) have very low yields. Often, well over half of the ICs produced are not usable. Since failures often cannot be detected until a IC is completed and are nearly impossible to repair, such low yields mean that much of the process capacity is consumed producing worthless scrap. Improving yields, therefore, can often provide a significant boost to process capacity.

Inventories

Inventories in the XTM process are also important to analyze. Inventories impose direct financial costs since they require additional working capital, increased floor space, and insurance. They also increase cost due to damage and obsolescence. We will look at what drives the need for inventories in detail later in the course, so for now we will focus only on basic definitions and concepts.

There are four basic types of inventory:

> *Raw materials inventory* - This is the inventory of incoming material and parts. In the case of XTM, it would consist of the inventories of tube stock and the various components purchased from their outside suppliers.
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> *Work in process inventory* - Commonly given the acronym WIP, these are the inventories of semi-finished parts and subassemblies between the various operations of a production process. In the case of XTM, the two significant WIP inventories are the cut tubes waiting for welding and the frames in the paint area that are drying and/or waiting for another coat of paint.
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> *Finished goods inventory* - This is the inventory of final product waiting to be shipped or purchased by customers. In the case of XTM, no finished goods inventory is carried since each frame is specially ordered.
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> *Pipeline inventory* - Also known as in-transit inventory, this is material that is being transported from one location to another. For example, XTM ships 30 units per day to customers on average. With a shipping time of 7 days, this implies an average of 7 days x

30 units/day = 210 units of pipeline inventory in XTM's distribution process. Pipeline inventory can also exist between operations of production process if they are physically separated.

What purpose do these various inventories serve? Some are largely unavoidable - for example, pipeline inventory. The only way to reduce pipeline inventory is to cut back on the production rate (not terribly desirable) or to speed up the delivery time. In XTM's case, this may mean considering a different mode of transportation, for example airfreight.

WIP inventory is present for a variety of reasons. As with pipeline inventory, some WIP inventories are largely unavoidable due to the time required for various operations. For example, consider the painting process at XTM. Since total drying time is one day (8 hours), there must be on average 1 day x 30 units/day = 30 units in inventory due purely to the delays in drying.

Some WIP may result from producing in batches. For example, consider an operation that produces in batches of 100 units that is followed by an operation that consumes one unit at a time. If the processes are balanced, the WIP inventory between the two operations will follow a saw-tooth pattern, as shown in Figure 3, starting at 100 units when a batch from the first operation is added to the inventory and declining in a straight line to zero as the batch is consumed by the second operation, at which time a new batch from the first operation is added to the inventory bringing it back up to 100 units. Thus, there is an average of 50 units of WIP inventory due to the batch operation.

This type of WIP is called a *cycle stock*, because it is caused by the cyclic nature of the batch operation. Cycle stocks are quite common in many processes and occur for a variety of reasons. For example they can arise when shipping economics drive firms to transfer materials or products in bulk quantities or when a supplier’s discounts create incentives to order in large quantities.

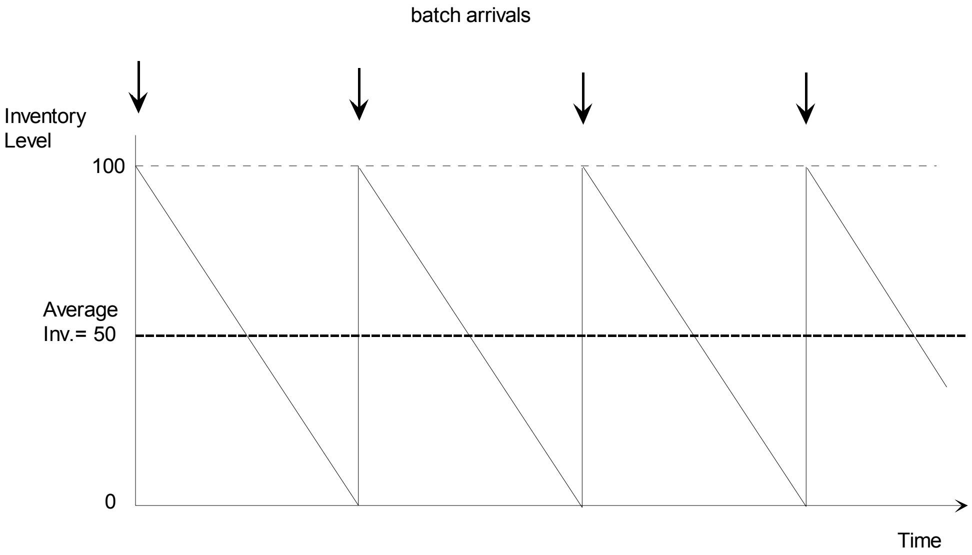

Figure 3: Example of cycle stocks cause by batch production

Another reason for WIP inventory was alluded to above in the discussion on balanced processes. In many cases, it may be desirable to keep WIP in cases where there is a high degree of unreliability in a particular operation as a hedge against starvation. Such inventory is frequently termed *safety stock*, since it serves as a hedge against supply or demand uncertainties.

Finished goods and raw materials inventories are kept for similar reasons. If suppliers deliver in batches or are unreliable, then some amount of raw materials cycle stock and/or safety stock may be necessary. Likewise, if the final product is assembled in batches and/or customer demand is uncertain, then cycle and/or safety stocks of finished goods are common. We will discuss in some detail how one should manage these various inventories later in the course. For now, a qualitative understanding of each is sufficient.

Also, note that XTM does not carry finished goods inventory. This mode of operation is referred to as a *make-to-order* (MTO) process. In other cases, called *make-to-stock* (MTS) processes, a firm may build a finished goods inventory in anticipation of sales. In general, most make-to-order process carry smaller amounts of finished goods inventories than do make-to-stock processes.

Throughput time

Another characteristic of interest to XTM is the timeliness of their process; specifically, how long does it take them to deliver a finished product to their end customers? The time required to fulfill an order is called the order *throughput time*, and the time XTM promises to a customer is called their order *lead-time*. (The two may differ, because XTM may promise a time that is somewhat longer than average to ensure it reliably meets its promise.)

To gain a feel for the competitive significance of order lead-time, imagine that you are a customer contemplating the purchase of a XTM bicycle and that one option you have is purchasing a more standardized model from the dealer's stock. Would your decision be influenced by the time it takes to get a customized XTM model? Most probably, yes. You might purchase an XTM if the lead-time is one week, but decide against XTM if the lead-time quoted is two months, especially if it is the beginning of the summer!

To understand XTM's throughput time performance, we again turn to the process flow diagram of Figure 2. One approach to estimating XTM's throughput time is simply to add up the processing and transportation times of each operation. There are a total of 4.0 hours of total processing time, 8 hours of drying time, and 7 days of transportation time in distribution. This gives roughly 8.5 days of total processing and transit time. Is this a good estimate? In general, no. This is simply the total processing and transport time; it does not include the *waiting time*, i.e. the time parts and subassemblies spend waiting to be processed at various stages in the process.

The total time to complete the manufacture of the product - including both processing time and waiting time - is called the *manufacturing throughput time*. One can also talk of the “fabrication throughput time”, “packaging throughput time”, etc. to denote the throughput time at a particular stage of production as well. (As a caution, some people use “cycle time” to refer to throughput time as well, but we will avoid this use of the term. However, you should be aware of this use in your outside reading.)

Little’s law

To compute the throughput time at XTM, we need to introduce an important relationship, known as *Little's law*.[3] Define the following:

λ = the production rate (e.g. units/hour) of a process
N = the average number of units in inventory
T = average throughput time of the process

Little's law says that these three quantities must satisfy the relation

$$N = \lambda T$$

That is, given any two of these measurements, the third is uniquely determined by the above relation. We have actually already seen an example of this relationship in looking at the pipe-line inventory at XTM. We saw that if λ=30 units/day, and if the shipping throughput time is T = 7 days, then the pipe-line inventory, N, must be 210 units, i.e λT. Little's law applies to more than just pipe-line inventories, and indeed generally holds for any process for which the quantities N, λ, and T are well defined. Consider cash flows for example. If a firm has average sales of λ=\$250,000 per month, and if its account receivable balance averages N = \$900,000, then its customers must take on average $T = N/\lambda$ =\$900,000 / \$250,000 = 3.6 months to pay.

Let us now apply Little's law to the XTM process to estimate throughput time. The only significant inventory identified in the description is the 250 units of cut frame WIP in front of the welding area. (The 30 units of inventory in painting represent WIP inventory due to drying time, and we have already accounted for the drying time.) Using Little's law, we see that N = 250 units, λ = 30 units/day, and thus the throughput time due to the cut frame WIP is $T = N/\lambda$ = 8.3 days.

Adding the 8.3 days throughput time to the 8.5 days of process and transit time gives total throughput time of roughly 17 days. Note that fully half of this throughput time is due to waiting time in the welding WIP. Actually, this is not unusual. It has been estimated that on the order of 80-90% of the time products spend in most manufacturing facilities is spent waiting. By this standard, XTM is doing rather well. However, this 17-day figure is only an average throughput time; actual times may vary about this value, due to machine breakdowns, parts shortages, short-term variations in demand, and a host of other process variabilities. Thus, it might be reasonable to expect XTM to quote a 4 week lead-time to its dealers.

Set-Ups, lot sizes and run lengths

Note that in the welding operation, fully 45 minutes of time is spent setting up and positioning the jig to hold the tubes for welding. This is an example of what is called a *set-up* or *changeover* time. Many operations require some set-up time before operations can be performed. Tools may have to be changed, vessels may need cleaning, equipment may have to be reconfigured, adjustments may be required, etc. Set-ups are non-productive time, and in general, one would like

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[3] This relationship is named after Professor John D. Little of MIT, who is credited with providing the first rigorous proof of it in 1961. The relationship existed as a “folk theorem” long before Little's paper appeared.

to avoid performing them if possible. One means of doing this is to produce an entire *batch* or *lot* of products or parts of a given type after each set-up, so that a separate set-up is not needed for each one. The size of the batch is called the *lot size* and amount of time spent producing a batch is called the *run length.* This so-called *batch production* is the predominant mode of production in the industrialized world.

Producing in lots allows one to spread the time and cost of a set-up over a large number of units, thus increasing both the capacity and (by some measures) the efficiency of the process. The downside is that batch production causes cycle stocks to form, and the larger the batch, the larger the cycle stock. This leads directly to higher inventories, which adds to a firm's assets (since inventories require working capital to finance). By Little's law, batch production also increases the throughput time of the process. We will discuss how one sets lot sizes later in the course. For now, we again aim for a qualitative understanding.

Let's consider the impact of introducing batch production in XTM's case. Suppose instead of having welders perform a set-up for each frame, we could produce a smaller number of standard frame sizes and have each welder produce a lot of 10 frames of a given type after each set-up. What would be the effect on the XTM process? First, it would reduce the direct labor cost of each unit since now the 45 minute set-up is spread over ten units, resulting in a cycle time of only 45+4.5=49.5 minutes versus 90 minutes previously. Thus, at the $30 per hour wage rate of the welders, direct labor costs for welding drop to $24.75 per unit from $45 per unit. This increases the contribution margin per unit from $85 to $105.25, or from 11.33% of sales to 14.03% of sales, which is a 20% increase in contribution margin. At current output, the effect on profits is dramatic; profits increase from $222,000 per year to $367,620 per year, a 65% improvement! Clearly, these are dramatic improvements from what, on the surface, is a seemingly minor change in XTM's operations.

Batch production has other positive effects for XTM. Recall that welding is the bottleneck of XTM's operation, and only a modest increase in output (from 600 to 640 units per month) could be achieved under the current process. With batch production, however, the welding time per unit has been reduced from 1.5 hours to 49.5 minutes (0.825 hours). Thus, the capacity of the welding area is now 7.27 units/hour or 1,164 units per month, close to double its current capacity. Indeed, under this batch production scheme, welding is no longer the bottleneck; the bottleneck has been broken, and now the assembly area, with a capacity of 4.67 units/hour or 747 units per month, is the bottleneck. If XTM could sell all this new potential output, its profits would skyrocket to $553,000 per year. Note that other than the increase in cycle stock caused by the set-up, no new fixed assets are required, so this change could produce a 250% increase in ROA – all this from changing a little set-up procedure in the welding area!

Of course, it's not likely that the decision to move to batch production would be so clear-cut. For one thing, batch production will introduce other inventories into the process. For example, XTM may have to batch up incoming orders according to frame size or perhaps move to make-to-stock production to implement batch production. This will introduce cycle stocks and delays at other processes. The material and value-added costs of any extra inventories would have to be financed, increasing XTM's need for working capital, thus partially off-setting the increase in ROA.

Flexibility

Another factor to consider in the potential change to batch production is the flexibility of XTM's process. Currently, it is highly flexible, allowing XTM to customize its product to the needs of every customer. However, in moving to batch production, XTM would need to standardize its frame sizes in order to allow batch production of a relatively small number of sizes. Otherwise it may find itself producing many bicycles in sizes that rarely get ordered, which would drive up inventories. Producing in smaller batches would reduce these inventories but also increase costs, because the set-up time cost would be spread over fewer units. Exactly how many sizes are economical to produce and what batch sizes are most economical would require further analysis. Overall, however, batch production would reduce the flexibility of XTM's process.

Standardizing sizes, however, may conflict with the XTM’s customized approach to configuring bicycles. Will customers pay extra and tolerate long lead-times if XTM's product becomes more standardized? Perhaps XTM could move to make-to-stock production entirely, producing only a standard line of model sizes and colors, but then what would distinguish XTM's product from any other mass-produced bicycle? Are their costs of production under batch production low enough to compete in the mass market? Would they lose their niche among enthusiasts? All these questions are serious issues for XTM management in contemplating a process change.

Whatever decision XTM's management makes going forward, process flow analysis of the type outlined above will play a crucial role in understanding the consequences of process changes.