Welcome to Apex Tube

Apex Tube Company is a typical discrete parts manufacturer that we will use to illustrate the process of creating continuous flow. Apex produces a variety of tubular products for automotive, truck, and heavy-equipment applications. Two years ago Apex responded to pressure from its customers for lower prices, higher quality, more frequent deliveries, and more rapid response to changing demand by taking a hard look at its manufacturing operations.

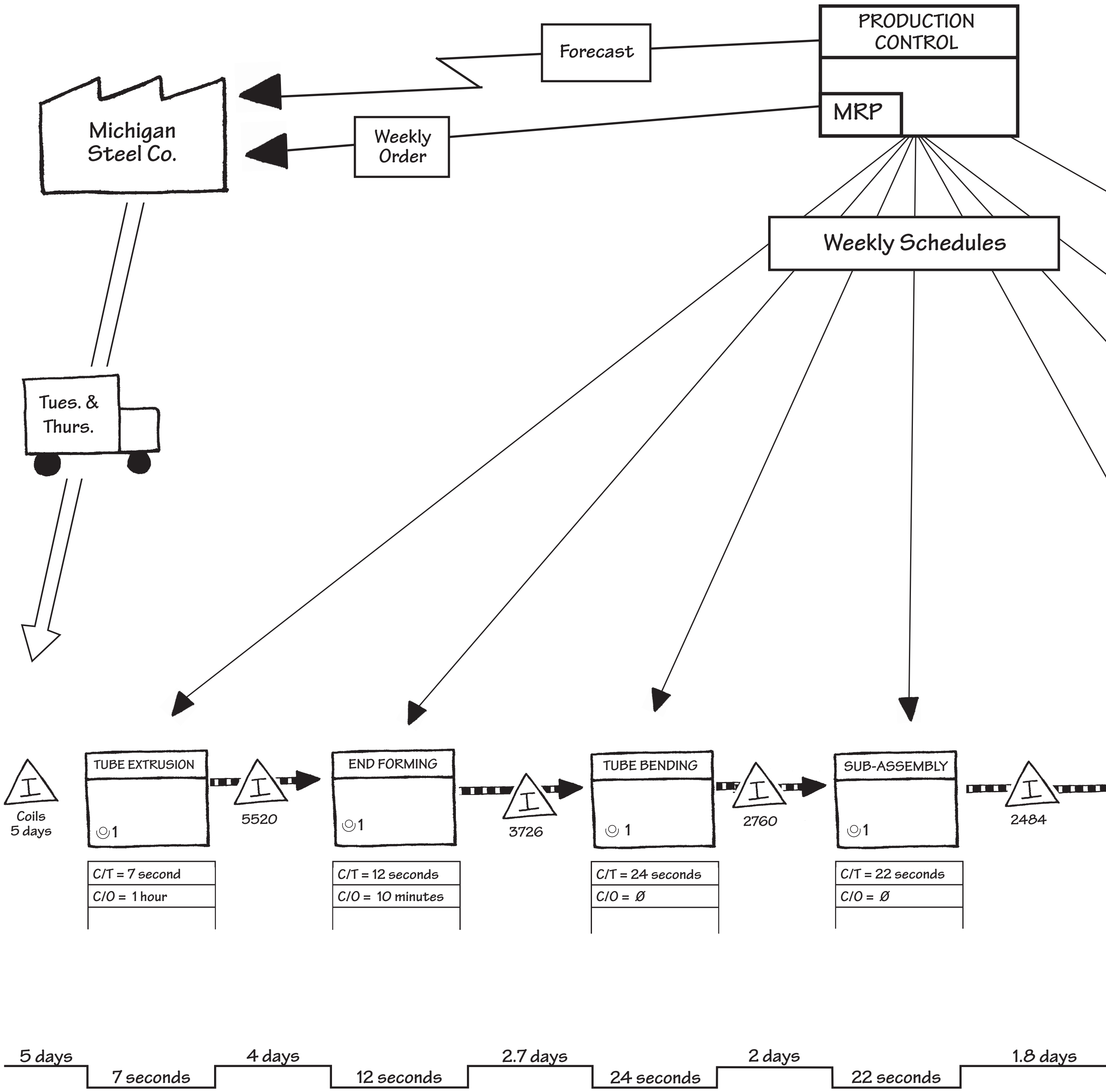
For many years the company had organized its fabrication and assembly processes by department with each product visiting each department as necessary. The resulting maze of spaghetti-like product movements was hard to manage and even harder to improve. Apex managers therefore took the first step recommended in *Learning to See* and conducted an analysis of their products to find product families that could be managed individually.

Apex managers drew up a product family matrix that grouped products by similar sequence of final processing (pacemaker) steps and machines.

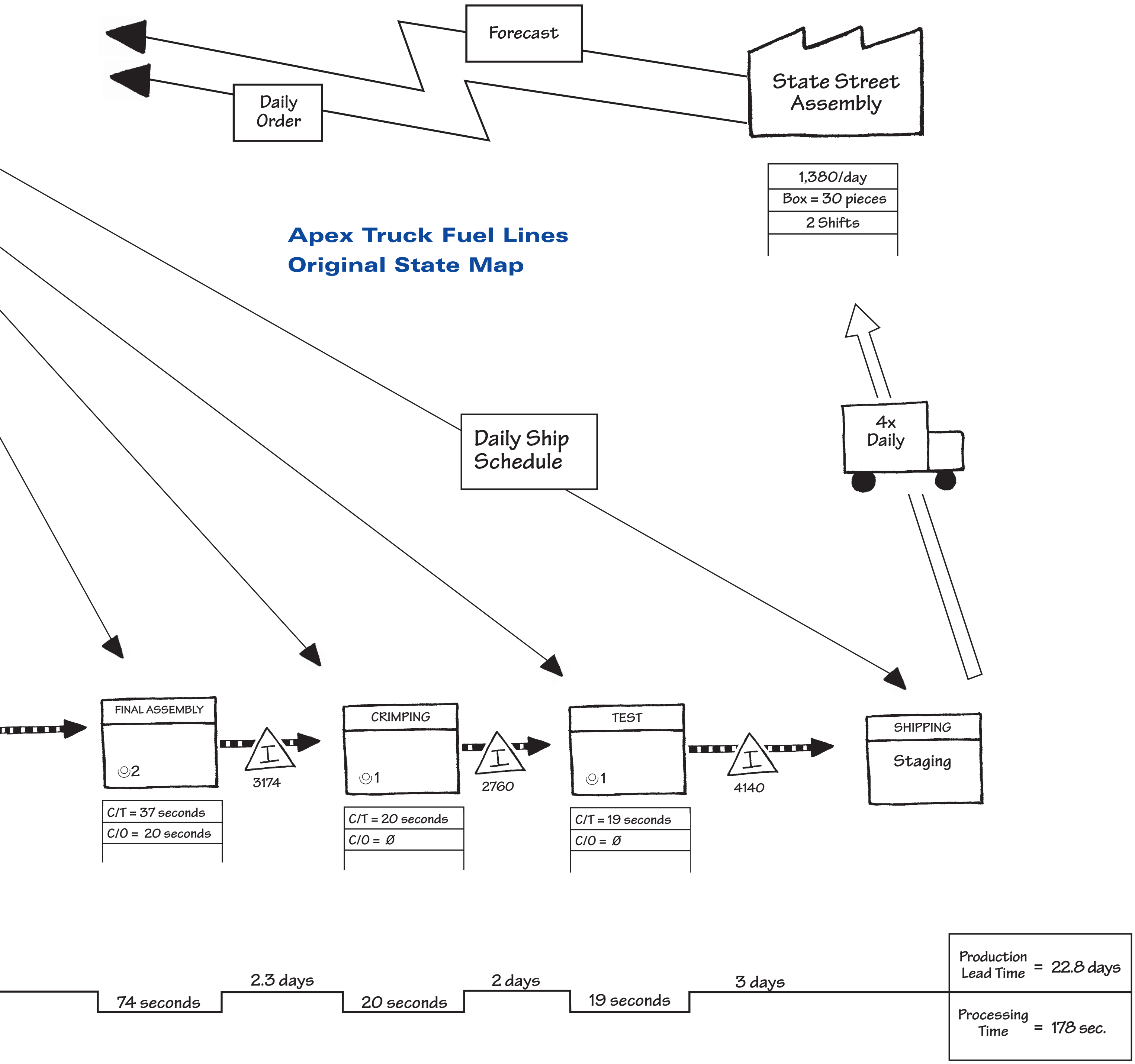
Apex's Product Family Matrix

		Assembly Steps and Machines							
		end form	pierce	braze	bend	sub-assembly	final assembly	crimp	test
PRODUCTS	automotive	X				X	X	X	X
	truck S	X			X	X	X	X	X
	truck L	X			X	X	X	X	X
	truck A	X			X	X	X	X	X
	heavy truck		X	X	X				X
	heavy equipment	X	X	X	X		X		X

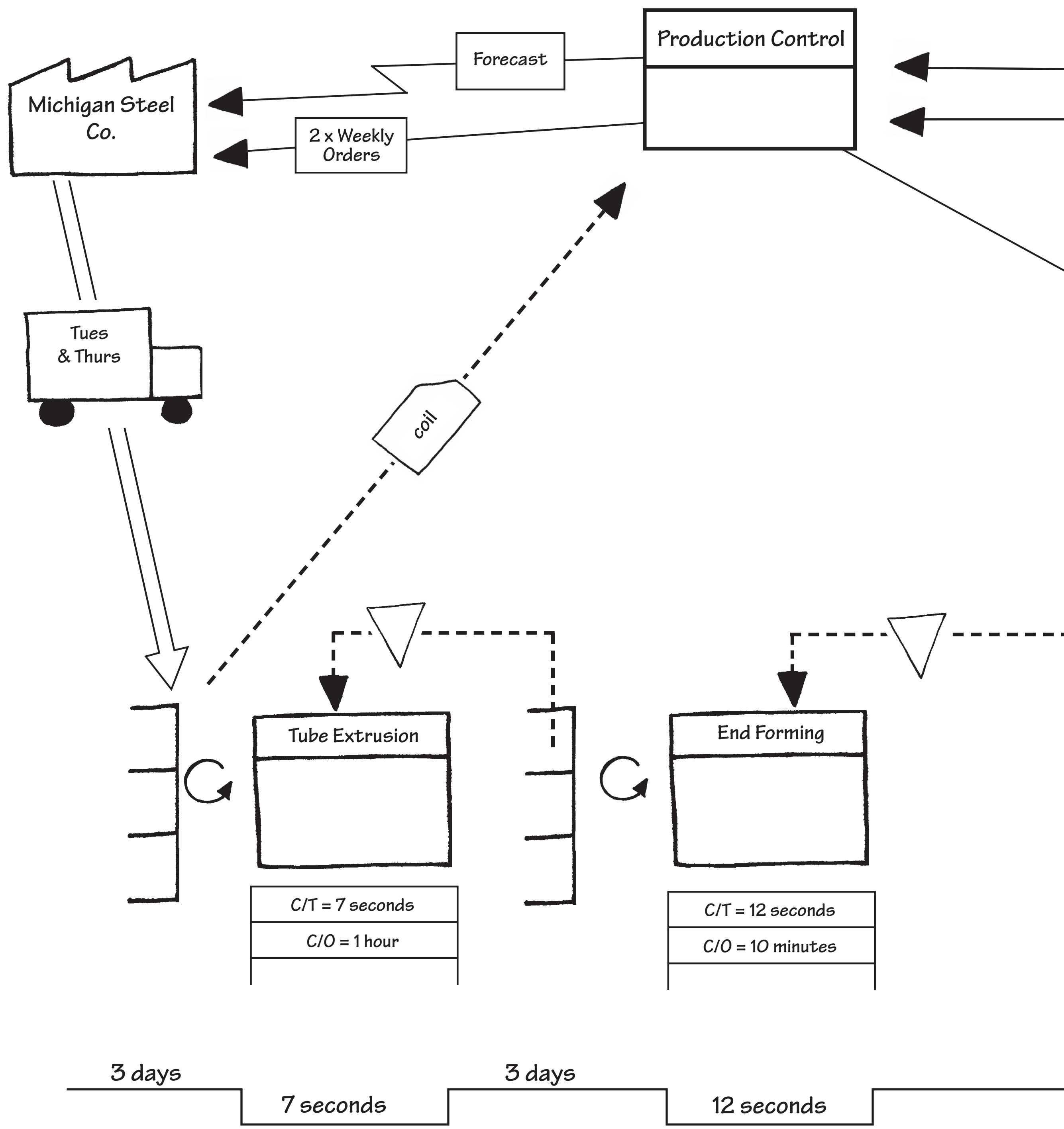
The light-truck product family made the greatest revenue contribution to Apex and was under the heaviest price pressure. Apex appointed a Value Stream Manager for this product family, who drew a current state value stream map. This product family is shipped to the State Street assembly plant in three variants: a short-hose assembly (S) for the short wheelbase truck, long-hose (L) for the long wheelbase model, and an alternative-fuel (ethanol) assembly (A) offered as an option on this vehicle.



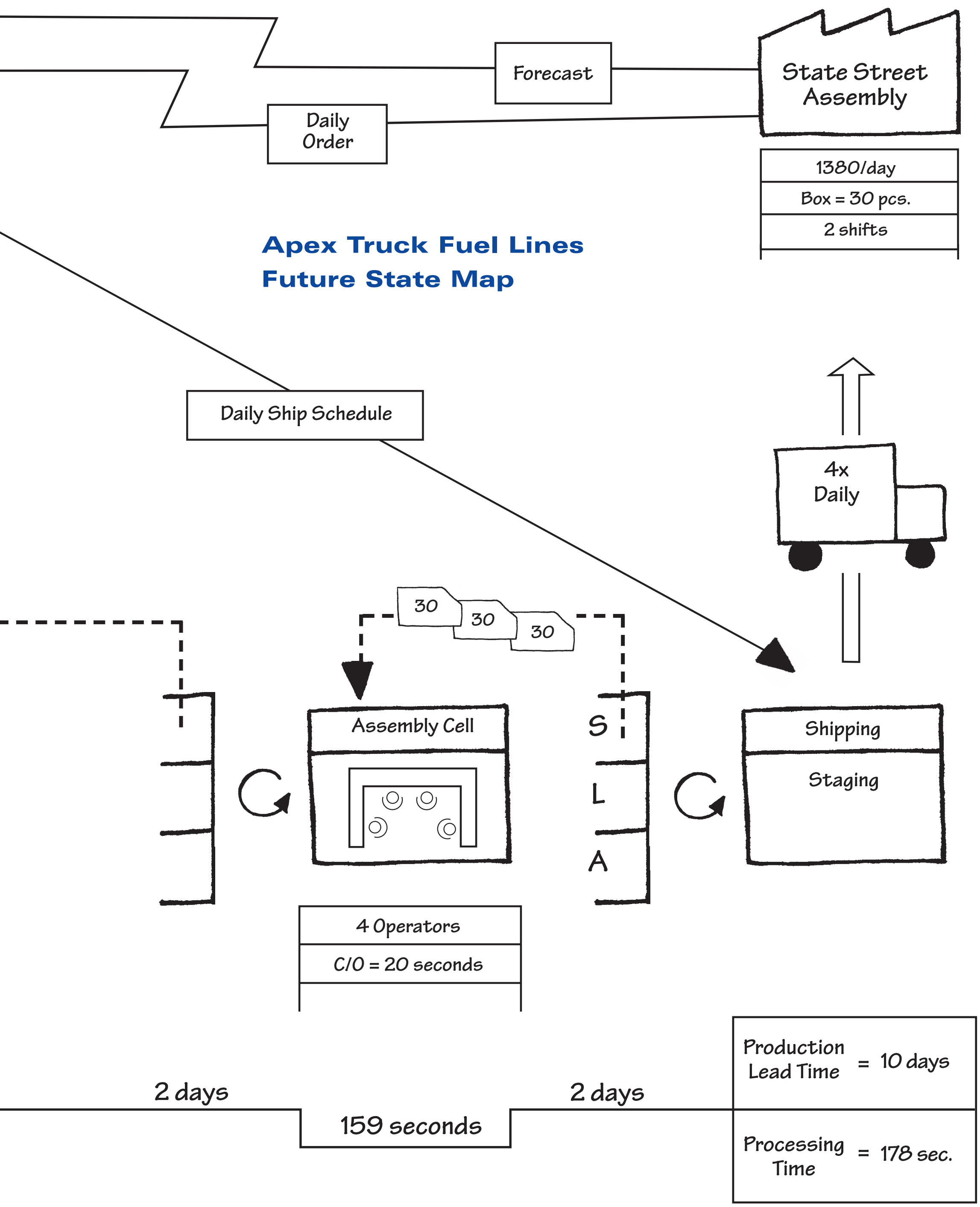
With their batch and queue production system based on a process village layout, Apex managers were not too surprised to learn that actual processing time was less than 0.01% of lead time and that much of the floor area devoted to this product was either for storing inventory or to provide access between process steps. In short, nothing flowed and it was very difficult for Apex to respond to changing customer requirements even with very large in-process inventories.



Apex managers quickly decided to create a continuous flow cell for the five final fuel line processing steps. (Before doing this they made sure, of course, that enough machines were still available in the process villages to sustain production for the other products in the plant.) Shortly afterward they also developed supermarket pull systems between the new cell and the two upstream fabrication steps that would continue to operate in a batch mode shared



across several product families. These pull systems replaced the schedules previously used to regulate these processes. Through hard work and by suspending traditional rules of thumb on how quickly change could happen, Apex was able to design and implement the future state shown here.



Apex Truck Fuel Lines
Future State Map

Apex started its fuel line value stream improvement at the right place: the 'pacemaker' process. The pacemaker involves production steps that are dedicated to a particular family of products and responds to orders from external customers. A well run pacemaker sends smooth demand signals upstream to the pull loops of the remaining batch fabrication processes, which respond to requirements from internal customers.

Apex managers and engineers made another good decision by minimizing their initial investment and keeping the cell simple. For example, they could have created a more extended continuous flow by incorporating an end-forming press into the fuel line cell. But such a press would have required substantial capital investment. (In the future Apex may decide to apply some of the cost savings from its improvements to purchase and add a press to the cell.) They decided to install a simple, inexpensive, flexible operator-based cell designed for State Street Assembly's needs. This is more likely to be highly reliable and well-suited to sending smooth signals up the value stream.

Apex managers chose a classic U-shaped layout for their new operator-based cell, as illustrated on the next page. In only a few days they were able to move machines and configure the new cell to achieve striking reductions at this process in lead time and floor space required, while dramatically increasing the number of pieces produced per production associate.

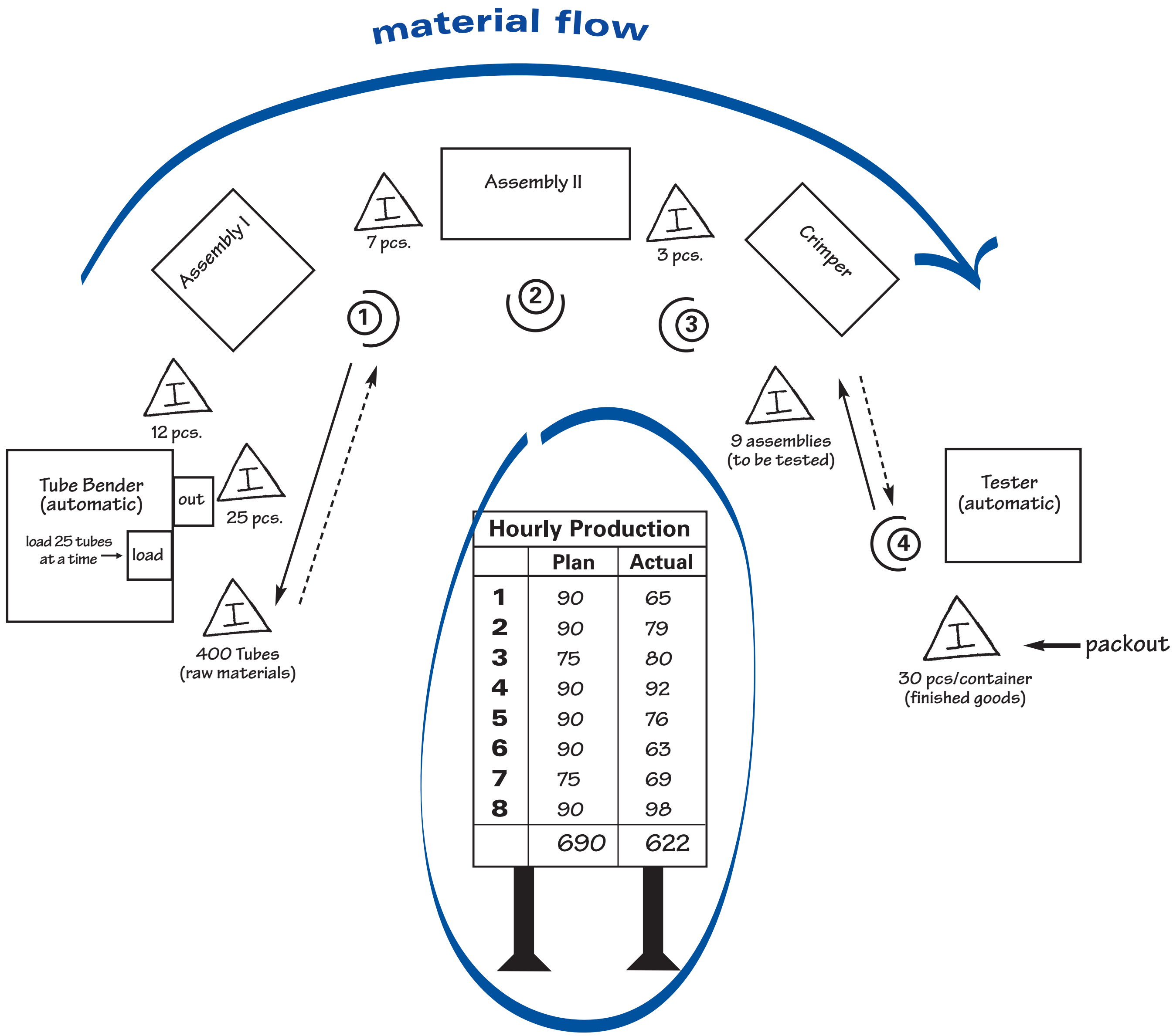
Apex's Progress with Continuous Flow

	Original State	Current State
Continuous Flow	No	No
Production per Shift (actual/target)	unstable ≈622/690	unstable ≈622/690
Space (sq. feet)	1130	580
Assembly Lead Time (WIP x Takt)	11 days	37 min
Number of Operators	6	4
Productivity (pieces/associate/hr)	13.5	20
Functions Effectively as Pacemaker	No	No

A Closer Look — With Eyes for Flow

Apex managers, engineers, and production associates were excited about their new fuel line cell. After all, they quickly increased productivity by 50% while halving space requirements and dramatically slashing lead times. Yet when you look at the Apex cell with "eyes for flow" you should actually be disappointed. A walk through the fuel line cell will show why.

Apex's fuel line cell — current state



Hourly Production	Plan	Actual
1	90	65
2	90	79
3	75	80
4	90	92
5	90	76
6	90	63
7	75	69
8	90	98
	690	622

The first step when we visit a facility is typically to go see the current situation with our own eyes and ask, "What is the problem?" At Apex, the first thing we notice is the production output chart at the entrance/exit of the cell showing planned and actual production. Looking at the output figures we wonder, "Why is there so much variation, and why does total production fall short of planned production?" More specifically, "Why is the cell achieving only two-thirds of planned output during many hours of the shift?" Is the problem incapable machines that make bad parts? Is it machines that won't run? Is a supplier shipping bad parts, or are parts missing? And who reacts when these problems occur?

Whatever the cause, the variation in output is clear evidence that cell performance can be greatly improved. We are even more certain of this when we note that in two hours out of eight the cell actually produced more than the plan, which is just as bad as being under the target. Four production associates were assigned to the cell the entire shift, so a change in staffing can't explain the variations. Unless this was achieved by hurrying, unacceptably risking stress injuries and bad quality, there must be waste in the process.

We begin to see a source of variation and waste when we closely examine the first two steps in the production sequence: the tube bender and the first assembly operation. The first production associate has to leave her regular work area every 25 pieces, or about every 16 minutes if the cell is producing to takt time (as explained below in Question 2). This requires three minutes and means that either the material flow stops or the tube bender and the first two assembly steps are all decoupled from one another. This means no continuous flow.

As we continue to walk around we notice that there are various quantities of inventory between every operation and that the production associates are each anchored to their machine, which often means they have to wait while the machines cycle.

Variable inventory buffers between workstations are an inefficient way to balance uneven workloads. When a buffer gets too full, the supplying operation often takes an unofficial break — perhaps to get materials or do other out-of-cycle work — while the downstream station catches up. Operations are decoupled, allowing each to produce batches instead of one piece at a time.

Decoupled operations, which we call ‘islands’, bake the waste of overproduction and the waste of waiting into a cell, causing them to be repeated many times every shift, day, week, month, and year. Tiny wastes often don’t seem significant to managers just visiting the process (and apparently are not visible to Apex managers), but think about them as they add up more than 600 times per shift!

Decoupled operations also make it difficult to notice production problems as they happen. When a problem occurs the rest of the stations keep on working. By the end of a shift the unnoticed problems add up and the production volume falls short of the target. Pacemaker processes, in particular, need to be manageable. Problems or abnormalities need to be spotted as they occur and support personnel must respond to them quickly. Production associates cannot react to and fix significant production problems, find and eliminate the causes of those problems, and at the same time still achieve full production!

Finally, as we complete our tour we note that the Apex cell is laid out in a very wide “U”. This defeats one of the main objectives of a U–shaped cell layout: Permitting flexible deployment of operators by moving work areas into close proximity. Both the first and last production associates are moving back and forth over considerable distances to handle materials. Flow stops every time they leave a station to backtrack.

Our conclusion, at the end of our walk through Apex’s cell, is that there is actually no continuous flow anywhere. Instead we see only erratic and intermittent flow — as indicated by the small piles of inventory between each machine and the fluctuating output from hour to hour. Indeed, this cell is really just a ‘module’ of adjacent machines and operators producing at best ‘fake flow’ that misleads the untrained eye.

THREE FLOWS

As you look at your own cells or lines, tune your eyes to check...

1. Does information flow?
- **Does everyone know the hourly production target?**
- **How quickly are problems and abnormalities noticed?**
- **What happens when there are problems and abnormalities?**

2. Does the material flow?
- **Does the workpiece move from one value-adding processing step right to the next value-adding step?**

3. Do the operators flow?
- **Is the operators' work repeatable and consistent within each cycle?**
- **Can the operator efficiently go from performing one value-adding work step (work element) to the next?**

Targets for Apex's Fuel Line Cell

	Original State	Current State	Target
Continuous Flow	No	No	Yes
Production per Shift (actual/target)	? / 690	unstable ≈622 / 690	690 / 690
Space (sq. feet)	1130	580	252
Assembly Lead Time (WIP x Takt)	11 days	37 min	200 sec
Number of Operators	6	4	2
Productivity (pieces/associate/hr)	13.5	20	40
Functions Effectively as Pacemaker	No	No	Yes

While Apex's new cell performance is much better than the original process village layout, a careful effort to achieve true continuous flow through proper process design and operation can double labor productivity, halve the needed space, reduce lead time by a further 90%, and dramatically improve both quality and responsiveness to customer requirements. Realistic targets for this cell, which we will show you how to achieve in the pages ahead, are shown in the right hand column of the table above.

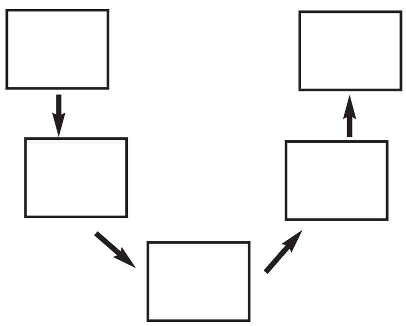
We'll get started by posing the first of eleven questions you should go through as you strive to develop true continuous flow in your own cells and lines. The questions require careful work and attention by your entire team, but you will discover that the answers are invaluable once they are incorporated in your business.

Question 1: Do You Have the Right End Items?

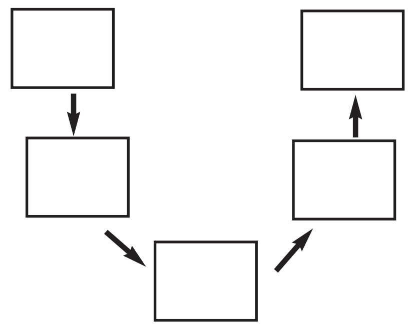
Apex has already determined their product families and assigned three end items to its fuel line cell. However, as you consider your own situation, you may have to think carefully about the right products to assign to your pacemaker process. Here are some guidelines we've found helpful.

1) Flexibility. Sometimes demand is high enough to allow you to dedicate individual products to their own cells or lines like this:

Product A

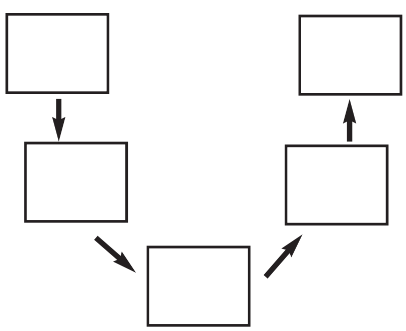


Product B

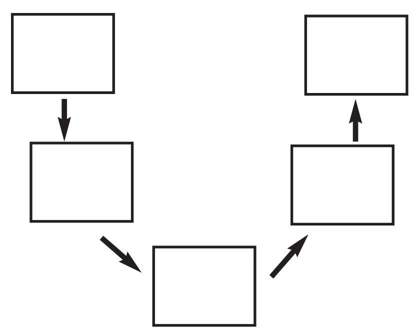


However, if demand gyrates between products and you can keep changeover times short, you are often better off sharing products between mixed-model cells like this:

Products A & B



Products A & B



The total capacity is the same in both cases but the ability of each process to accommodate shifts in demand between the two products is much greater in the second case. The demand for one product within a family may vary, while the demand for a whole product family is often more stable.

2) Variation in Total Work Content. The total work content — that is the operator time required to process one piece from start to finish — should not vary by more than about 30% between the different end items processed in the cell, especially when a moving conveyor is used. When the work content varies too much it becomes difficult to maintain flow and productivity. In such cases you may want to split the cell or assign some rare or low-volume end items to other cells. (Some facilities even create a separate line or cell to handle low-volume end items, until product engineers can reduce the content differences between the items via design changes.)

3) Similarity of Processing Steps and Equipment. When the steps required to build different products within the cell vary too much (i.e., when some products skip some processing steps) operators will have to "shift gears" every time they change to assembling a variant of the product. This reduces productivity and increases the chance of quality problems. Again, sometimes it is better to produce variants with markedly different processing steps in different cells.

4) Takt Time (Production Pace). Takt time is the rate at which customers require finished units. It is determined by dividing the total available production time per shift by the customer demand rate per shift (see the equation at right). As a general guideline, when takt time for a cell falls below ten seconds the operators' jobs may become highly repetitive and stressful. When high demand calls for very short takt times you should consider using multiple footprints of the cell, possibly side-by-side, instead of a single high-speed cell. This is particularly appropriate if the capital requirements of additional cells can be kept low through utilization of simple equipment.

Conversely, when takt time slows to more than about 120 seconds, the number of work elements sometimes gets so high that work motions can be difficult to standardize. In such cases consider adding additional but similar end items to the cell to bring down the takt time. Of course, with some products it will simply be impossible to set takt times below 120 seconds because volume requirements are inherently low, even when several different end items are run through the same cell or line. (With long takt times it can get difficult to have all parts at the line for the operators for the different product variations. Sometimes you have to increase the parts delivery frequency or deliver certain parts in the assembly sequence.)

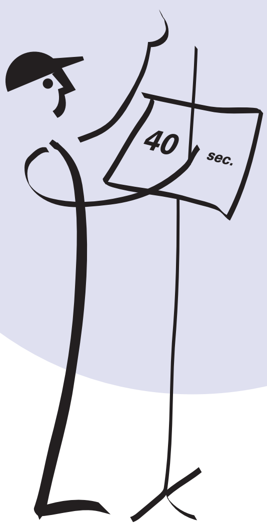
5) Customer Location. When customers for a product are widely dispersed geographically, it may make sense to split up the work into multiple lines, each located near a different customer. This makes sense particularly when shipping costs and duties for finished units are high, when there are potential exchange-rate losses, when lead times for components are long, or when local infrastructure (supervision, buildings, etc.) is available at reasonable cost.

Question 2: What is the Takt Time?

Having decided what products to produce in the pacemaker, the next task for Apex managers was to determine the takt time. ('Takt' is a German word for a pace or beat, often likened to a conductor's baton.) Takt time is a reference number that is used to help match the rate of production in a pacemaker process to the rate of sales.

takt time

Used to help synchronize pace of production with the pace of sales



$$\textbf{takt time} = \frac{\textbf{your available work time per shift}}{\textbf{customer demand per shift}}$$

$$\textbf{example:}\quad \frac{\textbf{27,600 seconds}}{\textbf{690 pieces}} = \textbf{40 seconds}$$

this means: **The customer is buying this product at a rate of one every 40 seconds.**

Sales are usually calculated on a daily or weekly basis but most pacemaker processes are actually up and running only some fraction of each day or week. Since the point of takt time is to pace actual production, the most sensible thing to do is to divide the number of products demanded daily or weekly into the number of shifts operated in that time period to determine demand per production shift. For example, the customer demand for Apex's light truck fuel lines is currently 6900 units per week and Apex operates its fuel line cell ten equal shifts per week. Thus the demand per shift is 690 units.

Once demand per shift is known the final step in the calculation of takt time is to divide this number into the 'effective working time' per shift. This is start-to-stop shift time minus any scheduled operator breaks, meetings, cleanups, etc. Because takt time must represent the actual customer demand rate *do not* subtract time for unplanned machine downtime, changeovers, or other internal problems.

Apex operates two 8-hour shifts Monday through Friday, 6:00 AM to 2:30 PM, and 3:30 PM to Midnight. There are two 10-minute breaks each shift but no scheduled downtime for maintenance. This means Apex has 27,600 seconds of effective working time in each shift.

480 min. (8 hours) – 20 min. of breaks = 460 min. x 60 sec./min. = 27,600 seconds

By dividing 690 units into 27,600 available seconds we determine the takt time: 40 seconds.

$$\frac{\textbf{27,600 seconds}}{\textbf{690 units}} = \textbf{40 seconds per unit}$$

This is the rate of customer demand, the all important 'beat' of the market. Notice that takt time is expressed in 'seconds-per-unit' because it is easier for everyone to understand and use than decimals of minutes. Similarly, we use 'seconds-per-unit' rather than 'pieces-per-hour' to describe actual production rates, or 'cycle time'. Comparing takt time and cycle time is the easiest way to answer the simple but critical questions: "How frequently does the customer need one piece?" and "How frequently do we actually make one piece at our pacemaker process?"

There is one additional point that may be very important in your own takt time calculations, the amount of variation in customer orders. In Apex's case the 6900 unit per week demand was relatively easy to determine because Apex is supplying a massive automotive assembly plant whose own takt time does not change frequently. But what if long-term average demand and day-to-day actual demand are different?

We suggest that you check the range of daily customer demand variation by reviewing actual shipments (not orders) over the past twelve months. Your cell must be able to handle sustained demand. For occasional spikes in demand it is generally better to operate at a steady takt time (based on average long-term demand) and either hold a buffer stock of finished goods or run some daily overtime to ensure your ability to serve the customer. Changing takt time from day to day is inefficient, disrupts the work pace, and increases the potential for quality problems.

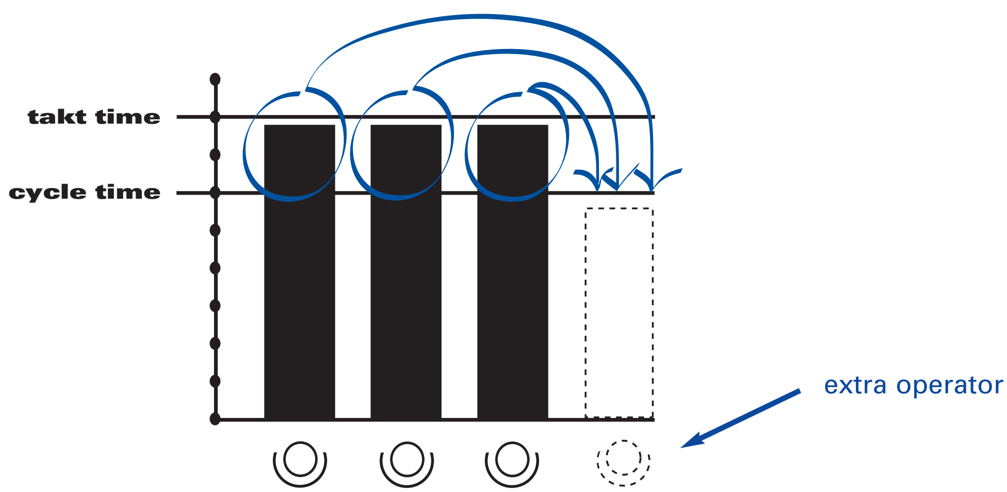
Lastly, regarding future demand for new products, it can be difficult to make accurate forecasts far in advance. When future demand is uncertain it may be wiser to add capacity in steps, as increased demand actually materializes, rather than designing your pacemaker now for a peak demand that may not appear.

Cycle Time

Cycle time is how frequently a finished unit actually comes off the end of your pacemaker cell. We often find processes that are operated at cycle times faster than takt time. For example, if you are running your facility three full shifts (perhaps to achieve high machine utilization) you will probably always need cycle times slightly below takt time because there is never any time available to catch up if your equipment or materials system fails. And to some degree these sorts of problems will always occur in manufacturing!

However, keep in mind that when you chronically cycle much faster than takt time you increase the chances of overproducing and may be using extra operators. (As the diagram below shows.) Much worse, you conceal your production problems and reduce the incentive to find and eliminate their causes. It is important to maintain a certain tautness at the pacemaker to ensure that problems get noticed quickly and receive fast response by support staff.

Cycling much faster than takt may require more people

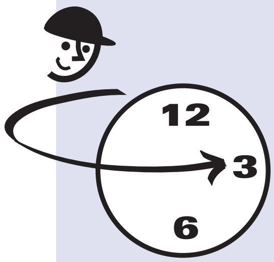


Note:

The inevitability of problems in manufacturing is one of the reasons why many production facilities in the Toyota group of companies run their pacemaker processes for two shifts with a one to four hour gap between shifts. Then there is time to make up production losses with a little overtime at the end of each shift.

Setting the Pace

As you go through the calculations to determine your own pacemaker takt time we need to explain one final point: It is seldom the case that there is only one correct takt time!



Remember that takt time is customer demand (which you can't change) divided into available production time (which you can change.) Specifically, you can adjust:

1) The available production time — the number or length of shifts.
2) The number of end items produced in a cell.
3) The number of cells making a particular end item.

The pace of production is one of the most critical considerations for the design of your processes. Here you will often have some choices to make. For example:

- A cell that has a takt time of 40 seconds over two shifts could also be run at 20-second takt in only one shift. In some cases it is easier and less costly to manage only one shift, particularly if running a second shift means extra support structure and paying night premiums. An added bonus is that the waste of waiting time is easier to see and eliminate when takt time is shorter.

- The size, weight, and complexity of a product can influence what is a reasonable cycle time and the number of motions for each operator. Producing a light, low-complexity product with only a few work elements per operator to a 10-second takt time may be fine. But when operators are working on larger, heavier or more complex products it can be better to work to a longer takt time and assign more work elements to each operator.

- When new products are introduced, substantial savings in capital investment can be achieved by adding them to existing cells rather than building additional cells. This will decrease the takt time for those cells.

- As you launch your new cell it is often much better to utilize a temporary and separately held 'safety stock' of specific finished goods to protect your customer and to set your cycle time only slightly faster than takt time. The tension this produces forces you and your staff to address the causes of production interruptions.

With experience you will gradually learn what's best for you. The key point for the moment is that you must know what the takt time is and how it was determined.