

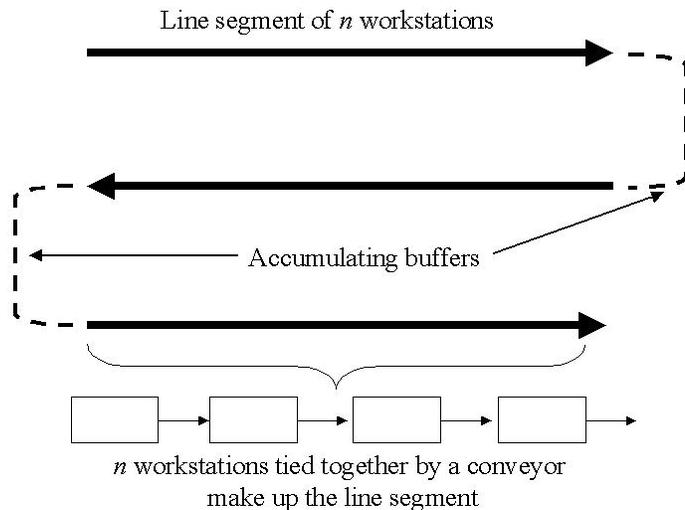
Use of a Queueing Model to Design a Lean System

Prepared as a basis for class discussion by Jamie Flinchbaugh¹.

Toyota has evolved the design of their vehicle assembly plants for 50 years. Much of the work coincided with the development of the Toyota Production System² and has evolved through periods of trial and error. In this case, with the corresponding model found in *lean_factory.xls*, you have the opportunity to use a queueing model to explore the relationship that Toyota discovered when developing the Toyota Production System.

A brief explanation of the factory dynamics

In a factory using the andon process³, buffers are used to create independence among departments attempting to push decision making further down in the hierarchy and create mini-companies within the factory. This is attained by physically promoting significantly more independent departments or line segments than a traditional assembly plant would have, as depicted in the figure. A line segment may consist of somewhere between 20-40 workstations. Separating each line segment is an accumulating buffer that can hold several work cycles of product. The buffers allow each of the teams to make decisions regarding stopping the line to fix problems. The buffers also increase the independence in operating metrics. These buffers seem to violate the principle that inventory is waste and should be eliminated; instead these buffers de-couple one line segment from another, and thus prevent downtime at one segment from shutting down downstream segments on account of no inventory.



¹ Jamie Flinchbaugh is a Fellow in the Leaders for Manufacturing Program, Class of 1998, and is sponsored by Chrysler Corporation. This case is extracted from *Implementing Lean Manufacturing Through Factory Design*, an MIT Thesis by Jamie Flinchbaugh, 1998.

² This case requires a working knowledge of the Toyota Production System. An adequate understanding can be reached by reviewing Harvard Business School case study *Toyota Motor Manufacturing, U.S.A., Inc.* (case number 9-693-019, September 5, 1995, prepared by Kazuhiro Mishina).

³ The andon process: each line worker can signal for help from the team leader if there is a quality problem. The team leader makes a decision on whether or not to stop the line, but if at all possible, will make sure that the quality problem is fixed before leaving the workstation. This results in problem solving closer to the problem and very little rework, resulting in a better quality product.

As far as managing the line, one group leader leads the team in each line segment. Under the group leader may be three or four team leaders who support teams of 6-10 team members. Both team members and the team leader are union jobs. The group leader has much more broad responsibility than in a traditional assembly plant, to the extent that they act as the president of a mini-company, with the upstream line segment as the supplier and the downstream line segment as the customer.

What about the factory designer?

The factory designer must relate this operational understanding into the physical design parameters of a factory. The designer must balance investment cost decisions with the operating performance of the factory such as cost, quality, and throughput. You, as factory designer, must be concerned with the relationships between the operation of the andon system (fix quality in-station) and throughput losses.

If a series of processes or workstations have equal capacity, but their production varies (either within cycle times or through downtime), the output will never equal capacity. Said another way, the system's realized capacity, or system throughput, will always be lower than the capacity of the process with the minimum stand-alone capacity. In order to get the desired capacity, there are three compensating techniques that can be used independently or in combination:

- Reduce processing variation
- Provide excess capacity so that realized throughput equals customer demand
- Provide decoupling buffers between processes to reduce the impact adjacent processes have on each other

Each of these solutions has other factors or trade-offs to consider. Providing buffers increases system lead-time, which in turn increases work-in-process inventory, hurts problem solving capabilities, and allows more opportunities for in-system damage. Providing excess capacity could be restated as allowing for lower plant efficiency. Excess capacity is costly both to investment and variable costs. Reducing processing variation, which would mean both variance within cycle times and improving equipment uptime, is perhaps the least costly, but requires significant and specific skills within the organization. Although Toyota uses all three solution points to some degree, reducing processing variation is their primary focus.

The three compensating techniques are not a complete factory design, but they do compose the strategic factory design. While these design factors exist for any factory, we need to relate them to the design of a vehicle assembly plant. Achieving strategic goals relating to variation, capacity, and buffers will be achieved through management of the physical design features described in the following table.

Table of design features

<i>Physical design parameters</i>	<i>What they represent</i>	<i>Base case values</i>
Number of line segments	The total number of workstations is broken up into line segments. The size of the line segments is determined by how many pieces the total is broken up into, which is the number of buffers plus one.	This value does not show up explicitly in the model. It is represented in the length of the line segments. It should be considered, however, because each new line segment represents significant cost. The base case represented six line segments.
Length of line segments (or # stations / segment)	The length of the line segments is the total number of workstations, typically 250-500 for an assembly plant, divided by the number of line segments.	We settled on a value of 33, which is in the ballpark of Toyota's factories. If there were no buffers, i.e. a traditional assembly plant, this value would reach 200-500.
Size of buffers (or accumulator size)	The size of the buffers represents how many vehicles can be held in each buffer between line segments.	We settled on a value of 15. Buffer size drives conveyor length and sometimes floor space, requiring investment dollars.
Plant uptime (or P[downstream segment starved])	This represents the percent of available time to produce final product. The factory only loses final product when the last downstream segment is starved. No factory has 100 percent uptime. The realized capacity, which must meet customer demand, is the plant uptime times the segment's minimum theoretical capacity process.	This is an output of the math model. It is the primary performance metric to evaluate the overall design. We settled on a probability of starvation of 8 percent, which can be restated as 92 percent uptime.
Percent over-speed	If the upstream line segment runs at a faster pace than the downstream segment, it can partially make up for lost production from downtime.	The model includes the takt time ⁴ of both the upstream and downstream line segments. Our values are 103 seconds for the downstream segment, and 100 seconds for the upstream segment, which results in a percent over-speed of 3 percent.
Shift structure	The plant can run with one, two, or three shifts per day. Few assembly plants run with one, but one or two shifts represents windows of opportunity to run overtime, reset buffers, or do preventive maintenance. A three-shift policy runs shifts back-to-back not allowing for these activities.	We settled on a two-shift policy, followed by Toyota, which allows for the possibilities stated at left. What happens to uptime if these activities are hampered?
Variation (or E[# cycles before failure])	This value represents the number of expected completed jobs before an andon signal results in a line stop.	Based on data from Toyota ⁵ , we settled on a value of 550. Is it fair to use Toyota's quality data for another automotive producer?

⁴ Takt time is a term used by Toyota that is consistent, but not equal to, cycle time. The true definition of takt time is the available minutes of production in a day divided by the daily customer demand. Here the value substituted is more represented by the pace of the conveyor (or the available time per workstation), which can be set independently for each line segment.

⁵ Mishina, Kazuhiro. *Toyota Motor Manufacturing, U.S.A., Inc.* Harvard Business School case # 9-693-019, September 5, 1995.

Instructions for class

- 1) Open the Excel 97 spreadsheet titled *lean_factory.xls* that contains the model.
- 2) Using the shaded cells in the sheet *Results Page*, examine the relationship between factory performance and the following parameters:
 - a) Line segment length (vary # stations per segment for both segments)
 - b) Percent over-speed (vary the upstream takt time)
 - c) Reduce process variation (vary the E[# cycles before failure] for both segments)

Note – the spreadsheet permits you to change other parameters: the probability the upstream segment is starved (currently at 0.07); the mean time to repair (MTTR) for both segments; the hours per shift. You should leave these as is.

- 3) Use the *Tradeoff Curves* sheet to determine the correct buffer size for each solution set. Maintaining the downstream segment takt time at 103 seconds and shifts at 2/day and 8 hours / shift, the factory's throughput (or E[# finished cars/day]) must meet demand of 480 vehicles.

Questions for reflection

The following set of questions is not to be answered for class. However, to give you a feel for the kinds of questions that a person who is implementing this model must address, we have included several of the key questions that the design team had to think about.

- 1) What seems a reasonable design solution for the factory?
- 2) Where does the role of variation reduction fit into the model? Can this be considered an input to the design? What must be in place to change this parameter?
- 3) What are the limitations of the model? What assumptions are included?
- 4) How would you manage an understanding of the investment costs when using this model?
- 5) How can we communicate our insights generated from using the model to others both inside and outside manufacturing?