Production line dynamics: What counts is what actually comes out of your line

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In high-volume production, it is the price of the end product that matters. Purchasing decisions for production equipment therefore usually boil down to price divided by output modified by some efficiency factor. However, the number of good products that are ***really*** *produced is determined by the machine design, line layout, number of machine stoppages and board quality.* ***That*** *is what determines whether you have made the correct purchasing decision. Since unbuffered lines are less efficient than buffered ones, buffering needs to be considered when the line is purchased.*

The key to good line throughput is balancing the various items of equipment to maintain a steady pulse of boards coming from the production line: the cycle time. Most important here is the pick & place equipment, with the screen printer coming in second.

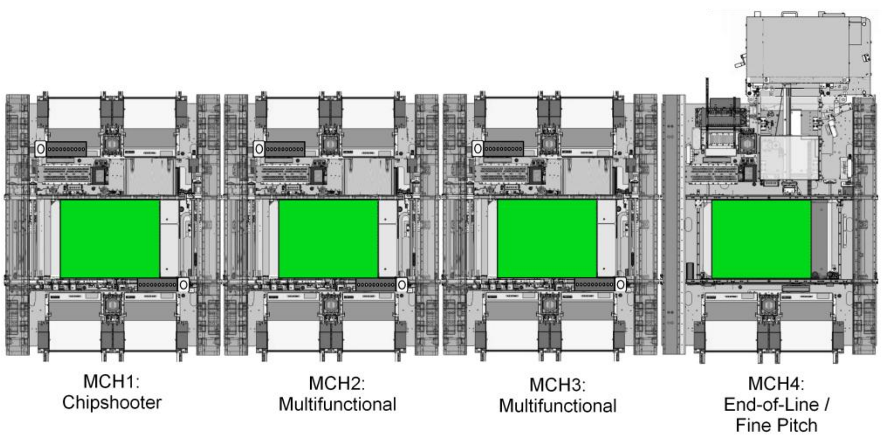


Figure 1: Example line

A typical pick & place manufacturing line will consist of a chipshooter (which may be a multifunctional machine, but mostly placing chips) as the first machine, with the last machine placing fine pitch or more complex components. In between, multifunctional modules take care of a wide component range and expand feeding positions. For the remainder of this article, the line illustrated in Figure 1 is taken as an example.

In an ideally balanced line, all machines would have identical cycle times (Figure 2).

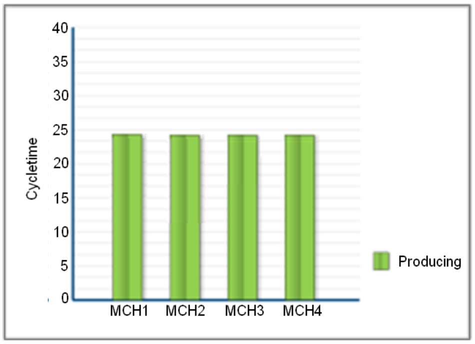


Figure 2: A balanced line with all four machines in line placing at equal cycle times

Line blocking and starvation

In this ideal situation (machines with no placement or other errors whatsoever), good line performance monitoring software will detect whether the optimizing software has balanced the line correctly and is predicting the cycle time reliably. Figure 3 shows an unbalanced line that will lead to inefficient manufacturing. Equipment with cycle times that are too long will block faster machines earlier in the line which then cannot get rid of their boards, while following machines will starved due to the lack of supply of boards. In Figure 3, wrong optimizing causes machine 3 to produce with a too long cycle time, blocking machines 1 and 2. Machine 4 has a shorter cycle time (although a lower output machine, IC count is usually less than 10% of the total component count, so this is not uncommon for end-of-line placers) but because of the long cycle time of machine 3, it suffers more board starvation.

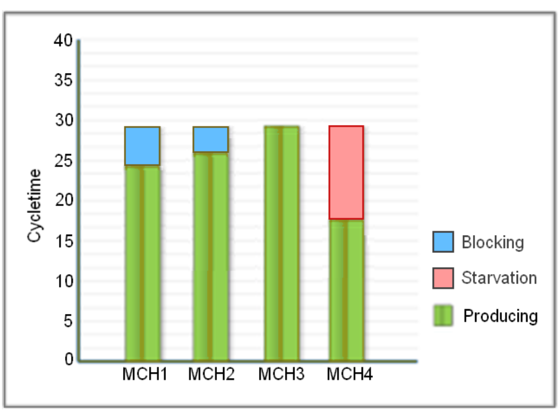


Figure 3: An unbalanced line, where machine 3 has too long a cycle time

Memory-less error distribution

No machine operates flawlessly throughout its production life. Pick errors, tape problems, minor cleaning actions (e.g. nozzles), tapes running empty, breaks in parts supply to the line, and rejected components can all degrade the cycle time. So, the first difference from (and usually an addition to) the ideal cycle time comes from errors or maintenance cycles (with screen printers this could be the cleaning cycles).

If all errors occurred all at the same time with exactly the same time to correct, the line would still be perfectly balanced. In reality, this is far from true. They do not occur at the same time and they don’t all take the same time to recover. Errors are random, as is the time it takes to recover from them. So a machine starves because no boards are supplied to it, and it in turn blocks the line because it is itself a bottleneck. The more machines or modules in the line, the likelier they are to work (very) inefficiently because of these random error effects.

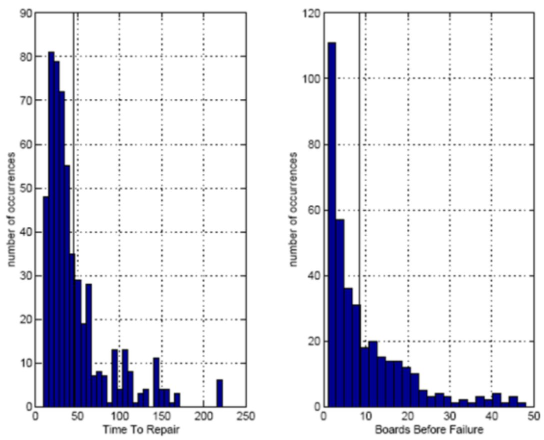


Figure 4: Line Dynamics, showing the recovery time per error (left) and the number of boards produced between two subsequent errors (right)

Figure 4 shows an example of line dynamics during a production run. The type of error differs a lot. A simple miss in picking the component will cause a delay lasting less than a second and is self correcting. At the other end of the range is a serious stoppage which can only be corrected by manual intervention. How often an error occurs is often less important than how long it takes to correct it. So, it is important to measure both the frequency of errors (the boards between failure shown in Figure 4) and the time to repair per error type, and link the two charts together.

Buffering – the first improvement to line dynamics

Production lines must have some buffering. This reduces the effect of starvation and blocking, since taking a PCB to avoid blocking can at the same time provide a PCB to avoid starvation. Buffers are an ideal solution to keep the line flowing for errors that are relatively fast to recover from. Here, it's better to have 10 errors that each take 30 seconds to recover from than 5 errors that take a minute to recover from.

The longer it takes to recover from an error, the higher the chance that blocking/starvation will occur. But as small errors are a fact of life, a line without buffering is by definition a less efficient line. A drawback of buffering is that it will lengthen the line unless it is embedded in the equipment's design.

The next question is how many buffers and where to place them effectively in the line. If machines or any connected modules are not by default equipped with buffering positions, there is unfortunately no ready-made answer except to take the modules apart and add conveyors/buffers in between. But the higher the volume and shorter the cycle time, the need for (multiple) buffer positions grows and they seem necessary before and after every pick & place machine. When it is known beforehand that equipment will strongly interact, buffers should be included by default. The scheduled cleaning cycles of a screen printer give an example: buffers after the screen printer should prevent the first machine from starving during the cleaning cycle. Just as with cleaning of printer stencils, it is not uncommon for end of line solutions to perform more difficult tasks that are likely to ask more (and mostly longer) intervention from the operator. Buffering in front of the equipment is here recommended to avoid it blocking the line.

Adding buffers significantly increases the overall line throughput. It will also however increase line length by adding hardware to the line and so increase chance of failures and PCBs subject to stoppages. Buffers are also "uncovered positions" and PCBs there will gather more dust. Most problematic of all are buffer positions which are also shuttle gates, which are subject to misalignment (operators bumping against them) and can therefore cause transport failures. It is therefore important to calculate the minimum buffers/conveyors required in the production line.

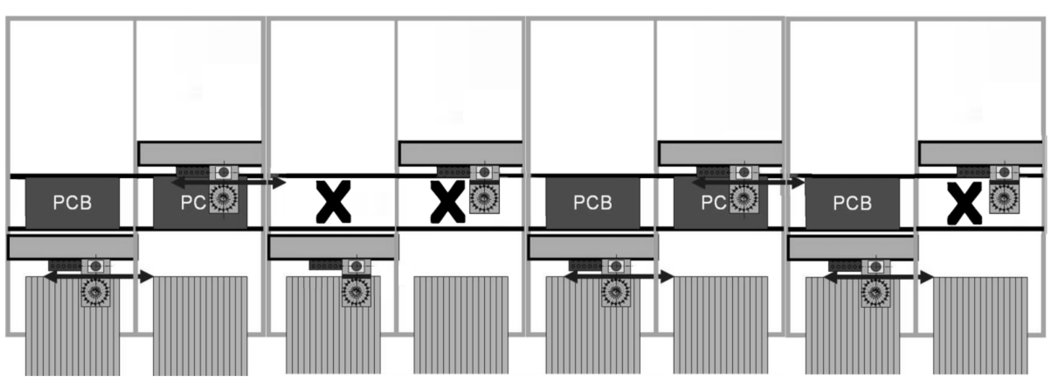


Figure 5: Un-buffered line: will lead to starving or blocking

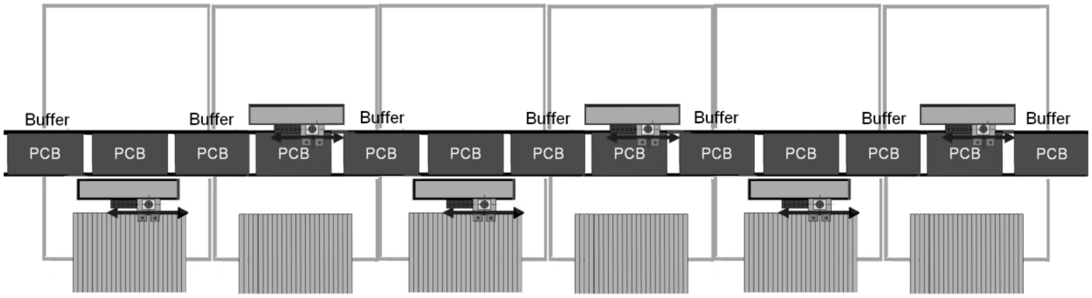


Figure 6: Buffered line: one PCB (sometimes two) is buffered between machines

Unlike Figure 5, the system in Figure 6 will produce PCBs at a steady heartbeat as the buffer positions decrease the negative effect of line dynamics, such as starving or blocking.

Line dynamics second remedy – bottleneck analysis

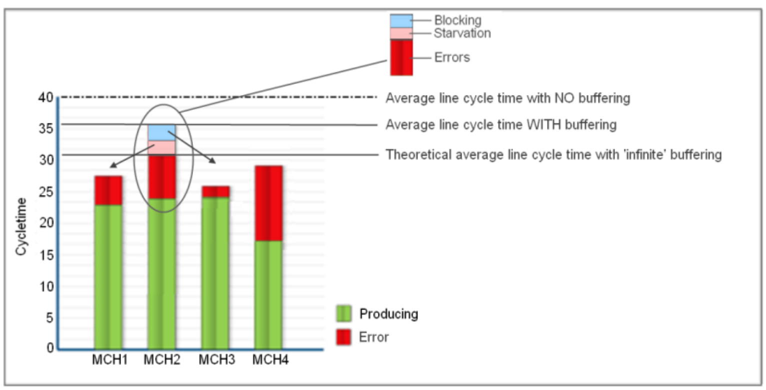


Figure 7: Bottleneck analysis

For each machine, but particularly the bottleneck machine, the main 'bottleneck errors' of the machine itself should be analyzed, with the root causes of starvation and blocking. These are mainly caused by the errors of the up- and downstream machines respectively. Once the root causes are solved for the bottleneck machine, another machine will become the bottleneck and the same analysis should be done. In a high volume line, early analysis will optimize the production line. High mix environments are even more dynamic as the line content can differ daily, and these should have the optimum line layout and optimizing schedule for typical production.

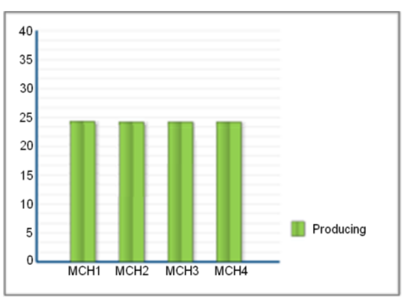
In Figure 7, the bottleneck machine is number 2. Errors from this machine determine that the line will never have an average cycle time of below 30 seconds, even with unlimited buffering. Some buffering will improve the average cycle time, shown in Figure 7 as 35 seconds. Reducing the cycle time of the line will require analyzing (and solving) the root causes of the errors, blocking and starvation of this machine before moving on to the analysis of the next bottleneck machine.

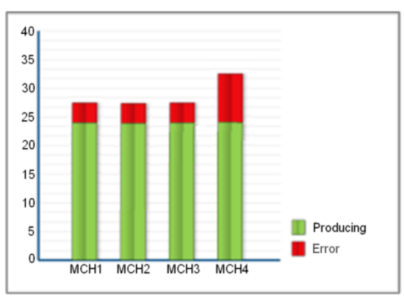
Common issues causing blocking or starvation

Printers require a frequent cleaning cycle, and buffers should be added between the printer and first machine to prevent blocking. Assembléon's new MCP screen printer incorporates cleaning in parallel with board alignment to reduce the number of required buffer positions.

Automated Optical Inspection can also be a bottleneck, requiring buffers before or afterwards. Besides the actual failures, AOI equipment is known for finding false failures that require intervention. The more reliable the placement process, the better the AOI can perform its task. A-Series equipment has high board yield (lowest board defect rate in the industry), but also no inconsistent placement variations (component spread**)** on the placement of components, improving mount and check reliability significantly.

Straightforward chipshooting and standard IC placement applications can often have the same cycle time. Mostly, though, the end-of-line placer has more difficult tasks (e.g. snap-ins, connectors, shields, odd-forms, low-quantity reels, tray feeding) that in practice raise the chance of errors. If so, a fully balanced line is not always advisable. If possible, a lower load end–of-line solution (pulling) with buffering in front overcomes this machine's more variable process times. Balancing in this case, done in a lot of production environments, moves chip components to the less utilized end-of-line placer just to equalize the workload. This gives a theoretical output gain but in practice it will only add up to the cycle time of this end-of-line placer (Figure 8). As an example, end-of-line placers have larger feeder sizes with fewer components per reel. They run empty quite quickly and most times these reels are not spliced and so they run empty (even when there are alternates). Additionally, the more complex the components in these tapes, the higher the error occurrences this placer has.





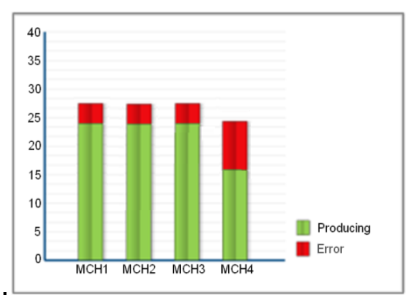


Figure 8a, b and c: a) to b) Balancing leading to unbalancing, c) practical approach by reducing load on end-of-line placer

The process stability along the line is important. The more modules in a line the more their behavior will differ, especially over time (different software, firmware, drivers, updates, local tweaking etc.) until the system gets out of control. The anticipated cycle time will therefore never be met and actual throughput becomes quite disappointing. It is therefore very important to match optimizing software and machine software. Tuned components should be centralized instead of localized to avoid continuous uncontrollable variations at line level.

Getting the best out of the line also needs the support of the equipment manufacturer. Assembléon's process expertise group offers line assessments, measuring the effective process time and performing line simulations. That brings quantitative improvements by unraveling the influence of errors on line level and offering recommendations on improving line layout and buffer positions to maximize productivity (Figure 9).

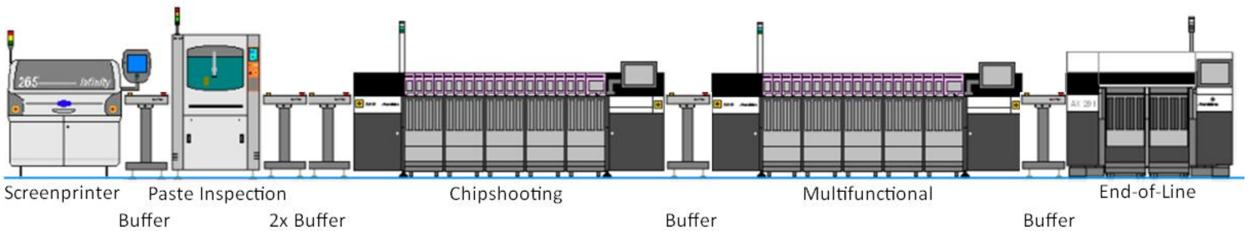


Figure 9: High volume line with buffer positions to overcome variations in line dynamics