Why sacrifice throughput for change-over time?

Getting the most out of your equipment in small batch manufacturing.

The struggle to survive in the world of manufacturing is prompting many volume-driven manufacturing sites in the west to specialize in small batch manufacturing. The aim is to bring value to their customers with fast-turnaround prototyping and reduced introduction times. Pressures are constantly increasing to reduce response times, though, even during peak production periods. It is therefore crucial to manufacture as efficiently as possible by eliminating the time consuming elements in a high-mix environment. Mostly, that means trading in machine throughput for more – and time consuming – change-overs. As change-over is a major contribution to machine idle time, the machine design determines how that affects the throughput and machine performance in a high mix environment.

For high volume small batch manufacturing, product diversity is also a challenge and often overseen by just one or two operators. When asked what is the most time consuming element in high mix manufacturing, the answer will mostly be ‘setting up feeders’. With the minimum number of operators, the aim is to have the fewest setup changes per shift. However, the machine setup determines three things: how effectively your products come off the line; the predictability of your output (“can I deliver on time?”); and the reliability of your customer quotes. With the right machine design, there is no real reason to trade in throughput for change-over flexibility.

Predictable throughput in small batch manufacturing

Commitments to on-time delivery mean that your manufacturing line must deliver what has been promised. Equipment that is not producing is wasting time, and if your estimates are regularly out by 10% (or more) then you will have 10% less business than predicted.

Predictability and throughput depend on two things:
1. The output calculated by optimizers must be very close to reality.
2. Machine idle time should be reduced to a minimum.

Small batch manufacturing may also imply just enough components and boards to produce the batch. That means pick & place quality must also be assured to avoid component shortages or reduced yield as a result of poor placement/printing quality.

A setup strategy can range from structured (and balanced) all the way through to a fairly random one (the ‘just put that feeder anywhere’ approach). The more variable (or random) a setup, the more the throughput will be affected by unbalanced loads on individual modules and therefore unbalanced cycle times for those modules. Depending on the type of equipment, the varying mix of components amongst jobs in a ‘random’ setup determines how machine heads are used. Poor head usage can produce seriously de-rated output. How predictable will it then still be?

Optimizer predictability

The fewer variables an optimizer needs to work with, the higher the predictability in practice. Variables that influence the outcome are:

- Collect sequence
- Place sequence
- Total travel path
- Type of head
- Number of nozzle exchanges required
- Component mix
- Alignment method
- Component handling class and speed classes
- Setup optimization/strategy
- Servicing of the production line, making sure all modules run with same software 'behaviour'.

Figure 1 shows the path of a turret/revolver/multi-pipette system (left) and single-pick single-place system (right). The method on the left can be influenced by many of the factors mentioned above, and the more variations in the product on the line the greater the difference in its behaviour. The method on the right, on the other hand, is hardly influenced by any of these factors and so contributes to the predictability and reliability of your optimizing software: what you calculate is what you get.

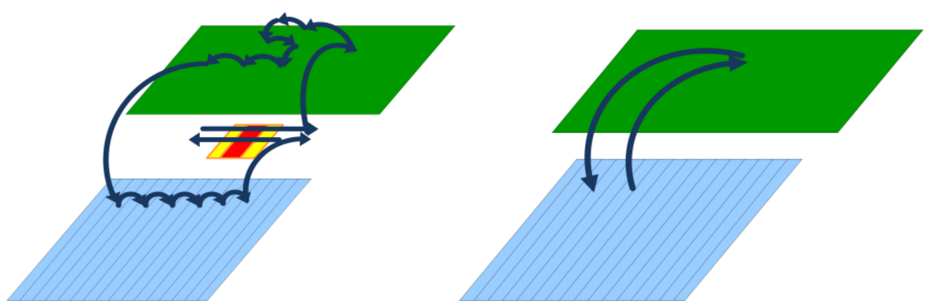

Figure 1. Collect-and-place path vs. single-pick single-place path.

Operator response time: buffering increases throughput

Buffering is essential to get the best out of a line since equipment errors may for example require correction by an operator. Buffering allows time for the operator to do this while making sure that other equipment in the production line is not blocked (waiting for the next module to accept a pcb) or starved (waiting for the previous module to supply a pcb).

Particularly where a line has few operators (typically in high-wage countries), buffering will immediately boost throughput. It compensates for differences in cycle times caused by the daily dynamics of the line (errors, empty feeders, other disturbances). Here it is essential, and generally the more buffer positions the better. However, the available floor space (line length) and other practical considerations (the number of operators, average cycle time) determine the degree of buffering that gives the most effect. In general, a line without buffers has, by definition, poor throughput. Buffers can be incorporated into the system design itself, or as separate units between machines.

Buffering to raise throughput is only possible if setup and production schedule are geared towards family setups or batch sizes where the aim is for best average output per setup (which can be over several jobs). If the cycle times of the modules differ (e.g. a 'random' feeder setup strategy for each individual machine), then blocking and starvation will occur and even buffering will not help. Line throughput will seriously be affected (Figure 2).

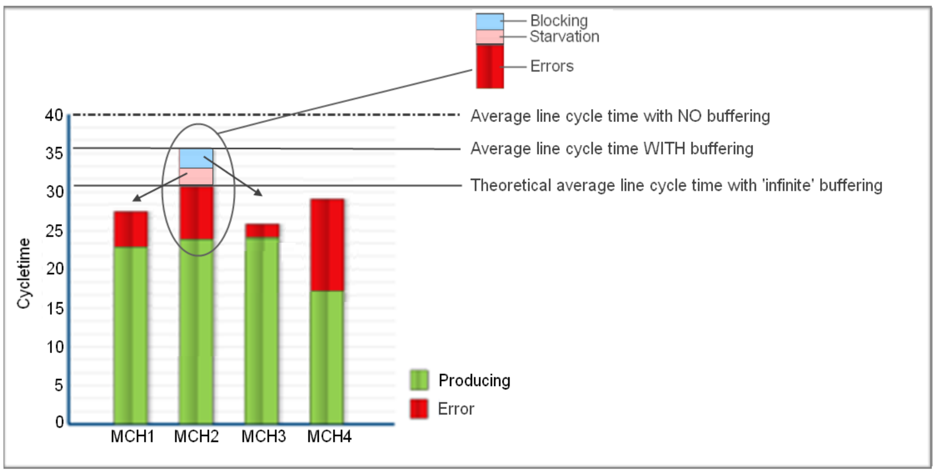

Figure 2. Total effect of throughput with line dynamics, with or without buffering

Head types and derating

The best head would be one where all pipettes could handle all components simultaneously with no nozzle exchange and all with the same speed (placing ICs as fast as chips). Such a head does not exist but the closer we approximate to that, the easier it is to estimate the time taken to produce a batch because the output per machine is very predictable for any product at any time. That enhances the reliability of customer quotes.

Most equipment today uses single- or multiple-gantry based systems. The head types differ, however, with revolver, turret, multi-pipette beam (single or multiple rows) and single-head (carrying only one component) types. See Figure 3.

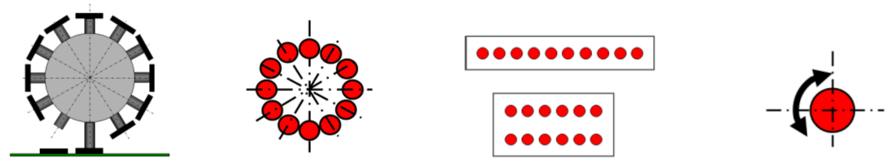

Figure 3. Head types: *Revolver head* *Turret* *(Multi) pipette beam* *Single pick head*

With r*evolver heads,* the larger the diameter of the revolver, the larger the distance between individual pipettes and the larger the range of components supported (Figure 4). The rotational forces on these heads are very high (up to 4G). Because of this, the nozzles on the head are optimized for each individual component type (very specific). The large number of unique code numbers in a small batch environment cause derating (Figure 5) due to the increased number of nozzle exchange sequences required to cope with this variety. Rotational forces can also be high *after* alignment, when placement repeatability can suffer from non-correctable variations. These are of no concern if within the limits of self alignment in paste, but can be a real problem if products require accurate absolute placement.

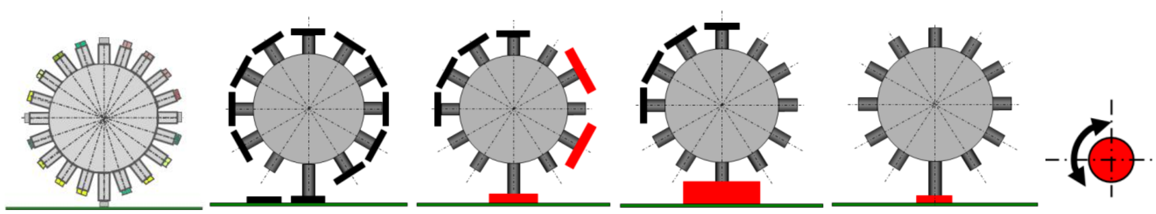

Figure 4. Revolver head utilization

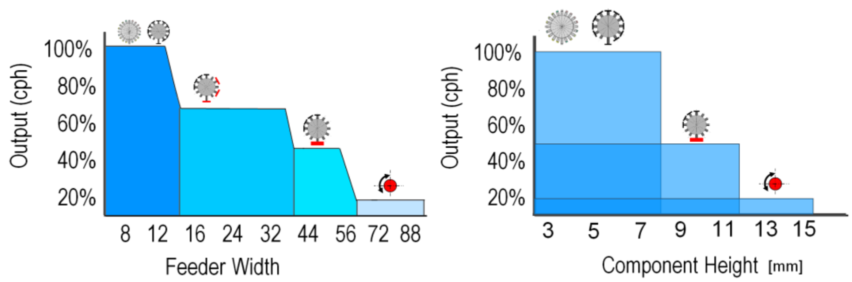

Figure 5. Derating because of component width and/or height

Another disadvantage of this type of head design is its large diameter and mass. It therefore uses heavier motors and so more energy than the other designs. The unique relation between nozzle and component also leads to a large amount of air being used, which also consumes more energy. In the face of high energy prices and universal concern about carbon emissions and power shortages, this design has a questionable future.

Turret heads come in many forms, from specialized chip shooting to multifunctional to fine-pitch types (Figure 6). Swapping heads in small batch manufacturing is usually not practical so a correct head choice is essential. Dedicated heads (as with chipshooters) provide a high degree of predictability. When component mixes are needed (usually with fewer modules in a production line) then multifunctional heads are preferred instead of dedicated heads. Multifunctional heads are less sensitive to component size and height, but more sensitive to derating (so the throughput is harder to predict).

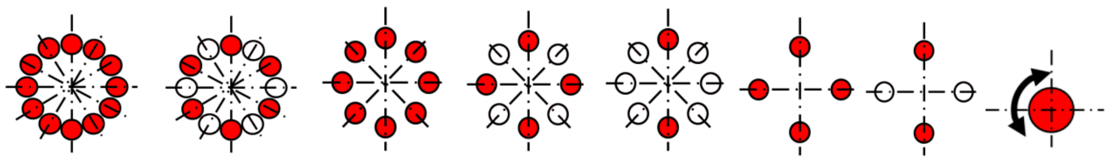

Figure 6. Utilization of turret head w.r.t. component size

The advantage of *multi-pipette beams* (Figure 7) is that the same beam can work first as a chip shooter and next as a fine-pitch placer. There are normally few nozzle changes – another advantage. Programs are much easier to balance between machines, but with these heads the more random setups can very quickly lead to derating. Also, only a few pipettes can be used for IC placement because higher accuracy requires special hardware for some pipettes. The derating (Figure 8) and its effect on up- and downstream equipment makes the real line output difficult to predict.

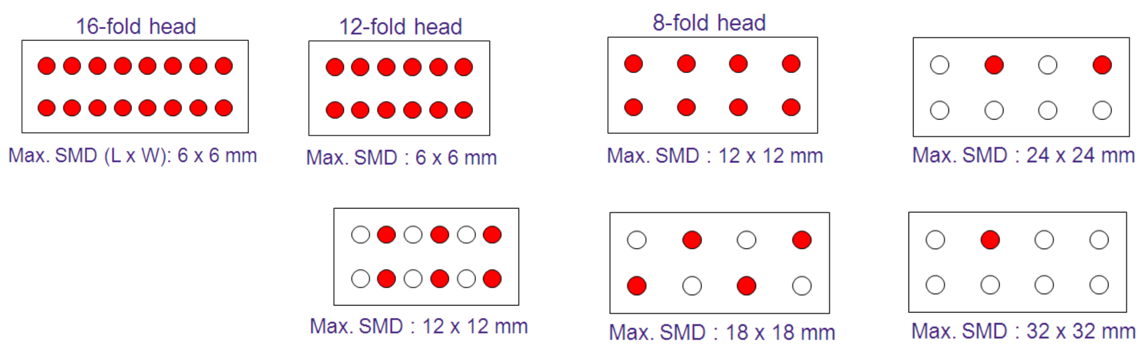

Figure 7. Utilization of pipette beam w.r.t component size

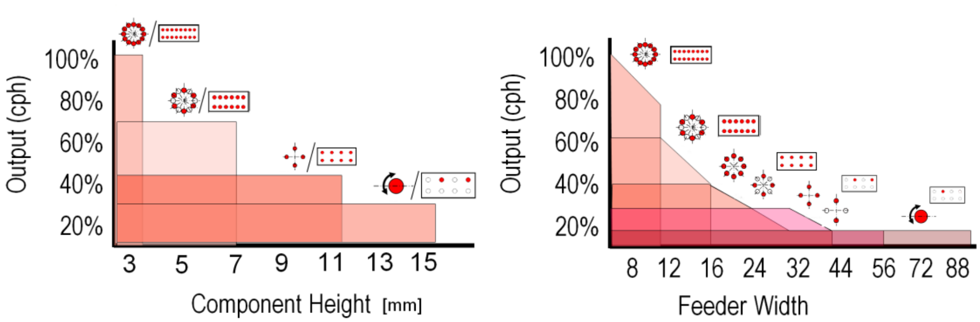

Figure 8. Derating as consequence of component size and /or component height

Single-head types have the important advantage that just one component is processed at a time and all motion profiles can be optimized per component (Figure 9). Fewer nozzles are required to cover the standard component range, so fewer changes are needed. Each head can also process the entire component range. The restricting factor with these head types is usually the type of alignment. While some components can be aligned on the fly with a laser, for example, the rest need to be pre-aligned with a camera. However, the output of single head types is very predictable as there are only two real variables (Figure 10), and nearly all components are processed at the same speed. Although a single-head design might look slower than multi-head systems, the modules can today reach real outputs up to 50,000 components an hour. Handling virtually all components in the same way has least effect on throughput and has a major advantage for product quality because the pick & place operations are controlled for each individual component.

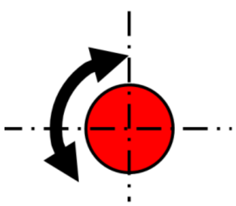

Figure 9. Utilization of single-head single-pick (100%)

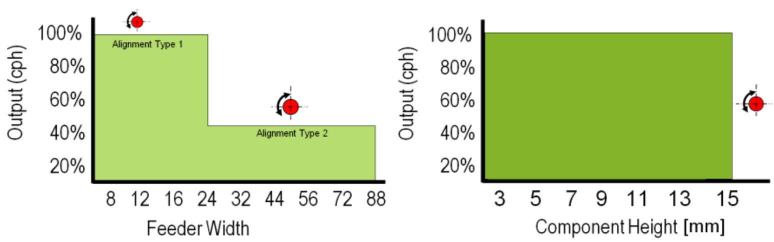

Figure 10. Derating because of component size and/or component height]

No reason to trade throughput for flexibility

For small batch manufacturing, there is therefore no real reason to trade throughput for flexibility. With the right setup and grouping strategy, trade-offs can be kept to a minimum for equipment that is predictable by design. Additionally, providing buffer positions as standard (or placing additional buffers in the line) will overcome imbalances in cycle times. That will also help operators to correct any errors without affecting the throughput, which is very important when running lines with just one or two operators.