Diagram

Description automatically generated**Parallel Making Vessels with Shared Packing**

This summarizes analysis of a manufacturing operation with parallel making systems feeding a shared packing system. The analysis is simplistic but provides insights on constraints and governing behaviors. It assumes that both making systems have the same, constant, batch time, tb and that packing (aka filling) a batch takes a constant time, tp. The model is in the file **Bottleneck Analysis.xlsx.**

The model suggests defining an “Operation Productivity Ratio” or **OPR** for benchmarking. The goal in an operation like the above diagram is to maximize throughput from the batch making systems. OPR is the ratio of number of batches produced versus the theoretical number that could be made if there were no packing bottleneck.

The model showed that the ratio, “r”, of batch making time (per parallel line) to batch packing time determines whether the process is bottlenecked by packing or not. If **r =** **tb/tp** is greater than 1.0, on average, batch-making will need to wait on packing. Whereas, if **r** is less than or equal to 1.0, batch making will generally not need to wait on previous batch packing. The current analysis was based on constant **tb** and **tp**, but real world wait times will depend on variability. This makes it beneficial to design the operation with a buffer to have a **r** less than 0.8 or 0.9 to allow for variability.

The example model below contains OPR calculations for a hypothetical range of **r** values and a hypothetical 90 minute batch time. OPR has a value of 1.0 (100%) in the limiting case where the downstream systems allow batch making to run back-to-back. An example would be the limiting case where batch pumpout were instantaneous and into a packing surge vessel such a new batch could begin immediately after the previous one completes. Over our simulated range, OPR varied from 91% to 8%. The graph shows how **OPR** depends on **r**. If the operation is highly packing constrained (**r** > 2), there is limited OPR (aka capacity) benefit from reducing **r**. However, if **r** is less than 2, further reductions yield relatively large improvements in OPR.

**Batch-by-batch Simulation (rows show progression of batches)**

Table

Description automatically generated

**Summary Model (rows show characteristics as r [Column A] increases)**

Table

Description automatically generated with medium confidence

Chart, line chart

Description automatically generated

Chart, box and whisker chart

Description automatically generated

As a next step, the simulation can be extended to situations where Vessels A and B make products that have different batch times. This may suggest optimization opportunities. A second extension will be to consider “campaign effects” to avoid adding extended changeover times in either making or packing. Finally, the batch times and packing times can be allowed to vary around their mean to create realistic variability and study how much OPR buffer is needed below 1.0.

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**Appendix**

Operation Productivity Ratio, OPR, for Parallel Making Systems in Series with Shared Packing System

Process Design for this case study is single packing system fed by parallel making vessels having a constant batch time, tb.  The packing system has a constant packing time, tp, to pack (aka fill) a batch into finished product containers

OPR = Operation productivity ratio = number of batches produced divided by number of theoretical if no packing limitation

L = number of making vessels (aka "Making Lines"); the lines produce "Batches" as their unit of production, but n\_batches ties to pounds or kg sold

Qb = Batches made per time

Qb = L/(tb + tp) Rate of batches per time if making is bottleneck (tb/L ≥ tp)

Qb = 1/tp Rate of batches per time if packing is bottleneck (L doesn't matter since packing is constantly busy)

Qbth = L/tb      Batches per time - Making only without effect of packing

OPR depends on number of lines only if Making is bottleneck

* If tb/L < tp then Packing is bottleneck. In this case, Qb = 1/tp
* if  tb/L ≥ tp then Making is bottleneck. Qb = L/(tb + tp) since batches get made and packed with no bottleneck delay.  Number of batches is multiplied by L to reflect combined output of multiple making systems

OPR = Qb/Qbth Ratio Batch rate actual to batches theoretical

Define r to be ratio of packing time to making time:

r = tp/tb

If Making bottleneck:

OPR = tb/(tb + r tb) = 1/(1 + r)

OPR =

If Packing bottleneck:

OPR = 1/(r L)