Optimising the design of buffer preparation in bioprocessing facilities

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M.Sc. Business Analytics – 2017

Aim

To develop a methodology and a software tool for finding the optimum number, size, assignment and scheduling of buffer preparation vessels, to aid in the design of a large-scale bioprocess facility.

Sample Input Data

Vessel data

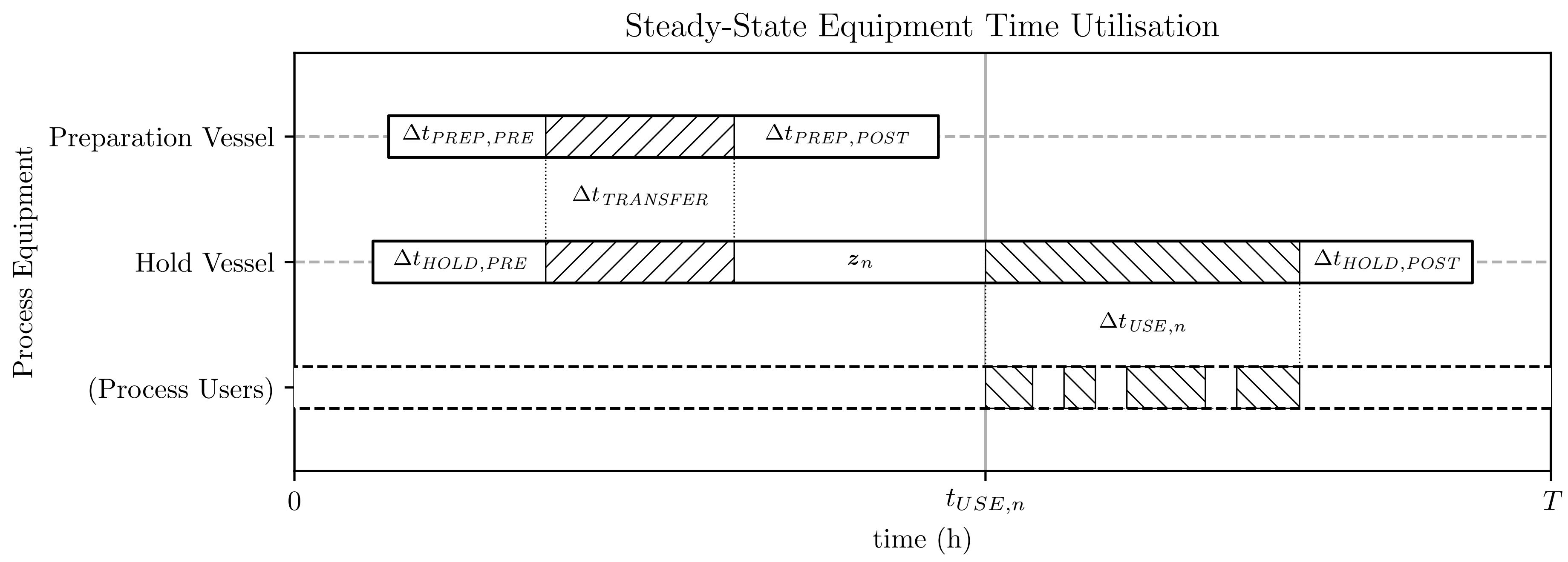
names	volumes V_m (l)	costs c_m (−)
1000 l	1000.0	63.10
2000 l	2000.0	95.64
3000 l	3000.0	121.98
4000 l	4000.0	144.96
5000 l	5000.0	165.72
6000 l	6000.0	184.88
8000 l	8000.0	219.71
10 000 l	10 000.0	251.19
12 000 l	12 000.0	280.83
16 000 l	16 000.0	333.02
18 000 l	18 000.0	357.41
20 000 l	20 000.0	380.73
22 000 l	22 000.0	403.14
25 000 l	25 000.0	435.28
30 000 l	30 000.0	485.59

Buffer data

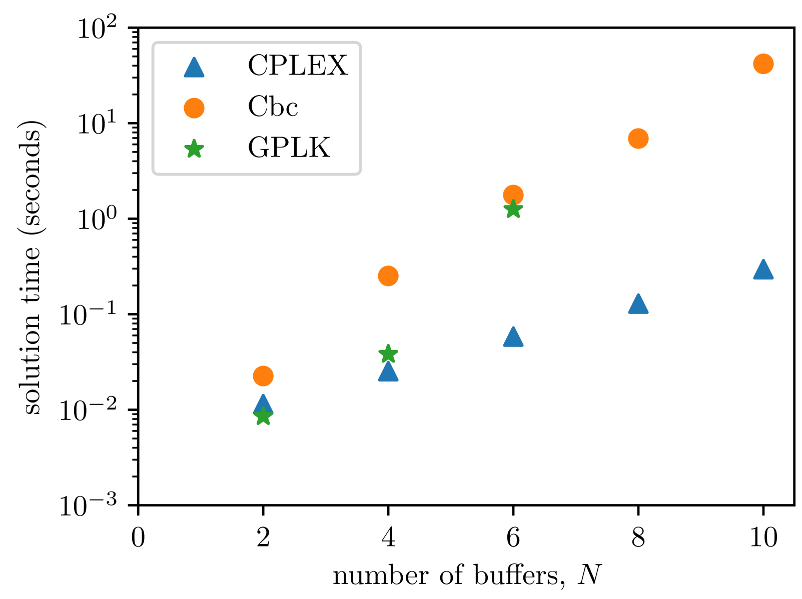
names	required volumes U_n (l)	use start times $t^*_{USE,n}$ (h)	use durations $\Delta t_{USE,n}$ (h)
Buffer #1	24 427.13	76.23	20.56
Buffer #2	5487.29	0.21	49.77
Buffer #3	2588.36	25.78	24.56
Buffer #4	7102.05	46.79	27.77
Buffer #5	1020.87	87.7	36.58
Buffer #6	19 508.79	35.52	58.53
Buffer #7	23 073.55	42.26	39.71
Buffer #8	25 454.10	48.38	43.47
Buffer #9	24 088.67	4.18	55.41
Buffer #10	3172.46	48.31	23.27
Buffer #11	24 752.71	76.38	45.80
Buffer #12	13 445.31	73.93	34.25

Parameters

symbol	short description	value	unit
T	process cycle time	96.0	h
$\Delta t_{PREP,PRE}$	prep pre duration	12.0	h
$\Delta t_{PREP,POST}$	prep post duration	1.5	h
$\Delta t_{TRANSFER}$	transfer duration	2.0	h
$\Delta t_{HOLD,PRE}$	hold pre duration	8.0	h
$\Delta t_{HOLD,POST}$	hold post duration	1.5	h
$\Delta t_{HOLD,MIN}$	minimum hold duration	12.0	h
$\Delta t_{HOLD,MAX}$	maximum hold duration	60.0	h
$f_{MINFILL}$	minimum fill ratio	0.3	−
f_{UTIL}	maximum utilisation ratio	0.8	−



Schedule for a single buffer, for a single batch. Plot shows input timing parameters and the buffer hold duration decision variable, z_n. Use of the buffer by the process may be discontinuous.



Solution duration as a function of problem size and solver selection – each data point is the arithmetic mean of 100 iterations.

Methodology

The problem was modelled as a mixed-integer linear programming (MILP) problem.

Implementation

- MILP model solved via the python PuLP API.
- The CPLEX, Cbc and GLPK solvers were used.

Business Contribution

- Reduces time taken to generate early-stage designs.
- Method developed provides provably optimum solutions; previous methods did not.
- Ability for a design firm to provide a provably optimum solution, with supporting graphics, increases the value of their design offering.

Academic Contribution

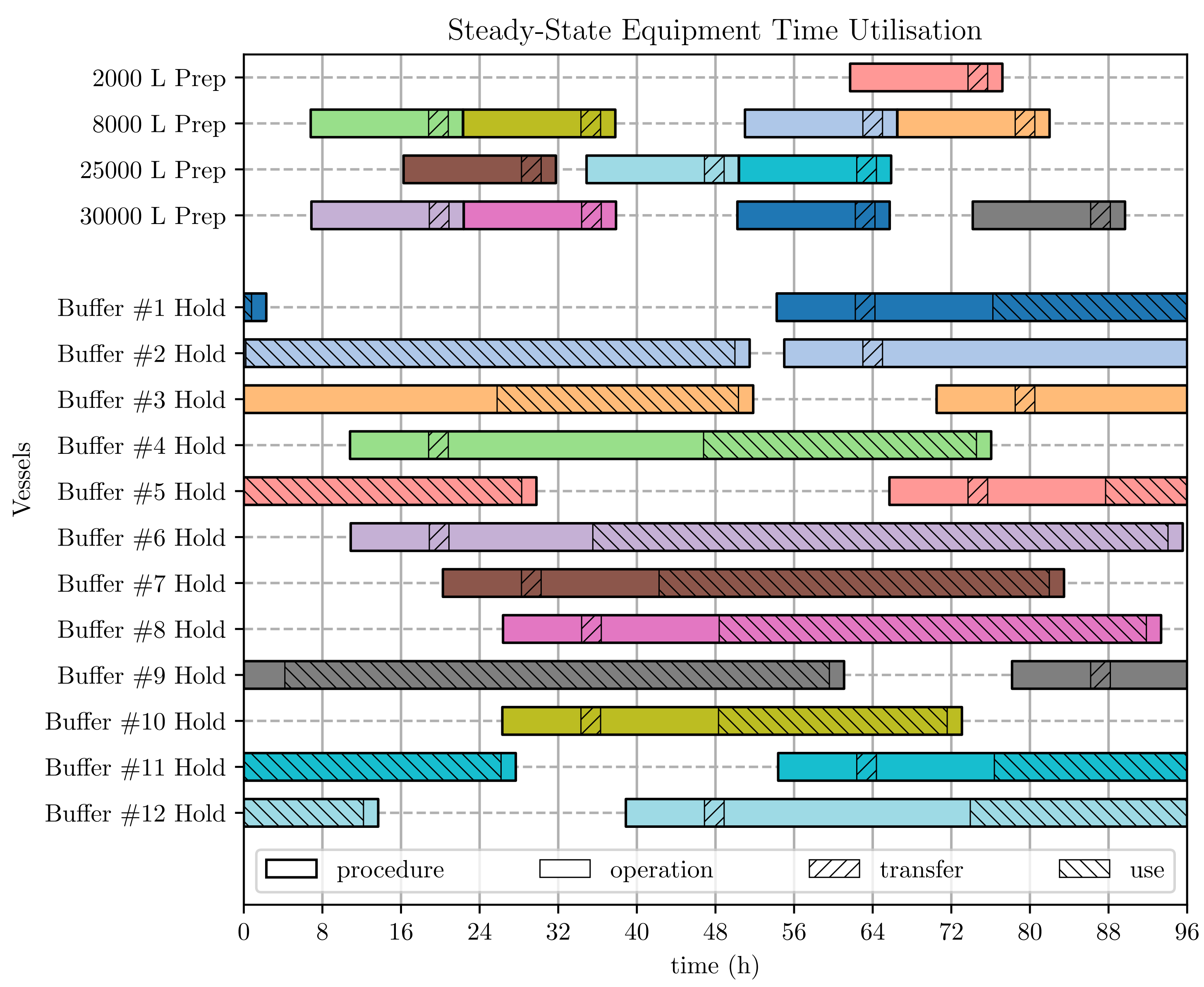
Work in the field of bioprocessing design has, to date, largely concentrated on the area of *process design*, whereas this study looks at *facility design*, contributing to the fields of biotechnology and linear programming.

Scope for Further Work

- Add more complexity/features to model.
- Use model in conjunction with Monte Carlo simulation to ensure designs can cope with variability

Results

For the data set shown above; one 2000 l vessel, one 8000 l litre vessel, one 25 000 l vessel and one 30 000 l litre vessel are required for buffer preparation. Results are best visualised in an *equipment time utilisation* plot.



Equipment Time Utilisation plot showing a feasible schedule for a single cycle window at steady-state with minimal buffer vessel cost.

Conclusions

- A working, usable model was developed which generated optimal results.
- Solution time is exponential in the number of buffers.

Check out the source code at: `https://github.com/multipitch/dissertation`