Objectives

• Discuss some key scientific and economic concepts behind flow.
  • Queueing
  • Batch size reduction
  • Fast feedback
  • Congestion control
• Interest you in exploring more advanced ideas.
Queueing
Traffic at rush hour illustrates the classic characteristics of a queueing system.
The Effect of Capacity Utilization

Queue Size vs. Capacity Utilization

\[ L_q = \frac{\rho^2}{1 - \rho} \]

Notes: Assumes M/M/1/\(\infty\) Queue, \(\rho\) = Capacity Utilization, \(L_q\) = Length of Queue
The Economic Tradeoff

To Maximize Profits, Minimize Total Cost

Dollars

Total Cost

Cost of Excess Capacity

Cost of Delay

Excess Product Development Resource
The Effect of Variability

Queue Size with Different Coefficients of Variation

Allen-Cuneen Approximation for Queue Length

\[ L_q = \frac{\rho^2 \cdot C_{Arrival}^2 + C_{Service}^2}{1 - \rho^2} \]

\( C = \text{Coefficient of Variation} \ (\sigma/\mu), \text{Coefficient for exponential distribution} = 1 \)

Notes: Assumes M/G/1/\( \infty \) Queue, \( \rho = \text{Capacity Utilization} \)
Batch Size Reduction
Finding Optimal Batch Size

Economic Batch Size

Items per Batch

Cost

Transaction Cost, Holding Cost, Total Cost
“There are not many men who understand the theory underlying the economic size of lots, and so a knowledge of it should be of considerable value.”

Ford W. Harris
Production Engineer
Factory,
The Magazine of Management
Volume 10, Number 2
February 1913
pp. 135-136, 152

Figure I. An increase in the size of the order results in an increased interest charge and a decreased set-up cost. The curves show this graphically and indicate a minimum total cost in this case at 2,200 units.
Economic Lot Size

\[ C_T = C_t + C_h \]

\[ C_T = \frac{FN}{Q} + \frac{QVH}{2} \]

\[ \frac{dC_T}{dQ} = 0 = -\frac{FN}{Q^2} + \frac{VH}{2} \]

\[ \frac{FN}{Q^2} = \frac{VH}{2} \]

\[ Q^2 = \frac{2FN}{VH} \]

\[ Q = \sqrt{\frac{2FN}{VH}} \]

\[ C_T = \text{Total Cost per year} \]

\[ C_t = \text{Cost of all batches per year} \]

\[ C_h = \text{Holding Costs per year} \]

\[ F = \text{Fixed cost per batch} \]

\[ N = \text{Total items per year} \]

\[ Q = \text{Items per batch} \]

\[ H = \text{Holding Cost per year (as percent of item cost)} \]

\[ V = \text{Cost per item in batch} \]

Optimal Lot Size!
Economic Lot Size

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**Optimal Lot Size**

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The Effect of Transaction Cost

• When we decrease the fixed transaction cost we create a smaller optimal batch size.
• When we adopt this new optimal batch size we obtain a lower total cost.
• Thus, our one-time investment in enabling smaller batches is returned in form of a recurring stream of lower total costs.

Total Cost at Optimal Batch Size

\[ T_C = \sqrt{2 \cdot FNVH} \]
Transaction Cost Drives Total Cost

Economic Batch Size

Cost

Batch Size

Old Optimum Batch Size

New Optimum Batch Size

Old Transaction Cost
Old Total Cost
New Transaction Cost
New Total Cost
Fast Feedback
Better to Monitor Queues than Cycle Time

Cumulative Quantity

- Time 21: 400 Passengers Arrive, Queue up 5x by Time 22
- Time 41: Cycle Time up 2x

Better to Monitor Queues than Cycle Time
React Quickly to Rising Queues

Time 21: 400 Passengers Arrive, Queue up 5x by Time 22

Queue Reduction

React by Time 24

Cumulative Quantity

Arrivals
Departures

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Congestion Control
Traffic Flow

Flow = Speed x Density

\[
\frac{\text{Vehicles}}{\text{Hour}} = \frac{\text{Miles}}{\text{Hour}} \times \frac{\text{Vehicles}}{\text{Mile}}
\]
Highway Throughput

Originally observed by Bruce Greenshields in 1934.
Feedback Effects

Where should we operate this system?
Learning from Transportation Networks I.

1. Maximum flow does not occur at either maximum speed or maximum occupancy.
2. Optimization requires tradeoffs between speed vs. occupancy.
3. Flow is unstable when occupancy exceeds the optimum level and stable below this point.
4. Fast responses are critical because queues grow faster than they shrink.
5. We should exploit both provisioning and active congestion management.
Learning from Transportation Networks II.

7. We should add capacity margin in zones of high variation.
9. Queues produce spontaneous variation.
10. Lane changing can improve flows or worsen them.
11. Queue control improves with scale; scheduling becomes more difficult with scale.
12. We can make fast effective adjustments by combining centralized information and decentralized control.
Some Take Aways

1. Both capacity and queues cost money.
2. Quantify the economics of your tradeoffs.
4. Exploit the flat bottom of the U-curve.
5. Reduce batch size before adding capacity.
6. Enable smaller batches by reducing transaction costs.
7. Transaction cost reduction will usually pay for itself.
8. Monitor queues instead of cycle time.
9. React quickly to expanding queues.
10. Design your process to tolerate variability.
11. Operate your process to minimize the effect of variability.
12. Look beyond the ideas of manufacturing.
“It's wonderful and dense. Filling and satisfying even in small bites. Like fine cheese.”
– Torbjörn Gyllebring (@drunkcod)