Queueing Model to Design a Lean System

- Context and Intent
- What does the model do?
- What do you find?
- How might a design team use the tool

Context: Automobile Assembly Line

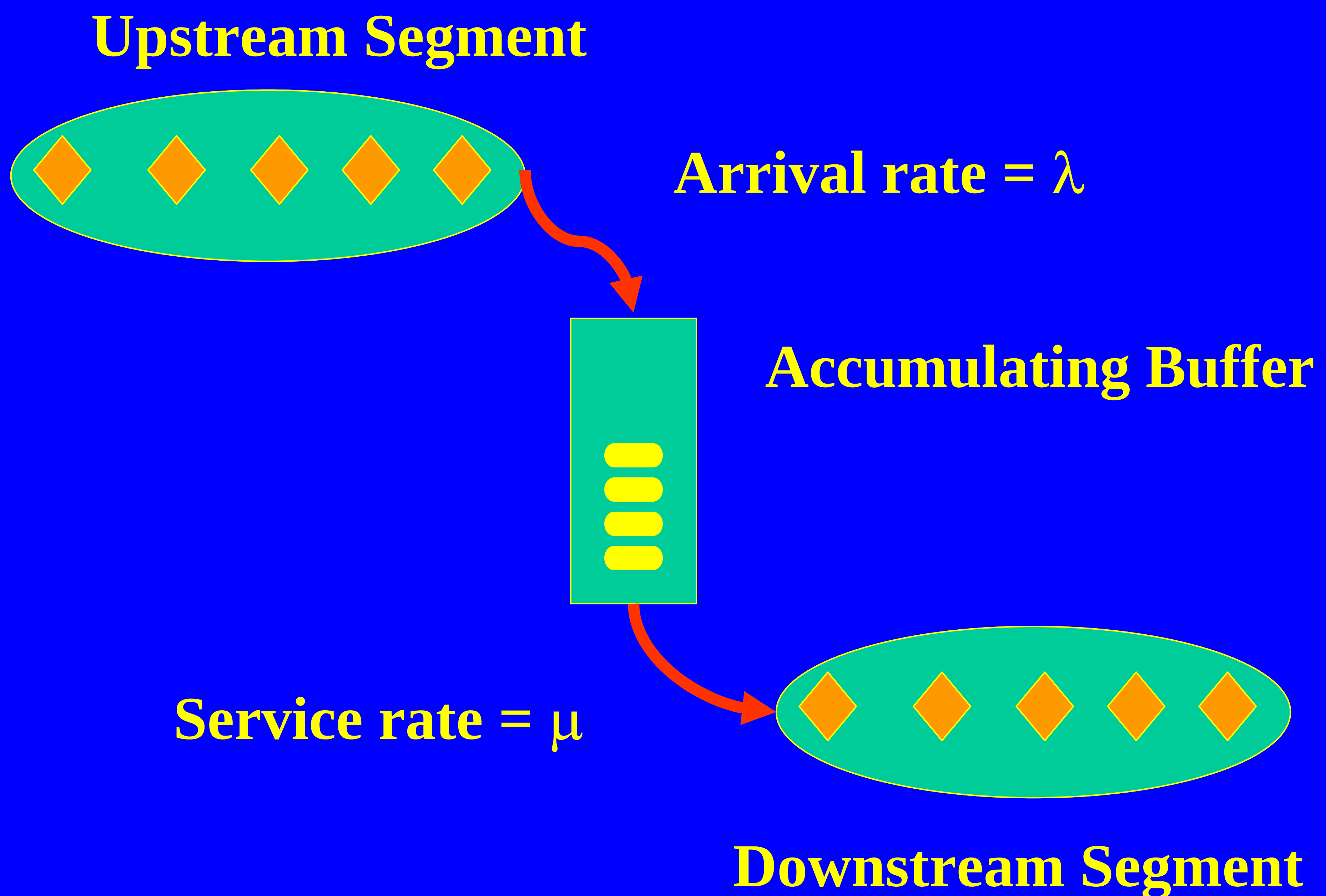
- Organized into line segments, separated by de-coupling buffers
- Each line segment operates as an independent mini-company:
  - 20 – 40 work stations in series
  - 30 – 50 people
  - 1 group leader, 3 – 4 team leaders, 6 – 10 members per team

What are the Design Issues?

- How many stations per segment?
- For given segments, how big should the buffers be?
- What if's:
  - Reduce variability?
  - Increase overspeed?

Spreadsheet Model

- Intent – provide a vehicle for learning, understanding and exploration; developing insights into key trade-offs; identifying key leverage points
- Provides rough-cut analysis, and would be used along with a more detailed simulation to validate design


Upstream Segment
Arrival rate = λ
Accumulating Buffer
Service rate = μ
Downstream Segment

Queueing Model

- Single server queue, finite waiting room = buffer size
- Assumes Poisson arrivals, exponential service times
- Reports throughput rate and average buffer inventory

Questions Being Addressed by this Spreadsheet

1. What is the expected number of completed cars per day?
2. For a given accumulator size, what is the probability that the downstream segment is starved?
3. For a given accumulator size, what is the probability that the upstream segment is blocked?
4. What are the performance characteristics (MTBF, MTTR, efficiency) of the segments?

Key Assumptions

1. Stations modeled as bernoulli random variables; stations are i.i.d.
2. Segments modeled as binomial random variables.
3. Accumulator is modeled as a M/M/1/c queue where c is the accumulator size+1
4. Shaded cells denote user-specified inputs, unshaded cells denote final or intermediate outputs

Upstream Segment		Downstream Segment		Explanation
p(station failure)	0.0018	p(station failure)	0.0018	Probability that a station experiences a minor failure during a cycle
E[# cycles until failure]	550	E[# cycles until failure]	550	Expected number of production cycles until a minor failure at station
# stations/segment	33	# stations/segment	33	The number of stations that comprise a segment
p(segment failure)	0.0583	p(segment failure)	0.0583	The probability that a segment fails during a cycle
p(upstream segment starved)	0.07			The probability that the upstream segment is starved
TAKT time (seconds/car)	100	TAKT time (seconds/car)	103	The cycle time of each station, measured in seconds
# hrs/shift	8	# hrs/shift	8	The number of hours of production per shift
# shifts/day	2	# shifts/day	2	The number of production shifts per day
Maximum # cars/day	576	Maximum # cars/day	559.2233	The maximum number of cars processed per day
MTBF	17.1565	MTBF	17.1565	Mean number of cycles between segment failures (assumes no idling)
MTTR	1	MTTR	1	Mean number of cycles required to repair segment
Stand-alone efficiency	0.9449	Stand-alone efficiency	0.9449	The efficiency of the segment (assumes no idling)

Results

Accumulator size	15	The maximum number of cars that can be held in the accumulator
P(downstream seg. starved)	0.08	The probability that the downstream stage is starved
P(upstream seg. blocked)	0.04	The probability that the upstream stage is blocked
Expected stock level	6.06	The expected number of cars in the accumulator
E[# finished cars/day]	483.88	The expected number of cars completed each day

Basic Relationships

$$\Pr(\textit{station fails per cycle}) = \frac{1}{550} = 0.0018$$

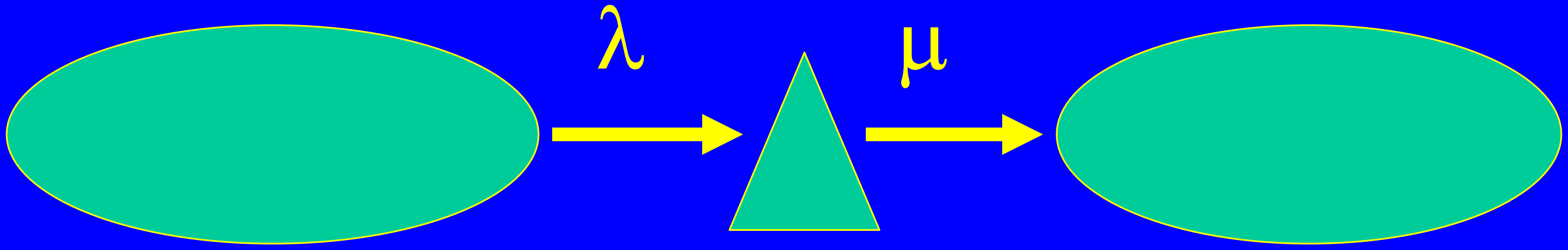
$$\Pr(\textit{segment fails per cycle}) = \left(1 - \left(1 - \frac{1}{550}\right)^{33}\right) = 0.0583$$

$$MTBF = \frac{1}{\Pr(\textit{segment fails per cycle})} = 17.2$$

$$MTTR = 1$$

$$Efficiency = \frac{MTBF}{MTBF + MTTR} = 0.9449$$

Queueing Metaphor



Arrival Process

$$\lambda = \frac{\left(1\text{-Pr}\left[\text{segment fails}\right]\right)\left(1-\text{Pr}\left[\text{upstream starved}\right]\right)}{\text{Takt time (sec's/car)}}$$

For base case

$$\lambda = \frac{\left(1-.0583\right)\left(1-.07\right)}{100 \ \text{sec/car}} = .0088 \text{ car/sec } = .528 \text{ car/min}$$

Service Process

$$\mu = \frac{\left(1\text{-Pr}\left[\text{segment fails}\right]\right)}{\text{Takt time (sec's/car)}}$$

For base case

$$\mu = \frac{\left(1 - .0583\right)}{103 \ \text{sec/car}} = .0091 \text{ car/sec} = .546 \text{ car/min}$$

What do you find?

- Vary size of line segment?
- Vary the overspeed?
- Vary the process variation?

Stations/ segment	Buffer	Stock	Thruput per day	segments
25	12	4.9	484	12
33	15	6.1	484	9
40	20	7.9	484	8
50	37	12.9	484	6

Takt time	Buffer	Stock	Thruput /day	Stations
103	24	7.8	484	32
100	15	6.1	484	33
97	12	5.3	484	34
95	10	4.6	484	35
90	8	4.0	484	37

Cycles/ failure	Buffer	Stock	Thruput/ day
250	100	20.5	468
350	45	14.6	484
450	27	10.1	484
550	15	6.1	484
650	13	5.3	484
750	12	4.5	484

Conclusion

- How might a design team use the tool?
- Illustrative design trade off – buffer requirements vs. size of segment
- Rough cut tool for exploratory analysis and what if's