Gap

- Uncontrolled movements
- Space in traffic stream for vehicle/pedestrian to cross or merge
- Used to design facilities, place signing and control
- Driver must determine when gap is large enough and when it is their turn to enter
  - Evaluate gaps
    - Availability of gaps (gaps of a particular size)
  - Decide to accept gap -- “gap acceptance”

What determines whether a driver will take a gap?

- Distribution of gaps – f(total volume, directional distribution, number of lanes, platoon existence and characteristics).
  - Volume is important, less gaps and drivers may take smaller gaps
- Required gap sizes – f(type of maneuver, number of lanes, speed, sight distances, length of time vehicle has been waiting, and driver characteristics) stop or yield?
  - Maneuver type (crossing, merging, diverging, weaving)
  - Driver characteristic: P/R time, risk level, ability to see
  - Environmental characteristics (longer gap on snow covered roads)
  - Road characteristics (2 lane versus 4-lane, etc)

Critical Gap

- Minimum time interval that allows entry to one vehicle and is acceptable to a driver
- a particular driver would reject any gaps < the critical and accept any gaps >= the critical gap
- Greenshields defines as gap accepted by 50 percent of the drivers – acceptable average minimum time gap
- from study at stop controlled intersections, median acceptance headway:
- right-turn: 5.5 seconds
- thru: 5.8 seconds
- left-turn: 6.6 seconds

Gap acceptance measurement

- Plots gaps accepted against gaps rejected
- Raff's critical gap method – time gap where a vehicle is equally likely to accept a gap as reject– assumes drivers select appropriate gaps

Figure 6: Raff's critical gap method

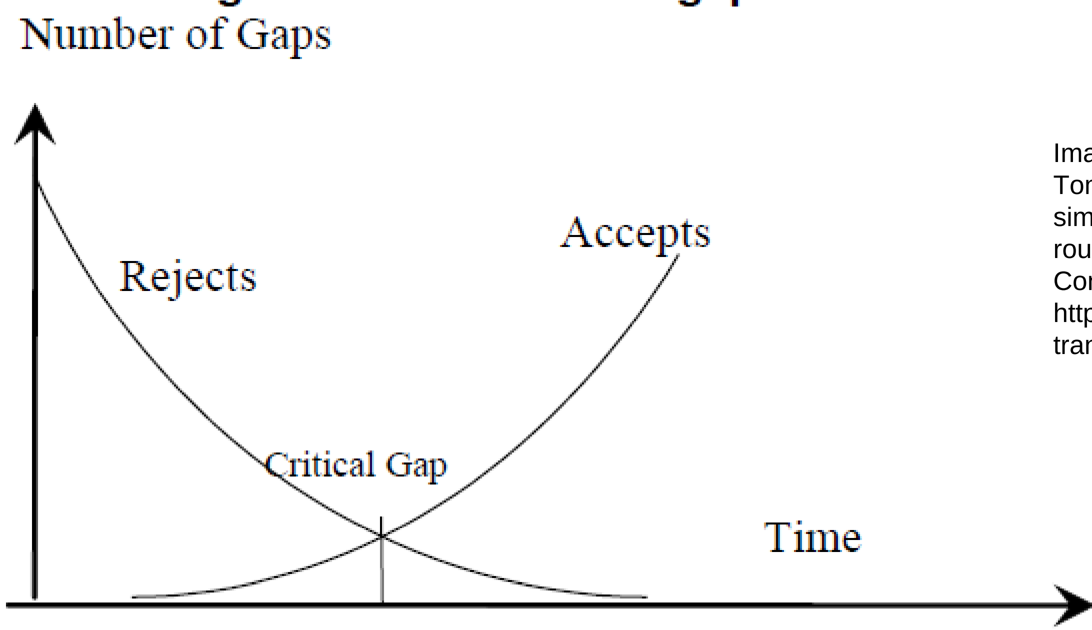


Image source: Noel Kay, Sonal Ahuja, Tan Na Cheng, Tom van Vuren, Mott MacDonald. Estimation and simulation gap acceptance behavior at congested roundabouts. Proceedings of the European Transport Conference. 2006. http://www.etcproceedings.org/conference/european-transport-conference-2006

Gap Distribution

- Delay of vehicles in minor streams wishing to merge onto the major street is based on frequency of arrivals of the main stream of vehicles at the merge area
- for light to medium traffic flow, vehicle arrival is randomly distributed
- for light to medium traffic flow, vehicle arrival is Poisson Distributed (assumptions of gamma and exponential distributions have also been made)

Example

What is probability that a driver will be able to make a right turn at a stop sign

Right turn requires 5.5 seconds to execute

$P(0) = (950 - 1)e^{-0.26*5.5}$

$P(0) = 0.24$

24% chance of a gap of 5.5 seconds or larger

SLH10

How many gaps in an hour?

949 * 0.24 = 223.4 gaps/hr

Slide 6

SLH10 Shauna Hallmark -- CTRE, 9/9/2009

Previous equations hold for Poisson distribution:

Assumptions of Poisson distribution may not hold for heavy traffic
Gaps of a certain size are less likely because drivers maintain specific distances

Queuing

- Occurs when demand exceeds capacity for a period of time or arrival headway is less than service time
- May be moving or stopped
- Occurs at controlled intersections, ramp metering, and under congested conditions at other locations
- Queuing theory uses mathematical algorithms to determine the probability that an arrival will be delayed, expected waiting time for all arrivals, etc.

Queuing

- Elementary queuing theory: single channel queue
- Queue forms when arrivals wait for service or an opportunity, such as a green light or a gap
- Service can be provided in one or more channels

Queuing

- Depends on arrival pattern, type of service, and service pattern

Arrival distribution*:*

- distribution that characterizes arrivals
- for light-to-medium traffic usually assumes Poisson
- Can be deterministic (fixed) or stochastic (random)

Arrival rate:

- rate of arrival (i.e. usually expressed as sec/veh or sec/ped)

Queuing

Service Method: method used to service arrivals

- first-in first-served: units are served in order of arrival
- last in-first served: service is in reverse of arrival (elevator)
- priority based: arrivals are directed to a certain priority level and then served by priority level (giving priority to buses, commercial line at a bank, first class boarding on an airline)

Queuing

Characteristics of queue length:

- maximum length of queue or maximum number of units in a queue if the queue is finite (finite capacity in a waiting room)
- no restrictions on length of queue

Service Distribution:

- distribution of service time
- usually random for traffic
- Poisson or negative exponential have been used

Queuing

Service rate

- capacity of server, rate of service (i.e. usually expressed as seconds/veh, sec/ped)
- usually considered random
- commonly use Poisson and negative exponential

Departure rate: actual rate of departure

Number of channels: number of waiting or service lines (single channel or multichannel)

Queuing

Oversaturated or under saturated queues:

- oversaturated are those where arrival rate > service rate
- under saturated are those where arrival rate < service rate
- length of an under saturated queue will reach a steady-state
- length of an oversaturated queue will never reach a steady state but will continue to increase with the arrival of units

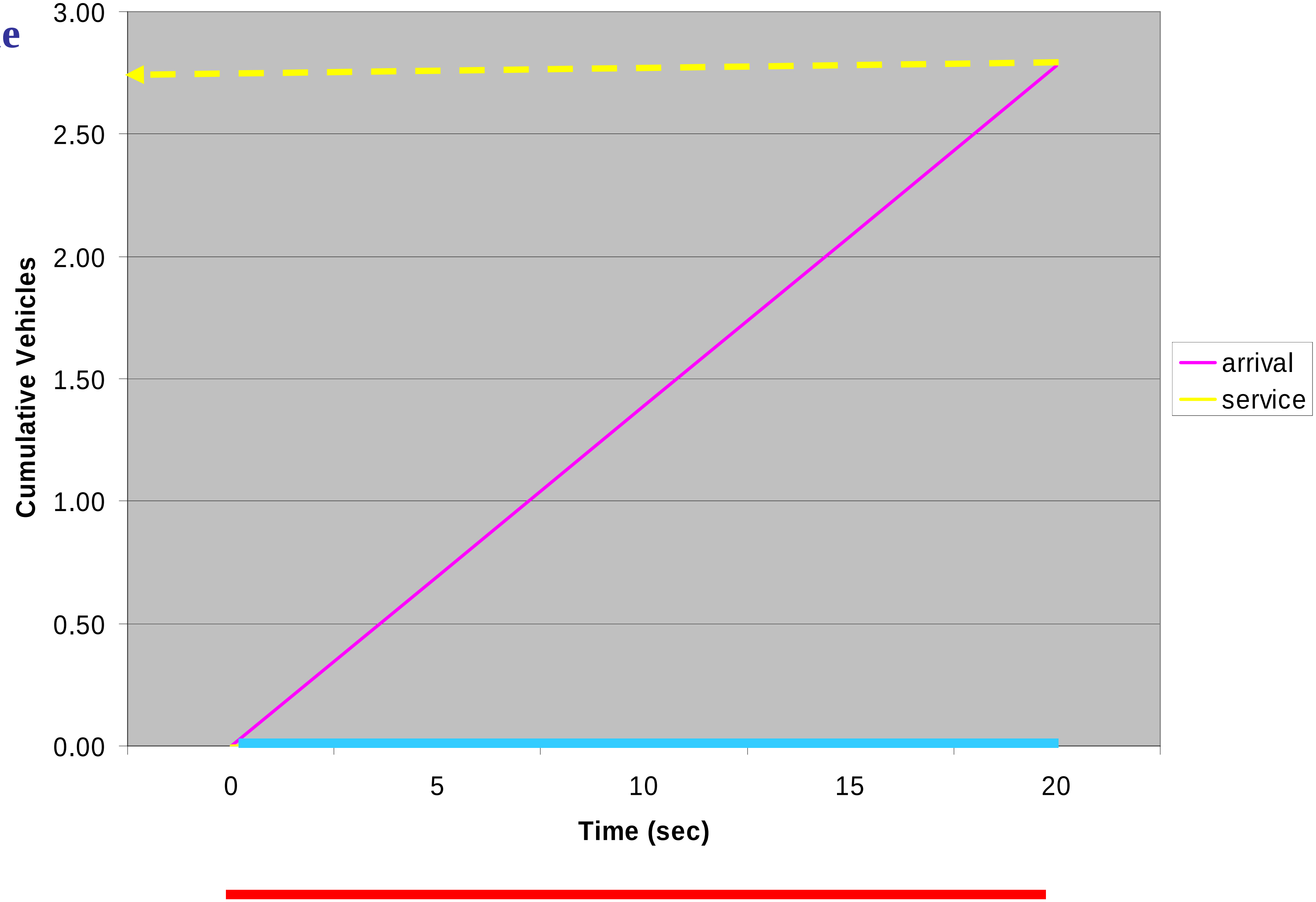
Intersection Example

time	arrival	service
0	0.00	0.00
5	0.69	0.00
10	1.39	0.00
15	2.08	0.00
20	2.78	0.00
25	3.47	1.67
30	4.17	3.33
35	4.86	4.86
40	5.56	5.56
45	6.25	6.25
50	6.94	6.25
55	7.64	6.25
60	8.33	6.25
65	9.03	6.25
70	9.72	7.92
75	10.42	9.58
80	11.11	11.25
85	11.81	11.81
90	12.50	12.50
95	13.19	14.17
100	13.89	15.83
105	14.58	17.50
110	15.28	19.17
115	15.97	20.83
120	16.67	22.50
125	17.36	24.17
130	18.06	25.83
135	18.75	27.50
140	19.44	29.17

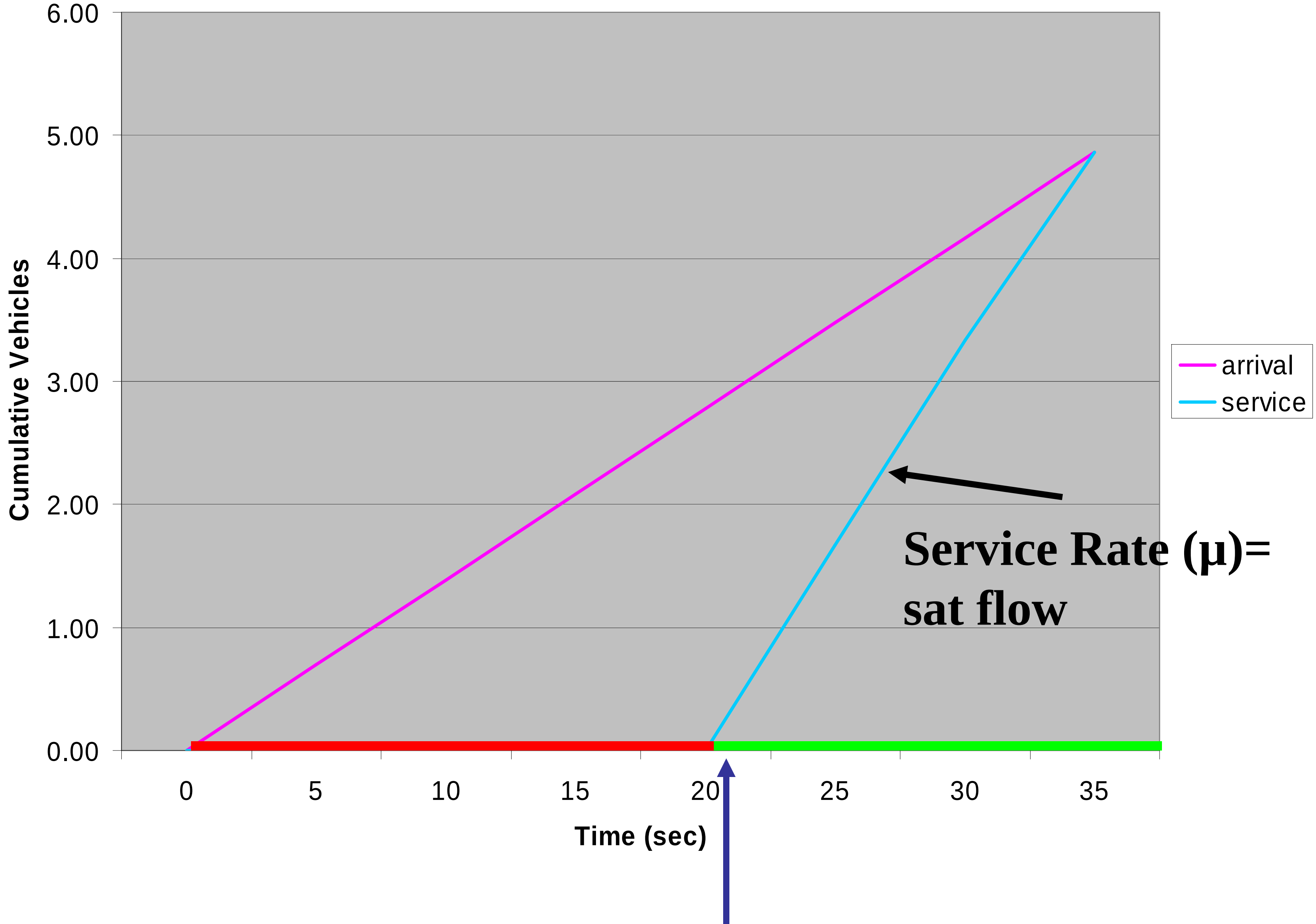
2.78 vehicles arrive during red

3.47 vehicles arrive during green

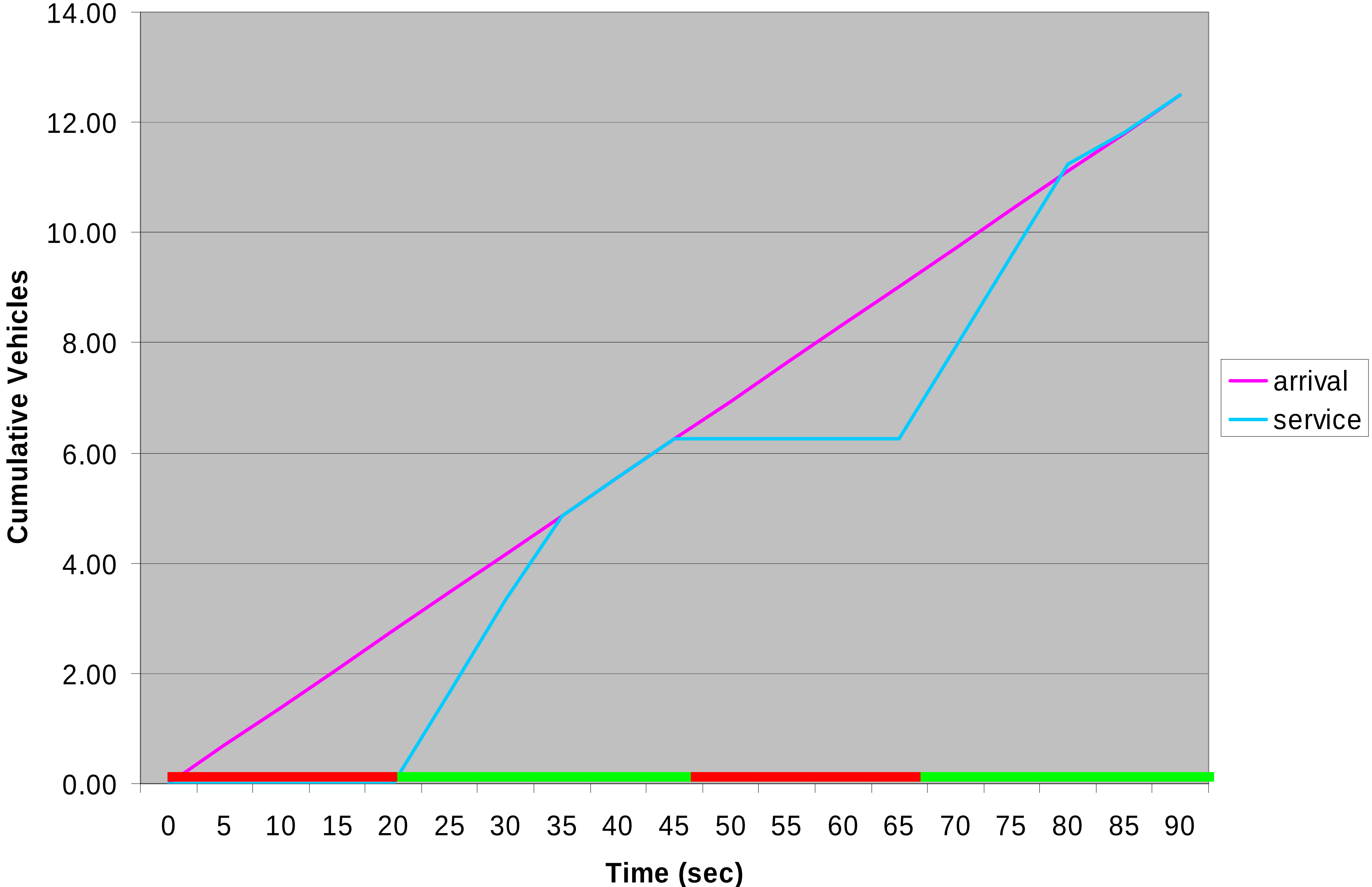
2.78 veh arrive and queue



1st cycle red phase, vehicles arrive regularly and queue

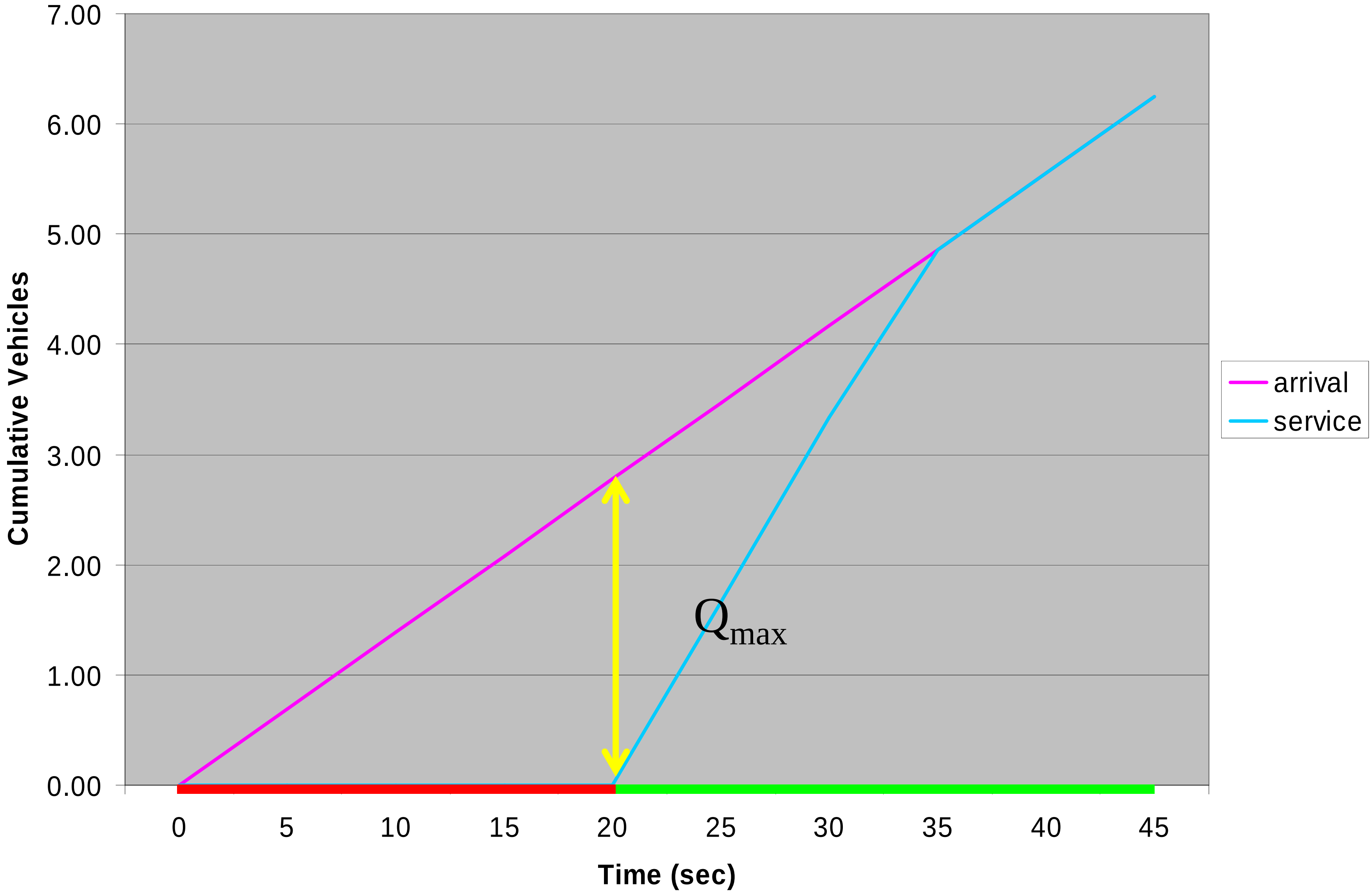


Light turns green and vehicles depart at saturation flow rate until queue from red and those arriving during green phase clear

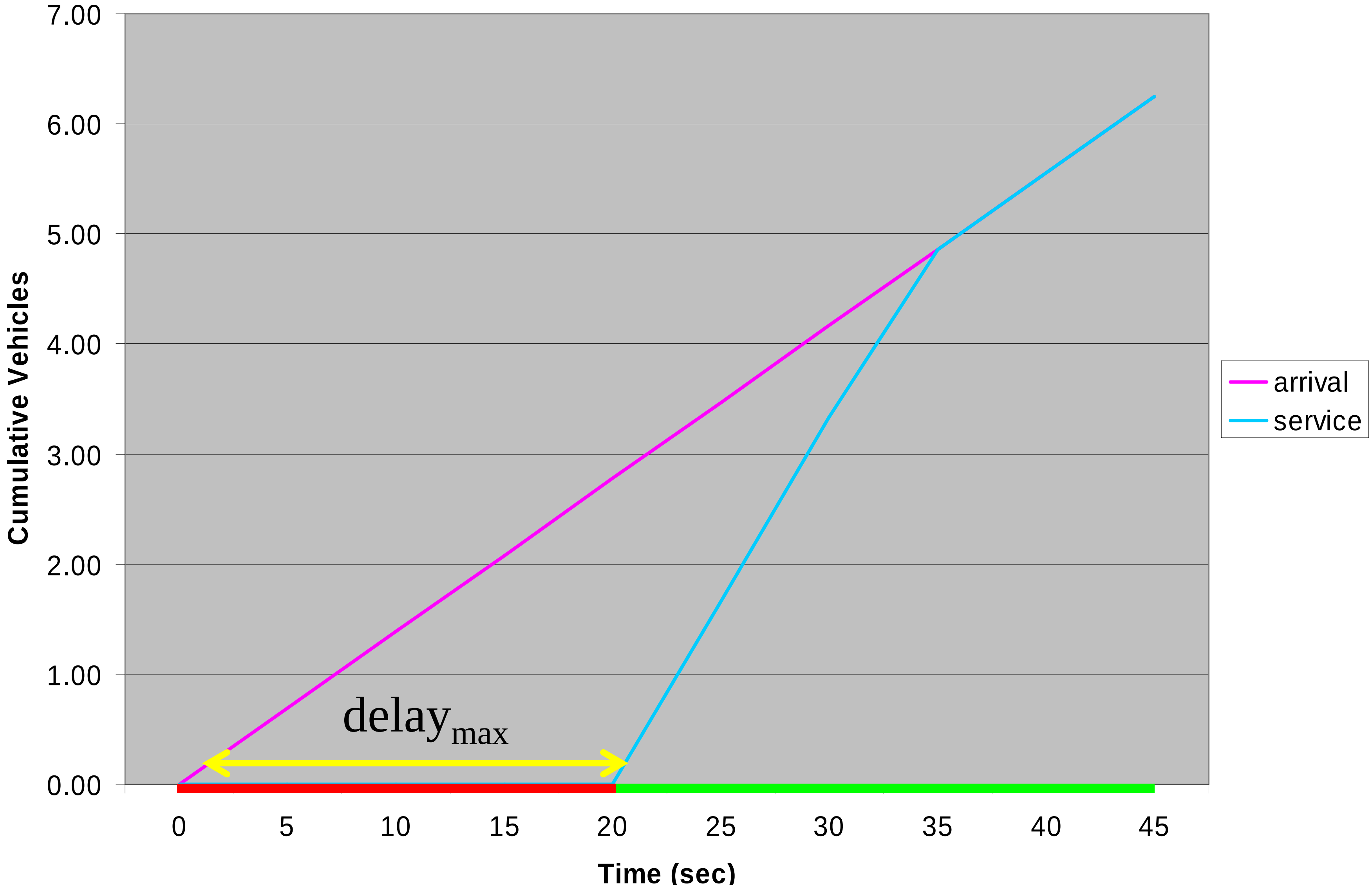


Queuing over several cycles

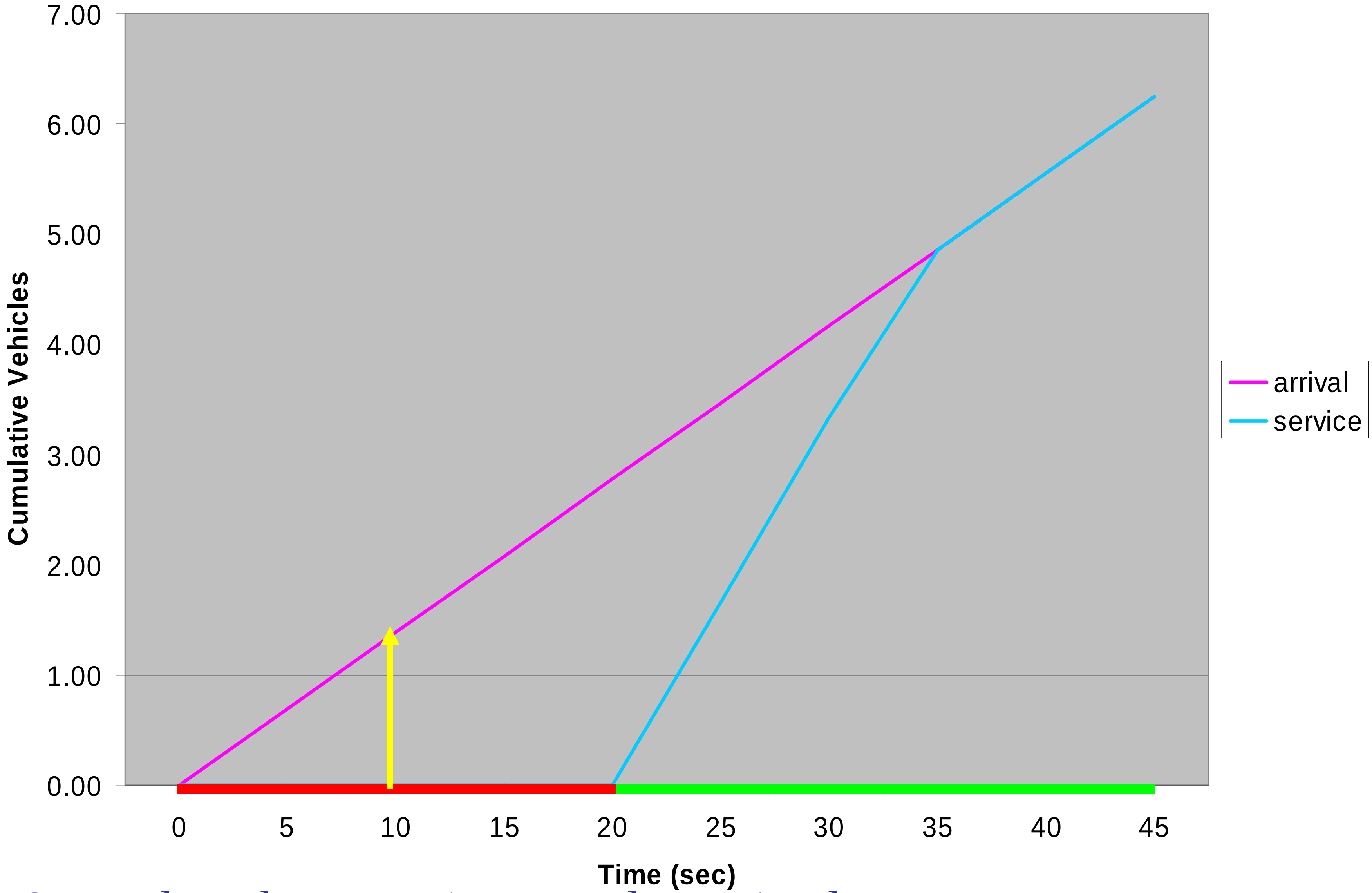
Triangles are identical and each represents 1 cycle



Maximum queue = 3 vehicles

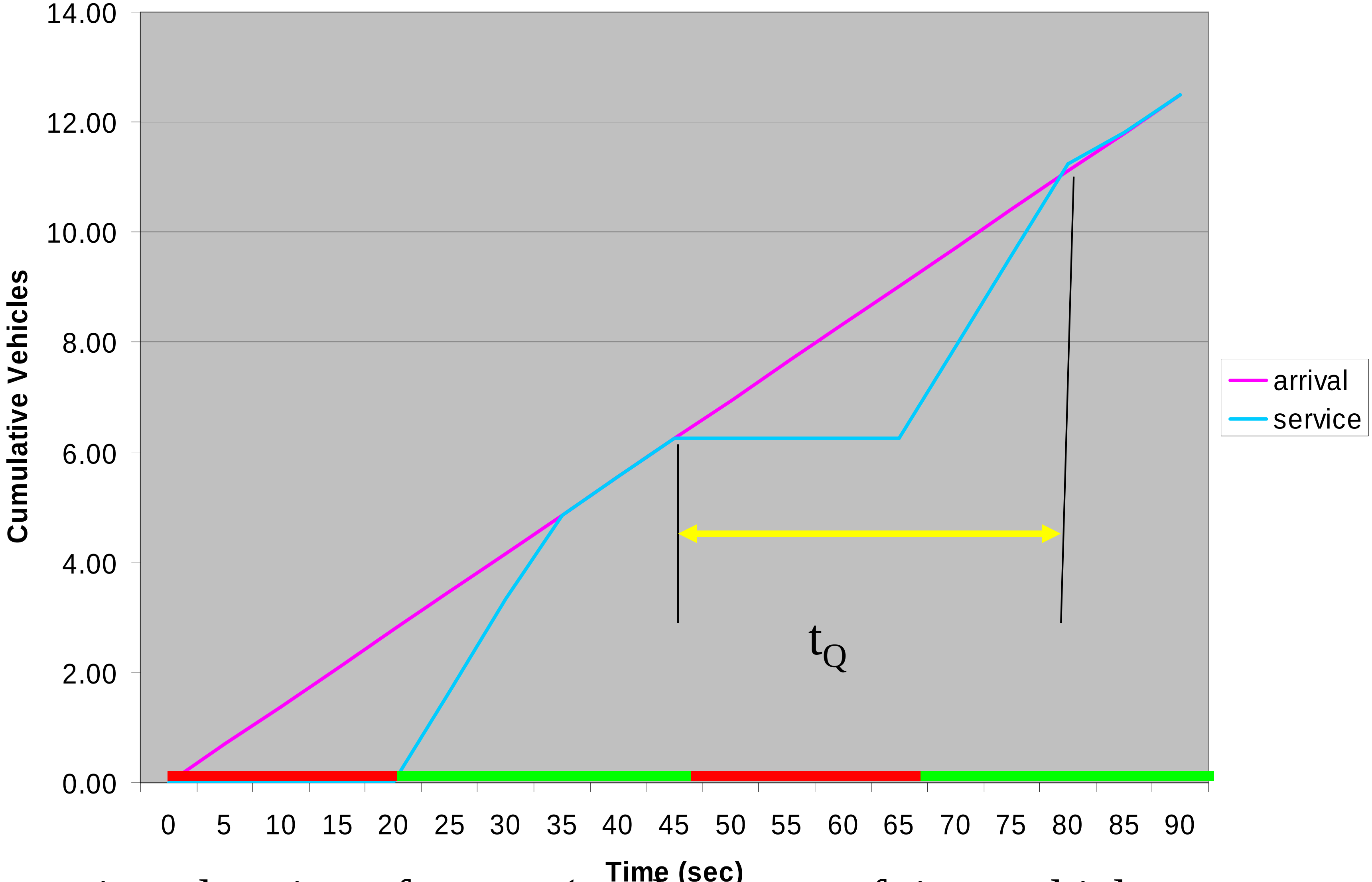


Maximum delay (vehicle that arrived first during red and waited for green to clear assuming vehicle$_1$ arrived at t = 0, could have arrived several seconds after start of red)



Queue length at any time can determined

At 10 seconds after red phase, ~ 1.3 vehicles are in queue



t_Q: time duration of queue (total amount of time vehicles are queuing, time during red and time during green when queue is dissipating until service rate = arrival rate

Stochastic, Single Channel Infinite Queue, under saturated

- Stochastic: has some randomness, vehicles don’t arrive every *x* seconds, some arrive sooner, some later, queuing can occur if arrival rate < service rate
- Deterministic, vehicles arrive regularly, queuing does not occur when arrival rate < service rate

Example

A ramp meter system allows 1 vehicle every 30 seconds to enter freeway
Vehicle arrives every 45 seconds

What is the mean queue length at the ramp meter?

Eq. 6.50

$$E(m) = \frac{q^2}{Q(Q-q)}$$

q = arrival rate = expressed as veh/hour
= (1 veh/45 sec)(3600 sec/hr) = 80 veh/hr

Q = service rate = (1 veh/30 sec)(3600 sec/hr) = 120 veh/hr

$$E(m) = \frac{q^2}{Q(Q-q)} = \frac{(80 \text{ veh/hr})^2}{120(120-80)} = \underline{1.33 \text{ veh}}$$

Example

What is the average time a vehicle will spend in queue before being served?

Eq. 6.51

$$E(w) = \frac{q}{Q(Q-q)} = \frac{80 \text{ veh/hr}}{(120)(120-80)} = \underline{\mathbf{0.017 \text{ hr/veh} = 60 \text{ sec}}}$$

Example

What is the probability 8 or more vehicles will be in the system?

Equation 6.55

$$P(n > N) = \left(\frac{q}{Q}\right)^{N+1}$$

$$P(n > 7) = \left[\frac{80 \text{ veh/hr}}{120 \text{ veh/hr}}\right]^{7+1} = \underline{0.039}$$

= <u>4% chance 8 or more vehicles will be waiting to enter freeway</u>