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Queue Analysis, Applications of Probability & Concept of Urban Planning to Solve the Queue Problem in Transportation Engineering

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Abstract:
Queue is the study of traffic behavior near a certain section where demand exceeds available capacity. Queues can be seen in many common situations: boarding a bus or train or plane, traffic signal, etc. One of the major issues in the analysis of any traffic system is the analysis of delay. A microscopic model of traffic flow attempts to analyze the flow of traffic by modeling driver-driver and driver-road interactions within a traffic stream which respectively analyzes the interaction between a driver and another driver on road and of a single driver on the different features of a road, these theory deals with various types of arrival & departure rate of vehicle & traffic behavior. Queue discipline deals with FIFO, LIFO, SIRO, etc. The probability of exactly "n" vehicles arriving over time "t" time interval calculated by using probability theory. Similarly no vehicle comes over time period "t" also calculated by using probability theory.
This paper also discusses how to solve the queue problem by improving urban design, city planning, Zoning laws that encourage mixed-use development which reduces distances between residential, commercial, retail, and recreational destinations (and encourage cycling and walking) Carfree cities, car-light cities, and eco-cities designed to eliminate the need to travel by car for most inhabitants. Transit-oriented developments are residential and commercial areas designed to maximize access to public transport by providing a transit station or stop (train station, metro station, tram stop, or bus stop)

1. Introduction

Queue is the study of traffic behavior near a certain section where demand exceeds available capacity. Queues can be seen in many common situations: boarding a bus or train or plane, traffic signal, etc. One of the major issues in the analysis of any traffic system is the analysis of delay. Delay is a more subtle concept. It may be defined as the difference between the actual travel time on a given segment and some ideal travel time of that segment. This raises the question as to what is the ideal travel time. In practice, the ideal travel time chosen will depend on the situation; in general, however, there are two particular travel times that seem best suited as benchmarks for comparison with the actual performance of the system. These are the travel time under free flow conditions and travel time at capacity. Queuing theory- Mathematical study of waiting lines, using models to show results, and show opportunities, within arrival, service, and departure processes. All of these theories are based on application of probability theory. So, in this article my objective to establish the mathematical relationship between queue formation & probability theory.
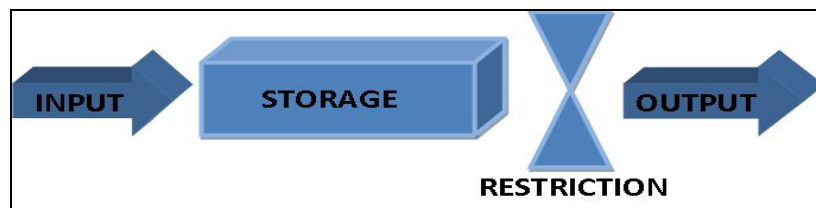

Figure 1: A Schematic of Queue System

2. Fundamentals of Queuing Theory

2.1. Microscopic Traffic Flow

A microscopic model of traffic flow attempts to analyze the flow of traffic by modeling driver-driver and driver-road interactions within a traffic stream which respectively analyzes the interaction between a driver and another driver on road and of a single driver on the different features of a road. Many studies and researches were carried out on driver's behavior in different situations like a case when he meets a static obstacle or when he meets a dynamic obstacle. Several studies are made on modeling driver behavior in another following car and such studies are often referred to as car following theories of vehicular traffic. Based on the departure rate and arrival rate pair data, the delay of every individual vehicle can be obtained.
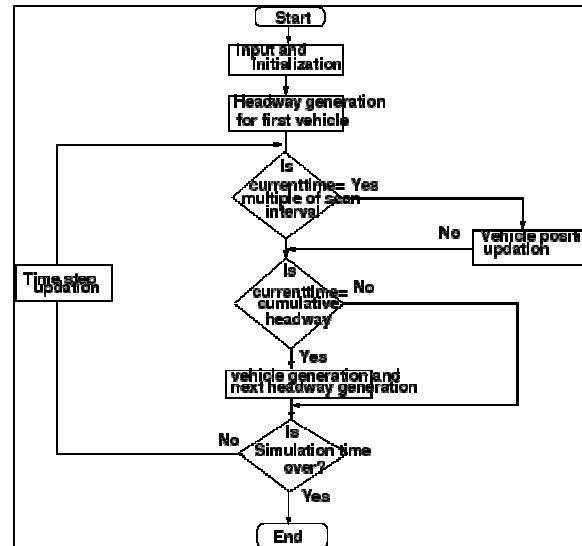
Figure 2: Microscopic Traffic Simulation

2.1.1. Mean Arrival rate (λ)
It is rate at which customers arrive at a service facility. It is expressed in flow (customers/hr or vehicles/hour in transportation scenario) or time headway (seconds/customer or seconds/vehicle in transportation scenario). If inter arrival time that is time headway (h) is known, the arrival rate can be found out from the equation: $\lambda = 3600/h$

2.1.2. Mean arrival rate (μ)
It is the rate at which customers (vehicles in transportation scenario) depart from a   transportation facility. It is expressed in flow (customers/hr or vehicles/hour in transportation scenario) or time headway (seconds/customer or seconds/vehicle in transportation scenario). If inter service time that is time headway (h) is known, the service rate can be found out from the equation: $\mu = 3600/h$

2.1.3 Queue discipline
- **First in first out (FIFO):** If the customers are served in the order of their arrival, then this is known as the first-come, first-served (FCFS) service discipline. Prepaid taxi queue at airports where a taxi is engaged on a first-come, first-served basis is an example of this discipline.
- **First in last out (FILO):** Sometimes, the customers are serviced in the reverse order of their entry so that the ones who join the last are served first. For example, assume that letters to be typed, or order forms to be processed accumulate in a pile, each new addition being put on the top of them. The typist or the clerk might process these letters or orders by taking each new task from the top of the pile. Thus, a just arriving task would be the next to be serviced provided that no fresh task arrives before it is picked up. Similarly, the people who join an elevator first are the last ones to leave it.
- **Served in random order (SIRO):** Under this rule customers are selected for service at random, irrespective of their arrivals in the service system. In this every customer in the queue is equally likely to be selected. The time of arrival of the customers is, therefore, of no relevance in such a case.
- **Priority Service:** Under this rule customers are grouped in priority classes on the basis of some attributes such as service time or urgency or according to some identifiable characteristic, and FIFO rule is used within each class to provide service. Treatment of VIPs in preference to other patients in a hospital is an example of priority service.
- **Processor (or Time) Sharing:** The server is switched between all the queues for a predefined slice of time (quantum time) in a round-robin manner. Each queue head is served for that specific time. It doesn't matter if the service is complete for a customer or not. If not then it'll be served in its next turn. This is used to avoid the server time killed by customer for the external activities (e.g. Preparing for payment or filling half-filled form).
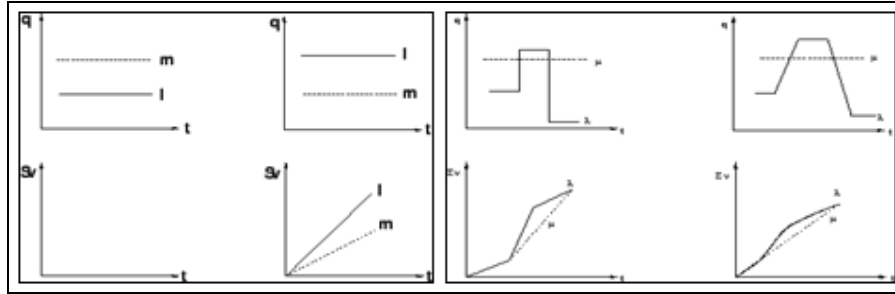
Figure 3: Constant arrival & Service Rate
Figure 4: Varying Arrival & Varying Service rate

3. Poisson Distribution & Application of Probability Theory
A Poisson experiment is a statistical experiment that has the following properties:
- The experiment results in outcomes that can be classified as successes or failures.
- The average number of successes (λ) that occurs in a specified region is known.
- The probability that a success will occur is proportional to the size of the region.
- The probability that a success will occur in an extremely small region is virtually zero.

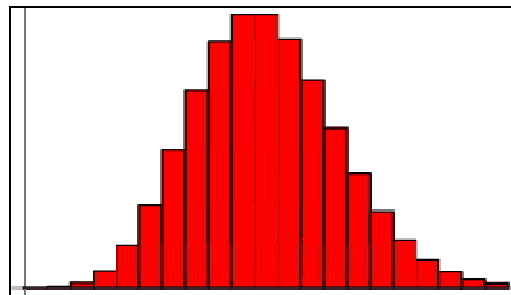Note that the specified region could take many forms. For instance, it could be a length, an area, a volume, a period of time, etc.(http://stattrek.com/probability-distributions/poisson.aspx)

Figure 5: Poisson Distribution

$$P(n) = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$$

P(n)	= probability of exactly n vehicles arriving over time t
n	= number of vehicles arriving over time t
λ	= average arrival rate
t	= duration of time over which vehicles are counted

3.1. Poisson Ideas
- Probability of exactly 4 vehicles arriving - P(n=4)
- Probability of less than 4 vehicles arriving - P(n<4) = P(0) + P(1) + P(2) + P(3)
- Probability of 4 or more vehicles arriving - P(n≥4) = 1 – P(n<4) = 1 - P(0) + P(1) + P(2) + P(3)

4. Queue Notation
- Popular notations:
  - D/D/1, M/D/1, M/M/1, M/M/N
  D = deterministic distribution
  M = exponential distribution
  N = number of lane
- D/D/1 - Use only when absolutely sure that both arrivals and departures are deterministic, for single lane
- M/D/1 - Controls unaffected by neighboring controls, for single lane
- M/M/1 – Both arrival & Departures are exponentially distributed, for single lane
- M/M/N - Both arrival & Departures are exponentially distributed, for N number of lanes

4.1. Factors that could affect in this analysis
- Neighboring system (system of signals)
- Time-dependent variations in arrivals and departures
  Peak hour effects in traffic volumes, human service rate changes
- Breakdown in discipline
  People jumping queues! More than one vehicle in a lane!

5. Queue Analysis – Graphical

5.1. Cumulative Input-Output Diagram (Newell Curve)

Based on the departure rate and arrival rate pair data, the delay of every individual vehicle can be obtained. Using the input-output (I/O) queuing diagram shown in the side figure, it is possible to find the delay for every individual vehicle: the delay of the ith vehicle is time of departure - time of arrival ($t_2 - t_1$). Total delay is the sum of the delays of each vehicle, which is the area in the triangle between the arrival (A(t)) and departure (D(t)) curves.
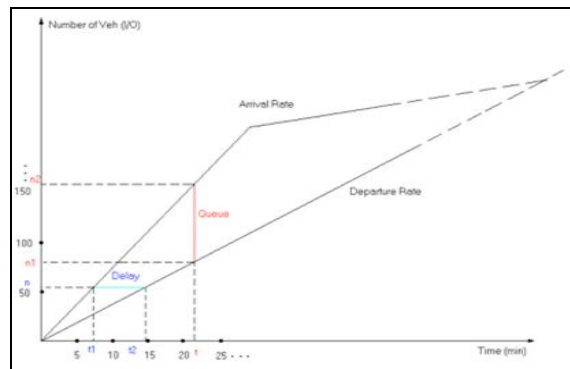

Figure 6: Cumulative Diagram of Queue Analysis

6. Queue Analysis – Numerical
- **M/D/1**
  Average length of queue
  $$\overline{Q} = \frac{\rho^2}{2(1-\rho)} \qquad \rho = \frac{\lambda}{\mu} \qquad \rho < 1.0$$

  Average time waiting in queue
  $$\overline{w} = \frac{1}{2\mu}\left(\frac{\rho}{1-\rho}\right)$$

  Average time spent in system
  $$\bar{t} = \frac{1}{2\mu}\left(\frac{2-\rho}{1-\rho}\right)$$

  λ = arrival rate μ = departure rate [for single lane road]

- **M/M/N**

  Average length of queue
  $$\overline{Q} = \frac{P_0 \rho^{N+1}}{N!N}\left[\frac{1}{(1-\rho/N)^2}\right] \qquad \rho = \frac{\lambda}{\mu} \qquad \rho/N < 1.0$$

  Average time waiting in queue
  $$\overline{w} = \frac{\rho + \overline{Q}}{\lambda} - \frac{1}{\mu}$$

  Average time spent in system
  $$\bar{t} = \frac{\rho + \overline{Q}}{\lambda}$$

- **M/M/N – More Stuff**

Probability of having no vehicles

$$P_0 = \frac{1}{\sum_{n_c=0}^{N-1} \frac{\rho^{n_c}}{n_c!} + \frac{\rho^N}{N!\left(1 - \rho/N\right)}}$$

Probability of having n vehicles -

$$P_n = \frac{\rho^n P_0}{n!} \ \ \text{for n} \leq \text{N} \qquad P_n = \frac{\rho^n P_0}{N^{n-N} N!} \ \ \text{for n} \geq \text{N}$$

- Probability of being in a queue - $P_{n>N} = \dfrac{P_0 \rho^{N+1}}{N! N\left(1 - \rho/N\right)}$

λ = arrival rate μ = departure rate   N = number of lane

7. Real Life Causes (Example) Of Queue Generation
For Roads:
- Geometric Bottlenecks (lane drops, hard curves, hills)
- Traffic Signals and Intersection Controls
- At-Grade Crossings with other Modes (Railroad crossings, drawbridges, etc.)
- Toll Booths

For Trains and Transit:
- Platform Capacities
- Fare Gates
- Ticket Windows/Ticket Machines

For Aviation and Airports:
- Runways
- Designated Minimum Safe Following Distances for Planes (by government)
- Ticketing Counters/Check-in Procedures
- Security Checkpoints
- Baggage Systems
- Terminal Capacity for Planes

8. How to Solve "Q" Problem?
- City planning and urban design (wikipedia.org/wiki/Urban design)
- Urban design is the process of designing and shaping cities, towns and villages. Whereas architecture focuses on individual buildings, urban design address the larger scale of groups of buildings, of streets and public spaces, whole neighborhoods and districts, and entire cities, to make urban areas functional, attractive, and sustainable.
- Urban design is an inter-disciplinary subject that unites all the built environment professions, including urban planning, architecture, civil and municipal engineering
- Urban design demands a good understanding of a wide range of subjects from physical geography, through to social science, and an appreciation for disciplines, such as real estate development urban economics, political economy and social theory. These all should be understood by the planner to solve the queue problem, and to solve the traffic jam.
- Urban design is about making connections between people and places, movement and urban form, nature and the built fabric. Urban design draws together the many strands of place-making, environmental stewardship, social equity and economic viability into the creation of places with distinct beauty and identity. Urban design is derived from but transcends planning and transportation policy, architectural design, development economics, engineering and landscape. It draws these and other strands together creating a vision for an area and then deploying the resources and skills needed to bring the vision to life. Thus it may be considering solving these kind of transportation problems.
- Zoning laws that encourage mixed-use development, which reduces distances between residential, commercial, retail, and recreational destinations (and encourage cycling and walking) (wikipedia.org/wiki/Mixed-use development)

[Mixed-use development is—in a broad sense—any urban, suburban or village development, or even a single building, that blends a combination of residential, commercial, cultural, institutional, or industrial uses, where those functions are physically and functionally integrated, and that provides pedestrian connections. The term ("a mixed-use development") may also be used more specifically to refer to a mixed-use real estate development project—a building, complex of buildings, or district of a town or city that is developed for mixed-use by a private developer, (quasi-) governmental agency, or a combination thereof.

Traditionally, human settlements have developed in mixed-use patterns. However, with industrialisation as well as the invention of the skyscraper, governmental zoning regulations were introduced to separate different functions, such as manufacturing, from

residential areas. In the United States, the heyday of separate-use zoning in the U.S. was after World War II, but since the 1990s, mixed-use zoning has once again become desirable as the benefits are recognized. These benefits include:

- greater housing variety and density
- reduced distances between housing, workplaces, retail businesses, and other destinations
- more compact development
- stronger neighborhood character
- pedestrian and bicycle-friendly environments]
  - Carfree cities, car-light cities, and eco-cities designed to eliminate the need to travel by car for most inhabitants.
  - Transit-oriented development are residential and commercial areas designed to maximize access to public transport by providing a transit station or stop (train station, metro station, tram stop, or bus stop).

9. Conclusion
The queuing models often assume infinite numbers of customers, infinite queue capacity, or no bounds on inter-arrival or service times, when it is quite apparent that these bounds must exist in reality. Often, although the bounds do exist, they can be safely ignored because the differences between the real-world and theory is not statistically significant, as the probability that such boundary situations might occur is remote compared to the expected normal situation. Sometimes several studies show the queuing models are based on assumptions. In other cases the theoretical solution may either prove intractable or insufficiently informative to be useful. Alternative means of analysis have thus been devised in order to provide some insight into problems that do not fall under the scope of queuing theory, although they are often scenario-specific because they generally consist of computer simulations or analysis of experimental data. In practical cases software use to measure and solve the queue problem, INTEGRATION microscopic traffic simulation software is used as the main simulation tool. A first objective of this software is to compare the number of stops and queue QueensOD Software is a model for estimating origin-destination traffic demands based on observed link traffic flows, observed link turning movement counts, link travel times and, potentially, additional information on drivers' route choices .At the same time improvement of urban planning concept are very much essential to solve the problem, in a urban area transit oriented development is very helpful to solve any transportation problem like "Q".

10. References
1. Mannering, F.L.; Kilareski, W.P. and Washburn, S.S. (2003). Principles of Highway Engineering and Traffic Analysis, Third Edition (Draft). Chapter 5
2. Transportation Research Board. (2000). Highway Capacity Manual 2000. National Research Council, Washington, D.C.
3. Determination and Evaluation of Traffic Congestion cost - Ingo Hansen
4. Faculty of Civil Engineering and Geosciences
5. www.team-bhp.com › Team-BHP › Around the Corner › Shifting gears
6. INTEGRATION © RELEASE 2.40 FOR WINDOWS: User's Guide – Volume I: Fundamental Model Features
7. Transportation Engineering – Khisty & Lal.
8. wikipedia.org/wiki/Mixed-use development
9. wikipedia.org/wiki/Urban design
10. Lecture notes in Traffic Engineering And Management, Date 19/Feb/14, civil engg. dept. (http://www.civil.iitb.ac.in/~vmtom/1111_nptel/585_Queuing/plain/plain.html)
11. James H Banks. Introduction to transportation engineering. Tata Mc-Graw Hill, 2004.
12. Frederick S. Hillier and Gerald J. Lieberman. Operations Research. CBS publishers, 2019.
13. Adolf D. May. Fundamentals of Traffic Flow. Prentice - Hall, Inc. Englewood Cliff New Jersey 07632, second edition, 1990.
14. C S Papacostas. Transportation engineering and planning by Papacostas. C. S, 3rd edition, Prentice-Hall of India in 2001. Prentice-Hall of India, 2001