1 Introduction to traffic engineering

1.1 Transportation Engineering

Transportation engineering is the application of technology and scientific principles to the planning, functional design, operation, and management of facilities for any mode of transportation in order to provide for the safe, rapid, comfortable, convenient, economical, and environmentally compatible movement of people and goods.

1.2 Traffic Engineering

Traffic engineering is the phase of transportation engineering that deals with the planning, geometric design and traffic operations of roads, streets and highways, their networks, terminals and relationships with other modes of transportation.

1.3 Objectives of traffic engineering

- Safety is the primary objective – More than 40,000 people die each year in traffic accidents. Safety can be provided for the public through positive programs, good practice, knowledge, and proper procedure.
- Speed: While speed of travel is much to be desired, it is limited by transportation technology, human characteristics, and the need to provide safety. (Higher speed means shorter travel time. Interstate highways encourage long distance trips.)
- Comfort – Involves the physical characteristics of vehicles and roadways and their influenced by our perception of safety
- Convenience – The ease of making trips and the ability of transport systems to accommodate all travel needs

- Economy – Try to provide the best possible systems for the money. There is little in modern transportation systems that can be termed “cheap.”Highway and other transportation systems involve massive construction, maintenance, and operating expenditures, most of which are provided through general and user taxes and fees. Nevertheless, every engineer, regardless of discipline, is called upon to provide the best possible systems for the money
- Environmental compatibility – Provide sustainable transport systems. All transportation systems have some negative impacts on the environment. All produce air and noise pollution in some forms, and all utilize valuable land resources.

1.4 Components of Traffic Systems

Four critical components of traffic system are

- Road users - drivers, pedestrians, bicyclists and passenger
- Vehicles - private and commercial
- Roadways - Streets and highways
- Control devices

1.5 Transportation Modes

We have different modes (listed below), and these modes can be used according to different factors that can affect person or vehicle movements.

1. **Road transport**:
    a. Vehicles,
    b. Buses,
    c. Heavy vehicles,
    d. Motor cycle,
    e. Bicycle.

2. **Railways:**
    a. Surface,
    b. Underground,
    c. Elevated,
    d. Tramway (light rail)
3. **Air transport.**
4. **Water transport.**
5. **Pipeline**

While the factors that affecting person and vehicles movement selection are:

1. Effect of mode type
2. Effect of roadway type
3. Effect of composition of traffic

1.6 Standard References for the Traffic Engineer

- *Highway Capacity Manual (HCM)*
- *Traffic Engineering Handbook*
- *Fundamental of Transportation Engineering (on-line)*
- Traffic and Highway Engineering (Garber and Lester)

2 Traffic flow

Traffic flow is the study of the movements of individuals drivers and vehicles between two points and the interactions they make with one another. Studying traffic flow is very difficult because a driver behavior is something that cannot be predicted. However drivers tend to behave within a reasonably consistent rang and, thus, traffic streams tend to have some reasonable consistency and can be roughly represented mathematically.

The traffic flow characteristic shows the dynamic change at different time intervals through the day. Although traffic flow by its non-linear nature is complex, traffic congestion can be a certain extent predicted and controlled as the drivers tend to behave within the stream range.

However, the catch is that this is true only if the variables on which their representation depends are known with infinite precision. Meanwhile, the challenge here is how to deal with these unstable different traffic problems. The important issue which establishes the core of different techniques is to define and understand the traffic variables conditions. The main variables which can emerge and impact on the performance of the traffic road system will be defined in the next section and their relations will be presented.

The traffic flow theory classified the traffic movement in the network into two main streams, interrupted and uninterrupted traffic flow and it is essential to understand them.

1. Uninterrupted flow: can be defined as “All the flow regulated by vehicle-vehicle interactions and interactions between the vehicle and the roadway” such as the traffic in the highway. Some important features are listed below:
    a. There is no controlled access.
    b. Can be seen in freeways and long sections of rural highways
    c. There is no traffic signals (stop points)
    d. Stream characteristic depends on geometric design, vehicles and others

2. Interrupted flow: All the flows are regulated by an external means" such as traffic signal. Some important features are listed below:
    a. Traffic signals can be applied
    b. Stopping and restarting points
    c. Platoons may happen

2.1 Traffic flow primary variables

Many variables play a fundamental role in characterizing, modelling and studying the dynamic of traffic. In our problem, the most important variables are; speed, flow and density. They are essential for designing, analyzing and controlling the transportation systems, they will be detailed below:

- **Speed** can be defined as "The rate of change of its position" expressed as the distance per unit time. Generally, it is expressed by kilometers per hour (km/h) or mile per hour (m/h). The symbol of the speed is (υ), and the free flow speed is designated by (Vmax). Speed is one of the most important variables which can measure the performance of different types of roads.
- **Flow** is "The amount of traffic passing a point or on a lane or roadway during a designated time interval". The symbol for flow is (q), and the maximum flow is (qmax). It is expressed by the number of vehicles using the road per specific time.

$$q=\frac{3600\,N}{t_{measured}}$$

N: no. of vehicles

- **Density,** the third main variable, it is “The number of vehicles occupying a length of a lane or roadway at a particular instant”. It is expressed by the number of vehicles per kilometers. The symbol for density is (k).

$$K=\frac{N}{L}$$

K: Density

N: no. of vehicles

L: length of roadway

2.2 Relationships between Speed, Flow and Density

Speed, flow, and density are all related to each other. The relationships between speed and density are not difficult to observe in the real world.

2.3 Basic formula

The formula below shows the relation between the variables:

$$q = \rho * \upsilon$$

Where:

q: Flow

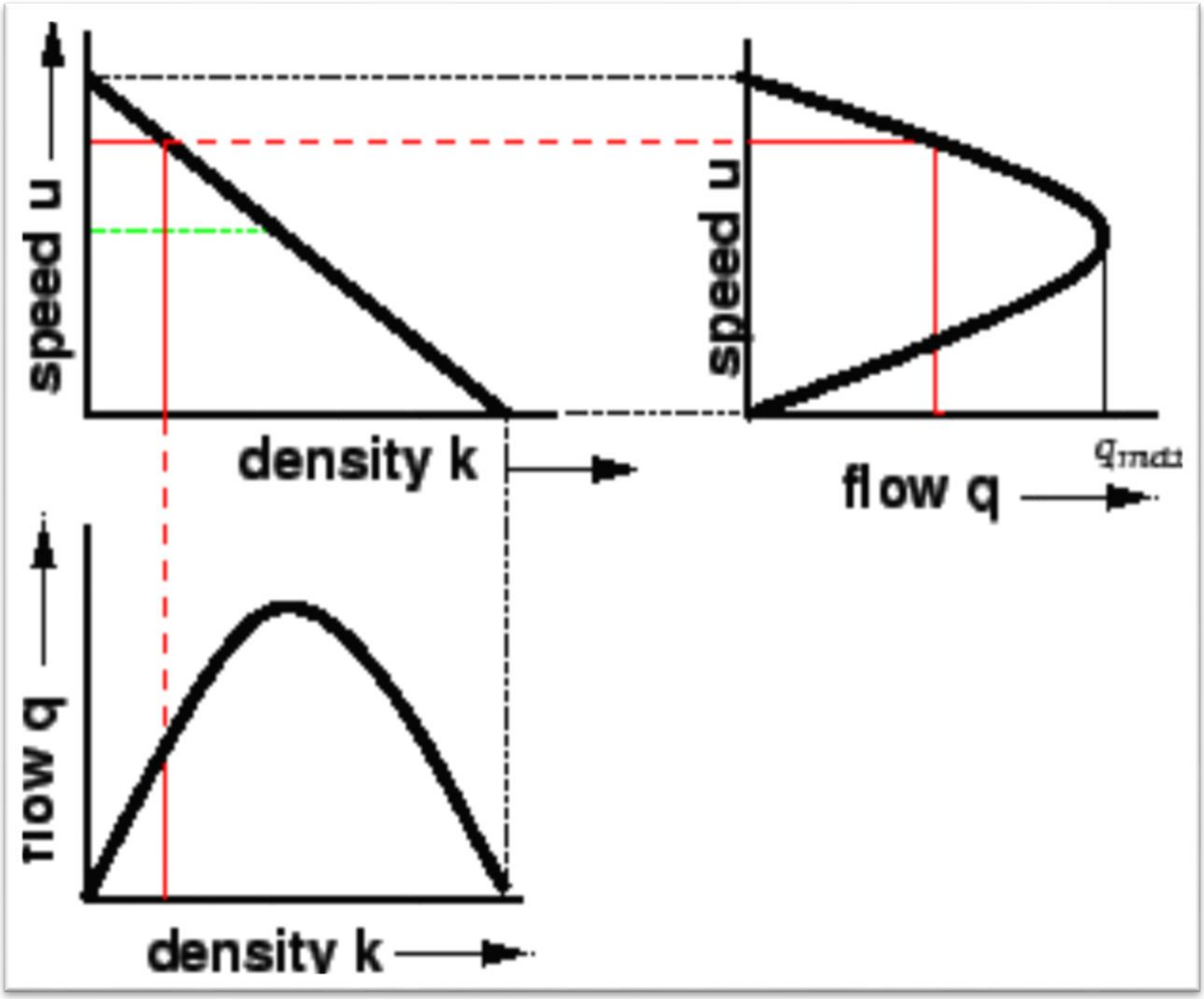
ρ: Density

υ: Speed

If two variables can be known, then, the third variable can be calculated through the basic equation above.

To facilitate collecting the main traffic data along the road, it is adequate to select collecting two of them and the third variable can be determined using the diagram (Figure below). Thus, the diagrams show the continuous curves and most of these main elements under the effect of changing environmental conditions, non-homogeneity of vehicles in the traffic stream. The Figure shows the relationships between the main basic road variables.

- Speed-Density diagram
- Speed-Flow diagram
- Flow-Density diagram



Traditional fundamental diagram of traffic

Figure above shows the relationships between the main basic road variables, three critical statues can be spotted in the figure:

- When there are no cars in the facility, density is zero (k= 0), and flow is zero. Speed is purely theoretical for this condition and would be whatever the first driver would select, probably the highest possible value.
- When density becomes so high that all vehicles stop (k= 0), the flow (q) is also zero. This is because there is no movement and vehicles cannot pass a point on the roadway. The density at which all movement stops is called the jam density.
- Flow is increasing (density as well) from zero while speed is starting to decrease which is equivalent to low and medium density and flow. Density still increases with a decline steadily in the speed before the capacity is achieved. Capacity can appear either in a high speed and low density or in low speed and high density. Moreover, there is a speed-flow-density diagram which interprets the interesting points on these diagrams aggregately.

2.4 Time mean speed

Time mean speed ($\overline{V_t}$) = arithmetic mean of speeds of vehicles passing a point

$$\overline{V_t} = \frac{1}{N} \sum_{n=1}^{N} v_n$$

2.5 Space mean speed

Space mean speed is defined as the harmonic mean of speeds passing a point during a period of time. It also equals the average speeds over a length of roadway

$$\overline{V_s} = \frac{N}{\sum_{n=1}^{N} \frac{1}{v_n}}$$

2.6 Headway

2.6.1 Time headway

Time headway ($\square_t$) is the differences between the time when the front of the vehicle arrives at a point on the highway and the time of the front of the next vehicle arrives at the same point (in seconds)

The average time headway ($\overline{h_t}$) = average travel time per unit distance * average space headway.

$$\overline{h_t} = \bar{t} * \overline{h_s}$$

2.6.2 Space headway

Space headway ($\square_s$) is the differences in position between the front of the vehicle and the front of the next vehicle

$$\overline{h_s} = \overline{V_s} * \overline{h_t}$$

2.7 Observation (Triangular or Truncated Triangular)

Actual traffic data is often much noisier than idealized models suggested. However what we tend to see is that as density rises, speed is unchanged to a point (capacity) and then begins to drop if it is affected by downstream traffic . for a single link , the relationship between flow and density is thus more triangle than parabolic. When we aggregate multiple links together (e.g. networks) we see more parabolic shape.

2.8 Modeling traffic flow

The fundamentals of traffic flow theory and its application can be classified into three categories:

2.8.1 Microscopic traffic modeling

Micro-simulation models have the ability to model each individual vehicle behavior within a network. In theory, such models provide a better, and „purer', representation of actual driver behavior and network performance. These models deal with an individual vehicle movement within the traffic system, its travel time, speed, and how the driver is moving.

Microscopic models have a wide range of advantages. We summarized them in bullets below:

- Micro-simulation models are very useful where the increasing system complexity and uncertainty can be involved in the operation of the urban traffic networks.
- The microscopic models are based on some traffic factors which have the ability to manage the movement of individual vehicles in a transport network.
- Microscopic simulation models are able to evaluate various traffic management alternatives in order to determine the optimum solution for any traffic scenario and provision of visualization for the case under study.
- traffic data is rarely constant and repeatable, so many reliable suggestions can be offered for different traffic problems such as congestions, incident management

2.8.2 Macroscopic traffic modeling

(Also traditional transport models) are defined as "Providing an aggregated representation of demand, typically expressed in terms of total flows per hour". In other words, they deal with characteristics of the section of any road.

2.8.3 Mesoscopic traffic modeling

Mesoscopic models consist of microscopic and macroscopic approaches to provide a high efficiency describing all key characteristics of the road. For example, if the drivers decide to change lanes, this is a microscopic aspect, while this decision should depend on the densities and speeds which are obtained from a macroscopic model.

2.9 Examples

Example. 1

Given 5 observed velocities (60, 35, 45, 20 and 50) km/h, what is the time-mean speed and space-mean speed?

Sol.
Time-mean speed:

$$\overline{V_t} = \frac{1}{N} \sum_{n=1}^{N} v_n$$

$$\overline{V_t} = \frac{1}{5} (60+35+45+20+50)$$

$$\overline{V_t} = 42\text{km/h}$$

Space mean speed

$$\overline{V_s} = \frac{N}{\sum_{n=1}^{N} \frac{1}{v_n}}$$

$$\overline{V_s} = \frac{5}{\frac{1}{60}+\frac{1}{35}+\frac{1}{45}+\frac{1}{20}+\frac{1}{50}}$$

$$\overline{V_s} = 36.37 \text{ km/h}$$

Example. 2

Given that 40 vehicles pass a given point in 1 minute and transverse a length of 1 kilometer. What is the flow, density and headway?

Sol.

Flow can be computed following the eq. below:

$$q = \frac{3600\ (40)}{60}\ 2400 \text{ veh/h}$$

Density can be computed following the eq. below:

$k = \frac{40}{1} = 40$ veh/km

For this example, time headway can be computed following some steps as below:

Find space mean speed,

$q = k\overline{V_s} \longrightarrow \overline{V_s} = 2400/40 = 60$

Find space headway

$K = 40 = \frac{1}{\overline{h_s}}$

$\overline{h_s} = 0.025$km =25m

Find time headway

$$\overline{h_s} = \overline{V_s} * \overline{h_t}$$

$$\overline{h_t} = \frac{25}{60*1000/3600}$$

$$\overline{h_t} = 1.5 \text{ sec.}$$

Question (H.W.):

For the figure below, location and speeds of four vehicles on a two-lane highway at a instant of time. The figure below shows the vehicles travelling at constant speeds on a two-lane highway between two points (A & B). Determine the flow, density, time mean speed, and space mean speed. (Use the information determined in the figure)