Pedestrian and Vehicular Traffic Characteristics for Synthetic-Hybrid Mobility Models

RONAN J. SKEHILL, MICHAEL BARRY, SEAN MCGRATH
Wireless Access Research Group
Department of Electronic and Computer Engineering
University of Limerick
Limerick,IRELAND

Abstract: - Synthetic mobility models can be used to simulate the movement of a traffic unit or a group of traffic units in a telecommunication network. Characteristics of pedestrian and vehicular traffic, such as speed-flow, speed-density and flow density are often neglected in current synthetic mobility models. The analysis, emulation and simulation of telecommunication networks with mobile users using models such as the random walk are therefore inaccurate. This paper presents a review of pedestrian and vehicular characteristics and classifies them using the concept of Level of Service. This paper highlights parameters that can be used to improve the accuracy of synthetic mobility models. In the case of vehicular traffic the paper also presents street classification which will further improve the realism of synthetic models.

Key-words:- Pedestrian, Vehicular, Synthetic, Mobility Model

1 Introduction

Pedestrian and vehicular characteristics have not changed dramatically over the centuries. The fundamentals that govern traffic characteristics (such as speed) have not changed at all. These fundamentals can be applied to modelling pedestrian or vehicle traffic in a wide range of engineering disciplines. Mobility models have been used in telecommunication engineering to represent user movement in cellular networks. Methods used to described these movements have been either synthetic or trace. Trace models are based on empirical data gathered over a period of time for a certain area. From the empirical information characteristics such as speed-flow, flow-density and speed-density can be extracted. On the other hand, synthetic models are mathematically based and can be used in any scenario and environment easily. The trade-off between synthetic and trace models is realism and flexibility. Trace models can not be extended to represent larger areas or population without distorting the validity of the collected data. Synthetic models lack the realism of trace models. A synthetic-hybrid model can be considered to be a model that has the flexibility of synthetic models with the realism of empirical trace models. This paper provides guidelines to select and incorporate empirical data from pedestrian and traffic engineering into synthetic models. Section 2 presents the fundamentals of traffic analysis and Level of Service which can been used to describe both pedestrian and vehicular traffic. Section 3 and section 4 present the characteristics of pedestrian mobility and vehicular mobility respectively and illustrate the characteristics in a set of tables. Section 5 concludes the paper.

2 Fundamentals of Traffic Analysis

Traffic engineering covers a wide selection of traffic units from pedestrians, cyclists, cars to high speed vehicles but the fundamentals apply to all. In order to understand the fundamentals the terms often used in the field, described here (source [1]), are modified to include pedestrian traffic.

Flow Volume (P) – the number of traffic units passing a point in a unit of time. In pedestrian design the flow is expressed as pedestrians per metre width of the walkway per minute, with vehicles this is measured with the number of cars per lane per hour.

Speed (S) – expressed in distance per unit of time, generally in metres per unit of time. When modelling pedestrians or traffic, the speed is the average speed of all the traffic passing through a section. When modelling traffic unit characteristics, the common expressions of speed are: Free-flow, running and travel speed.

Density (ρ) – the number of traffic units per unit of area. For traffic and pedestrians alike it is often expressed in units per square metre. This is effective in describing pedestrians, but can lead to, especially with cars and larger vehicles, being expressed in tenths. This may be hard to visualise so an alternative way of expressing density is using its reciprocal M, the Area Module.

Headway – the time and distance separation between traffic units.

Queue – one or more traffic units waiting for service. Queue lengths and durations will vary according to the traffic flow characteristics.

2.1 Traffic Stream Models

Based on these definitions, the classic traffic analysis flow equation, derived from an analogy to fluid in a channel, is expressed as follows:

$$P = S \times \rho \tag{1}$$

with typical units of Flow Volume (P), speed (S), and density (ρ) being traffic unit per unit time, traffic unit speed per unit time and traffic unit per unit area.

An alternative version of this equation can be expressed as rates collected directly through point measurements, and by definition require measurement over time.

$$P = \frac{N}{t} \tag{2}$$

Where N is the number of observed traffic units, and t is time. Flow rates are usually expressed in terms of traffic units per hour, although the actual measurement interval can be much less.

2.2 Speed–Density Model

Focusing on the Speed-Density relationship, assuming a single traffic unit in the environment (that is on a motorway or walking on a footpath), the traffic unit will be able to travel freely at the maximum speed it is permitted and capable of. This free-flow speed is denoted by (S_f). The speed S of the traffic unit (and surrounding traffic units) will decease as the number of traffic units increases, so much so until everyone is stopped $S = 0$. At this point the density is denoted by ρ_j. This relationship can be mathematically represented by Eq. 3.

$$S = S_f(1 - \frac{\rho}{\rho_j}) \tag{3}$$

Justification of this model is well documented, the most cited work was carried out by Greenshield in 1935 [2]. An interesting aspect of this particular model as stated by Hall in Chapter 2 of [3] is that its empirical basis consisted of half a dozen points in one cluster near free-flow speed, and a single observation under congested conditions. The linear relationship comes from connecting the cluster with the single point. As Greenshields stated (p. 468), "since the curve is a straight line it is only necessary to determine accurately two points to fix its direction." What is surprising is not that such simple analytical methods were used in 1935, but that their results (the linear speed-density model) have continued to be so widely accepted for so long.

2.3 Flow–Density Model

Using the linear relationship of speed and density, a parabolic flow-density model can be derived by subsituting Eq. 3 into Eq. 1.

$$P = S_f(\rho - \frac{\rho^2}{\rho_j}) \quad (4)$$

This is referred to as the traffic flow capacity or simply the capacity of the environment. Two points are worthy of note, firstly the maximum flow rate P_m of the environment is the highest rate of traffic unit flow the environment is able to support. The second point, which corresponds to the maximum flow rate is the traffic unit density ρ_m. These values, along with mean average speed S_m can be derived by differentiating Eq. 4.

$$\frac{dP}{d\rho} = S_f(1 - \frac{2\rho}{\rho_j}) = 0 \quad (5)$$

and since the free-flow speed S_f is not equal to zero,

$$\rho_m = \frac{\rho_j}{2} \quad (6)$$

Substituting Eq. 6 into Eq. 3 gives

$$S_m = S_f(1 - \frac{\rho_j}{2\rho_j}) = \frac{S_f}{2} \quad (7)$$

and using Eq. 6 and Eq. 7 into Eq. 1 gives

$$P_m = S_m\rho_m = \frac{S_j\rho_j}{4} \quad (8)$$

2.4 Speed–Flow Model

The seminal work on this topic was the paper by Greenshields in 1935, in which he derived the following parabolic equation for the speed-flow curve on the basis of a linear speed-density relationship together with the equation, flow = speed × density. Using a rearranged Eq. 3, the speed–flow relationship can be given as:

$$\rho = \rho_j(1 - \frac{S}{S_f}) \quad (9)$$

subsituting this into Eq. 1 obtains

$$P = \rho_j(S - \frac{S^2}{S_f}) \quad (10)$$

This results in a parabolic function as shown in Figure 1. The curve shows when flow levels are low, traffic units can obtain maximum speed, when the flow levels increase speed decreases, when approaching maximum number of traffic units per unit area, the flows and speed declines.

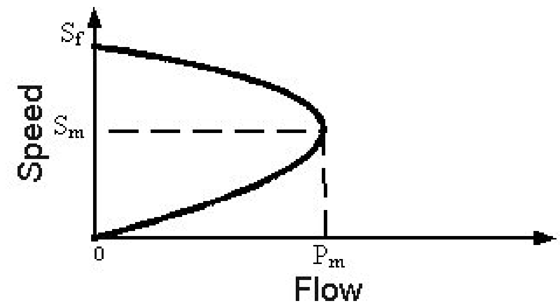

Figure 1: The Speed–Flow Relationship.

2.5 Level-of-Service Concept

The Highway Capacity Manual, the most recent being [4], developed a standard for six levels of design, based on service volume and a qualitative evaluation of driver inconvenience. The qualitative evaluation takes into consideration the freedom to choose speed, the ability to overtake and pass other vehicle and to change lanes. Level-of-Service definitions generally describe traffic conditions in terms of speed and travel time, volume and capacity, freedom to manoeuver, traffic interruptions, comfort and convenience, and safety. Level-of-Service is represented by letter designations, ranging from LoS A to LoS F, with LoS A representing the best operating conditions and LoS F the worst. The concept, though designed for vehicles, can be applied to the pedestrian environment and in [5] Fruin developed a Level-of-Service for pedestrians..

The effect of Level-of-Service [A-F] on traffic units is generic for pedestrians and vehicles, that is, traffic units with LoS A conditions are able to travel at their desired speed, with low to no interaction from other traffic units.

3 Pedestrian Flow Characteristics

3.1 Space Requirements

Fruin researched crowds in the early 1970's. His book *"Pedestrian Planning and Design"* [5] has been cited in many of the present guidelines for pedestrian planning. This research has become the standard for many subsequent building design and planning operations. Pedestrian Planning address the fundamental human measurements. Fruins' data finds that his measure for a fully clothed male labourer is 22.8 inches by 13 inches (57.9cm by 33cm). Anthropomorphic sizes for a large cross section of the worlds population were obtained from [6] where Still concluded the average size of a person is: breath $45.58cm$, depth $28.20cm$ with an area of $0.2m^2$. The Highway Capacity Manual [4] simplified body ellipse by combining both to give an average is using the of $0.50m \times 0.60m$. The total area of $0.30m^2$ represents the basic space requirement for a single pedestrian. This is the practical minimum standing space for pedestrians. In evaluating a pedestrian facility, an area of 0.75 m2 is used as the buffer zone for each pedestrian. A walking pedestrian requires a certain amount of forward space. This forward space is a critical dimension, since it determines the speed of the trip and the number of pedestrians that are able to pass a point in a given time period. The forward space is categorised into a pacing zone and a sensory zone. Fruin states the length of pacing zone is dependent on the age, sex, and physical condition of the pedestrian and has a linear relationship with speed. The sensory zone is an area that is required by the pedestrian for perception, evaluation and reaction, it is based on human perception and psychological factors and thus it can not be physically measured. There is no direct correlation between the LoS and sensory zones.

3.2 Pedestrian Speed

When unimpeded by crowd density or other traffic frictions, pedestrians may vary their walking speeds over a wide range. From Fruins work [5] the distribution of free-flow walking speeds is obtained from the survey of about 1000 pedestrians inside the Port Authority Bus Terminal and Penns station in New York City. The average speed for all males, all females and the combination of all pedestrians in the surveys were 82.296, 77.4192, 80.772 metre per minute [5]. From this study, assuming that they represent a normal population distribution, a statical inference can be made that normal pedestrians have a free-flow walking speeds of greater than 30 metres per minute and speeds below this represent human shuffling and not normal walking. Conversely, walking speed of greater than 105 metres per minute can be considered as running. Table 1 illustrates necessary parameters that can be incorporated into synthetic models.

Milazzo II et al. [7] provide comprehensive research to develop a basis for revised operational analysis procedures for transportation facilities with pedestrian traffic units where the flow is not interrupted by traffic control devices. The paper contains both new and revised Level-of-Service tables for analysing various types of uninterrupted pedestrian facilities. It details the results of a review and synthesis of American and international literature as part of a Federal Highway Administration study of pedestrian and bicycle facilities conducted by North Carolina State University between 1995 and 1998.

4 Vehicle Flow Characteristics

The speed of vehicles on urban streets is influenced by three main factors: street environment, interaction among vehicles, and traffic control. As a result, these factors also affect quality of service. The street environment includes the geometric characteristics of the facility, the character of roadside activity, and adjacent land uses. Thus, the environment reflects the number and width of lanes, type of median, driveway/access-point density, spacing between signalised intersections, existence of parking, level of pedestrian activity, and speed limit. The interaction among vehicles is determined by traffic density, the proportion of cars, trucks and buses etc., and turning movements. Traffic control (including signals and signs) force a portion of travelling vehicles to slow or stop. The

LOS	Pedestrian Occupancy	Flow Volume (P)	Speed (S)	v/c ratio
A	>5.6 (m^2 per person)	16	>1.30	$\leq$ 0.21
B	3.7 - 5.6	16-23	1.27 – 1.30	0.21 – 0.31
C	2.2 - 3.7	23-33	1.22 – 1.27	0.31 – 0.44
D	1.42 - 2.2	33-49	1.14 – 1.22	0.44 – 0.65
E	0.75 - 1.42	49-75	0.75 – 1.14	0.65 – 1.0
F	<0.75	variable up to 82	$\leq$0.75	variable

Table 1: Level-of-Service for Pedestrian of 58cm x 33cm Dimension

delays and speed changes caused by traffic control devices reduce vehicle speeds; however, such controls are needed to establish right-of-way.

4.1 Free-Flow Speed

The street environment, that is, the Class of street (I–IV) affects the drivers speed choice. When vehicle interaction and semaphores are not factors, the speed chosen by the average traffic unit is referred to as the free-flow speed. Free-flow speed is the average speed of the traffic stream when traffic volumes are sufficiently low that drivers are not influenced by the presence of other vehicles and when intersection traffic control (i.e., signal or sign) is not present or is sufficiently distant as to have no affect on speed choice. As a consequence, Free-flow speed is typically observed along mid-portions of the urban street segment.

4.2 Running Speed

A problem with free-flow speed is that vehicular users in telecommunication networks rarely travel at Free-flow speed. Most of the time, the presence of other vehicles restricts the speed of a vehicle in motion because of differences in speeds among drivers or because downstream vehicles are accelerating from a stop and have not yet reached free-flow speed. As a result, vehicle speeds tend to be lower than the free-flow speed during moderate to high-density conditions. One speed characteristic that captures the effect of interaction among vehicles is the average running speed. This speed is computed as the length of the segment divided by the average running time. The running time is the time taken to traverse the street segment, less any stop-time delay.

4.3 Travel Speed

The presence of traffic control on a street segment tends to reduce vehicle speeds below the average running speed. A speed characteristic that captures the effect of traffic control is average travel speed. This speed is computed as the length of segment divided by the average travel time. The travel time is the time taken to traverse the street segment, inclusive of any stop-time delay.

4.4 Urban Street Classification and Travel Speeds

According to the Highway Capacity Manual [4], four urban street classes are defined. The classes are designated by number (i.e., I, II, III, and IV) and reflect unique combinations of street function and design. The Classification of the urban street and associated travel speed is given as :

Class I High Speed. Consist of very low density levels multi-lane roads with shoulders. Speed limits of 70–90 kmph.

Class II Suburban. Low Density suburban area with low density multi-lane roads with speed limits of 60–75 kmph.

Class III Intermediate. Consisting of Moderate density multilane divided or undivided; one-way, two-lane. Speed limit 50–67 kmph.

Urban Street	I	II	III	IV
FFS(km/h)	90–70	70–55	55–60	55-40
TFFS (km/h)	80	65	55	45
LOS	**Average Travel Speed (km/h)**			
A	>72	>59	>50	>41
B	>56-72	>46–59	>39–50	>32–41
C	>40-56	>33-46	>28–39	>23-32
D	>32-40	>26–33	>22–28	>18–23
E	>26–32	>21-26	>17–22	>14-18
F	≤26	≤21	≤17	≤14

Table 2: Urban Street LoS By Class; source [4] pp15–3

Class IV Urban. Consisting of high density undivided one way, two way, two or more lanes. Speed Limits 40–55 kmph.

Table 2 shows appropriate values to use in synthetic models when modelling urban streets of type Class I-IV. The Free Flow Speed Range for each class of street and a Typical Free Flow Speed is associated with this range. Using Level of Service concept, each street classification is further broke down to give the average travel speed.

5 Summary

Pedestrians and vehicles obey the same fundamentals, i.e. the Speed–Density, Flow–Density and Speed–Flow models. Substantial research in transportation engineering has provided empirical information for pedestrian and vehicle traffic, based on the geographical and classification of streets. This research can be summarised with the Table 2 and Table **??**. The tables shows corresponding traffic unit speed, density and flow rate. From pedestrians and vehicular measurements [4] it is known the peak intensities of car and pedestrian traffic during a day do not necessarily coincide. The mobility characteristics of vehicle and pedestrian traffic can be summarised as: (i) Temporal dependency: Physical constraints of the traffic entity itself, the speed of traffic changes continuously and gently instead of abruptly, i.e. the current velocity is dependent on the previous velocity. (ii) Spatial dependency: The movement pattern of traffic may be influenced by and correlated with nodes in its vicinity. (iii) Geographic restrictions: In many cases, the movement of traffic may be restricted along the walkway, street or a freeway.

In summary this paper outlines the mobility characteristics of an urban environment, from a pedestrian and vehicular point of view, and from an overall urban environment. The paper provides Level of Service, Free-flow speed for pedestrians and vehicles, it also provides the corresponding density level for the traffic units that can be included in synthetic-hybrid mobility models.

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